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The Intergenerational Transmission of Mathematics Achievement in Middle Childhood: A Prospective Adoption Design

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Abstract

The present study uses a parent-offspring adoption design to examine the dual roles of heritable and environmental influences on children's mathematics achievement. Linked sets (N = 195) of adopted children, adoptive parents, and birth parents each completed a measure of mathematics fluency (i.e., simple computational operations). Birth parent mathematics achievement and adoptive father mathematics achievement positively correlated with child achievement scores at age 7, whereas adoptive mother and adopted child mathematics achievement scores were not significantly associated with one another. Additionally, findings demonstrated no significant effects of gene-environment (GxE) interactions on child mathematics achievement at age 7. These results indicate that both heritable and rearing environmental factors contribute to children's mathematics achievement and identify unique influences of the paternal rearing environment on mathematics achievement in middle childhood.

Keywords

mathematics achievement; heritability; fathers; intergenerational transmission; GxE interplay; middle childhood

Low mathematics achievement is prevalent in the United States. For example, on the 2017 National Assessment of Educational Progress, only 40% of U.S. fourth graders were at or

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above proficiency on measures of mathematics achievement. Because early mathematics achievement establishes critical trajectories for future academic achievement (Jordan et al., 2009; Watts et al., 2014), young children who struggle to grasp basic mathematics concepts early in schooling are at risk for facing similar challenges later in schooling. Investigations into the etiologies of mathematics achievement can elucidate the factors that contribute to mathematics achievement across childhood. The present study used an adoption design to estimate heritable (i.e., birth parent mathematics achievement) and environmental (i.e., adoptive mother and father mathematics achievement) contributions to variability in mathematics achievement in middle childhood.

The Intergenerational Transmission of Mathematics Achievement

Intergenerational transmission is a process by which parents intentionally or unintentionally transfer psychological and behavioral traits to their offspring (Hart et al., 2019; van Bergen et al., 2014). A limited, but growing literature examines the transfer of mathematics knowledge from parents to offspring, with findings demonstrating positive associations between parent and child mathematics achievement (Blevins-Knabe et al., 2007; Braham & Libertus, 2017; Brown et al., 2011; Duncan et al., 2009; Heineck & Riphahn, 2009; Hertz et al., 2007; Navarro et al., 2018; Plug & Vijverberg, 2003; Sacerdote, 2002). Braham and Libertus (2017) found that parent mathematics achievement positively predicted 5- to 8-year old children’s mathematics achievement after accounting for covariates.

A common interpretation of parent-child associations is that environmental processes (e.g., socialization, modeling) underlie parental investments in offspring via time, resources, and parental behaviors. These environmental transmission processes are thought to causally explain links between parent variables (e.g., achievement, behaviors) and child mathematics achievement. Additional work examines effects of family environmental factors, including socioeconomic status (SES; Elliott & Bachman, 2018), domain-specific parental language (mathematics and spatial language; Borriello & Liben, 2018; Gunderson & Levine, 2011), and the home learning or home numeracy environments (Huntsinger et al., 2016; LeFevre et al., 2009; Melhuish et al., 2008) on child mathematics achievement. Although study findings are inconsistent, they sometimes demonstrate positive correlations between these factors and child mathematics achievement (e.g., Blevins-Knabe et al., 2000; Missall et al., 2015; Thompson et al., 2017).

Intervention research provides additional support for the notion that environmental factors influence mathematics achievement. For example, early education intervention programs have been shown to enhance later academic achievement (Campbell et al., 2012), and some programs specifically target parents. One preschool program increased children’s school readiness gains beyond initial effects of a classroom intervention by supplementing classroom exposure with a parent-targeted home-learning curriculum (Bierman et al., 2017). Taken together, most correlational and experimental work suggests parents can be a source of *environmental variability* for children’s mathematical learning, and that what parents *do* with children influences variability in mathematics achievement.

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A Behavioral Genetics Approach to Understanding Variability in Mathematics Achievement

An issue with assuming that socialization factors (e.g., parental input) explain intergenerational associations is that most developmental studies examine parent-child correlations using samples of biologically related parents and children. The use of biologically related families makes it challenging to discern whether parent-child associations are due to influences of shared genes between parents and children (i.e., heritable influences), to influences of the experiences parents and children share, or to some combination thereof (Moore & Neiderhiser, 2014; Plomin et al., 1977).

Genetically sensitive designs can clarify the contributions of environmental processes (i.e., parental socialization) on the intergenerational transmission of developmental outcomes by studying families with varying degrees of genetic relatedness (e.g., twin and sibling studies, adoption studies). Twin and sibling studies can account for both similarity (shared environment) and differences (nonshared environment) in the environment shared by family members to estimate effects of heritable and environmental influences. Such studies indicate large effects of heritable influences and small, but significant, effects of shared environmental influences on mathematics achievement in middle childhood (Hart et al., 2009; 2010; Kovas et al., 2007a; 2013; Luo et al., 1994; Petrill et al., 2012; Thompson et al., 1991). Adoption studies can estimate heritable and rearing environmental contributions to parent-offspring similarity by examining family triads (i.e., birth parents, adoptive parents, and the adopted child). Specifically, birth parents provide genes to the adopted child placed in adoptive homes at or near birth (and birth mothers provide the prenatal environment) but do not provide the rearing environment, whereas genetically unrelated adoptive parents provide the child's rearing environment. Few adoption studies examine the etiology of mathematics achievement, however, studies investigating a related construct, IQ (Alarcón et al., 2000), indicate slightly larger effects of heritable compared to environmental influences (Scarr & Weinberg, 1977; Loehlin et al., 1989). Genetically informed research thus suggests that both heritable *and* environmental factors are key contributors to the intergenerational transmission of mathematics achievement.

Gene-Environment Interplay

Genetically sensitive designs can estimate unique heritable and environmental contributions on human traits. Although these estimates are important, far more complex processes involving the interplay between heritable and environmental factors, including gene-environment correlation (*r*GE) and gene-environment interaction (GxE), also drive child development (Moore & Neiderhiser, 2014; Plomin et al., 1977). GxE is a process by which effects of an environment (e.g., home learning environment) depend on individuals' genetic propensities. Behavioral genetics designs are uniquely suited to unpack these processes and reveal exactly *how* complex behavioral traits develop over time. Prior GxE work has examined whether family factors moderate heritable influences on children's cognitive abilities and academic achievement (Rhemtulla & Tucker-Drob, 2012; Tucker-Drob et al., 2011; Turkheimer et al., 2003). Rhemtulla and Tucker-Drob (2012) found that heritable

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influences on mathematics achievement at age 4 were larger for children raised in families with higher, rather than lower, SES backgrounds, suggesting that genetic propensities for mathematics are expressed when children experience socioeconomic advantages.

This study uses a parent-offspring adoption design to examine whether GxE interactions underlie variability in children's mathematics achievement. The birth parents and adoptive parents provide unique contributions to child outcomes, with birth parents providing heritable influences, as the child is placed with adoptive parents closely after birth, and adoptive parents providing the postnatal environment for the adopted child. This has the added benefit of eliminating potential confounds of passive *r*GE (when design assumptions are met; i.e., no selective placement) and helping to better specify potential GxE findings.

The Present Study

To disentangle heritable and environmental pathways of intergenerational transmission, we examined whether birth parents' mathematics achievement (heritable influences) and adoptive parents' mathematics achievement (rearing environmental influences) were associated with the adopted child's mathematics achievement at age seven. We also examined whether contributions of heritable influences on children's mathematics achievement were moderated by the quality of the rearing environment (i.e., levels of adoptive parent mathematics achievement).

A secondary study question concerned effects of biological sex of the adoptive parents and the adopted child on child mathematics achievement at age 7. Very little work has examined whether parent biological sex differentially influences child mathematics achievement. Some behavioral work suggests that parent biological sex influences children's learning experiences, such that mothers engage in more achievement-related activities (e.g., homework; play activities) with their children than fathers (Foster et al., 2016; Grolnick & Slowiaczek, 1994; Levin et al., 1997). Foster et al. (2016) found that, even though engagement in educational activities at home with young children was higher for mothers than fathers, both maternal and paternal educational involvement predicted children's mathematics achievement. However, this finding was only true for children whose mothers had earned less than a bachelor's degree. For children with more highly educated mothers, only maternal, and not paternal, educational involvement predicted children's mathematics achievement. Another study found that mothers', compared to fathers', engagement in mathematics-related activities at home was more related to children's mathematics performance in early schooling (del Río et al., 2017). These studies also align with the finding that mothers are children's primary caregivers (Craig, 2006; Nomaguchi et al., 2005). To the best of our knowledge, this study is the first genetically informed study to examine whether pathways between parent and child mathematics achievement vary by parent biological sex.

Investigations into the influence of child biological sex on mathematics achievement have been of long-standing interest in psychology, with early research demonstrating a gender gap in mathematics achievement, favoring boys over girls (e.g., Anastasi, 1958; Benbow & Stanley, 1980). Since the 1990s, however, meta-analyses and other studies examining this

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question have demonstrated that mathematics achievement does not substantially differ between males and females (Hyde et al., 1990; Hyde, 2005; Hyde et al., 2008; Kersey et al., 2018; Lindberg et al., 2010). Almost no behavioral genetics work has examined effects of child biological sex on mathematics achievement. One twin study found no differences in the etiologies of boys' and girls' mathematics achievement at age 10 (Kovas et al., 2007b).

Hypotheses

We hypothesized that (1) birth parent mathematics achievement (heritable influences) would be positively associated with adopted child mathematics achievement, that (2) there would be differential effects of adoptive parent mathematics achievement (rearing environmental influences) on child mathematics achievement, such that adoptive mothers' influence would explain a unique amount of variance above and beyond variance explained by adoptive fathers' achievement, although both associations would be positive, and that (3) adoptive mother, but not adoptive father, mathematics achievement would moderate the effects of birth parent mathematics achievement (GxE interaction) on child mathematics achievement, such that heritable influences would be stronger when adoptive mothers had higher, rather than lower, mathematics achievement. For child biological sex, we did not expect to find differential etiologies of boys' and girls' mathematics achievement. Finally, we had no expectations for whether adopted child sex would differentially impact effects of heritable influences, environmental influences, or GxE interactions, as no behavioral genetics study has previously considered differential effects of both parent and child biological sex on the etiology of mathematics achievement.

Method

Participants and Procedure

Participants were from Cohort I of the Early Growth and Development Study (EGDS; n = 195 adoption-linked families: adopted child, adoptive parents, and birth parents), a multisite, longitudinal study of adopted children and their birth and adoptive parents (Leve et al., 2019). Birth fathers participated in 34.9% of the families. At the time of assessment, adopted children were 7 years old (M_{age} = 7.01 years; SD = .15; Range = 6.76 to 7.49 years). Table 1 displays additional descriptive information about the analytic sample. Participants were recruited from 2003 to 2006 from adoption agencies throughout the United States. Families were eligible for the study based on the following criteria: (a) the adoption was domestic, (b) the child was placed prior to 3 months of age (M = 7.11 days postpartum, SD = 13.28), (c) the child was placed with a non-relative adoptive family, (d) the infant had no known major medical conditions (e.g., extreme prematurity; extensive medical surgeries), and (e) the birth and adoptive parents could at least read or understand English at an eighth-grade level. Data collection occurred via home visit assessments and online questionnaires. For additional information about study recruitment procedures, sample, and assessment methods, see Leve et al. (2019).

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Attrition Analyses

Of the 361 participating families in Cohort I, 166 were excluded from analyses because of listwise deletion (listwise $n = 195$). Participants were excluded because at least one member of every family unit (birth mother, adoptive mother, adoptive father, adopted child) was missing data on a main study variable ($n = 145$) or a covariate ($n = 21$). Attrition analyses indicated only one difference between participating and nonparticipating families: adoptive fathers with data were younger than those without data, $t(355) = 2.77$, $p = .006$, $d = 0.35$.

Measures

Mathematics achievement—We examined a basic facet of mathematics achievement, *mathematics fluency* (i.e., accuracy and speed on arithmetic problems), because mathematics fluency is predictive of mathematics achievement (Jordan et al., 2003; Mazzocco et al., 2008) and facilitates the acquisition of more complex mathematical thinking (Hartnedy et al., 2005). We assessed mathematics fluency with standardized scores on the mathematics fluency subtest of the Woodcock-Johnson III Achievement Tests (W-J III; Woodcock et al., 2001), which requires individuals to solve as many simple addition, subtraction, and multiplication problems as possible in three minutes.

The mathematics achievement measure was administered to children at age 7, to adoptive mothers and fathers when children were 6 and 7 years old, respectively, and to birth parents when children were 4.5 years old. Because fewer birth fathers participated in the study, we averaged birth mother and birth father scores (when both birth parents' data were available; 30.3% of the sample; $r = .27$, $p \leq .05$, not shown in Table 2) to create a composite measure of birth parents' mathematics achievement. When only one birth parent completed the mathematics fluency measure (birth mother only, 65.1%, birth father only, 4.6%), we used achievement scores from the birth parent with available data.

Covariates—We considered four covariates in relation to the main study variables: obstetric complications, adoption openness, parent education level, and other subscales of the W-J III. We examined obstetric complications (e.g., neonatal complications, prenatal drug use, exposure to toxins) because such risks, along with heritable influences, could contribute to similarities between biological mothers and offspring, and potentially lead to overinflated estimates of heritable influences on child outcomes (Marceau et al., 2016). We examined openness in adoption – contact and exchange of information between birth and adoptive parents – because post-adoption contact between biological and adoptive parents could make it difficult to disentangle heritable and environmental influences (for details, see Ge et al., 2008). Parent education level for birth mothers, birth fathers, adoptive mothers, and adoptive fathers was assessed on a scale from 1 to 7, with "1" representing the lowest level of education (less than a high school degree) and "7" representing the highest level of education (graduate program). Finally, we included three other measures of the W-J III (i.e., letter-word identification; reading fluency; word attack), to control for non-mathematics related parent and child cognitive skills.

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Analytic Strategy

We examined correlations between covariates and the main study variables and residualized any covariates with significant associations ($p < .05$) from main study variables, and then used standardized residuals in all subsequent analyses.

A hierarchical regression analysis examined main effects of mathematics achievement scores for (Step 1) birth parents, (Step 2) adoptive fathers, and (Step 3) adoptive mothers on adopted child scores. We then examined whether birth parent scores moderated effects of adoptive father scores, and moderated effects of adoptive mother scores, on child scores (Step 4). Finally, we examined effects of adopted child biological sex on child mathematics achievement scores (Step 5).

Results

Descriptive Statistics

Table 2 displays descriptive statistics and correlations for mathematics achievement scores (both with and without covariates residualized) for the analytic sample. Prior to residualizing covariates, mathematics achievement between adoptive mothers and fathers were significantly correlated with one another. Adopted child mathematics achievement scores were not related to birth parent, adoptive mother, and adoptive father scores prior to residualizing covariates. Finally, results indicated no significant correlations between any main study variable and adopted child biological sex.

Heritable and Rearing Environmental Influences on Children’s Mathematics Achievement

As depicted in Table 3, the overall regression model was significant. For heritable effects, we found a significant positive association between birth parent and adopted child mathematics achievement scores. For environmental influences, we found a positive association between adoptive father and adopted child scores, but no association between adoptive mother and adopted child scores. Thus, accounting for adoptive father scores explained significantly more variance in adopted offspring mathematics achievement scores than did birth parent scores alone, but the inclusion of adoptive mother scores along with birth parent and adoptive father scores did not account for significantly more variance in adopted child scores compared to the variance explained by including only birth parent and adoptive father scores.

Additional analyses revealed no significant main effect of child biological sex on adopted child mathematics achievement and no interactions between adoptive parent sex and adopted child sex on adopted child scores. Moreover, neither adoptive mother nor adoptive father mathematics achievement scores significantly moderated the association between birth parent and adopted child mathematics achievement scores. We thus trimmed child biological sex and all interaction variables from the final model.

Discussion

The present study used a parent-offspring adoption design to clarify the intergenerational transmission of mathematics achievement at age 7. In line with prior research (Kovas et al.,

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2007b), the present findings indicate significant heritable influences on children's mathematics achievement. Additionally, these findings highlight the importance of the rearing environment, or at least aspects of the rearing environment represented by adoptive fathers' mathematics achievement, for children's achievement. However, this environmental influence was only evident for adoptive fathers, and not mothers. Moreover, we found no evidence to suggest that adoptive parents' achievement moderated associations between birth parent and adopted child mathematics achievement. Finally, child biological sex had no influence on the etiology of children's mathematics achievement.

One clear implication of this work is that both heritable and rearing environmental influences contribute to the familial transfer of mathematics achievement. Heritable contributions to adopted children's mathematics achievement persisted even after accounting for influences of adoptive mother and father achievement. Similarly, rearing environmental contributions, via adoptive father mathematics achievement, persisted even after accounting for influences of biological parents' and adoptive mothers' achievement. Together, the joint effects of heritability and adoptive fathers' mathematics achievement explained more variance in adopted children's mathematics achievement than did individual influences of either factor. Furthermore, this work went beyond investigating the independent influences of heritable and environmental factors by considering the influence of GxE interactions (i.e., moderation effects) on mathematics achievement, although we found no evidence for such interactions in this study.

We were surprised to find significant associations between mathematics achievement for children and adoptive fathers, but not mothers, because prior work indicates that mothers are children's primary caregivers (Craig, 2006; Nomaguchi et al., 2005). Additional work suggests that mothers', but not fathers', engagement in mathematics-related activities at home is associated with mathematics performance in early schooling (del Río et al., 2017). However, few studies in developmental psychology have considered effects of paternal influences on child mathematics achievement. The inclusion of father data was a strength of the current study, and its findings highlight the importance of studying mothers *and* fathers in developmental research.

One potential explanation for this finding is that children may receive a higher quantity and quality of support from fathers than from mothers during mathematics-related learning activities. Moreover, children may place more value on mathematics activities with fathers than with mothers, as even young children endorse stereotypes supporting the notion that mathematics is for boys (Cvencek et al., 2011). Hart et al. (2016) found that fathers engaged in more mathematics activities with children than did mothers, although this parent sex difference did not affect children's mathematics achievement. Future work should attempt to replicate and extend the present study findings to determine whether paternal influences are consistently stronger than maternal influences on child mathematics outcomes. Additionally, future research should investigate direct observations of mother-child and father-child play during mathematics activities to examine whether parenting behaviors vary by biological sex.

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Finally, our findings indicated that child biological sex did not influence heritable and environmental contributions to children's mathematics achievement. This finding aligns with the gender similarities hypothesis, which proposes that boys' and girls' mathematics achievement is more similar than different (Hyde, 2005; Hyde et al., 2008). These findings also replicate results from twin research suggesting no differences in the etiologies of boys' and girls' mathematics outcomes (Kovas et al., 2007b).

Despite our best efforts, this study had some limitations. First, we used a single measure to assess mathematics achievement, which likely did not capture the full range of children's mathematics competencies in middle childhood. At this developmental stage, children are capable of more than just addition, subtraction, and multiplication, and should also be able to understand number relations (e.g., ordering of numbers; relative size of objects) and numbering (e.g., counting; number estimation). Moreover, research indicates additional, unique heritable influences on child performance in timed versus untimed mathematics measures (Hart et al., 2010), and we did use a timed measure of mathematics in the present investigation. Thus, etiological sources of variance that emerged in the present study might have differed if we had assessed other measures of mathematics achievement. Future work examining heritable and environmental sources of mathematics achievement should include a variety of measures that tap into developmentally appropriate subcomponents of mathematics achievement.

Another limitation is that adoptive families had high educational and economic backgrounds and limited ethnic diversity. However, demographic characteristics of our sample were similar to the other large adoption study in the United States, the Colorado Adoption Project (Plomin & DeFries, 1985), and were representative of birth and adoptive families from participating adoption agencies in the present study (Leve et al., 2019). Nonetheless, in the current study, demographic characteristics of adoptive families (e.g., high economic and educational backgrounds, low ethnic diversity) differed from those of birth families, indicating a potential restriction of range in the environment of adopted children. Despite this difference, research indicates insubstantial effects of restriction range on heritable and environmental estimates (McGue et al., 2007). It is consequently unlikely that range restrictions influenced the present study findings.

A final limitation was that we assessed adoptive parents' mathematics achievement rather than specific parenting factors that could be related to child mathematics achievement. Thus, the specific environmental mechanism underlying the association between fathers' mathematics achievement and children's mathematics achievement is unknown. Future studies should investigate more specific measures of parenting, including parental supportiveness (Casey et al., 2014). Finally, based on the findings reported here, it is essential that future research examine paternal, and not just maternal, characteristics that may influence child mathematics achievement.

This study has a number of strengths due to its design and the sample composition. To the best of our knowledge, this is one of the first studies to test the intergenerational transmission of mathematics achievement using an adoption design. The present findings corroborate evidence from other genetically sensitive studies, namely, twin studies,

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indicating substantial heritable influences and modest shared environmental influences on mathematics achievement at age 7. However, our study was unique in its ability to examine contributions of environmental influences from adoptive mothers *and* adoptive fathers by assessing mathematics achievement in both parents. With the inclusion of both adoptive parents, we were able to demonstrate that environmental influences were evident and substantial via adoptive fathers', but not adoptive mothers' achievement scores. Thus, this is the first study, to date, to shed light on the intergenerational transmission of mathematics achievement from the rearing environment provided by mothers and fathers using a genetically sensitive design. This is important because both parents influence heritable and rearing environmental factors. Moreover, within families, parenting behaviors may vary across parents and differentially influence child outcomes.

The present study examined intergenerational effects on mathematics achievement at one point in development, when children were seven years old. Future research should address whether these intergenerational transmission pathways have similar effects on mathematics achievement at different points in development. Behavioral genetics research suggests that, for mathematics (and cognitive abilities), environmental influences are strongest in early childhood, whereas heritable influences are strongest later in life (e.g., Kovas et al., 2007a). Future research should examine whether parents' mathematics achievement, particularly fathers' achievement, might be more influential on children's mathematics knowledge across development.

Genetically sensitive designs offer a powerful way for researchers to ensure that heritable influences do not confound effects of the rearing environment on child outcomes. The present findings demonstrate the utility of using genetically sensitive designs to identify the degree to which environmental factors shape children's developing mathematical competencies. These findings also highlight a need for more research to consider effects of fathers when examining parent-child associations for mathematics achievement. An important implication of this work is that intergenerational transmission processes linking parent and child traits are not one-dimensional. By including various potential sources of intergenerational transmission, we were able to clarify key contributions of heritable *and* environmental processes on mathematics achievement in middle childhood.

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References

Anastasi A (1958). Differential psychology (3rd ed.). New York: Macmillan.

Alarcón M, Knopik VS, & DeFries JC (2000). Covariation of mathematics achievement and general cognitive ability in twins. Journal of School Psychology, 38(1), 63–77. 10.1016/s0022-4405(99)00037-0

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Benbow CP, & Stanley JC (1980). Gender differences in mathematical ability: Fact or artifact? Science, 210, 1262–1264. 10.1126/science.7434028 [PubMed: 7434028]

Bierman KL, Heinrichs BS, Welsh JA, Nix RL, & Gest SD (2017). Enriching preschool classrooms and home visits with evidence-based programming: Sustained benefits for low-income children. Journal of Child Psychology and Psychiatry, 58(2), 129–137. 10.1111/jcpp.12618 [PubMed: 27550828]

Blevins-Knabe B, Austin AB, Musun L, Eddy A, & Jones RM (2000). Family home care providers' and parents' beliefs and practices concerning mathematics with young children. Early Child Development and Care, 165(1), 41–58. 10.1080/0300443001650104

Blevins-Knabe B, Whiteside-Mansell L, & Selig JP (2007). Parenting and mathematical development. Academic Exchange Quarterly, 11(2), 76–81.

Borriello GA, & Liben LS (2018). Encouraging maternal guidance of preschoolers' spatial thinking during block play. Child Development, 89(4), 1209–1222. 10.1111/cdev.12779 [PubMed: 28295204]

Braham EJ, & Libertus ME (2017). Intergenerational associations in numerical approximation and mathematical abilities. Developmental Science, 20(5), 1–11. 10.1111/desc.12436

Brown S, McIntosh S, & Taylor K (2011). Following in your parents' footsteps? Empirical analysis of matched parent-offspring test scores. Oxford Bulletin of Economics and Statistics, 73(1), 40–58. 10.1111/j.1468-0084.2010.00604.x

Campbell FA, Pungello EP, Kainz K, Burchinal M, Pan Y, Wasik BH, … Ramey CT (2012). Adult outcomes as a function of an early childhood educational program: An abecedarian project follow-up. Developmental Psychology, 48(4), 1033–1043. 10.1037/a0026644 [PubMed: 22250997]

Casey BM, Dearing E, Dulaney A, Heyman M, & Springer R (2014). Young girls' spatial and arithmetic performance: The mediating role of maternal supportive interactions during joint spatial problem solving. Early Childhood Research Quarterly, 29(4), 636–648. 10.1016/j.ecresq.2014.07.005

Craig L (2006). Does father care mean fathers share?: A comparison of how mothers and fathers in intact families spend time with children. Gender & Society, 20, 259–281. 10.1177/0891243205285212

Cvencek D, Meltzoff AN, & Greenwald AG (2011). Math-gender stereotypes in elementary school children. Child Development, 82(3), 766–779. 10.1111/j.1467-8624.2010.01529.x [PubMed: 21410915]

del Río MF, Susperreguy MI, Strasser K, & Salinas V (2017). Distinct influences of mothers and fathers on kindergartners' numeracy performance: The role of math anxiety, home numeracy practices, and numeracy expectations. Early Education and Development, 28, 939–955. 10.1080/10409289.2017.1331662

Duncan GJ, Kalil A, Mayer SE, Tepper R, & Payne MR (2009). The apple does not fall far from the tree In Bowles S, Gintis H, & Groves MO (Eds.), Unequal Chances: Family Background and Economic Success (pp. 23–79). Princeton, NJ: Princeton University Press 10.1515/9781400835492.23

Elliott L, & Bachman HJ (2018). How do parents foster young children's math skills?. Child Development Perspectives, 12(1), 16–21. 10.1111/cdep.12249

Foster TD, Froyen LC, Skibbe LE, Bowles RP, & Decker KB (2016). Fathers' and mothers' home learning environments and children's early academic outcomes. Reading and Writing, 29, 1845–1863. 10.1007/s11145-016-9655-7

Ge X, Natsuaki MN, Martin D, Leve LD, Neiderhiser JM, Shaw DS, … Reiss D (2008). Bridging the divide: Openness in adoption and post-adoption psychosocial adjustment among birth and adoptive parents. Journal of Family Psychology, 22(4), 529–540. 10.1037/a0012817 [PubMed: 18729667]

Grolnick WS, & Slowiaczek ML (1994). Parents' involvement in children's schooling: A multidimensional conceptualization and motivational model. Child Development, 65(1), 237–252. 10.2307/1131378 [PubMed: 8131650]

Gunderson EA, & Levine SC (2011). Some types of parent number talk count more than others: Relations between parents' input and children's cardinal-number knowledge. Developmental Science, 14(5), 1021–1032. 10.1111/j.1467-7687.2011.01050.x [PubMed: 21884318]

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Hart SA, Ganley CM, & Purpura DJ (2016). Understanding the home math environment and its role in predicting parent report of children's math skills. PLoS ONE, 11(12), 1–30. 10.1371/journal.pone.0168227

Hart S, Little C, and van Bergen E (2019). Nurture might be nature: Cautionary tales and proposed solutions. 10.31234/osf.io/j5×7g

Hart SA, Petrill SA, & Thompson LA (2010). A factorial analysis of timed and untimed measures of mathematics and reading abilities in school aged twins. Learning and Individual Differences, 20(2), 63–69. 10.1016/j.lindif.2009.10.004 [PubMed: 20161680]

Hart SA, Petrill SA, Thompson LA, & Plomin R (2009). The ABCs of math: A genetic analysis of mathematics and its links with reading ability and general cognitive ability. Journal of Educational Psychology, 101(2), 388–402. 10.1037/a0015115 [PubMed: 20157630]

Hartnedy SL, Mozzoni MP, & Fahoum Y (2005). The effect of fluency training on math and reading skills in neuropsychiatric diagnosis children: A multiple baseline design. Behavioral Interventions, 20(1), 27–36. 10.1002/bin.167

Heineck G, & Riphahn RT (2009). Intergenerational transmission of educational attainment in Germany: The last five decades. Jahrbücher Für Nationalökonomie Und Statistik, 229(1), 36–60. 10.1515/jbnst-2009-0104

Hertz T, Jayasundera T, Piraino P, Selcuk S, Smith N, & Verashchagina A (2007). The inheritance of educational inequality: International comparisons and fifty-year trends. The B. E. Journal of Economic Analysis and Policy, 7(2), 1935–1682. 10.2202/1935-1682.1775

Huntsinger CS, Jose PE, & Luo Z (2016). Parental facilitation of early mathematics and reading skills and knowledge through encouragement of home-based activities. Early Childhood Research Quarterly, 37(4), 1–15. 10.1016/j.ecresq.2016.02.005

Hyde JS (2005). The gender similarities hypothesis. The American Psychologist, 60(6), 581–592. 10.1037/0003-066X.60.6.581 [PubMed: 16173891]

Hyde JS, Fennema E, & Lamon SJ (1990). Gender differences in mathematics performance: a meta-analysis. Psychological Bulletin, 107, 139–155. 10.1037/0033-2909.107.2.139 [PubMed: 2138794]

Hyde JS, Lindberg SM, Linn MC, Ellis AB, & Williams CC (2008). Gender similarities characterize math performance. Science, 321(5888), 494–495. 10.1126/science.1160364 [PubMed: 18653867]

Jordan NC, Hanich LB, & Kaplan D (2003). A longitudinal study of mathematical competencies in children with specific mathematics difficulties versus children with comorbid mathematics and reading difficulties. Child Development, 74(3), 834–850. 10.1111/1467-8624.00571 [PubMed: 12795393]

Jordan NC, Kaplan D, Ramineni C, & Locuniak MN (2009). Early math matters: Kindergarten number competence and later mathematics outcomes. Developmental Psychology, 45(3), 850–867. 10.1037/a0014939 [PubMed: 19413436]

Kersey AJ, Braham EJ, Csumitta KD, Libertus ME, & Cantlon JF (2018). No intrinsic gender differences in children's earliest numerical abilities. NPJ Science of Learning, 3, 1–10. 10.1038/s41539-018-0028-7 [PubMed: 30631462]

Kovas Y, Haworth CMA, Dale PS, & Plomin R (2007a). The genetic and environmental origins of learning abilities and disabilities in the early school years. Monographs of the Society for Research in Child Development, 72(3), 1–144. 10.1111/j.1540-5834.2007.00439.x [PubMed: 17661895]

Kovas Y, Haworth CMA, Petrill SA, & Plomin R (2007b). Mathematical ability of 10-year-old boys and girls: Genetic and environmental etiology of typical and low performance. Journal of Learning Disabilities, 40(6), 554–567. 10.1177/00222194070400060601 [PubMed: 18064980]

Kovas Y, Voronin I, Kaydalov A, Malykh SB, Dale PS, & Plomin R (2013). Literacy and numeracy are more heritable than intelligence in primary school. Psychological Science, 24(10), 2048–2056. 10.1177/0956797613486982 [PubMed: 24002885]

Krinzinger H, Kaufmann L, Gregoire J, Desoete A, Nuerk H-C, & Willmes K (2012). Gender differences in the development of numerical skills in four European countries. International Journal of Gender, Science and Technology, 4(1), 62–77. Retrieved from: http://genderandset.open.ac.uk

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LeFevre J-A, Kwarchuk S-L, Smith-Chant BL, Fast L, Kamawar D, & Bisanz J (2009). Home numeracy experiences and children's math performance in the early school years. Canadian Journal of Behavioural Science, 41(2), 55–66. 10.1037/a0014532

Leve LD, Neiderhiser JM, Ganiban JM, Natsuaki MN, Shaw DS, & Reiss D (2019). The early growth and development study: A dual-family adoption study from birth through adolescence. Twin Research and Human Genetics, 1–12. 10.1017/thg.2019.66 [PubMed: 30661510]

Levin I, Levy-Shiff R, Appelbaum-Peled T, Katz I, Komar M, & Meiran N (1997). Antecedents and consequences of maternal involvement in children's homework: A longitudinal analysis. Journal of Applied Developmental Psychology, 18(2), 207–227. 10.1016/S0193-3973(97)90036-8

Lindberg SM, Hyde JS, Petersen JL, & Linn MC (2010). New trends in gender and mathematics performance: a meta-analysis. Psychological Bulletin, 136, 1123–1135. 10.1037/a0021276 [PubMed: 21038941]

Loehlin JC, Horn JM, & Willerman L (1989). Modeling IQ change: Evidence from the Texas Adoption Project. Child Development, 60(4), 993–1004. 10.2307/1131039 [PubMed: 2758892]

Luo D, Petrill SA, & Thompson LA (1994). An exploration of genetic g: Hierarchical factor analysis of cognitive data from the Western Reserve Twin Project. Intelligence, 18(3), 335–347. 10.1016/0160-2896(94)90033-7

Marceau K, De Araujo-Greecher M, Miller ES, Massey SH, Mayes LC, Ganiban JM, … Neiderhiser JM (2016). The perinatal risk index: Early risks experienced by domestic adoptees in the United States. PLoS ONE, 11(3), 1–11. 10.1371/journal.pone.0150486

Mazzocco MMM, Devlin KT, & McKenney SJ (2008). Is it a fact? Timed arithmetic performance of children with mathematical learning disabilities (MLD) varies as a function of how MLD is defined. Developmental Neuropsychology, 33(3), 318–344. 10.1080/87565640801982403 [PubMed: 18473202]

McGue M, Keyes M, Sharma A, Elkins I, Legrand L, Johnson W, & Iacono WG (2007). The environments of adopted and non-adopted youth: Evidence on range restriction from the Sibling Interaction and Behavior Study (SIBS). Behavior Genetics, 37(3), 449–462. 10.1007/s10519-007-9142-7 [PubMed: 17279339]

Melhuish EC, Sylva K, Sammons P, Siraj-Blatchford I, Taggart B, Phan MB, & Malin A (2008). Preschool influences on mathematics achievement. Science, 321, 1161–1162. 10.1126/science.1158808 [PubMed: 18755959]

Missall K, Hojnoski RL, Caskie GIL, & Repasky P (2015). Home numeracy environments of preschoolers: Examining relations among mathematical activities, parent mathematical beliefs, and early mathematical skills. Early Education and Development, 26(3), 356–376. 10.1080/10409289.2015.968243

Moore GA, & Neiderhiser JM (2014). Behavioral genetic approaches and family theory. Journal of Family Theory & Review, 6(1), 18–30. 10.1111/jftr.12028 [PubMed: 24678347]

Navarro MG, Braham EJ, & Libertus ME (2018). Intergenerational associations of the approximate number system in toddlers and their parents. British Journal of Developmental Psychology, 36(4), 521–539. 10.1111/bjdp.12234 [PubMed: 29377230]

Nomaguchi KM, Milkie MA, & Bianchi SM (2005). Time strains and psychological well-being: Do dual-earner mothers and fathers differ?. Journal of Family Issues, 26(6), 756–792. 10.1177/0192513X05277524

Petrill SA, Logan J, Hart SA, Vincent P, Thompson LA, Kovas Y, & Plomin R (2012). Math fluency is etiologically distinct from untimed math performance, decoding fluency, and untimed reading performance: Evidence from a twin study. Journal of Learning Disabilities, 45(4), 371–381. 10.1177/0022219411407926 [PubMed: 21890908]

Plomin R, DeFries JC, & Loehlin JC (1977). Genotype-environment interaction and correlation in the analysis of human behavior. Psychological Bulletin, 84(2), 309–322. 10.1037/0033-2909.84.2.309 [PubMed: 557211]

Plomin R, & DeFries JC (1985). A parent-offspring adoption study of cognitive abilities in early childhood. Intelligence, 9, 341–356. 10.1016/0160-2896(85)90019-4

Plug E, & Vijverberg W (2003). Schooling, family background, and adoption: Is it nature or is it nurture? Journal of Political Economy, 111(3), 611–641. 10.1086/374185

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Rhemtulla M, & Tucker-Drob EM (2012). Gene-by-socioeconomic status interaction on school readiness. Behavior Genetics, 42(4), 549–558. 10.1007/s10519-012-9527-0 [PubMed: 22350185]

Sacerdote BI (2002). The nature and nurture of economic outcomes. American Economic Review, 92(2), 344–348. 10.1257/000282802320191589

Scarr S, & Weinberg RA (1977). Intellectual similarities within families of both adopted and biological children. Intelligence, 1(2), 170–191. 10.1016/0160-2896(77)90003-4

Thompson LA, Detterman DK, & Plomin R (1991). Associations between cognitive abilities and scholastic achievement: Genetic overlap but environmental differences. Psychological Science, 2(3), 158–165. 10.1111/j.1467-9280.1991.tb00124.x

Thompson RJ, Napoli AR, & Purpura DJ (2017). Age-related differences in the relation between the home numeracy environment and numeracy skills. Infant and Child Development, 26(5), 1–13. 10.1002/icd.2019

Tucker-Drob EM, Rhemtulla M, Harden PK, Turkheimer E, & Fask D (2011). Emergence of a gene-by-socioeconomic status interaction on infant mental ability from 10 months to 2 years. Psychological Science, 22(1), 125–133. 10.1177/0956797610392926 [PubMed: 21169524]

Turkheimer E, Haley A, Waldron M, D’Onofrio B, & Gottesman II (2003). Socioeconomic status modifies heritability of IQ in young children. Psychological Science, 14(6), 623–628. 10.1046/j.0956-7976.2003.psci_1475.x [PubMed: 14629696]

van Bergen E, van der Leij A, & de Jong PF (2014). The intergenerational multiple deficit model and the case of dyslexia. Frontiers in Human Neuroscience, 8 10.3389/fnhum.2014.00346

Watts TW, Duncan GJ, Siegler RS, & Davis-Kean PE (2014). What’s past is prologue: Relations between early mathematics knowledge and high school achievement. Educational Researcher, 43(7), 352–360. 10.3102/0013189X14553660 [PubMed: 26806961]

Woodcock RW, McGrew KS, & Mather N (2001). Woodcock-Johnson III Tests of Achievement. Itasca, IL: Riverside Publishing Company 10.1007/springerreference_180722

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Research Highlights

- Birth parent mathematics achievement was positively related to adopted child mathematics achievement at age 7, indicating heritable influences on mathematics outcomes.
- Adopted child mathematics achievement was positively related to adoptive father, but not mother, mathematics achievement, indicating differential parent influences on mathematics outcomes.
- Findings indicated no significant gene-by-environment interactions on children's mathematics achievement in middle childhood.
- Results suggest the unique contributions of heritable *and* environmental influences on children's mathematics achievement in middle childhood.

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Table 1

Sample Descriptive Statistics

	Birth parents	Adoptive mothers	Adoptive fathers	Adopted children
Age at child birth, *M* (*SD*)	23.75 (5.82)	37.22 (5.20)	37.69 (5.24)	
Age at child placement (days), *M* (*SD*)				6.67 (12.46)
Race (%)				
Caucasian	69.2	91.4	90.2	57.6
African American	11.3	3.6	5.0	11.1
Hispanic/Latino	5.6	2.5	1.7	9.4
Multiethnic	6.7	1.1	1.1	20.8
Other	7.1	1.4	2.0	1.1
Median education level	HS degree	4-year college	4-year college	
Median annual household income ($US)	25,001 – 40,000	100,001 –125,000	125,001 –150,000	

Notes. Due to missing birth father data on ethnicity and race variables, birth parents' ethnicity is only representative of birth mothers.

Abbreviation: HS = high school.

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Table 2

Descriptive Statistics and Correlations for Mathematics Achievement in Linked-Family Triads

Mathematics Achievement	*M* (*SD*)	1	2	3	4
1 Birth parent	91.21 (12.46)	–			
2 Adoptive father	105.99 (12.27)	.07 (.03)	–		
3 Adoptive mother	105.92 (10.04)	.10 (.09)	.16* (.12)	–	
4 Adopted child	101.42 (15.05)	.13 (.18*)	.10 (.16*)	.11 (.11)	–

Notes. Raw correlations and residualized correlations (in parentheses) between main study variables are presented.

* $p < .05$.

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Table 3

Summary of Hierarchical Regression Analysis for Adopted Child Mathematics Achievement (*n* = 195)

	b	*SE*	*B*	R^2	*F* Change
Step 1				.03	6.40*
Birth parent MA	.21*	.08	.18*		
Step 2				.06	4.80*
Birth parent MA	.20*	.08	.17*		
Adoptive father MA	.15*	.07	.15*		
Step 3				.06	1.15
Birth parent MA	.19*	.08	.17*		
Adoptive father MA	.14*	.07	.15*		
Adoptive mother MA	.08	.07	.08		

Notes. $F(3, 191) = 4.16$, $p < .01$, $R^2 = .06$. Abbreviation: MA = Mathematics Achievement.

* $p < .05$.