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THE INTERGENERATIONAL TRANSMISSION OF MATHEMATICS ACHIEVEMENT: A GENETICALLY INFORMED STUDY

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ABSTRACT

Developmental psychologists aim to identify factors that influence children's mathematics development. However, most phenotypic work does not account for effects of heritable contributions to mathematics development. Because heritability influences mathematics achievement, understanding how genes *and* environments work together to impact mathematics achievement would better clarify the intergenerational processes that influence mathematics development within families. This dissertation, which is situated within a bioecological framework, used a prospective adoption design to disentangle genetic and environmental influences on mathematics achievement in middle childhood, and to test for transactional associations between these pathways on child mathematics achievement. First, this study examined whether there were direct effects of heritable factors, including birth mother math achievement and EF, and environmental factors, including various adoptive mother and father parenting behaviors, on adopted child mathematics achievement at age 7. Findings suggested that mathematics achievement is transmitted through a heritable factor, birth mother math achievement, but not through birth mother EF. Moreover, adoptive father but not mother, a) sensitive parenting behavior marginally predicted adopted child mathematics achievement and b) structured parenting behavior marginally predicted adopted child EF, suggesting that child cognitive outcomes are transmitted through environmental pathways from fathers, but not mothers. Second, this study examined associations between heritable influences and environmental factors and found that birth mother EF marginally predicted adoptive mother sensitive parenting at age 4.5, suggestive of an evocative gene-environment correlation. Taken together, these findings indicate that mathematics achievement is transmitted from parents to children via heritable pathways and paternal, but not maternal, parenting behaviors. This dissertation highlights the utility of using genetically-informed designs to understand etiological sources influencing mathematics achievement in childhood.

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Chapter 1. INTRODUCTION

Mathematics achievement is a strong predictor of children's future educational achievement (e.g., Duncan et al., 2007; Watts, Duncan, Siegler, & Davis-Kean, 2014) and has long-term implications for occupational earnings and success, health, and psychological well-being (Adkins & Noyes, 2016; Altonji, Blom, & Meghir, 2012; Murnane, Willet, & Levy, 1995; Rivera-Batiz, 1992; Reyna, Nelson, Han, & Dieckmann, 2009). For example, one study of a British cohort found that mathematics achievement at age 10 predicted future earnings more than 2 decades later, when participants were age 34 (Adkins & Noyes, 2016). The long-term consequences of mathematics achievement substantiate the need for a thorough understanding of the etiologies of childhood mathematics achievement: A clear understanding of the heritable *and* early life environmental factors that influence mathematics achievement, as well as the potential co-action between these factors, can clarify how mathematics achievement develops and potential targets for intervention on child mathematics learning.

The field of cognitive development, specifically the area of math development, has largely focused on the environmental mechanisms of how cognitive abilities impact children's mathematics achievement (Blevins-Knabe, Whiteside-Mansell, & Selig, 2007; Elliott & Bachman, 2018), despite evidence that children's mathematic achievement is both environmentally *and* genetically influenced (Kovas, Harlaar, Petrill, & Plomin, 2005). Additionally, genetically influenced child traits may evoke particular experiences in the home (or lack thereof), that may further influence mathematics achievement across childhood (Docherty, Kovas, & Plomin, 2011; Rutter, 2006). One such heritable trait, child executive function (EF), a set of higher-order cognitive skills, is thought to be particularly useful for learning mathematics (e.g., Bull, Espy & Wiebe, 2008; Passolunghi, Vercelloni, & Schadee, 2007; McClelland et al., 2014), and may thus help explain individual differences in child mathematics achievement in early elementary school. Without using genetically informed designs, we cannot understand *how* the rearing environment is impacting children's mathematics achievement and whether genetically-influenced traits such as EF contribute to mathematics development. Therefore, the current dissertation addresses this issue by including both environment (rearing environment) and genetic (heritable) influences on children's later mathematical achievement, allowing me to disentangle these influences and examine the underlying processes that impact children's math achievement.

Mathematics Development in the Early Elementary School Years

In infancy, children are sensitive to an array of basic mathematical concepts, including numerosity, ordinality, and counting (Geary, 1995). As children progress into toddlerhood and the preschool years, their skeletal knowledge and understanding of these concepts increases gradually, and then develops more rapidly during middle childhood (i.e., in primary school). At this time, children are expected to learn increasingly difficult mathematical concepts. By the end of kindergarten, for example, children should be proficient in counting objects, comparing sets of numbers, writing numerals, and have a conceptual understanding of the principles of addition and subtraction. In the years following kindergarten, children are taught to build on these foundational concepts in order to apply them to more sophisticated problem-solving strategies and to solve more difficult problems, including addition and subtraction (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). Thus, from early to middle childhood, children must synthesize and expand upon fundamental mathematics concepts to develop refined strategies and generalizable methods that facilitate mathematics achievement throughout their life.

The 2015 National Assessment of Educational Progress (NAEP) found that only 40% of fourth graders demonstrated adequate proficiency in mathematics. This is a critical concern as mathematics achievement has been shown to be highly stable across development (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004). For example, mathematics achievement in early elementary school strongly predicts mathematics achievement throughout middle childhood and even into adolescence (e.g., Duncan et al., 2007; Jordan et al., 2006; Watts et al., 2014). Moreover, associations between early and later achievement are stronger for mathematics than for other academic domains, including literacy (Duncan et al., 2007).

Given that empirical evidence highlights the powerful effects of early mathematics achievement on later mathematics achievement, it is important to understand the factors that influence early childhood mathematics learning. One such factor examined in the present study is parenting influences on child mathematics achievement, as recent empirical evidence demonstrates correlations between parenting and child mathematics achievement (Braham & Libertus, 2017). Additionally, given that some empirical work implies executive function (EF) is a prerequisite for learning mathematics (e.g., Clements, Sarama, & Germeroth, 2016), the current study examines effects of child EF on later child mathematics achievement in middle childhood.

Intergenerational Transmission of Mathematics Achievement

Intergenerational transmission refers to the notion that behavioral and psychological traits are transmitted, or *passed down*, from generation to generation within families. Developmental research mainly focuses on intergenerational transmission from biological parents to children, examining parent-child associations between the same (e.g., parent and child mathematics achievement) or somewhat different (e.g., parenting behavior and child mathematics achievement) constructs. It is typical for links between behavioral traits across generations to be attributed to environmental processes like parental socialization. Consistent with this, there has been a specific focus on understanding parent socialization behaviors during play-based experiences with children, experiences that are assumed to be both provided by and guided by parents.

Although very little empirical work has examined the intergenerational transmission of mathematics achievement, studies have examined the intergenerational transmission of general cognitive abilities, a construct which is highly correlated with mathematics achievement. Such work provides empirical evidence of positive associations between parent and child general cognitive abilities (Anger & Heineck, 2010; Björklund, Hederos Eriksson & Jänti, 2009; Black, Devereux, & Salvanes, 2009; Braham & Libertus, 2017; Brown, McIntosh, & Taylor, 2011; Heineck & Riphahn, 2009; Hertz et al., 2007; Plug & Vijverberg, 2003; Sacerdote, 2002). For example, in a series of studies, parent cognitive abilities explained a significant amount of variance in offspring cognitive abilities, even after controlling for educational attainment and family background (Anger, 2011; Anger & Heineck, 2010).

Studies that have investigated links between parent and offspring mathematics achievement have also found positive associations between the two (Braham & Libertus, 2017; Blevins-Knabe et al., 2007; Brown, McIntosh, & Taylor, 2011; Crane, 1996; Duncan, Kalil, Mayer, Tepper & Payne, 2005). For example, Brown and colleagues (2011) examined parent mathematics achievement in relation to offspring mathematics achievement at approximately age

7, and found a small, but significant, positive association between parent and child achievement. A more recent study found positive associations between parent and child achievement on various mathematics measures, assessed when children were between the ages of 5 and 8, even after controlling for parent beliefs about the importance of mathematics for their children (Braham & Libertus, 2017).

A small literature concerning mathematics development focuses on the effects of parenting practices and behaviors that may influence young children's mathematics learning in the early school years. In one such study, associations between parent mathematics anxiety and the mathematics achievement of their first- and second-grade children were examined while controlling for the amount of mathematics homework help parents provided (Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015). Parental help with homework moderated the associations between parent mathematics anxiety and child mathematics achievement. Parent mathematics anxiety was negatively associated with child mathematics achievement at the end of the school year, but only for parents who engaged in higher frequencies of math homework help with children. These results suggest that increased exposure to mathematics-relevant experiences with parents may facilitate the transmission of mathematics achievement from parents to children. This notion is consistent with other empirical studies that emphasize the importance of child exposure to mathematics-related experiences at home, and especially the power of parental support during these mathematics-specific experiences, for child mathematics achievement (e.g., LeFevre et al., 2009; Skwarchuk, Sowinski, LeFevre, 2014).

Although the majority of this work suggests that parents influence child mathematics achievement via socialization and other environmental mechanisms, it is extremely unlikely that mathematics achievement is transmitted from parents to offspring *only* via parenting behaviors. In fact, multiple mechanisms, including heritable influences, can transmit achievement from parents to children, and the effect of any one mechanism can depend on effects of other mechanisms. This study used a behavioral genetic design to examine heritable and environmental mechanisms linking early parenting behaviors and later child mathematics achievement.

The current study was guided by a bioecological framework (Bronfenbrenner & Ceci, 1994), which postulates that the child is impacted by multiple levels of environmental influences, from the microsystem, the child's most immediate environment (e.g., parents, home), to the more distant macro level influences (e.g., government policy, laws). In addition, this framework incorporates aspects of the child and suggests that *proximal processes*, or increasingly complex interactions between the developing child and the immediate environment, drive child development. This framework proposes that variation in inherited human traits depends on the joint function of heritable factors *and* on characteristics of the developing *person* and the environment (i.e., *contexts*), the nature of the outcome being studied, and the *time* period in which a child develops. Moreover, this framework supports the notion that heritable and environmental processes are interdependent, so that their impact on child development systematically varies by the factors mentioned above.

Guided by this framework, the current study considered two influences (heritable and parenting influences) and the interplay between these influences, on child mathematics achievement. Furthermore, because this framework emphasizes that characteristics of a child can impact the *process* of development (i.e., mathematics learning) as well as the *outcomes* of development (i.e., mathematics achievement), the study considered the effects of a particular child cognitive characteristic, child EF, on the association between parenting behavior and child mathematics achievement. By examining the roles of heritability, parenting behaviors, and child EF on child mathematics achievement, this study aimed to identify and delineate some of the proximal processes that underlie the effects of heritability and parenting behaviors. Finally, given the importance of development in this framework, effects of parenting and child EF were assessed in *early childhood*, a time when children spend a substantial amount of time with their parents, on subsequent mathematics achievement at age 7 (Bronfenbrenner & Ceci, 1994). The next sections discuss empirical evidence for the roles of parenting, heritability, and child EF on children's mathematics achievement, respectively.

Mathematics Achievement: Mechanisms of Transmission

Parenting as an environmental mechanism. Vygotsky's (1978) sociocultural framework of human development supports the notion of parents as primary agents of child development. This model suggests that interactions with experienced social partners (i.e., parents, other adults) influence cognitive development, with the help of *cultural tools* (e.g., algebraic symbols; language; counting; graphs). These tools mediate the transmission of information from parents to children. A central tenet of Vygotsky's theory is the *zone of proximal development* (ZPD), or the distance between what children are capable of achieving when solving a task on their own compared to what they are capable of achieving when solving a task with assistance from a more knowledgeable social partner. In the ZPD, parents can implicitly fine-tune their guidance to a level just beyond children's understanding, which requires children to rely on parents to successfully complete a task. Continued engagement in parent-guided interactions enables children to engage in more sophisticated activities than they could alone. As a result, children have access to more advanced knowledge than would be possible without parents, allowing children to gradually expand their cognitive thinking. This theory emphasizes the role of external social agents (e.g., parents and cultural learning materials) to trigger child development.

Empirical evidence. Guided by theories emphasizing parents' ability to maximize children's learning via parental resources (e.g., knowledge and cultural tools; Vygotsky, 1978), parenting influences are often examined in the context of the home environment, as the *home learning environment* is thought to include proximal (e.g., engaging in educational activities with children; parent-child discussions or interactions surrounding educational topics) and distal (e.g., providing learning materials to children) parenting practices and behaviors (Bradley & Caldwell, 1995). Parental influences in the home environment have been examined in various ways in order to capture the range of relevant math-related experiences children may have at home. One common strategy is to examine the frequency and quality of children's engagement in learning experiences at home, both with and without parents (Blevins-Knabe & Musun-Miller, 1996; Kleemans et al., 2012; LeFevre et al., 2009). The most common measure used to examine the quality of the home environment is the Home Observation for Measurement in the Environment inventory assessment (HOME; Bradley & Caldwell, 1984). This measure permits researchers to examine home environment characteristics and parenting practices that are considered important for child development and academic achievement, such as the types of play and reading materials available to children, amount of verbal stimulation parents provide to children, and maternal responsiveness and warmth. Findings from studies examining associations between the home environment and child academic achievement show that the quality of children's experiences in the general home learning environment (e.g., access to books; book reading; parent and child talk) encourages general cognitive ability and language development (e.g., Melhuish et al., 2008; Son & Morrison, 2010; Totsika & Sylva, 2004; Whitehurst & Lonigan, 1998).

A few studies have examined effects of the general home learning environment on child mathematics achievement, specifically (e.g., Blevins-Knabe et al., 2000; Bradley, Caldwell, & Rock, 1988; Crane, 1996; Melhuish et al., 2008). For example, after controlling for child, parent, preschool, and school characteristics, Melhuish and colleagues (2008) found that the quality of children's general home learning environment at ages 3 to 4 affected later mathematics achievement at age 10. In particular, effects of the home learning environment were significant for later mathematics achievement when quality of the environment was medium to high, but not low. An older study (Bradley et al., 1988) examined broad facets of the home learning environment when children were 6 months, 2 years, and 10 years, in association with children's mathematics achievement at age 10. The general home environment characteristics measured at each age included parent responsiveness and acceptance of the child, organization of the environment, parent provision of appropriate play materials, parental involvement, and the variety of stimulation in the home. The early childhood home environment (when children were 6 months) was not correlated with child mathematics achievement at age 10. In contrast, play provisions and parent involvement at age 2 were both significantly correlated with a composite measure of child achievement that included reading, language arts, and mathematics, but neither measure substantially correlated with mathematics achievement alone. The following variables of the home environment at age 10 were positively associated with child mathematics achievement at age 10: emotional climate of the home, parent involvement, and the overall home environment. Finally, parent involvement, family participation with the child, and the overall home environment, all measured at age 10, were positively associated with a composite measure of child achievement that included reading, language arts, and mathematics at age 10. Although only a handful of studies have specifically examined effects of the home learning environment on mathematics outcomes, their findings suggest positive effects of parenting and the rearing environment on mathematics achievement, at least some of the time.

More recently, studies have focused on understanding specific ways that parents can engage children's *mathematics* learning in the home environment. The *home numeracy environment* refers to a variety of mathematics-related activities and experiences that children engage in at home, both with and without parents (Blevins-Knabe & Musun-Miller, 1996; Saxe et al., 1987). As with prior work on the general home learning environment and with the home literacy environment, these experiences are often measured in two ways. First, researchers assess whether children engage in mathematics-related activities alone or with their parents (Blevins-Knabe & Musin-Miller, 1996). Solitary play activities thought to encourage children's mathematics thinking include reciting numbers, ordering and counting objects, while shared parent-child experiences are similar experiences, but include input from parents during the activity. For example, parents can help children to count objects, identify shapes, write numerals, or match various sets of objects with numbers. Second, researchers consider whether play activities are *formal*, or intend to directly teach mathematics to children (e.g., counting objects, writing numbers) or *informal* (i.e., unintentionally teach mathematics to children via implicit guidance; e.g., as card games; board games; cooking, carpentry, or craft activities that require measurement or quantifying objects) (LeFevre et al., 2009; Skwarchuk et al., 2014). For example, block-building activities are considered informal because the primary goal is to construct objects with the blocks even though, in doing so, they teach children to measure, count, and classify objects, to consider the spatial properties, shape, and dimension of objects, and to consider the spatial relationships between and within objects. By engaging in play and activities that require children to think about mathematical concepts and reasoning strategies, children are thought to experience gains in their mathematical reasoning, especially when parents provide feedback to support their children's goal-directed activities.

Studies examining the effects of child solitary play in construction-related activities have mostly found positive associations between child play in these activities and mathematics achievement across early childhood into adolescence. For example, Verdine and colleagues (2014a; 2014b) found child block construction skills at age 3 predicted mathematics achievement at ages 3 and 4. Associations between block construction skills and mathematics achievement were also found concurrently during middle childhood for 7-year-old children (Nath and Szücs, 2014). Moreover, longitudinal associations between preschoolers' block construction skills and children's mathematics achievement in late childhood and adolescence have been found in at least one study (Stannard, Wolfgang, Jones, and Phelps, 2001). These findings suggest that solitary child engagement in mathematics activities can influence mathematics achievement across development, at least into adolescence.

Many studies examining both child engagement in solitary play and in parent-child interactions with mathematics activities find positive associations between frequency of play engagement and children's early mathematics achievement (e.g., Kleemans, Peeters, Segers, & Verhoeven, 2012; LeFevre, Clarke, & Stringer, 2002; LeFevre et al., 2010). For example, higher frequencies of parental supports for adding simple sums was associated with Canadian and Greek 5-year-olds' symbolic number knowledge (LeFevre et al., 2010) and with achievement in kindergarten (Kleemans et al., 2012). Studies using experimental designs and naturalistic observation also provide evidence for links between mathematics play and mathematics achievement (Whyte & Bull, 2008; Gunderson & Levine, 2012; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010; Ramani & Siegler, 2008, Siegler & Ramani, 2008; Young-Loveridge, 2004).

Other studies, however, report mixed findings for associations between mathematics experiences and mathematics achievement (Blevins-Knabe et al., 2000; Blevins-Knabe & Musun-Miller, 1996; Huntsinger, Jose, Larson, Balsink Krieg, & Shaligram, 2000; LeFevre et al., 2002; Pan, Gauvain, Liu, & Cheng, 2006). In fact, numerous studies have failed to provide evidence of positive links between child engagement in mathematics activities, both with and without parents, and child mathematics achievement (e.g., Blevins-Knabe, Austin, Musin, Eddy, & Jones, 2000, Study 3; LeFevre et al., 2009; LeFevre et al., 2010; Missall et al., 2015; Pan et al., 2006). For example, Blevins-Knabe and colleagues (2000) found that the frequency of parent-reported child engagement in mathematics activities at home was not significantly associated with mathematics achievement in 4- to 6-year old children. One of the earliest studies (Blevins-Knabe & Musin-Miller, 1996) examined links between 33 mathematics-related items and children's mathematics achievement. Of the 33 items, 8 were associated with preschool-age children's mathematics performance (e.g., child mentioning number facts; parent or child saying the words 1, 2, 3). However, half of those items were positively correlated with achievement while the other half were negatively correlated with achievement (e.g., teaching the child to recite numbers; showing the child how to count). Similarly, Skwarchuck (2009) found positive associations between frequency of more complex mathematics activities in the home (e.g., comparing numbers, solving arithmetic problems) and child mathematics achievement for children ranging from about ages 4 to 5½, but negative associations between simpler mathematics activities in the home (e.g., counting, reciting numerals) and mathematics achievement. These inconsistencies limit the conclusions that can be drawn about the importance of mathematics-learning experiences at home and children's mathematics learning.

A number of explanations have been proposed to explain inconsistencies in the literature. First, differences in classifications of the *formal* and *informal home numeracy environment* may contribute to disparate findings across studies. A lack of consensus about exactly what should count as a mathematics activity in the literature leads some researchers to classify certain activities as math-related, and others to not include the same activities in their study at all. Studies that help researchers to clarify and validate the specific kinds of activities that can be considered relevant to mathematics learning can help researchers to develop more reliable measures to assess the quality of the rearing environment and parental behaviors that should be examined in relation to mathematics learning.

Another possibility is that other factors may help to explain associations between parental behaviors during mathematics-related activities and child mathematics achievement. For example, Dearing et al. (2012) measured maternal cognitive characteristics (i.e., spatial skills) along with 6-year-old girls' home learning environment, spatial skills, and their mathematics achievement. Maternal spatial skills directly predicted daughters' spatial skills and mathematics achievement, but these links were not mediated by the parent-provided rearing environment. A follow-up study (Casey, Dearing, Dulaney, Heyman, & Springer, 2014) analyzed the effects of maternal teaching behaviors during a mathematics activity on daughters' mathematics achievement, and found that a) the link between the quality of maternal teaching behaviors and daughter mathematics achievement was mediated by daughter spatial skills, b) the link between maternal spatial skills and child mathematics achievement was mediated by both maternal support and daughters' spatial skills, and c) the link between the general home learning environment and daughters' mathematics achievement was mediated by daughters' verbal and spatial skills. These findings suggest that associations between the home rearing environment and children's mathematics achievement are complex and that many factors are likely to be involved in addition to parenting behaviors. As mentioned above, one such factor is parents' own mathematics achievement, which may influence both parent behaviors and child mathematics achievement via heritable influences and other processes.

Finally, another possibility is that fathers, who, unlike mothers, are not often studied in the literature examining parenting and child mathematics achievement, may play a crucial role in children's mathematics development. Empirical work provides support for the notion that fathers may be just as, if not more, influential to child mathematics learning, as mothers (Borriello et al., in preparation).

The current study examined the effects of parenting behaviors during a joint parent-child interaction with a mathematics activity in early childhood on subsequent child mathematics achievement at age 7. In most of the studies mentioned thus far in this section, the home environment and relevant parenting factors are viewed as *environmental mechanisms* of transmission. Inherent in this assumption is that intergenerational transmission is unidirectional, from parents to children, with parent characteristics, behaviors, and beliefs transferring, intentionally or unintentionally, to children. This unidirectional perspective requires that parenting is independent of the child and acts an *external* force that imposes on children to shape their developmental outcomes. Using data from a parent-offspring adoption design, this study is one of few to examine whether links between parenting behaviors in the rearing environment and child mathematics achievement in the early school years remain even after accounting for heritable effects on mathematics achievement.

Maternal versus Paternal Parenting Behavior on Child Mathematics Achievement

The current dissertation also aims to examine whether direct and indirect effects of parenting behaviors for subsequent mathematics achievement depend on parent gender. Although the literature supports the notion that parenting influences can positively impact children's cognitive development, most empirical work examining this association has exclusively considered the effects of mothers and not fathers (Levin et al., 1997; Saracho & Spodek, 2008; Tracey & Young, 2002). Bronfenbrenner's ecological systems theory (1986) supports the notion that, as a member of the child's microsystem, fathers can play an integral role in children's cognitive development. Children's reciprocal and increasingly complex interactions with their fathers, just as with their mothers, are thought to spur proximal processes that can promote child mathematics development. To fully understand pathways towards mathematics learning and achievement, it is critical to consider contributions of fathers as well as mothers, especially for children in western, industrialized countries, where maternal and paternal roles are becoming increasingly similar, with both parents engaging in more caregiving responsibilities, including education-related activities (e.g., Fagan, Day, Lamb, & Cabrera, 2014).

Much empirical work investigating influences of mothers and fathers on child mathematics development has tended to use parent reports about child engagement in home-based mathematics activities. Some such work suggests that mothers spend more time than fathers with children in learning-based activities (Yeung, Sandberg, Davis-Kean, & Hofferth, 2001). For example, a recent study (Foster, Froyen, Skibbe, Bowles, & Decker, 2016) found that mothers were significantly more likely than fathers to play number games or do mathematics activities with children, and to provide children with math workbooks at home. Moreover, maternal involvement, as compared to father involvement, with children at home was a far stronger predictor of child achievement in math and reading. Despite this, father involvement was marginally significant ($\sim p = .06$) predictor of child achievement, even after accounting for effects of maternal involvement at home and maternal education level. Although the above evidence suggests that maternal parenting behaviors may have a larger impact on child achievement than father behaviors, it also suggests that paternal behaviors can contribute to child achievement to some degree, thus underscoring the importance of considering both mother and father influences on child mathematics achievement.

Similar to this study, Del Rìo, Susperreguy, Strasser, and Salinas (2017) recently examined concurrent links between mother and father engagement in mathematics activities with their 5-year-old children at home and children's mathematics achievement. No differences were observed in the amount of mathematics activities mothers and fathers engaged with children in at home. However, mothers, but not fathers, did report engaging more often in these activities with daughters than with sons, and mothers from low socioeconomic (SES) backgrounds reported engaging more frequently in these activities than mothers from high SES backgrounds. Moreover, maternal, but not paternal, engagement in mathematics activities with children was associated with higher child mathematics achievement in kindergarten. These findings suggest that maternal, as compared to paternal, parenting behaviors may play a larger role in children's mathematics learning.

Results from other studies comparing maternal and paternal parenting behaviors in relation to child mathematics outcomes are less consistent. Illustratively, a study by Sorariutta and Silvèn (2018) examined dyadic play interactions between parents, both fathers and mothers, and their 2-year-old children, and children's later spatial and mathematics outcomes at ages 3 and 4. Specifically, the researchers measured parent autonomy support and scaffolding behaviors during play with their children and, rather than measure children's spatial or mathematics achievement, child comprehension and production of spatial and mathematics language was instead measured. Overall, patterns between maternal and paternal behaviors and child outcomes were fairly similar, although some differences emerged. First, paternal autonomy support predicted child spatial language at age 4, but not at age 3, while maternal autonomy support did not predict spatial language at either age. Second, father scaffolding predicted child spatial language again at age 4, but not age 3, whereas maternal scaffolding predicted child spatial language at ages 3 and 4, Third, paternal autonomy support predicted child mathematics language at ages 3 and 4, whereas maternal autonomy support predicted mathematics language at only age 3, and not age 4. Finally, regardless of parent gender, scaffolding predicted child mathematics language at both ages. These findings suggest that effects of parent gender may also depend on the type of parenting behavior being examined, children's age, and the particular facet of mathematical reasoning children are learning.

A study by McBride, Dyer, Liu, Brown, and Hong (2009) examined maternal and paternal behaviors when children were about 3.5-years-old in relation to children's later school achievement at about 8-years-old, with parents' later school involvement as a potential mediator of this association. Early parenting behaviors were operationalized as the frequency of parental engagement in "child-centered activities", including joint book reading and game playing. Although neither mother nor father early parenting behaviors directly impacted children's later school achievement, indirect pathways to later school achievement differed by parent gender. For mothers, early parenting behaviors were linked with later maternal school involvement and then, subsequent child achievement. This indirect path to achievement in middle childhood was not significant for fathers, however. The above findings are in contrast to a behavioral genetics study (Borriello et al., in preparation) that finds significant effects of paternal, but not maternal, influences on child mathematics achievement at age 7, after taking into account heritable influences *and* maternal influences on the child. Because of these mixed findings and the scant, though increasing, literature examining the influences of *both* mothers and fathers on child mathematics achievement, future work should continue examining whether paternal influences substantially contribute to child mathematics development.

Finally, Jacobs et al. (2005) examined whether mother-child versus father-child engagement in mathematics-related activities at home differentially impacted children's later mathematics achievement in elementary school. Compared to fathers, mothers spent more time involved in mathematics and science activities with children in kindergarten, first, second, and third grades. After grade three, however, there were no significant differences in how much time mothers and fathers spent involved in mathematics activities with children. Moreover, both mothers and fathers reported decreases in their involvement with children in math and science activities as children got older. Finally, mothers reported buying more math- and science-related items for sons than for daughters, regardless of child's age or grade in school. Finally, the authors noted that maternal involvement in mathematics-related parenting behaviors with children significantly related to children's later mathematics achievement after controlling for children's own self-perceptions of mathematics ability and interest in mathematics. The researchers make no mention of whether findings were similar for fathers or whether paternal involvement was tested in a similar model, so it is unclear how father involvement in mathematics activities contributed to later child achievement in this dataset.

Rather than considering effects of fathers above and beyond effects of mothers, two studies (Ryan, Martin, & Brooks-Gunn, 2006; Martin, Ryan, & Brooks-Gunn, 2007) examined additive effects of mother and father influences on child mathematics achievement. The researchers videotaped separate mother-child and father-child interactions and coded the quality of supportive parenting behaviors (i.e., sensitive responses to children; cognitive stimulation; positive regard; intrusiveness; detachment) parents used with their 2-year-old children. First, the researchers found that mother-father pairs tended to display similar parenting behaviors, such that children with mothers whose behaviors classified as highly supportive also had fathers whose parenting behaviors classified as highly supportive. It was not as likely that mothers with parenting behaviors that classified as highly supportive were paired with a father whose behaviors were classified as unsupportive. Next, the researchers examined whether classifications of parenting behaviors at child age 2 predicted children's mathematics achievement at age 5. Results demonstrated that children with 2 supportive parents had the highest mathematics achievement, followed by children with only one supportive parent, and finally, children with no supportive parents. Finally, if children had only one supportive parent, they tended to score higher in mathematics achievement if that supportive parent was a father, rather than a mother. These findings highlight the importance of considering maternal and paternal early parenting behaviors in relation to child mathematics achievement and indicate that considering each parent's behavior in relation to the other's is even better than only considering one parent's behavior after accounting for the other's. Taken together, the studies described here provide evidence to suggest that fathers and mothers may facilitate children's mathematics development, and that it is necessary to study both of these influences if one is to understand the complex proximal processes that impact mathematics achievement.

Heritability: An Additional Mechanism of Intergenerational Transmission

A serious concern with interpreting parent effects on child outcomes as environmentally-driven processes is that similarities between parent and child traits can also be due to shared genes as most studies in this area examine genetically related family members. Given that parents and children share genes and parents provide the rearing environment, it is impossible to distinguish whether the associations between the rearing environment and child outcomes are due to rearing environmental influences, shared heritable effects, or synergies between the two (Plomin, DeFries, & Loehlin, 1977; Scarr & McCartney, 1983). Studies using genetically informed designs, including twin and adoption studies, can help to clarify pathways of intergenerational transmission by disentangling environmental and heritable effects.

Twin studies compare phenotypic similarities and differences in monozygotic and dizygotic twins-pairs to estimate degrees of environmental and heritable contributions to constructs like mathematics achievement. Twin studies indicate that heritable influences on mathematics achievement increase from early to middle childhood. For example, in early childhood (i.e., ages 2 to 4), shared environmental influences – nongenetic influences that account for twin similarity – on mathematics achievement are substantial, ranging from 61 to 70% of the total variance (Oliver et al., 2004; Oliver, Dale, & Plomin, 2005; Lemelin et al., 2007; Walker, Petrill, Spinath, & Plomin, 2003), while heritable influences contribute modest amounts of variance to mathematics achievement, approximately 20 to 30% of the total variance. In contrast, heritable influences are substantial across middle childhood, accounting for about 60 to 70% of the total variance in mathematics achievement from ages 7 to 10 (e.g., Alarcòn, DeFries, Light, & Pennington, 1997; Hart, Petrill, & Thompson, 2010; Hart, Petrill, Thompson, & Plomin, 2009; Kovas et al., 2013; Kovas, Haworth, Petrill, & Plomin, 2007; Luo, Petrill, & Thompson, 1994; Petrill et al., 2012; Thompson, Detterman, & Plomin, 1991; Walker et al., 2003). Conversely, the effects of shared environmental influences on mathematics achievement tend to be only modest from ages 7 to 10, accounting for about 6 to 12% of the variance in achievement (Kovas et al., 2007; Thompson et al., 1991).

Parent-offspring adoption designs provide a different approach to examining how environmental and heritable influences may work together to explain individual differences in child mathematics achievement. In this design, heritable influences are estimated via child associations with birth parents, who provide genes (and birth mothers provide prenatal environment) to the adopted child placed at or near birth, but do not provide rearing environment. Rearing environmental influences are estimated via child associations with genetically unrelated adoptive parents, who provide adopted children with their rearing environment. A key difference between parent-offspring adoption studies and twin studies is that in the parent-offspring study heritable effects are intergenerational in nature rather than estimated as a function of the similarities of twins of differing degrees of genetic relatedness.

A number of adoption studies that have examined general cognitive abilities, a construct that shares substantial overlap in its etiology with mathematics achievement (Alarcon, Knopik, & DeFries, 2000; Hart et al., 2009; Spinath et al., 2006), indicate stronger effects of heritable than rearing environmental influences on mathematics achievement (e.g., Horn, Loehlin, & Willerman, 1989; Scarr & Weinberg, 1983; Scarr, 1976; Wadsworth, DeFries, Fulker, & Plomin, 1995), but also evince modest effects of the rearing environment (Scarr, 1976). More recently, mathematics achievement in 7-year-old children could be explained by birth parent and adoptive father mathematics achievement, but not by adoptive mother mathematics achievement (Borriello et al., in prep). These findings stress that more genetically sensitive research, such as the current study, is needed to help clarify effects of various pathways towards mathematics achievement, as well as the potential effects of child and parent characteristics.

Gene-Environment Correlation: Understanding Child Effects on Parenting Processes

Although genetically informed studies can identify mechanisms of transmission, exactly how these processes transmit traits across generations remains unclear. One possibility is that child-evoked processes explain parent-child associations in mathematics achievement, such that children systematically elicit responses and input from their environment (i.e., parenting) due to characteristics they inherited from their parents (Plomin et al., 1977; Scarr & McCartney, 1983).

The notion that children construct and modify their own physical, social, and symbolic environments aligns with Bronfenbrenner's proposition that proximal processes are reciprocal and dynamic in nature. Children's characteristics are likely to at least partially account for how children interact with certain aspects of their environments, including parenting, suggesting that parenting effects on child outcomes may stem from heritable traits that influence child behavior and, indirectly, parental responsivity.

Gene-environment correlation (*r*GE) refers most simply to a correlation between genotype and the environment. Three types of *r*GE are typically described: passive, evocative, and active *r*GE (Plomin et al., 1977; Scarr & McCartney, 1983). Passive *r*GE is due to children sharing both their rearing environment and genes with biological parents, so that genes they inherit from parents also influence the environment they are raised in. Evocative *r*GE refers to instances when children's genetically influenced traits and characteristics evoke reactions from their environment (i.e. parents). Active *r*GE occurs when children select environments that are correlated with their genotype. Evocative and active gene-environment correlations echo Bronfenbrenner's proposition that dynamic transactions between an active individual, with particular inherited characteristics or traits, and their immediate environments, enable children to actualize their genetic potential. Gene-environment correlations can help to clarify how synergistic processes of development may unfold.

A few studies have examined parent- and child-driven effects on child cognitive abilities (Lugo-Gil & Tamis-Lemonda, 2014; Tucker-Drob & Harden, 2012). For example, one twin study (Tucker-Drob & Harden, 2012) found that, after controlling for child cognitive ability at age 2, parent cognitive stimulation at age 2 predicted later child reading ability at age 4.

Moreover, after controlling for child cognitive stimulation at age 2, children's cognitive ability predicted the degree of cognitive stimulation they received from parents at age 4. That is, children's early cognitive ability was linked to parenting behaviors at a later age through a heritable pathway. These findings emphasize the importance of both heritable and environmental processes associations between parents and children across development. Moreover, this work serves as evidence for the fact that genetically informed research can provide insight into the pathways that enable parental influences to influence child development.

Links between child EF and mathematics achievement. Although findings from genetically informed studies indicates that both parenting and mathematics achievement are heritable (e.g., Horwitz & Neiderhiser, 2015; Kovas et al., 2007), very little, if any, research to date has accounted for potential gene-environment correlations on associations between parent behaviors and child mathematics outcomes. With the use of genetically informed research, it is possible to clarify how environmental and heritable factors influence parent-child associations related to mathematics achievement.

This study aims to consider how EF, an inherited child trait, may influence child mathematics achievement. EF (Blair & Razza, 2007; McClelland et al., 2007), comprises a set of cognitive processes used in planning, information processing, and problem solving in goal-directed behaviors (Beck, Schaefer, Pang, & Carlson, 2011; Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Stuss & Benson, 1986). Similar to mathematical thinking, EF processes develop rapidly in early childhood (for reviews, see Diamond, 2002; Zelazo & Müller, 2002). Moreover, although EF is thought to help children develop cognitive processes necessary for learning in various academic domains (Anghel, 2010), EF is thought to be particularly useful for learning mathematics as compared to other academic domains (e.g., Bull, Espy & Wiebe, 2008; Passolunghi, Vercelloni, & Schadee, 2007; McClelland et al., 2014). Some researchers argue that EF processes are a prerequisite for learning mathematics, as these skills aid children in using and developing cognitive processes that support mathematical thinking (e.g., Clements et al., 2016), and for this reason, this study examines influences of EF in early childhood (measured at age 6) on children's subsequent mathematics achievement at age 7, after accounting for other potential factors of interest.

EF processes are thought to underlie various higher-order cognitive abilities, including mathematics (e.g., Bull et al., 2008; Clements et al., 2016; Passolunghi et al., 2007). Most studies of EF rely on Baddeley and Hitch's (1974, see also Baddeley, 1996; 2000) model of working memory, which proposes a *central executive system* that controls the flow of information to and from its three "slave systems," the phonological loop, which processes language-related information, the visual-spatial sketchpad, which processes visual-spatial information, and the episodic buffer, which offers temporary storage of information by converging information from the two other slave systems and long-term memory into a single episodic representation. By allocating resources to these systems, the central executive controls EF processes that facilitate cognitive tasks and is consequently thought to influence a wide range of cognitive skills, including mathematics. This notion is supported by empirical work. For example, visual-spatial skills are shown to relate to young children's counting ability, while visual-spatial skills and phonological skills appear to impact children's arithmetic in middle childhood, with stronger effects of visual-spatial strategies arithmetic in younger than in older children, and stronger effects of phonological strategies in older than younger children (Bull et al., 2008; Holmes &

Adams, 2006; McKenzie, Bull, & Gray, 2003). This link is further supported by evidence demonstrating children with low mathematics achievement tend to perform poorly on visual-spatial measures (McLean & Hitch, 1999; van der Sluis, van der Leij, & de Jong, 2005; White, Moffitt, & Silva, 1992).

More recently, the central executive has been further delineated into three component, distinct EFs: *attention shifting* or *cognitive flexibility*, *inhibitory control*, and *working memory* (WM) also referred to as *updating* (Baddeley, 1996; Baddely & Della Sala, 1996; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Attention switching is the ability to disengage from an irrelevant set of tasks and switch to a new, more relevant set of tasks. Inhibitory control is the ability to suppress an automatic or dominant response to engage in a more goal-appropriate response. Updating is the ability to process, encode, and evaluate incoming information that may be relevant for a cognitively demanding task and then use relevant new information to revise information held in memory.

Each subcomponent of the central executive is thought to differentially influence mathematics reasoning and achievement, although there are many inconsistencies in the literature about these differences and the degree to which each contributes to mathematics achievement across development. Attention shifting, for example, is thought to support mathematics achievement by facilitating individuals to switch between cognitive strategies and complete subsections of multistep mathematics problems (Andersson, 2008; van der Sluis, De Jong, & van der Leij, 2007). Children with higher attention switching capacities tend to have higher mathematics achievement than those with lower attention switching capacities (Bull et al., 2008; Bull, Johnston, & Roy, 1999; Bull & Scerif, 2001; McLean & Hitch, 1999; Zamarian et al., 2006). Other work has does not support this association, however (e.g., Blair & Razza, 2004; Epsy et al., 2004; van der Sluis, de Jong, & van der Leij, 2004). Similarly, some empirical work supports a link between inhibition and mathematics achievement in childhood (e.g., Blair & Razza, 2004; Bull et al., 1999; Bull & Scerif, 2001; Mazzocco & Kover, 2007; St Clair-Thompson & Gathercole, 2006), while other work does not (Bull & Scerif, 2001; Van der Sluis et al., 2004). WM is thought to have the strongest relation to mathematics achievement out of all of the three subcomponents of EF, as information from long-term memory must be recalled and manipulated as individuals reason through mathematics problems (Andersson, 2008). A number of studies provide evidence for the link between WM and mathematics achievement in childhood and later in life (Bull et al., 2008; Kroesbergen et al., 2009; Mabbott & Bisanz, 2008; Passolunghi et al., 2007; Passolunghi, Mammarella, & Altoè, 2008; Raghubar, Barnes, & Hecht, 2010; Schuchardt, Maehler, & Hasselhorn, 2008; Vukovic & Siegel, 2010). WM, or updating, appears to be particularly impartment for arithmetic (e.g., Passolunghi & Cornoldi, 2008; Passolunghi, Cargnelutti, & Pastore, 2014)

Findings from some studies suggest that both concurrent and longitudinal associations exist between EF processes and mathematics achievement (e.g., Alloway & Alloway, 2010; Alloway, Alloway, & Wootan, 2014; Blair, Protzko, & Ursache, 2011; Blair & Razza, 2007; Bull, Espy, Wiebe, Sheffield, & Nelson, 2011; Bull et al., 1999; Cerda, Im, & Hughes, 2014; McClelland et al., 2014; Ng, Tamis-LeMonda, Yoshikawa, & Sze, 2014). For example, Nath & Szùcs (2014) examined concurrent links between 7-year-olds' visuospatial memory, performance on a construction activity, and mathematics achievement. Results showed that visuospatial memory fully mediated the association between building block assembly skills and children's mathematics achievement. These findings suggest EF plays an important role in linking environmental input relevant to mathematics learning and achievement in mathematics. In a longitudinal study, Verdine, Irwin, Golinkoff, & Hirsh-Pasek (2014) found that preschoolers' EF and spatial skills predicted much of the variance (about 70%) in children's mathematics achievement one year later. Another study of preschoolers found that attention span predicted children's subsequent mathematics achievement in young adulthood, controlling for achievement and other variables at age 7 (McClelland, Acock, Ciccinin, Rhea, & Stallings, 2013). Finally, a recent meta-analysis (Jacob & Parkinson, 2015) consistently demonstrated an average correlation of 0.31 between EF and mathematics achievement regardless of child age (preschoolers, middle childhood, and adolescents), subcomponent of EF, or whether associations were concurrent or predictive. These findings imply that EF likely contributes substantially to children's mathematical learning and achievement in childhood.

Relevant to the present study, findings from phenotypic studies also indicate that there are bidirectional associations between EF and parenting behaviors (e.g. Bernier, Carlson, Deschênes, & Matte-Gagné, 2012; Bernier, Carlson, & Whipple, 2010; Bibok, Carpendale, & Müller, 2009; Hammond, Müller, Carpendale, Bibok, & Liebermann-Finestone, 2012; Hughes & Ensor, 2009; Rhoades et al., 2011; Roskam, Stievenart, Meunier, & Noël, 2014). For example, a longitudinal study found bidirectional associations between measures of parenting and child EF, both of which were assessed when children were 36 and 60 months (Blair, Raver, Berry, & FLP (2014). Specifically, parent responsiveness and sensitivity to children at age 3 predicted children's EF at age 5, even after accounting for levels of children's EF at age 3. Bidirectional associations were found between parental responsiveness and child EF, but not for parent sensitivity and child EF. Child EF at age 3 months predicted change in parental sensitivity but parental sensitivity at age 3 did not predict child EF at age 6. That is, early child EF prompted increases in *both* parental responsiveness and sensitivity, but, later levels of child EF depended on the levels of parenting behaviors children received early in life, with only parental responsiveness significantly influencing later child EF. These findings suggest that parent behaviors across early and middle childhood can have substantial positive effects on later child cognitive traits, but that these effects may vary depending on the type of parenting behavior children receive. Moreover, these findings support the notion that developmental processes are transactional in nature, such that early environmental experiences can shape child outcomes *and* that, over time, child traits can shape the environments in which they develop.

This study examined pathways from parenting to child EF and subsequently, children's mathematics achievement in order to uncover whether child EF, mediates the association between parenting behaviors and child mathematics achievement in middle childhood. In doing so, the study can clarify whether heritable pathways account for parent-driven effects on child mathematics achievement.

The Current Study

This study aims to expand on prior research in a number of ways. First, the proposed study uses data from the Early Growth and Development Study (EGDS; Leve et al., 2013), a longitudinal parent-offspring adoption sample. While most research examining effects of parenting on mathematics achievement conceptualizes parents as "determiners" of child's environment and mathematics-learning experiences, contemporary evidence indicates that parenting influences are far more complex. In addition to environmental factors, other factors, including both parents' and children's heritable characteristics influence both parenting behaviors and the experiences parents provide to children. The EGDS allows the heritable and environmental contributions to parent-child associations to be disentangled. Moreover, passive gene-environment correlation is eliminated by design because the adoptive parents are genetically unrelated to the adopted child, thus making it far less likely that the rearing environment is correlated with child genotype because the child shares genes with the parent(s) who provide their rearing environment. Very few studies, if any, have examined the influences of young children's mathematics-related experiences with parents using a genetically sensitive design. In addition, the proposed work contributes to the literature by using a longitudinal design to examine parenting effects in early childhood on mathematics achievement at age 7. This is useful because empirical studies mostly examine concurrent parent-child associations (Blevins-Knabe, 2016). Finally, we also considered whether child characteristics contribute to associations linking parenting behaviors and child mathematics achievement. These methodological choices enabled us consider the temporal order of parent and child influences on later child mathematics achievement, which helps to exactly how these processes influence mathematics achievement.

Conceptualizing Parenting in the Present Study

We chose to examine parenting practices and child EF in early childhood because theoretical and empirical work suggests that cognitive development is particularly malleable in early childhood (Bronfenbrenner & Ceci, 1994; Carlson, 2005; Garon, Bryson, & Smith, 2008) and because during this period children spend a substantial amount of time with their parents. We focused on behaviors including parental sensitivity, scaffolding, and autonomy support, given research indicating these parenting behaviors can influence young mathematics and EF development during structured parent-child activities (e.g., Bernier et al., 2010; Hammond et al., 2012; Karreman, van Tuijl, van Aken, and Dekovic, 2008). Vygotsky's sociocultural framework (1978) supports the notion that these specific parenting behaviors could benefit children's cognitive development, as sensitivity (e.g., warm and attentive parenting) and scaffolding (structuring the task) would likely support children's engagement with, enjoyment of, and learning during the task, while autonomy support would encourage children to become increasingly competent and independent while completing the task. We describe the parenting measures used in the present study in more detail in the method section.

Study Aims

As displayed in Figure 1.1, this dissertation had the following research aims: a) estimate the effects of heritable factors, parenting behaviors at child age 4.5, and child EF at age 6 on mathematics achievement at age 7, b) identify if parenting behaviors at child age 4.5 are influenced by heritable factors, c) whether it is through inherited child factors (EF) at age 6 that parenting behaviors at age 4.5 influence mathematics achievement at age 7.

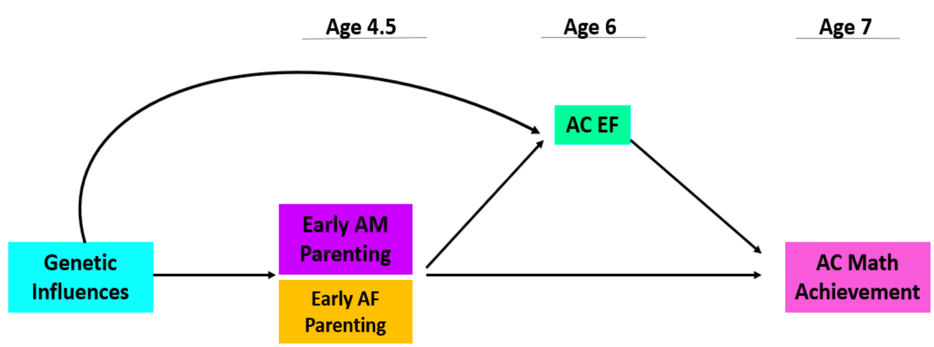

Figure **1.1**. Conceptual model of intergenerational transmission of child mathematics achievement at age 7. *Notes.* AM = adoptive mother; AF = adoptive father; AC = adopted child; EF = executive function.

Hypotheses

First I expected that heritable factors would positively associated with child outcomes (EF at age 6; mathematics achievement at age 7). Second, I expected to find direct effects of parenting behaviors. Specifically, for all adoptive parents, I expected to find positive associations between sensitive parenting and scaffolding behaviors at child age 4.5 on child EF at age 6 and child math achievement at age 7, and a negative association between directing and commanding behaviors at child age 4.5 and child math achievement at age 7. Third, given prior findings from genetically sensitive work (Borriello et al., in preparation), I expected both maternal and paternal parenting behaviors would impact child mathematics achievement, both directly and indirectly. However, I anticipated that, compared to adoptive mother parenting behaviors, adoptive father behaviors would be more strongly associated to child mathematics achievement. Because no previous work has used a genetically sensitive design to examine differential effects of mother and father parenting behaviors, we had no expectations for whether there would be differential effects of mother and father parenting on child EF after accounting for heritable influences. Fourth, I expected parenting to indirectly impact adopted child mathematics achievement through a heritable trait, adopted child EF. That is, I expected to that the associations from parenting behaviors to child mathematics achievement, mentioned above, would be mediated by child EF at age 6. Finally, I hypothesized that heritable effects (i.e., birth mother EF and mathematics achievement) of mathematics achievement and EF would evoke parenting behaviors at age 4.5, vis-à-vis some unmeasured child behaviors prior to age 4.5, suggesting that pathways to child outcomes (EF and math achievement) are driven by heritable influences.

Chapter 2. METHOD

Participants and Procedure

The current investigation included participants from Cohort I of the Early Growth and Development Study (EGDS; *N* = 361), a multisite, longitudinal study of adopted children and their birth and adoptive parents. Participants include birth parents, adoptive parents, and the child who was adopted at birth. Birth fathers participated in approximately 34% of the families from Cohort I. See Table 2.1 for additional descriptive information about the sample. Participants were recruited from 2003 to 2006 from 33 adoption agencies in 10 states throughout the Northwest, Southwest, and Mid-Atlantic, United States. Adoption agencies represent the full range of adoption agencies in the U.S., including agencies that were public, private, secular, religious, ones that favored open adoption and ones that favored closed adoptions. 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, *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 read or understand English at least at an eighth-grade level. Data were collected via home visit assessments and online questionnaires. The proposed study was based on three waves of the EGDS collected when children were 27, 54, and 84 months. For additional information about study recruitment procedures, sample, and assessment methods, see Leve et al. (2013).

Table **2.1**

Sample Descriptive Statistics

	BM	**AM**	**AF**	**AC**
Age at child birth, *M* (*SD)*	24.12 (5.89)	37.78 (5.50)	38.38 (5.78)	
Placement age (days), *M (SD*)				7.11 (13.28)
Race (%)				
Caucasian	71.1	91.4	90.2	57.6
African-American	11.4	3.6	5	11.1
Hispanic/Latino	6.7	2.5	1.7	9.4
Multiethnic	5	1.1	1.1	20.8
Other	5.8	1.4	2	1.1
Median education level	HS degree	4-year college	4-year college	
Median annual household income ($U.S.)	15,001 – 25,000	100,001 –125,000	100,001 –125,000	

Note. These demographics do not include same-sex couples. Abbreviation: HS = high school.

Abbreviations: BM = birth mother; AM = adoptive mother; AF = adoptive father; AC = adopted child.

Measures

Parenting behaviors. Parenting by adoptive parents was assessed when children were 4.5-years-old using interviewer impressions of parenting behaviors during two in-home teaching task activities, one with mothers and children, and one with fathers and children. In this task, the interviewer gave parent-child dyads a completed tangram puzzle to solve together. Mothers and fathers each tried to solve a puzzle with children, and each parent was given a different puzzle of similar difficulty so that children did not solve the same puzzle two times. Parents were told to have children make with rubber shapes by placing the pieces in the correct location on the board. Parents were instructed to try and let children solve the puzzle, but to offer any help that they thought was necessary. Parent-child dyads were given 3 additional pieces (2 squares and 1 half-circle) more than was needed to solve each tangram. After providing instructions, the interviewer indicated they would return in five minutes, slid the pieces off the board, and left the room.

For each parent, a single interviewer reported on three global parenting behaviors during the teaching task using a 4-point scale ranging from low (*very true)* to high (*not true*) with high scores indicating low levels of parenting behaviors. The first was a composite measure of *parental sensitivity* using two items, one measuring parents' level of insensitivity and lack of guidance during the task, and the other measuring parents' level of encouraging children to learn new cognitive strategies during the task. These items were averaged into one measure because they were moderately correlated (r = .47, p < .001). A second item measured how scaffolding parents made the task for children. Finally, a third parenting variable measured how directing and commanding parents were toward children during the task. See Table 2.2 for coding information.

Table **2.2**

Observer Ratings of Adoptive Parent Parenting Behaviors during the Teaching Task

Global Behaviors	**Brief Description**	**Rating**			
Sensitive Parenting	During Teaching Task, parent was sensitive/guided child.	1	2	3	4
	During Teaching Task, the child was encouraged to learn new cognitive strategies.	1	2	3	4
Scaffolding	During Teaching Task, parent structured the task to help the child complete it (scaffolding).	1	2	3	4
Directing and Commanding	During Teaching Task, parent was directing/commanding.	1	2	3	4

Notes. Interviewer ratings were coded from high to low, with 1 = very true; 2 = somewhat true; 3 = hardly true; 4 = not true.

Sensitive parenting was coded as a composite score of the two items described in this table.

Interviewers were trained to use the rating system prior to data collection. In line with the original measure (Weinrott, Reid, Bauske, & Brummett, 1981), interviewers were told that items should reflect their "impressions." The data represent an independent assessment by a single individual, which is similar to parent or teacher ratings from one individual. We chose to use this coding method because interviewer ratings from one individual have been associated with observational codes and child behavioral outcomes (Weinrott et al., 1981), and have been used in other published work (e.g., Capaldi et al., 2012).

We chose to examine adoptive mother and father parenting behaviors separately to examine the effect of each parent's behavior independent of the others, and because associations between the two were small. Finally, 20 adoptive parent pairs were in same-sex relationships (8 lesbian couples, 12 gay couples). To include these parents in the final sample, we averaged parenting behaviors across dyads and included average scores of lesbians as mother behaviors and those of gay men as father behaviors, while scoring the typical other-sex partner as missing scores. See Figure 3.1 for descriptive information and correlations between parenting variables.

EF. EF was assessed in birth mothers and in children using different, developmentally appropriate measures, both of which are described in detail in this section. Moreover, only birth mother EF was examined because associations between birth mother and father scores were not significant (r = -.01, p = .91), and because there was a high amount of missing data for birth father EF.

Birth mother EF. Birth mother EF was measured using a computerized *Color Stroop task*, in which, the color of a word interferes with its meaning (MacLeod, 1991), when children were 6-months-old. Participants were administered this task on a laptop computer. Participants were shown letter strings that spelled out the words “RED,” “BLUE,” “GREEN,” and “YELLOW” in color on the screen. In control trials, words and the colors they were shown in were congruent so that the meaning of the word displayed on the screen matched the color ink the word was printed in (e.g., the word “BLUE” was shown in blue ink). In interference trials, words and the colors they were shown in were non-congruent, so that the meaning of the word displayed on the screen did not match the color ink the word was printed in (e.g., the word “RED” was shown in blue ink). Participants indicated the font color in which the word was printed by pressing a key on the laptop’s keyboard, with “z” representing the font color red, “x” representing the font color green, “.” Representing the font color blue, and “/” representing the font color yellow. For each trial, the program marked whether participants key choices were correct or not. The mean reaction time for both the control and interference tasks were recorded. Then, we calculated a difference score between control and interference tasks by subtracting the percent of correct trials in the control task from the interference task. For this difference score, lower scores indicate lower levels of EF while higher scores indicate higher levels of EF.

Adopted child EF. Children's EF abilities were assessed at age 6 using a Go/NoGo task (Nosek & Banaji, 2001). In this task, children sat at in front of a laptop computer and were told they would play a computer game with shapes. Children were instructed to press a key on the keyboard every time a shape appeared on the computer screen except for when a circle appeared on the screen. Children were told to go as quickly as possible without making mistakes. The task included 84 trials (the first half were control trials) and took approximately 5 minutes to complete. After an incorrect response, children heard auditory performance feedback (i.e., a brief buzzing noise). Participants' percent of correct responses to non-control trials were recorded. Half of these trials required children to correctly press the button when children saw shapes other than a circle, and half of these trials required children to not press the button when a circle appeared.

Mathematics Achievement

Because we only examined birth mother EF, we chose to only examine birth mother mathematics achievement to maintain consistency across measures of heritable influences. Birth mothers and adopted children completed the Math Fluency subtest of the Woodcock Johnson III Tests of Achievement (Woodcock, McGrew, & Mather, 2001). This subtest measured the automaticity of basic arithmetic facts and required individuals to solve as many simple addition, subtraction, and multiplication problems, presented in written format, in three minutes. The mathematics fluency measure was administered to children at age 7 and to birth mothers when children were 4.5-years-old. Participants were told to work through the problems presented to them as quickly as possible without making any mistakes. Researchers used participants' W scores, a foundational metric of the W-J III test, in analyses.

Covariates

We included several control variables to ensure that variables unrelated to the study hypotheses would not confound study findings. Specifically, adoption openness, obstetric complications, parent education level, non-mathematics related cognitive abilities, and child biological sex.

Adoption openness. Adoption openness was included to control for potential similarities between birth parents and adopted children that are a result of contact or exchange of information between birth and adoptive parents. An assumption of the adoption design is that any similarities between birth parents and the adopted child are due to heritable influences (once prenatal influences are controlled for), and any contact between adoptive and biological parents could bias estimates of heritable influences and challenge this assumption. We measured openness in adoption when children were between 3 and 9 months to control for length of time since placement, which could potentially confound effects of adoption openness. Perceptions of openness in the adoption experience were measured using a composite of individual reports from birth mothers (obtained when the adopted child was 6 months), adoptive mothers, and adoptive fathers when the adopted child was 9 months old (for details, see Ge et al., 2008).

Obstetric complications. Perinatal complications (e.g., prenatal substance use, low birth weight) were considered as these complications may confound estimates of heritable and environmental influences on child outcomes (Eryigit-Madzwamuse, Baumman, Jaekel, Bartmann, & Wolke, 2014; Marceau et al., 2013, Seidman et al., 2000). We assessed birth mothers' obstetric complications during pregnancy and delivery with a composite measure incorporating self-report and medical records reports of birth mothers' pregnancy, delivery, and neonatal complications, including the use of drugs, alcohol, and tobacco, and exposure to toxins (Marceau et al., 2016).

Parent education level. We also considered parent education level for birth and adoptive parents because differences in parent education level and other proxies of SES contribute to disparities in the child's rearing environment (e.g., parenting behaviors) and children's cognitive outcomes (e.g., Dearden, Sibieta, & Sylva, 2011; Larson, Russ, Nelson, Olson, & Halfon, 2014). Parent education level was assessed on a scale from 1 to 7, with the lowest level of education receiving a score of 1 (less than a high school degree) and the highest level of education receiving a score of 7 (graduate program).

Other cognitive abilities. For birth parent and adopted child mathematics achievement, we controlled for non-mathematics related parent and child cognitive achievement using other measures of the W-J III, including (1) letter-word identification, (2) reading fluency, (3) basic reading skills, and (4) word attack. For birth mother and adopted child EF, we controlled for verbal IQ using standardized vocabulary subtest of the Wechsler Adult Intelligence Scale - III (WAIS) for mothers and the WPPSI for children, administered when children were approximately 4.5-years-old and 6-years old, respectively (Wechsler, 1997; 2002).

Child biological sex. To control for potential effects of child gender, we included child sex as a control variable with boys coded as 0 and girls coded as 1.

Chapter 3. RESULTS

Analytic Strategy

We conducted a series of pre-processing steps prior to data analyses. First, we examined descriptive statistics (e.g., means, standard deviations) for the main study variables. Variables with non-normative distributions were transformed to normalize data distributions. Next, we examined correlations between the main study variables and all potential covariates, and we regressed out any relevant covariates that were significantly associated with each main study variable. Finally, we standardized all main study variables to be able to compare variables on the same scale.

For the main data analyses, we conducted three sets of regression analyses to test whether adoptive mother and father parenting behaviors during a math activity with children at 4.5 years influenced children's subsequent mathematics achievement at age 7, while accounting for relevant heritable characteristics from birth mothers and accounting for adopted child EF at age 6. The three sets of regression analyses tested effects of adoptive mother and father sensitive parenting, scaffolding parenting, and directing and commanding behaviors, respectively.

Covariates

Birth mother variables. Both birth mother variables, math achievement and EF, were normally distributed. However, because birth mother math achievement was moderately to strongly correlated with birth mother education level ($r = .30$, $p \leq .001$), and with the word attack ($r = .44$, $p \leq .001$), letter-word identification ($r = .48$, $p \leq .001$), reading fluency ($r = .64$, $p \leq .001$), and the basic reading skills ($r = .50$, $p \leq .001$) subtests of the W-J III, we chose to residualize out these variables from math achievement scores. Birth mother EF was modestly correlated with obstetric complications (*r* = .15, $p \leq .01$), thus, this control variable was residualized out this from EF scores.

Adoptive mother variables. Natural log transformation was conducted on the adoptive mother sensitive parenting variable to correct for non-normal distribution; all other parenting variables for adoptive mothers were normally distributed. Because adoptive mother education level was correlated with scaffolding parenting (*r* = -.17, $p \leq .01$) and child biological sex was correlated with adoptive mother directing and correcting behaviors (*r* = .14, $p \leq .05$), we residualized these variables each variable, respectively.

Adoptive father variables. Similar to adoptive mother parenting variables, we conducted a natural log transformation on the adoptive father sensitive parenting variable to correct for non-normal distribution; all other parenting variables for adoptive fathers were normally distributed. We also residualized out adoptive father education level from adoptive father sensitive parenting (*r* = -.15, $p \leq .05$) and from adoptive father scaffolding parenting (*r* = -.20, $p \leq .001$). Adoptive father directing and correcting behaviors was standardized, as it did not correlate with any potential covariates.

Adopted child variables. Both adopted child variables, math achievement and EF, were normally distributed. However, because adopted child math achievement was substantially correlated with the word attack (*r* = .43, $p \leq .001$), letter-word identification (*r* = .54, $p \leq .001$), reading fluency (*r* = .58, $p \leq .001$), and the basic reading skills (*r* = .52, $p \leq .001$) subtests of the W-J III, we residualized out these variables from math achievement scores. Adopted child EF at age 6 was correlated with child biological sex (*r* = .20, $p \leq .001$), child EF measured at age 4.5 (*r* = .14, $p \leq .05$), and with child IQ at age 6 (*r* = .23, $p \leq .001$). Thus, we residualized out these control variables from child EF scores at age 6. Final models are reported in the following section.

Descriptive Analyses

Table 3.1 presents the means, standard deviations, and other descriptive analyses for the main study variables prior to regressing out any relevant covariates. Correlations among the main study variables after regressing out the relevant covariates are shown in Table 3.2.

Table **3.1**

Descriptive Statistics for Main Study Variables

Variables	*n*	*M* (SD)	Minimum	Maximum	Skewness	Kurtosis
Heritable influences						
1. BM Math achievement	325	513.26 (9.04)	488	532	-.02	-.19
2. BM EF	308	-123.12 (103.02)	-757.30	224.88	-.85	4.13
AM parenting behaviors at child age 4.5						
3. Sensitive parenting	271	.30 (.33)	.00	1.25	.61	-.76
4. Scaffolding	271	2.00 (1.02)	1.00	4.00	.83	-.38
5. Directing/commanding	271	3.48 (.78)	1.00	4.00	-1.27	.53
AF parenting behaviors at child age 4.5						
6. Sensitive parenting	262	.28 (.33)	.00	1.39	.86	-.18
7. Scaffolding	262	1.89 (1.00)	1.00	4.00	.98	-.11
8. Directing/commanding	262	3.39 (.84)	1.00	4.00	-1.07	-.05
AC characteristics at age 6						
9. EF	281	72.95 (12.14)	42.86	95.24	-.50	-.56
AC outcome at age 7						
10. Math achievement	288	484.56 (4.28)	477.00	498.00	.53	.29

Notes. Descriptives reflect raw values, but AM and AF sensitive parenting values were transformed. Abbreviations: BM = birth mother; EF = executive function; AM = adoptive mother; AF = adoptive father; AC = adopted child.

Table **3.2**

Bivariate Correlations among Study Variables

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Heritable influences										
1. BM Math achievement	-									
2. BM EF	.13*	-								
AM parenting at age 4.5										
3. Sensitive parenting	-.10	-.12	-							
4. Scaffolding	.03	-.10	.29**	-						
5. Directing/commanding	.05	-.05	-.26**	.04	-					
AF parenting at age 4.5										
6. Sensitive parenting	-.08	.06	.45**	.05	-.33**	-				
7. Scaffolding	.03	-.05	.12	.68**	.09	.22*	-			
8. Directing/commanding	.09	.05	-.17*	.09	.57**	-.34**	.10	-		
AC characteristics at age 6										
9. EF	-.00	-.12	.00	.03	.09	-.02	.10	.11	-	
AC outcome at age 7										
10. Math achievement	.14*	.01	-.04	.05	.03	.09	.05	-.07	.05	-

Notes. Correlations reflect variable scores after transforming and standardizing variables and residualizing out any relevant covariates. Abbreviations: BP = birth parent; BM = birth mother; EF = executive function; AM = adoptive mother; AF = adoptive father; AC = adopted child.

*$p < .05$., **$p < .01$

Primary Analyses

The primary aim of this study was to investigate both main and joint effects of heritable influences on math achievement (inferred from birth mothers' math achievement and EF) and adoptive parents' early parenting behaviors during mathematics-related activities that would influence children's mathematics achievement at age 7 both directly and indirectly, through adopted child EF at age 6.

We conducted three sets of hierarchical linear regression models to reach this goal, one examining effects of three different aspects of adoptive parents' parenting during a mathematics-relevant task: sensitive parenting, scaffolding, and directing and commanding behaviors (as well as examining effects of heritable influences and of adopted child EF at age 6). The six regression analyses in model 1 examined the effects of birth mothers' math achievement and EF, and adoptive mother and father sensitive parenting behavior on child EF at age 6 and child math achievement at age 7. The six regression analyses in model 2 examined the effects of birth mothers' math achievement and EF, and adoptive mother and father scaffolding behavior on child EF at age 6 and child math achievement at age 7. The six regression analyses in model 3 examined the effects of birth mothers' math achievement and EF, and adoptive mother and father directing and commanding behaviors on child EF at age 6 and child math achievement at age 7.

For each set of analyses, six regression models were tested. The first model tested direct effects of heritable influences (birth mother EF and math achievement), adoptive mother and father parenting behaviors at child age 4.5, and child EF at age 6, on child mathematics achievement at age 7. The second model tested direct effects of heritable influences (birth mother EF and math achievement) and adoptive mother and father parenting behaviors at child age 4.5 on adopted child EF at age 6. The third and fourth models tested direct effects of birth mother EF on adoptive mother and father parenting behaviors at child age 4.5, respectively, whereas the fifth and sixth models tested indirect effects, via some unmeasured child behavior, of birth mother math achievement on one adoptive mother and adoptive father parenting behavior, respectively.

For each regression analysis, we entered sets of predictors into the models stepwise the following pattern as relevant: Step 1 included heritable influences (i.e., birth mother mathematics achievement followed by birth mother EF), Step 2 included adoptive mother and father parenting behaviors at child age 4.5 (adoptive mother parenting behavior followed by adoptive father parenting behavior), and Step 3 included adopted child EF at age 6. All betas reported in the text below are standardized.

Model 1: Effects of Heritable Factors, Sensitive Parenting, and Child EF

In Model 1a, we tested direct effects of heritable influences, adoptive mother and father sensitive parenting at age 4.5, and adopted child EF at age 6 on AC math achievement at age 7. The overall model was not significant, $F(5, 219) = 1.71$, $p = .13$, $R^2 = .04$ (see Table 3.3). In Step 1, we found a significant positive effect for birth mother mathematics achievement, but no significant effect for birth mother EF, on adopted child mathematics achievement at age 7 [$b = .14$, $p = .04$; $b = -.01$, $p = .86$, respectively; $F(2, 219) = 2.09$, $p = .13$, $R^2 = .02$]. In Step 2, adoptive father, but not adoptive mother, sensitive parenting behavior marginally predicted adopted child mathematics achievement [$b = .14$, $p = .06$; $b = -.09$, $p = .22$, respectively; $F(4, 219) = 1.98$, $p = .10$, $R^2 = .04$]. In Step 3, adopted child EF at age 6 did not predict adopted child mathematics achievement at age 7 [$b = .05$, $p = .43$; $F(5, 219) = 1.71$, $p = .13$, $R^2 = .04$].

In Model 1b, we tested direct effects of heritable influences and adoptive mother and father sensitive parenting at age 4.5 on adopted child EF at age 6. The overall model was not significant, $F(4, 219) = 0.84$ $p = .50$, $R^2 = .02$ (see Table 3.4). In Step 1, there was a marginally significant effect of birth mother EF, but not mathematics achievement, on adopted child EF at age 6 [$b = -.13$, p .07; $b = .01$, $p = .85$, respectively; $F(2, 219) = 1.68$, $p = .19$, $R^2 = .02$]. In Step 2, neither adoptive mother nor father sensitive parenting significantly predicted adopted child EF [$b = -.01$, $p = .87$; $b = -.001$, $p = .99$, respectively; F(4, 219) = .84, $p = .50$, $R^2 = .02$].

Evocative *r*GE effects on sensitive parenting. We tested evocative effects of birth mother factors on adoptive parent sensitive parenting behavior with two regression analyses. In Model 1c, we tested effects of birth mother mathematics achievement on adoptive mother sensitive parenting at age 4.5. The overall model was not significant, $F(1, 243) = 2.27$, $p = .13$, $R^2 = .01$, as birth mother mathematics achievement did not predict adoptive mother sensitive at child age 4.5 ($b = -.10$, $p = .13$). In Model 1d, we tested effects of birth mother mathematics achievement on adoptive father sensitive parenting at age 4.5. The overall model was not significant, $F(1, 234) = 1.53$, $p = .22$, $R^2 = .01$, as birth mother mathematics achievement did not predict adoptive father sensitive parenting at child age 4.5 ($b = -.08$, $p = .22$). In Model 1e, we tested effects of birth mother EF on adoptive mother sensitive parenting at age 4.5. The overall model was marginally significant, $F(1, 230) = 3.07$, $p = .08$, $R^2 = .01$, with birth mother EF marginally predicting adoptive mother sensitive parenting at child age 4.5 ($b = -.12$, $p = .08$). In Model 1f, we tested effects of birth EF on adoptive father sensitive parenting at age 4.5. The overall model was not significant, $F(1, 222) = .79$, $p = .38$, $R^2 = .004$, as birth mother EF did not predict adoptive father sensitive parenting at child age 4.5 ($b = .06$, $p = .38$).

Table **3.3**

Regression Analyses for Model 1a: Effects of Heritable Influences, Sensitive Parenting at Child Age 4.5, and AC EF at Age 6 on AC Math Achievement at Age 7

	b	***SE***	***B***	***p***	R^2	***F* Change**
Step 1					.02	2.09
BM mathematics achievement	.14*	.07	.14*	.04		
BM EF	-.01	.07	-.01	.86		
Step 2					.04	1.85
BM mathematics achievement	.14*	.07	.14*	.04		
BM EF	-.03	.07	-.03	.65		
AM sensitive parenting	-.09	.08	-.09	.22		
AF sensitive parenting	.14	.08	.14	.06		
Step 3					.04	.63
BM mathematics achievement	.14*	.07	.14*	.04		
BM EF	-.03	.07	-.03	.72		
AM sensitive parenting	-.09	.08	-.09	.22		
AF sensitive parenting	.14	.08	.14	.06		
AC EF	.06	.07	.05	.43		

Notes. Betas are unstandardized. Abbreviations: BM = birth mother; EF = executive function; AM = adoptive mother; AF = adoptive father; AC = adopted child.

$F(5, 219) = 1.71$, $p = .13$, $R^2 = .04$.

*$p < .05$.

Table **3.4**

Regression Analyses for Model 1b: Effects of Heritable Influences and Sensitive Parenting Behavior at Child Age 4.5 on AC EF at Age 6

	b	***SE***	***B***	***p***	R^2	***F* Change**
Step 1					.02	1.68
BM mathematics achievement	.01	.07	.01	.85		
BM EF	-.12	.07	-.13	.07		
Step 2					.02	.02
BM mathematics achievement	.01	.07	.01	.86		
BM EF	-.12	.07	-.13	.07		
AM sensitive parenting	-.01	.08	-.01	.87		
AF sensitive parenting	-.001	.08	-.001	.99		

Notes. Abbreviations: BM = birth mother; EF = executive function; AM = adoptive mother; AF = adoptive father.

$F(4, 219) = 0.84$ $p = .50$, $R^2 = .02$

Model 2: Effects of Heritable Factors, Parental Scaffolding, and Child EF

In Model 2a, we tested direct effects of heritable influences, adoptive mother and father scaffolding at age 4.5, and adopted child EF at age 6 on AC math achievement at age 7. The overall model was not significant, $F(5, 219) = 1.07$, $p = .38$, $R^2 = .02$ (see Table 3.5). In Step 1, we found a significant positive effect for birth mother mathematics achievement, but no significant effect for birth mother EF, on adopted child mathematics achievement at age 7 [$b = .14$, $p = .04$; $b = -.01$, $p = .86$, respectively; $F(2, 219) = 2.09$, $p = .13$, $R^2 = .02$]. In Step 2, neither adoptive mother nor adoptive father scaffolding behavior predicted adopted child mathematics achievement [$b = .03$, $p = .75$ for each; $F(4, 219) = 1.20$, $p = .31$, $R^2 = .02$]. In Step 3, adopted child EF at age 6 did not significantly predict adopted child mathematics achievement at age 7 [$b = .05$, $p = .45$; $F(5, 219) = 1.07$, $p = .38$, $R^2 = .02$].

In Model 2b, we tested direct effects of heritable influences and adoptive mother and father scaffolding at age 4.5 on adopted child EF at age 6. The overall model was not significant, $F(4, 219) = 1.57$, $p = .18$, $R^2 = .03$ (see Table 3.6). In Step 1, there was a marginally significant effect of birth mother EF, but not mathematics achievement, on adopted child EF at age 6 [$b = -.13$, $p = .07$; $b = .01$, $p = .85$, respectively; $F(2, 219) = 1.68$, $p = .19$, $R^2 = .02$]. In Step 2, there was a marginal effect of adoptive father, but not mother, scaffolding behaviors on adopted child EF [$b = .16$, $p = .09$; $b = -.09$, $p = .32$, respectively; $F(4, 219) = 1.57$, $p = .18$, $R^2 = .03$].

Evocative *r*GE effects on scaffolding parenting. Finally, we tested evocative effects of birth mother EF on adoptive mother and father scaffolding behaviors by conducting two regression analyses. In Model 2c, we tested effects of birth mother mathematics achievement on adoptive mother scaffolding at age 4.5. The overall model was not significant, $F(1, 243) = .15$, p

= .70, R^2 = .001, as birth mother mathematics achievement was not a significant predictor of adoptive mother scaffolding behaviors at child age 4.5 (*b* = .03, *p* = .70). In Model 2d, we tested effects of birth mother mathematics achievement on adoptive father scaffolding at age 4.5. The overall model was not significant, $F(1, 234) = .15$, $p = .70$, R^2 = .001, as birth mother mathematics achievement was not a significant predictor of adoptive mother scaffolding behaviors at child age 4.5 (*b* = .03, *p* = .70). In Model 2e, we tested effects of birth mother EF on adoptive mother scaffolding at age 4.5. The overall model was not significant, $F(1, 230) = 2.36$, $p = .13$, R^2 = .01, as birth mother EF was not a significant predictor of adoptive mother scaffolding behaviors at child age 4.5 (*b* = -.10, *p* = .13). In Model 2f, we tested effects of birth EF on adoptive father scaffolding at age 4.5. The overall model was not significant, $F(1, 222)$ = .56, $p = .46$, R^2 = .003, as birth mother EF was not a significant predictor of adoptive father scaffolding parenting behaviors at child age 4.5 (*b* = -.05, *p* = .46).

Table **3.5**

Regression Analyses for Model 2a: Effects of Heritable Influences, Parental Scaffolding Behavior at Child Age 4.5, and AC EF at Age 6 on AC Math Achievement at Age 7

	b	***SE***	***B***	***p***	R^2	***F* Change**
Step 1					.02	2.09
BM mathematics achievement	.14*	.07	.14*	.04		
BM EF	-.01	.07	-.01	.86		
Step 2					.02	.32
BM mathematics achievement	.14*	.07	.14*	.05		
BM EF	-.01	.07	-.01	.92		
AM scaffolding behavior	.03	.09	.03	.75		
AF scaffolding behavior	.03	.09	.03	.75		
Step 3					.02	.56
BM mathematics achievement	.14*	.07	.14*	.05		
BM EF	.00	.07	.00	.10		
AM scaffolding behavior	.03	.09	.03	.72		
AF scaffolding behavior	.02	.09	.02	.82		
AC EF	.05	.07	.05	.45		

Notes. Abbreviations: BM = birth mother; EF = executive function AM = adoptive mother; AF = adoptive father; AC = adopted child.

$F(5, 219) = 1.07$, $p = .38$, $R^2 = .02$

*$p < .05$

Table **3.6**

Regression Analyses for Model 2b: Effects of Heritable Influences and Parental Scaffolding Behavior at Child Age 4.5 on AC EF at Age 6

	b	***SE***	***B***	***p***	R^2	***F* Change**
Step 1					.02	1.68
BM mathematics achievement	.01	.07	.01	.85		
BM EF	-.12	.07	-.13	.07		
Step 2					.03	1.46
BM mathematics achievement	.01	.07	.01	.86		
BM EF	-.12	.07	-.13	.07		
AM scaffolding behavior	-.09	.09	-.09	.32		
AF scaffolding behavior	.15	.09	.16	.09		

Notes. Abbreviations: BM = birth mother; EF = executive function; AM = adoptive mother; AF = adoptive father.

$F(4, 219) = 1.57$, $p = .18$, $R^2 = .03$

Model 3: Effects of Heritable Factors, Parent Directing and Commanding, and Child EF

In Model 3a, we tested direct effects of heritable influences, adoptive mother and father directing and commanding parenting behaviors at age 4.5, and adopted child EF at age 6 on AC math achievement at age 7. The overall model was not significant, $F(5, 219) = 1.55$, $p = .18$, $R^2 = .04$ (see Table 3.7). In Step 1, we found a significant positive effect for birth mother mathematics achievement, but no significant effect for birth mother EF, on adopted child mathematics achievement at age 7 [$b = .14$, $p = .04$; $b = -.01$, $p = .86$, respectively; $F(2, 219) = 2.09$, $p = .13$, $R^2 = .02$]. In Step 2, neither adoptive father nor adoptive mother directing and commanding parenting behaviors predicted adopted child mathematics achievement [$b = .10$, $p = .25$; $b = -.13$, $p = .11$, respectively; $F(4, 219) = 1.73$, $p = .15$, $R^2 = .03$]. However, the beta for adoptive father directing and commanding behaviors was quite large. In Step 3, adopted child EF at age 6 did not significantly predict adopted child mathematics achievement at age 7 [$b = .06$, $p = .36$; $F(5, 219) = 1.55$, $p = .18$], $R^2 = .04$.

In Model 3b, we tested direct effects of heritable influences and adoptive mother and father directing and commanding parenting behaviors at age 4.5 on adopted child EF at age 6. The overall model was not significant, $F(4, 219) = 1.66$, $p = .16$, $R^2 = .03$ (see Table 3.8). In Step 1, there was a marginally significant effect of birth mother EF, but not mathematics achievement, on adopted child EF at age 6 [$b = -.13$, p .07; $b = .01$, $p = .85$, respectively; $F(2, 219) = 1.68$, $p = .19$, $R^2 = .02$]. In Step 2, neither adoptive mother nor father directing and commanding behaviors significantly predicted adopted child EF [$b = .03$, $p = .77$; $b = .11$, $p = .20$, respectively; $F(4, 219) = 1.66$, $p = .16$, $R^2 = .03$].

Evocative *r*GE effects on parent directing and commanding behaviors. Finally, we tested evocative effects of birth mother EF on adoptive mother and father directing and commanding parenting behaviors by conducting two regression analyses. In Model 3c, we tested effects of birth mother mathematics achievement on adoptive mother directing and commanding parenting behaviors at age 4.5. The overall model was not significant, $F(1, 243) = .49$, $p = .49$, $R^2 = .002$, as birth mother mathematics achievement was not a significant predictor of adoptive mother directing and commanding parenting behaviors at child age 4.5 ($b = .05$, $p = .49$). In Model 3d, we tested effects of birth mother mathematics achievement on adoptive father directing and commanding parenting behaviors at age 4.5. The overall model was not significant, $F(1, 234) = 1.96$, $p = .16$, $R^2 = .01$, as birth mother mathematics achievement was not a significant predictor of adoptive father directing and commanding parenting behaviors at child age 4.5 ($b = .09$, $p = .16$). In Model 3e, we tested effects of birth mother EF on adoptive mother directing and commanding parenting behaviors at age 4.5. The overall model was not significant, $F(1, 230) = .66$, $p = .42$, $R^2 = .003$, as birth mother EF was not a significant predictor of adoptive mother sensitive parenting behaviors at child age 4.5 ($b = -.05$, $p = .42$). Finally, in Model 3f, we tested effects of birth EF on adoptive father directing and commanding parenting behaviors at age 4.5. The overall model was not significant, $F(1, 222) = .64$, $p = .43$, $R^2 = .003$, as birth mother EF was not a significant predictor of adoptive father directing and commanding parenting behaviors at child age 4.5 ($b = .05$, $p = .43$).

Table **3.7**

Regression Analyses for Model 3a: Effects of Heritable Factors, Directing and Commanding Behaviors at Age 4.5, and AC EF at Age 6 on AC Math Achievement at Age 7

	b	***SE***	***B***	***p***	R^2	***F* Change**
Step 1					.02	2.09
BM mathematics achievement	.14*	.07	.14*	.04		
BM EF	-.01	.07	-.01	.86		
Step 2					.03	1.35
BM mathematics achievement	.15*	.07	.15*	.03		
BM EF	.00	.07	.00	.10		
AM directing and commanding	.10	.08	.10	.25		
AF directing and commanding	-.13	.08	-.13	.11		
Step 3					.04	.85
BM mathematics achievement	.15*	.07	.15*	.03		
BM EF	.01	.07	.01	.91		
AM directing and commanding	.09	.08	.09	.26		
AF directing and commanding	-.14	.08	-.14	.09		
AC EF	.06	.07	.06	.36		

Notes. Abbreviations: BM = birth mother; EF = executive function AM = adoptive mother; AF = adoptive father; AC = adopted child.

$F(5, 219) = 1.55$, $p = .18$, $R^2 = .04$

*$p < .05$

Table **3.8**

Regression Analyses for Model 3b: Effects of Heritable Influences and Directing and Commanding Parenting Behaviors at Child Age 4.5 on AC EF at Age 6

	b	***SE***	***B***	***p***	R^2	***F* Change**
Step 1					.02	1.68
BM mathematics achievement	.01	.07	.01	.85		
BM EF	-.12	.07	-.13	.07		
Step 2					.03	1.64
BM mathematics achievement	.003	.07	.003	.97		
BM EF	-.13	.07	-.13	.06		
AM directing and commanding	.02	.08	.03	.77		
AF directing and commanding	.10	.08	.11	.20		

Notes. Abbreviations: BM = birth mother; EF = executive function; AM = adoptive mother; AF = adoptive father.

$F(4, 219) = 1.66$, $p = .16$, $R^2 = .03$

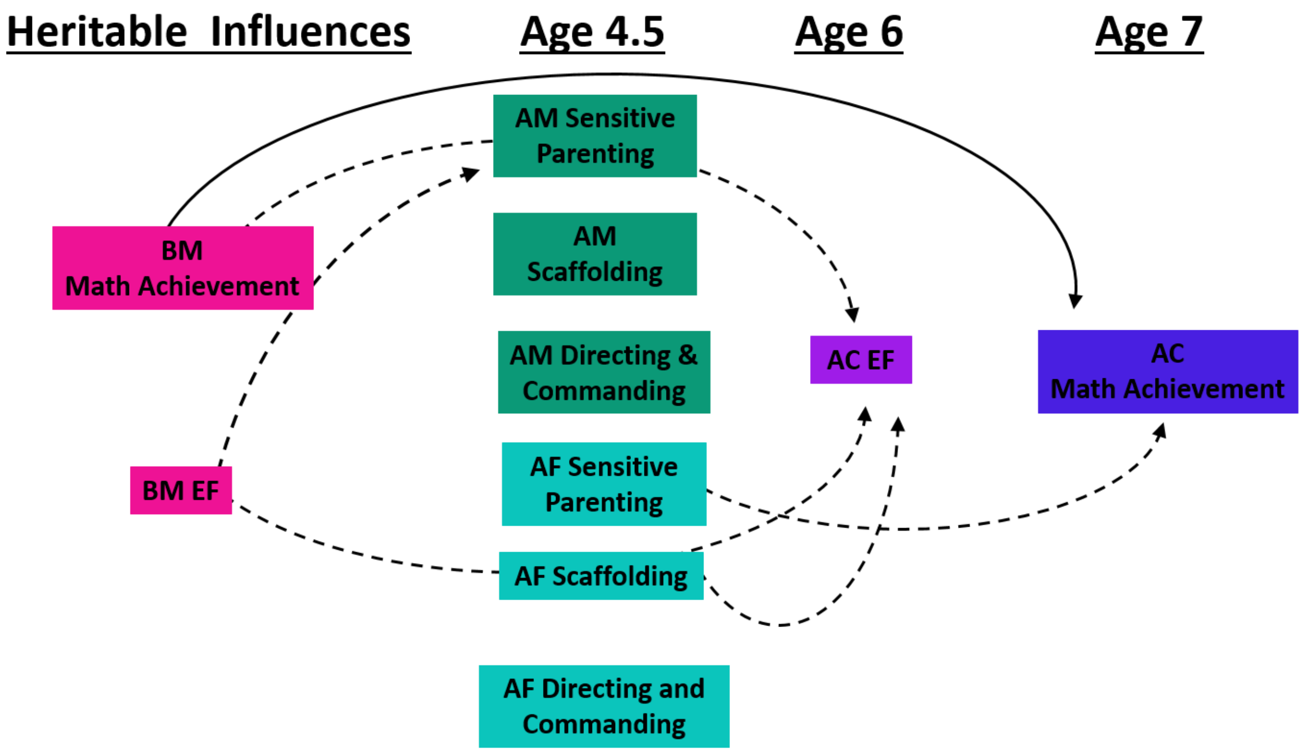

Figure 3.1. This conceptual model illustrates results across the entire study, demonstrating effects of heritable, adoptive mother and father sensitive parenting, structured parenting, and directing and commanding behaviors, and influences of adopted child EF at age 6 on adopted child mathematics achievement at age 7.

Notes. BP = birth parent; BM = birth mothers; AM = adoptive mothers; AF = adoptive fathers AC = adopted child; EF = executive function.

Black, solid lines indicate significant (standardized) betas at the p $\leq$ .05 level. Black, dashed lines indicate marginal (standardized) betas at the p $\leq$ .10 level. Gray, dashed lines indicate insignificant (standardized) betas.

Chapter 4. DISCUSSION

Summary of the Present Findings

The main goals of the present study were to clarify the processes through which parents influence child mathematics achievement and examine whether the various intergenerational processes driving this achievement are interdependent. We achieved these goals using a prospective longitudinal adoption design, which enabled us to examine the unique contributions of, and transactions between, heritable effects, mother and father parenting, and child EF on mathematics achievement in middle childhood. Consequently, this study was able to address a severe limitation of previous studies, the lack of regard for heritable contributions to correlations between parent and child mathematics achievement. The present findings demonstrated that both heritable and environmental factors contribute to mathematics achievement in middle childhood, but these findings were not perfectly aligned with our hypotheses. After briefly summarizing the findings, this discussion addresses discrepancies between expected results and the study findings, study strengths, potential directions for future research, and study limitations.

The first hypothesis tested whether there were direct effects of heritable factors on child outcomes. We found partial support for this hypothesis. We observed significant associations between birth mother and adopted child EF and between birth mother and adopted child mathematics achievement. These findings fit well with previous research examining heritable effects on child EF and child mathematics achievement (e.g., Borriello et al., in preparation; Leve et al., 2013; Plomin & Kovas, 2005), and suggest that the heritable effects between biological parents on their child account for similarities between parent and offspring mathematics achievement and EF. Contrary to our hypothesis, we did not find associations between birth mother EF and child mathematics achievement and between birth mother mathematics achievement and child EF. We will discuss this discrepancy in the section below.

The second hypothesis tested for direct effects of parenting behaviors on child math achievement such that as levels of sensitive parenting and parental scaffolding behaviors increased in parents, later child mathematics achievement would be higher, and that as levels of parent directing and commanding behaviors increased, later child mathematics achievement would be lower. We only found evidence for two marginal effects of parenting at 4.5 years on child math achievement at age 7, and for adoptive fathers *only* (hypothesis 3). First, contrary to our hypotheses, we found a *negative* association between paternal sensitive parenting and child mathematics achievement, such that lower levels of father sensitive parenting were related to higher levels of child mathematics achievement. Second, contrary to our hypotheses, we found a *positive* association between paternal directing and commanding behaviors and child math achievement, such that higher levels of paternal directing and commanding behaviors were associated with higher levels of child mathematics achievement. In a later portion of this section, we give explanations for these associations, which were not in the expected direction. Moreover, we comment on our lack of significant parenting findings and on significant parenting effects for adoptive fathers, but not mothers.

The fourth hypotheses tested whether a heritable child trait, EF, mediated the association between parenting behaviors at age 4.5 and child math achievement at age 7. However, almost no correlations were observed between parenting and child EF. The one exception, contrary to our hypotheses, was a negative association between adoptive father scaffolding behaviors at age

4.5 and child EF at age 6, such that higher levels of father scaffolding behaviors were related to lower levels of child EF. However, child EF at age 6 did not correlate with child mathematics achieve at age 7. Thus, we found no indirect effects of early parenting on mathematics achievement at age 7. The fifth and final hypothesis tested for evocative gene-environment correlations between heritable factors (birth mother EF and mathematics achievement) and adoptive mother and father parenting behaviors. The only relevant association we found was a positive association between birth mother EF and adoptive mother sensitive parenting at age 4.5. Although we only found partial support for a few of our hypotheses, these findings nonetheless underscore the importance of using genetically sensitive designs to investigate the etiological factors that influence children's mathematics learning and achievement. We elaborate on the study results and their implications below.

Direct Heritable Effects on Math Achievement and EF

To the best of our knowledge, this is one of extremely few studies to consider whether multiple heritable factors contribute to variation in mathematics achievement at age 7. In the present study, we considered the direct effects of two heritable influences on child EF, birth mother EF and birth mother mathematics achievement.

First, we found a marginal, positive association between birth mother EF and child EF, indicating a heritable etiology of EF (inhibitory control) in early to middle childhood. This evidence for a heritable effect was expected, given that EF is highly heritable in childhood (Groot, de Sonneville, Stins, & Boomsa, 2004; Lemery-Chalfant, Doelger, & Goldsmith, 2008; Polderman et al., 2007). Second, we found a positive association between birth mother and adopted child mathematics achievement. This finding is also in line with empirical work investigating the etiology of mathematics achievement in childhood (e.g., Plomin & Kovas, 2005).

Contrary to our hypotheses, however, we did not find associations between birth mother mathematics achievement, and child EF at age 6, and we did not find associations between birth mother EF and child mathematics achievement at age 7. A potential explanation for these insignificant heritable effects is that the proportion of variance that birth mother EF explains in adopted child EF may share substantial overlap with the variance explained by birth mother mathematics achievement, and similarly, there is likely genetic covariance between contributions of birth mother EF and mathematics achievement on child mathematics achievement. This shared covariance between phenotypic measures of birth mother EF and mathematics achievement is likely due to an underlying genetic factor that influences both EF and math achievement in birth mothers.

Empirical work examining whether common heritable and environmental factors are responsible for links between mathematics achievement and EF would help elucidate correlations between math and EF. However, the literature examining the etiologies of EF and mathematics achievement are largely separate. One recent study (Lukowski et al., 2014) investigated the genetic and environmental etiology underlying mathematics achievement and working memory, a subcomponent of EF. The authors found that substantial covariance exists between heritable influences on children's mathematics achievement and EF, with additive genetic influences accounting for about 89% of the correlation between WM and mathematics. Because this study examined WM, a different subcomponent of EF than the present study, future work is needed to confirm whether overlap exists between the heritable and environmental factors that influence other facets of children's EF, including inhibitory control, and mathematics achievement. We consequently suggest that some unspecified and unmeasured genetic variant that is common to EF and mathematics achievement, but also independent of general cognitive ability (e.g., Alarcòn et al., 2000; Hart et al., 2009; Kovas et al., 2005) is likely what results in birth mother characteristics' influence on child EF and child mathematics achievement.

The notion that mathematics achievement is influenced by some general genetic factor that influences a number of cognitive domains is in line with the *generalist genes* hypothesis, which states that a single set of genes (i.e., general heritable factor), is responsible for heritable effects on a variety of cognitive abilities (Plomin & Kovas, 2005). That is, a second reason that there may not have been associations between birth mother EF and child math achievement and between birth mother math achievement and child EF is because of a more general genetic factor, or set of genes, that accounts for variation between multiple cognitive domains, including EF and mathematics achievement. Future studies should examine whether inhibition and other components of EF share genetic overlap with various measures of mathematics achievement, rather than just with mathematics fluency, even beyond overlap with general genetic mechanisms. This would help clarify whether there is shared genetic etiology between EF components and mathematics domains, and consequently help explain variation in both traits.

One final potential explanation for the lack of association between birth mother EF and child mathematics achievement is that the measure used to assess birth mothers' EF did not capture aspects of EF that are more strongly linked with mathematics achievement. The Computerized Stroop task (Stroop, 1935) was used to assess birth mother EF, because the task requires participants to engage in color comparisons rather than numerical comparisons.

Empirical work by Bull and Scerif (2001) support this possibility, as they found a significant relationship between mathematics achievement and scores on an inhibition task requiring attention to numerical information, but no relationship between mathematics achievement and inhibition when participants had to attend to the color of stimuli on the color Stroop task. Moreover, the type of mathematics problems administered to children with the Woodcock-Johnson III were rather straightforward. Children simply had to solve addition, subtraction, and multiplication problems as quickly as possible. It may be that by age 7, simple arithmetic problems such as these require less active reasoning or use of EF skills and more retrieval of factual knowledge from long-term memory. Thus, it is possible this link would have been present had we used a different measure to capture birth mother EF, such as working memory, or had we used a more complex measure of mathematics reasoning, like the Applied Problems subtest of the WJ-III.

Similarly, an explanation for the lack of association between birth mother EF and child mathematics achievement could be the measure used to assess birth mother mathematics achievement, mathematics fluency. This task requires participants to complete as many addition, subtraction, and multiplication problems as possible in three minutes. Such a simple arithmetic task is not thought to rely heavily, if at all, on EF abilities for adults, who should be capable of retrieving answers from long-term memory rather than use short-term memory capacity to work through problems. Second, as previously stated, it is possible that birth mother mathematics achievement did not significantly relate to child EF because we assessed children's EF using a measure of inhibitory control that did not require attention to numerical information, given prior work suggests that this association depends on whether participants must attend to numerical information (e.g., Bull & Scerif, 2001). Nonetheless, these results indicate that shared genes between biological mothers and their children significantly contribute to associations between parent and child EF and mathematics achievement.

Direct Effects of Parenting Behaviors on Child Mathematics Achievement at Age 7

Another important contribution of this study was the examination of specific environmental influences, parenting effects, on child mathematics outcomes using a genetically sensitive design. In typical studies of the intergenerational transmission of behavioral or psychological traits from biological parent(s) to their child, any associations between parenting and child outcome measures may be confounded by passive *r*GE because parents and children share both genes and the child's rearing environment. Results indicated that two paternal parenting behaviors in early childhood, fathers' sensitive parenting behaviors and directing and commanding behaviors, impact children's mathematics achievement beyond heritable influences and maternal parenting behaviors. The unique effects of both birth mother math achievement and adoptive father sensitive parenting and directing and commanding behaviors explained more of the variance in the adopted child's mathematics achievement than each individual effect (of birth mother math achievement *or* a single adoptive father behavior) did alone. This study is one of *very few* studies to able to clarify that early environmental factors (i.e., paternal sensitive parenting and directing and commanding behaviors) positively contribute to child mathematics achievement in middle childhood even after accounting for heritable influences on mathematics achievement. Importantly, these findings provide a potential environmental mechanism through which researchers may be able to impact child mathematics learning, paternal parenting behaviors during mathematics activities with young children.

We were surprised to find no effects of any adoptive mother parenting behaviors and for adoptive father scaffolding parenting behaviors at age 4.5 on child mathematics achievement given prior work indicating these parenting behaviors are associated with child mathematics achievement in early and middle childhood (e.g., Gadeyne, Ghesquière, & Onghena, 2004; Martin, Ryan, & Brooks-Gunn, 2010; Smith, Landry, & Swank, 2000; Sorariutta & Silvèn, 2018). For example, one study (Sorariutta & Silvèn, 2008) examined scaffolding (e.g., scaffolding) behaviors in mothers and fathers during semi-structured play sessions with their 2-year-old children in relation to children's early mathematics achievement 1- and 2-years later. They found maternal and paternal scaffolding positively predicted child mathematics achievement at both ages 3 and 4. Similarly, Gadeyne and colleagues (2004) found that children whose mothers and fathers displayed low supportive behaviors (i.e., insensitivity) in kindergarten were more likely to have lower mathematics achievement in first and second grade. Nonetheless, the literature examining specific parenting behaviors in early childhood in relation to children's mathematics achievement in middle childhood comprises only a few studies, and these studies do not account for heritable influences on child mathematics outcomes. Thus, more research is needed to investigate this topic and elucidate the influences of parenting behaviors on later child mathematics achievement, even after controlling for heritable influences.

Overall, results indicating direct effects of heritable and some paternal parenting behaviors imply that in order to understand the processes driving the intergenerational transmission of mathematics achievement, it is absolutely crucial to consider effects of heritable and environmental pathways. These study findings thus provide further support for Bronfenbrenner and Ceci's (1994) theory that stipulates that *both* heritable influences and interactions with *multiple* persons in the microsystem can serve as proximal processes through which mathematical thinking can develop.

Differential Effects of Early Parenting Behaviors on Later Child Math Achievement

This study advances the literature by not only considering heritable and environmental effects on mathematics achievement in middle childhood, but by considering effects of *both* maternal and paternal parenting influences in early childhood. Although there is not much research examining specific maternal and paternal parenting behaviors (e.g., scaffolding; sensitive parenting) and later child mathematics learning, there is a growing literature examining the effects of parental engagement in mathematics activities in the home environment. Empirical work in this domain suggests that mothers spend more time than fathers engaging with children in mathematics-related learning activities (e.g., Yeung et al., 2001; Foster et al., 2016), especially in early elementary school (Jacobs et al., 2005). This finding is in line with empirical work in the field of literacy development, which suggests that mothers spend more time than fathers reading books with children (Clark & Foster, 2005; Duursma et al., 2008; Froiland & Davison, 2014). Given these findings, it was surprising to find that adoptive *father*, but not mother, sensitive parenting and directing and commanding behaviors at child age 4.5 marginally influenced child mathematics achievement at age 7 over and above heritable influences.

Only a few studies demonstrate links between father engagement in mathematics activities and child mathematics outcomes. Illustratively, Foster et al. (2016) examined maternal and paternal report of engagement in learning activities in the home context and found that paternal engagement in learning activities with children was a positive predictor of child academic achievement (including mathematics achievement), even after accounting for effects of maternal engagement in learning activities. However, father effects on child academic achievement were only evident for families with mothers who had low, but not high, levels of education (i.e., less than a bachelor's degree). A recent study (Hart, Ganley, and Purpura, 2016) also indicated that fathers, as compared to mothers, report spending more time engaging in certain kinds of mathematics activities at home with children, although other work suggests the opposite (i.e., mothers spend more time than fathers). These findings provide support for the present findings indicating positive effects of paternal parenting behaviors on child mathematics achievement.

It is also important to point out that the present study differs from the aforementioned work in that it is able to disentangle heritable and environmental forms of the intergenerational transmission of mathematics achievement. In fact, the current findings align well with prior work investigating the etiology of mathematics development using the EGDS (Borriello and colleagues, in preparation). Borriello et al. (in preparation) found that, after accounting for heritable influences, adoptive father, but not mother, mathematics achievement influenced child mathematics achievement at age 7. This study consequently advances this area of research by demonstrating marginal effects of two specific parenting behaviors, father sensitive parenting and directing and commanding behaviors, on later child mathematics achievement over and above effects of heritability and maternal parenting behaviors. Moreover, this work suggests that after accounting for heritable influences, paternal, but not maternal, parenting behaviors may impact child math achievement via environmental processes.

It is necessary, however, to determine why adoptive father, but not mother, sensitive parenting and directing and commanding behaviors influenced children's subsequent mathematics achievement. One possibility is that the same parenting behaviors are more impactful on later math achievement when they are expressed by fathers rather than mothers because children may be socialized to view construction activities such as the tangram puzzle task as a more masculine than feminine activity, and thus they are more influenced by parenting behaviors with fathers than with mothers during these kinds of experiences. That is, children may place more value on mathematics-related activities with fathers than with mothers, as even young children demonstrate implicit and explicit stereotypes that math is for boys (Cvencek, Meltzoff, & Greenwald, 2011). Another possibility is that there are differences in the quantity and quality of parents' everyday interactions with children, and over time, these differences may impact the way children learn from parents. In a meta-analysis, Leaper, Anderson, and Sanders (1998) examined whether differences in socialization processes for mothers and fathers could be observed in parent speech with their children. They found that when speaking with children, mothers use more supportive speech (e.g., praise; approval) and more negative speech (e.g., criticism; disagreement; disapproval) than fathers, while fathers use more directive speech (e.g., imperative statements; direct suggestions) and informing speech (e.g., opinions; explanations; descriptive statements) than mothers. Thus, it is possible that because children are more used to experiencing more directive and less supportive or sensitive behaviors from fathers than from mothers, generally, experiencing these parenting behaviors from fathers during a mathematics-related activity at age 4.5 had a substantial impact on children's later mathematics achievement in a way that it did not from mothers. More research is needed to investigate differential effects of various parenting behaviors during learning activities on subsequent child mathematics outcomes.

Indirect Effects of Early Parenting on Child Mathematics Achievement at Age 7

Parenting effects on child EF at age 4.5. Contrary to our hypotheses, we found almost no evidence of parenting effects on adopted child EF, after accounting for heritable influences on child EF. We anticipated parenting effects given evidence that sensitive parenting and parent scaffolding are positively associated with EF in early and middle childhood (e.g., Bernier, Carlson, & Whipple, 2010; Lowe et al., 2014; Müller et al., 2013; Towe-Goodman et al., 2014; Roskam, Stievenart, Meunier, & Noël, 2014; Sulik et al., 2015). However, a few studies have found null associations between parenting and child EF, as in the present study. For example, Eason and Ramani (2017) found no associations between parent scaffolding (referred to as elaborative guidance) and parent directing behaviors during a puzzle task and preschoolers' EF, although this study did not examine these variables using a longitudinal design.

We did find evidence for a trending negative association of adoptive father, but not mother, scaffolding behaviors, such that higher amounts of scaffolding behaviors at child age 4.5 were associated with lower child EF at age 6. This finding was significant over and above effects of maternal scaffolding parenting and heritable influences. This finding is similar to other studies that have found father effects on EF even after accounting for effects of mothers (Lucassen et al., 2015; Towe-Goodman et al., 2014). However, this significant effect of fathers was in an unexpected direction.

Although it was striking to find that higher levels of paternal scaffolding behaviors were associated with lower levels of later child EF, a number of factors might explain this association. First, it is possible that maternal and paternal parenting behaviors may differentially impact child outcomes. For example, maternal parenting behaviors that are considered positive for children may not necessarily have positive impacts on children when coming from fathers. This seems like a plausible assumption as mothers and fathers in this study engaged in similar amounts of scaffolding parenting behaviors, but only paternal behaviors were marginally predictive of later child EF. Perhaps, when children experience less directive guidance during goal-oriented math tasks from fathers, this level of guidance encourages children to be more autonomous and engaged when completing a task. This autonomy-supportive approach to parenting may encourage children to develop EF abilities useful to completing the task at hand. By giving children more freedom to think independently and solve the task on their own, fathers may have provided an opportunity for children to stimulate EF skills that would facilitate task completion.

Interestingly, a less structured play style is more common in mothers than in fathers. Moreover, fathers are typically more playful, physical, vigorous, and unpredictable during play compared to mothers, who engage in more predictable activities with children (Aesha, Halliburton, & Humphrey, 2013; Lamb, 2004). These higher levels of arousal and unpredictability from fathers during play interactions may facilitate children's EF development in a different way than play with mothers because it may require children to engage more attention and energy into the activities they are a part of. This type of higher paced play may generally encourage EF development. Moreover, because the present study's play activity was cognitively stimulating and related to mathematics, a masculine-stereotyped activity, children may have been more open engaging in cognitive reasoning that stimulates EF with fathers than with mothers.

These explanations are speculative, however. To the best of our knowledge, this is the only study to consider paternal scaffolding parenting or scaffolding behaviors in relation to young children's EF. The gap in research on paternal behaviors and child EF must be filled in order to come to stronger conclusions about how and why maternal and paternal parenting behaviors have differential effects on child EF. Finally, it must be noted that this is one of only a handful of studies that uses a genetically informed design to consider parent-child associations concerning EF development. Thus, inconsistencies in these findings compared to other findings in the literature are due to the fact that this study not only considers maternal and paternal parenting behaviors as potential influences on EF, but also considers heritable influences on EF. By disentangling heritable and environmental factors, this study was able to account for more etiological factors than other studies, which impacted the amount of variance parenting behaviors alone could account for. This study's findings support the notion that parents facilitate child EF development, but more specifically indicates parent contributions come primarily from heritable influences and from paternal, but not maternal, parenting influences.

Child EF and later mathematics achievement. Finally, contrary to our first hypothesis, we found no effect of child EF at age 6 on child mathematics achievement at age 7. This finding was highly unexpected given research findings that suggest that EF contributes to children's subsequent academic achievement (e.g., Clark, Pritchard, & Woodward, 2010; Davidse et al., 2014; McClelland, Acock, Piccinin, Rhea, & Stallings, 2013). For example, Clark et al. (2010) found that children's EF at age 3 was predictive of children's mathematics achievement in kindergarten after controlling for SES, earlier mathematics achievement, language and processing speed. Moreover, some studies suggest that inhibitory control, the particular subcomponent of EF, measured at age 6 in the present study, is uniquely predictive of academic achievement (e.g., Allan et al., 2014; Blair & Razza, 2007; Espy et al., 2004). For example, Blair and Razza (2007) found inhibitory control predicted child achievement across academic domains in early childhood, even after controlling for other subcomponents of EF and for general intelligence.

However, other studies have not been able to find longitudinal associations with EF predicting later mathematics achievement (e.g., Sabol & Pianta, 2012; Watts et al., 2015). Instead, some studies find that mathematics achievement can be predictive of EF (e.g., Watts et al., 2015). A common problem of many correlational and longitudinal analyses is that, often, researchers test effects of EF on later mathematics achievement without testing early effects of mathematics achievement on later EF (Clements et al., 2015). A number of longitudinal studies have found support for a bidirectional association between EF and mathematics achievement (van der Ven et al., 2012; Welsh et al., 2010). In their meta-analysis, Jacob and Parkinson (2015) assert that although their results indicate associations between EF and achievement across different age groups, subcomponents of EF, and measurement types (naturalistic vs. laboratory based), the data do not imply a causal relation from EF to achievement. Consequently, the present findings, though surprising, are sensible given inconsistencies in the literature.

In the present study, we aimed to examine (Hypothesis 4) whether parenting would indirectly influence child mathematics achievement through child EF, which is what previous work has found (Devine, Bignardi, and Hughes, 2016; Friedman et al., 2014), while accounting for heritable influences (dissimilar from prior work). However, after accounting for heritable influences, we did not find evidence that child EF acted as a mediating factor between early parenting behaviors and later child mathematics achievement. Although previous work has found this association (Devine et al., 2016; Friedman et al., 2014), an important caveat must be noted:

This body of literature is unable to fully articulate the complex nature of parenting as a phenotype that is influenced by both heritable and environmental factors. Although a number of studies have shown support for indirect effects of parenting on child mathematics achievement through child EF, none of these studies has accounted for effects of direct or indirect heritable influences on child achievement. For example, Devine et al. (2016) examined longitudinal associations between parenting, child EF, and child achievement and found that effects of parent scaffolding and negative parent-child interactions on children's later academic achievement were mediated by child EF. Another study (Friedman et al., 2014) found that parenting quality when children were ages 4.5 influenced children's EF at ages 6 and 8, and subsequent academic achievement at ages 8 and 10. These findings suggest that parents are able to impact children's academic achievement in middle childhood via early parenting influences on children's EF. Because our study is the first to consider heritable effects *and* indirect effects of parenting behaviors via child EF on mathematics achievement later in childhood, it is unclear whether other studies with genetically sensitive designs would find similar results. Future work should attempt to replicate these findings using genetically informed studies.

Evocative Gene-Environment Correlations

Finally, the present study aimed to consider whether parenting behaviors were significantly correlated with birth mother characteristics (EF and math achievement), which would indicate evocative gene-environment correlations (Hypothesis 5). We found evidence to suggest a marginally positive association between birth mother EF and adoptive mother sensitive parenting such that higher levels of birth mother EF corresponded with higher observer reported levels of maternal sensitive parenting during mother-child play. This finding suggests that the frequency of sensitive parenting adoptive mothers display towards adopted children is associated with a heritable influence, birth mother EF. It is thus quite possible that some unmeasured heritable child behavior occurring prior to adoptive mother parenting behaviors at child age 4.5 evoked later sensitive parenting behaviors from adoptive mothers at age 4.5. However, because we did not measure child behaviors prior to age 4.5, it was not possible to identify what child characteristics might have evoked sensitive parenting from mothers at age 4.5. Future work should consider multiple assessments of parent and child behaviors across childhood to better clarify the direction of effects between parent and child behaviors that might influence later child mathematics achievement.

Strengths and Suggestions for Future Research

This is one of very few studies to examine early parenting and child mathematics achievement using a genetically-sensitive design. The application of an adoption design made it possible to isolate heritable and environmental influences on child mathematics achievement. This ensured that associations between parenting and child mathematics achievement were environmental in nature, and not due to shared genetic influences between parents and children. To our knowledge, this is the first study to consider effects of specific parenting behaviors on subsequent child mathematics achievement when effects of heritable influences are removed. We employed a number of strategies to maximize the likelihood that genetic and environmental influences were disentangled. First, we recruited adopted children who were not selectively placed in adoptive family homes at birth and second, we included adoption openness as a covariate in analyses to statistically adjust for any contact between adoptive and birth families postadoption.

Additionally, the use of a parent-offspring adoption design enabled us to distinguish between heritable and parenting influences on child mathematics achievement and to consider how these factors may work together. Gene-environment correlations are associations between environmental influences (e.g., parenting behaviors) and heritable factors. Evocative gene-environment correlations, which are specifically examined through adoption studies (e.g. Ge et al., 1996; O'Connor, Deater-Deckard, Fulker, Rutter & Plomin, 1998), would indicate that variation in heritability evokes particular parenting behaviors towards children, which is in line with the bio-ecological model's (Bronfenbrenner & Ceci, 1994) proposal that proximal environments actualize genetic potential. Although we examined potential gene-environment correlations to assess whether heritable influences were associated with adoptive parenting behaviors, we only found a marginal evocative *rGE* between birth mother EF and adoptive mother sensitive parenting, a parenting behavior that was unrelated to later child mathematics achievement. Thus, we found no evidence for effects of *rGE* on mathematics achievement in middle childhood. Nonetheless, this is, to the best of our knowledge, the first study to investigate transactions between specific maternal and paternal parenting behaviors and child mathematics development. Given the paucity of research on evocative *r*GE in this literature, future behavioral genetics work should investigate associations between inherited child traits and subsequent parenting behaviors.

Another strength of the present study was the use of a longitudinal adoption design to consider effects of *both* maternal and paternal parenting behaviors on child mathematics achievement. To date, very little work in even the phenotypic literature have considered joint influences of mother and father parenting behaviors on child mathematics development. The present findings evince that paternal, rather than maternal, parenting effects influence child mathematics achievement are supported by prior research suggesting that the quality of parenting influences matter more than which parent provides that parenting (Cabrera, Shannon, & Tamis-LeMonda, 2007; Ryan et al., 2006). Moreover, our findings support the bioecological model's (Bronfenbrenner, 1998) proposition that child development unfolds via participation with caregivers who regularly engage in joint activities with children over extended periods of time, and that those activities involve progressively complex reciprocal interactions between the child and the caregiver. This proposition extends not only to the developing child's relationship with mothers, but also with fathers and other relatives, along with caregivers, teachers, and mentors. Additionally, differences between mothers and fathers, and children's perceptions of parents by gender, may lead to unique contributions from fathers above and beyond those of mothers. Individual characteristics of parents and children (e.g., gender; stereotypes) may result in stronger effects of parent-child relationships on child development for fathers, rather than mothers (or vice versa). We speculate that effects of father, but not mother, commanding and directing behaviors at child age 4.5 on later child math achievement are in part due to differences in mother and father parenting patterns, as well as children's differential perceptions of mother and father knowledge about particular learning domains due to gender stereotypes.

To measure the main study variables, we used four different sources of information (birth mother, adoptive mother, adoptive father, and observer) to reduce the shared method variance so no informant reported on both predictor and outcome variables of interest. Moreover, this study measured the quality of parenting behaviors via observer ratings based on parent-child interactions in a play activity. The use of an observer to report on parenting behaviors using direct observations of parent-child interactions is preferred over parent self-report, which may be susceptible to reporting bias.

Moreover, future studies should continue to investigate gene-environment interdependence in relation to mathematics development. Although the present study did not find significant effects of evocative gene-environment correlations on child math achievement, we predict that future work examining gene-environment interplay with different measures will find significant effects of gene-environment interplay. As researchers continue to investigate mathematics development using genetically sensitive designs, more investigations will examine parent and child characteristics that are specifically relevant for parenting and/or mathematics development (e.g., math or spatial language, math anxiety, depression; trait anxiety). A number of phenotypic studies of mathematics development suggest potential future investigations. Illustratively, Eason and Ramani (2017) examined child EF, parental guidance behaviors (directing and commanding behaviors), and children's performance on a parent-child math activity and a subsequent math activity that children engaged in without parents. They found that higher levels of directive guidance from parents during the joint play activity benefitted child performance on the independent math task, but only for children with high, not low, levels of EF. A genetically sensitive design could enable researchers to determine whether parent or child factors moderating or mediating parent-child traits have heritable or environmental origins. One genetically-informed study has found evidence for a gene-environment interaction on child mathematics achievement (Docherty, Kovas, & Plomin, 2010). Findings indicated that heritable influences on child math were stronger in homes with higher, rather than lower, levels of chaos, and when parents have higher, rather than lower, levels of negativity. Researchers can use genetically informed studies to identify ways that heritable effects on math achievement may influence, or depend on, individuals' exposure to negative or positive child-rearing experiences (e.g., parenting; learning activities).

Finally, a longitudinal design suggests a logical sequence of events for understanding how proximal processes influence child outcomes across development, although it is important to note that longitudinal designs cannot suggest causality. Although these findings present a logical temporal order between heritable influences, parenting behavior, and child outcomes, the present study only examined unidirectional pathways from parenting to subsequent child behavior. Because theoretical and empirical work indicates a reciprocal relationship between parents and children, it is highly likely that heritable characteristics of the child affect their parents' behaviors towards them (Scarr & McCartney, 1983). For example, it is possible that child EF during toddlerhood influenced our measures of maternal and paternal parenting behaviors at 4.5 years (e.g., Merz, Landry, Montroy, & Williams, 2016). Future studies should investigate the bidirectional influences between parents and children when examining links between parent behaviors and child mathematics development.

Together, these methodological practices allowed us to test family processes driving the integrational transmission of mathematics achievement. Because the extent literature is extremely small, we strongly recommend that more studies examine effects of heritability, parenting, and child characteristics on child mathematics development. Understanding whether links between parenting behaviors and child outcomes are genetically or environmentally mediated would clarify the origins of developmental processes driving parent-child associations.

Finally, it is important for future behavioral genetic studies to consider effects of child sex as well as parent sex, given evidence for sex-stereotypes in the domain of mathematics. Just as sex stereotypes may influence child perceptions of parent mathematics abilities, they may also influence parent perceptions of child abilities, and parent expectations for children's mathematics achievement (Jacobs et al., 2005). These perceptions and expectations may translate into differential parenting behaviors. For example, Hart and colleagues (2016) found that parents reported engaging in more mathematics-related activities in the home with sons than with daughters. These differential perceptions, expectations, and treatment of sons versus daughters in the arena of mathematics may have long-term consequences for children's achievement and interest in mathematics and other masculine-stereotyped domains. Although phenotypic literature reports the importance of parent and child gender for the intergenerational transmission of math achievement (Jacobs et al., 2005), almost no genetically sensitive research has examined whether sex-based stereotypes play a role in children's mathematics development over and above effects of heritable influences.

Study Limitations

Although the present study has various methodological strengths, it is necessary to make note of several study limitations. First, although the sample used in this study is representative of the population of domestic infant adoptions, it is not necessarily representative of a more heterogeneous sample of families (Leve et al., 2013). Adoptive parents had relatively high education and income levels, and were primarily Caucasian. These characteristics could potentially inflate estimates of heritable effects (Stoolmiller, 1999). This restricted range of adoptive family characteristics may also make it difficult to generalize the study findings to a more heterogeneous population of families and children. However, one study empirically tested whether adoption studies underestimate shared environmental influences due to range restrictions, and found no evidence for effects of range restriction on estimates of shared environmental variance (McGue et al., 2007).

Second, we estimated heritable influences using phenotypic traits of birth mothers but not birth fathers. This method of estimation potentially underestimates heritable influences because it does not include the heritable influences from birth fathers. Only 35% of participating families in the present study had birth fathers participate. This sample size was too small to include birth fathers in analyses, which precluded a more extensive examination of the study hypotheses. This issue of missing data is problematic. Missing data was a more general limitation in this dissertation, as data was missing from other family members within family sets as well. A related limitation of the study is that we inferred heritable influences from birth mother phenotypes. This estimation approach assumes that birth mother genotypes expressed in their phenotype were inherited by the child. However, such an estimation strategy does not ensure that heritable traits from biological mothers are genetically transmitted to children. Developmental epigenetic theories (Gottlieb, 1998, 2007) assert that phenotypes emerge from complex interactions between sequences of multiple genes, neural activities, and environments. Thus, our attempt to estimate effects of shared genes between birth mothers and children on child mathematics achievement may not accurately estimate the true effect of heritability, as the interplay between heritable influences and child cognitive development is highly complex.

A final limitation was that the present study used only a single measure of mathematics achievement, which likely does not capture the full range of children’s mathematics competencies in middle childhood. Mathematics fluency requires children to complete arithmetic problems including addition, subtraction, and multiplication as quickly as possible without making mistakes in three minutes. Because this measure is timed, it is thought to measure automaticity with basic arithmetic facts. Empirical work indicates that the timed component of math fluency makes it stand out from other math measures. Even though math fluency is related to other math measures, is also genetically distinct from them and is thought to reflect an additional dimension of math achievement (e.g., Hart, Petrill & Thompson, 2010; Mazzocco et al., 2008; Petrill et al., 2012). Thus, it is possible that the current findings may have been different had we used a different measure of mathematics achievement for both birth mothers and children. Future studies should address whether untimed measures of mathematics achievement are similarly related to heritable influences, parenting and child EF in early and middle childhood.

Conclusions

Despite these limitations, the present investigation underscores the importance of the unique influences of heritable effects and adoptive fathers' parenting behaviors in early childhood on children's subsequent mathematics achievement in middle childhood. Because these findings highlight the important role of *environmental* influences in paternal levels of insensitivity and directing and commanding behaviors during mathematics-related activities, these findings have implications for future intervention work. Because paternal, but not maternal, parenting behaviors had a significant effect on child math achievement even after accounting for heritable influences and adoptive mother influences, these findings point to fathers as effective "teachers" of mathematics proficiency. Given these findings, future work is needed to address the paucity of research examining father influences on child mathematics learning and achievement, and in cognitive development, more broadly. Moreover, more work is needed to further clarify processes that drive these paternal parenting behaviors to positively transmit math achievement to children. Once researchers have identified influential paternal behaviors and established an understanding of how these behaviors effectively transmit math achievement to children, we can create interventions that specifically target fathers and encourage effective parenting behaviors during math activities with children. Ultimately, researchers may be able to establish effective interventions that can increase children's mathematics achievement.

In summary, the present study clarifies the etiologies behind proximal parenting processes that drive the intergenerational transmission of mathematics achievement across early and middle childhood. Further, this study highlights the unique way in which adoption design enables researchers to go beyond estimates of heritable and environmental influences on child traits and explain *how* developmental processes unfold over time to influence the development of child traits. By disentangling and identifying the importance of heritable and environmental influences on child math achievement, the present study advances the field of mathematics development by indicating various parenting behaviors to target in educational intervention programs.

REFERENCES

Adkins, M., & Noyes, A. (2016). Reassessing the economic value of advanced level mathematics. *British Educational Research Journal*, *42*, 93–116.

Alarcòn, M., DeFries, J. C., Light, J. G., & Pennington, B. F. (1997). A twin study of mathematics disability. *Journal of Learning Disabilities*, *30*, 617–623.

Alarcòn, M., Knopik, V. S., & Defries, J. C. (2000). Covariation of mathematics achievement and general cognitive ability in twins. *Journal of School Psychology*, *38*, 63–77.

Allan, N. P., Hume, L. E., Allan, D. M., Farrington, A. L., & Lonigan, C. J. (2014). Relations between inhibitory control and the development of academic skills in preschool and kindergarten: A meta-analysis. *Developmental Psychology*, *50*, 2368–2379.

Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, *106*, 20–29.

Alloway, T. P., Alloway, R. G., & Wootan, S. (2014). Home sweet home: Does where you live matter to working memory and other cognitive skills? *Journal of Experimental Child Psychology*, *124*, 124–131.

Altonji, J. G., Blom, E., & Meghir, C. (2012). Heterogeneity in human capital investments: High school curriculum, college major, and careers. *Annual Review of Economics, 4*, 185–223.

Andersson, U. (2008). Working memory as a predictor of written arithmetical skills in children: The importance of central executive functions. *British Journal of Educational Psychology*, *78*, 181–203.

Anger, S. (2011). The intergenerational transmission of cognitive and non-cognitive skills during adolescence and adulthood. *Discussion Paper 5749. Bonn: IZA*, 1–39.

Anger, S., & Heineck, G. (2010). Do smart parents raise smart children? The intergenerational transmission of cognitive abilities. *Journal of Population Economics*, *23*, 1105–1132.

Anghel, D. (2010). Executive function in preschool children: Working memory as a predictor of mathematical ability at school age. *Revista Roamneasca Pentru Educatie Multidimensionala*, *2*, 5–16. https://doi.org/10.13140/RG.2.1.1650.1365

Aunola, K., Leskinen, E., Lerkkanen, M.-K., & Nurmi, J.-E. (2004). Developmental dynamics of math performance from preschool to grade 2. *Journal of Educational Psychology*, *96*, 699–713.

Baddeley, A., & Della Sala, S. (1996). Working memory and executive control. *Philosophical Transactions: Biological Sciences*, *351*, 1397–1404.

Baddeley, A. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology*, *49A*, 5–28.

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*, 417–423.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. A. Bower (Ed.), *The psychology of learning and motivations* (Vol. 8, pp. 47–90). New York, NY: Academic Press.

Beck, Danielle, M., Schaefer, C., Pang, K., & Carlson, S. M. (2011). Executive function in preschool children: Test-retest reliability. *Journal of Cognitive Development*, *12*, 169–193.

Bernier, A., Carlson, S. M., Deschênes, M., & Matte-Gagné, C. (2012). Social factors in the development of early executive functioning: A closer look at the caregiving environment. *Developmental Science*, *15*, 12–24.

Bernier, A., Carlson, S. M., & Whipple, N. (2010). From external regulation to self-regulation: Early parenting precursors of young children's executive functioning. *Child Development*, *81*, 326–339.

Bibok, M. B., Carpendale, J. I. M., & Müller, U. (2009). Parental scaffolding and the development of executive function. *New Directions in Child and Adolescent Psychiatry: Special Issue on social interaction and the development of executive function*, *123*, 17-34.

Bierman, K. L., Nix, R. L., Greenberg, M. T., Blair, C., & Domitrovich, C. E. (2011). Executive functions and school readiness intervention: Impact, moderation, and mediation in the Head Start REDI program. *Developmental Psychpathology*, *20,* 821–843.

Björklund, A., Hederos Eriksson, K., & Jäntti, M. (2009). IQ and family background: Are associations strong or weak? *IZA Discussion Paper No. 4305*, *10*. 999-1028

Black, S. E., Devereux, P. J., & Salvanes, K. G. (2008). Like father, like son? A note on the intergenerational transmission of IQ scores. *Economics Letters. IZA Discussion Paper No. 3651*, *105*, 138–140.

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development, 78*, 647–663.

Blair, C., Protzko, J., & Ursache, A. (2011). Self-regulation and early literacy. In S. B. Neuman, & D. K. Dickinson (Eds.), *Handbook of early literacy research* (Vol. 3; pp. 20–35). New York, NY: Guilford.

Blevins-Knabe, B., & Austin, A. M. B. (2016). *Early childhood mathematical skill development in the home environment*. Cham, Switzerland: Springer International Publishing.

Blevins-Knabe, B., Berghout Austin, A., Musun, L., Eddy, A., & Jones, R. M. (2000). Family home care providers' and parents' beliefs and practices concerning mathematics with young children. *Early Child Development and Care*, *165*, 41–58.

Blevins-Knabe, B., & Musun-Miller, L. (1996). Number use at home by children and their parents and its relationship to early mathematical performance. *Early Development and Parenting*, *5*, 35–45.

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

Borriello, G. A., Ramos, A.M., Neiderhiser, J. M., Natsuaki, M. N., Shaw, D., Reiss, D., Leve, L., & Neiderhiser, J. M. (in preparation). Investigating the etiology of mathematics abilities using a prospective-adoption design.

Bradley, R. H., & Caldwell, B. M. (1995). Caregiving and the regulation of child growth and development: Describing proximal aspects of caregiving systems. *Developmental Review*. *15*. 38-85.

Bradley, R. H., & Caldwell, B. M. (1984). The HOME Inventory and family demographics. *Developmental Psychology*, *20*, 315–320.

Bradley, R. H., Caldwell, B. M., & Rock, S. L. (1988). Home environment and school performance: A ten-year follow-up and examination of three models of environmental action. *Child Development*, *59*, 852–867.

Braham, E. J., & Libertus, M. E. (2017). *Intergenerational associations in numerical approximation and mathematical abilities*. *Developmental Science* (3rd ed., Vol. 20). Itasca, IL: Riverside Publishing Company.

Bronfenbrenner, U. (1986). Ecology of the family as a context for human development: Research perspectives. *Developmental Psychology*, *22*, 723–742.

Bronfenbrenner, U., & Ceci, S. J. (1994). Nature-nurture reconceptualized in developmental perspective: A bioecological model. *Psychological Review*, *101*, 568–586.

Bronfenbrenner, U., & Morris, P. A. (2006). The bioecological model of human development. In W. Damon & R. M. Lerner (Eds.), *Handbook of child psychology: Vol 1, Theoretical models of human development* (6th ed., pp. 793–828). New York: Wiley.

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*, 40–58.

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*, *33*, 205–228.

Bull, R., Espy, K. A., Wiebe, S. A., Sheffield, T. D., & Nelson, J. M. (2011). Using confirmatory factor analysis to understand executive control in preschool children: Sources of variation in emergent mathematic achievement. *Developmental Science*, *14*, 679–692.

Bull, R., Johnston, R. S., & Roy, J. A. (1999). Exploring the roles of the visual-spatial sketch pad and central executive in children's arithmetical skills: Views from cognition and developmental neuropsychology. *Developmental Neuropsychology*, *15*, 421–442.

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology*, *19*, 273–293.

Cabrera, N. J., Shannon, J. D., & Tamis-LeMonda, C. (2007). Fathers' influence on their children's cognitive and emotional development: From toddlers to pre-K. *Applied Developmental Science*, *11*, 208–213.

Capaldi, D. M., Pears, K. C., Kerr, D. C. R., Owen, L. D., & Kim, H. K. (2012). Growth in externalizing and internalizing problems in childhood: A prospective study of psychopathology across three generations. *Child Development*, *83*, 1945-1959.

Casey, B. M., 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*, 636–648.

Cerda, C. A., Im, M. H., & Hughes, J. N. (2015). Learning-related skills and academic achievement in academically at-risk first graders. *Journal of Applied Developmental Psychology*, *35*, 433–443.

Clark, C. A. C., Pritchard, V. E., & Woodward, L. J. (2010). Preschool executive functioning abilities predict early mathematics achievement. *Developmental Psychology*, *46*, 1176–1191.

Clark, C., & Foster, A. (2005). *Children's and young people's reading habits and preferences: The who, what, why, where and when*. London: National Literacy Trust.

Clements, D. H., Sarama, J., & Germeroth, C. (2016). Learning executive function and early mathematics: Directions of causal relations. *Early Childhood Research Quarterly*, *36*, 79–90.

Crane, J. (1996). Effects and of home environment, SES, and maternal test scores on mathematics. *Journal of Educational Research*, *89*, 305–314.

Cvencek, D., Meltzoff, A. N., & Greenwald, A. G. (2011). Math-gender stereotypes in elementary school children. *Child Development, 82*, 766–779.

Davidse, N. J., De Jong, M. T., & Bus, A. G. (2015). Causal relations among executive functions and academic skills from preschool to end of first grade. *English Linguistics Research*, *4*, 49–60.

Dearden, L., Sibieta, L., & Sylva, K. (2011). The socio-economic gradient in early child outcomes: Evidence from the Millennium Cohort Study. *Institute for Fiscal Studies*, *11*, 1–86.

Dearing, E., Casey, B. M., Ganley, C. M., Tillinger, M., Laski, E., & Montecillo, C. (2012). Young girls' arithmetic and spatial skills: The distal and proximal roles of family socioeconomics and home learning experiences. *Early Childhood Research Quarterly*, *27*, 458–470.

del Río, M. F., Susperreguy, M. I., 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.

Devine, R. T., Bignardi, G., & Hughes, C. (2016). Executive function mediates the relations between parental behaviors and children's early academic ability. *Frontiers in Psychology*, *7*, 1–15.

Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: Cognitive functions, anatomy, and biochemistry. In: Stuss, DT.; Knight, RT., editors. *The frontal lobes* (pp. 466-503). Oxford University Press; London.

Docherty, S. J., Kovas, Y., & Plomin, R. (2011). Gene-environment interaction in the etiology of mathematical ability using SNP sets. *Behavior Genetics, 41,* 141–154.

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., … Japel, C. (2007). School readiness and later achievement. *Developmental Psychology, 43,* 1428–1446.

Duncan, G., Kalil, A., Mayer, S. E., Tepper, R., & Payne, M. R. (2002). *The apple does not fall far from the tree*. (S. Bowles, H. Gintis, & M. O. Groves, Eds.), *Unequal chances: Family background and economic success*. Princeton, NJ: Princeton University Press.

Duursma, E., Pan, B. A., & Raikes, H. (2008). Predictors and outcomes of low-income fathers' reading with their toddlers. *Early Childhood Research Quarterly, 23,* 351–365.

Eason, S. H., & Ramani, G. B. (2017). Parental guidance and children's executive function: Working memory and planning as moderators during joint problem-solving. *Infant and Child Development, 26,* 1–24.

Elliott, L., & Bachman, H. J. (2018). How do parents foster young children's math skills? *Child Development Perspectives, 12,* 16–21.

Eryigit Madzwamuse, S., Baumann, N., Jaekel, J., Bartmann, P., & Wolke, D. (2015). Neuro-cognitive performance of very preterm or very low birth weight adults at 26 years. *Journal of Child Psychology and Psychiatry, 56,* 857–864.

Fagan, J., Day, R., Lamb, M. E., & Cabrera, N. J. (2014). Should researchers conceptualize differently the dimensions of parenting for fathers and mothers? *Journal of Family Theory & Review*, *6*, 390–405.

Fiscella, K., & Kitzman, H. (2009). Disparities in academic achievement and health: The intersection of child education and health policy. *Pediatrics, 123*(3), 1073–1080.

Foster, T. D., Froyen, L. C., Skibbe, L. E., Bowles, R. P., & Decker, K. B. (2016). Fathers' and mothers' home learning environments and children's early academic outcomes. *Reading and Writing*, *29*, 1845–1863.

Friedman, S. L., Scholnick, E. K., Bender, R. H., Vandergrift, N., Spieker, S., Hirsh Pasek, K., … Park, Y. (2014). Planning in middle childhood: Early predictors and later outcomes. *Child Development*, *85*, 1446–1460.

Froiland, J. M., & Davison, M. L. (2014). Parental expectations and school relationships as contributors to adolescents' positive outcomes. *Social Psychology of Education*, *17*, 1–17.

Froiland, J. M., & Davison, M. L. (2016). Home literacy, television viewing, fidgeting and ADHD in young children. *Educational Psychology*, *36*, 1337-1353.

Gadeyne, E., Ghesquière, P., & Onghena, P. (2015). Longitudinal relations between parenting and child adjustment in young children. *Journal of Clinical Child and Adolescent Psychology*, *33*, 347–358.

Ge, X., Cadoret, R. J., Conger, R. D., Neiderhiser, J. M., Yates, W., Troughton, E., & Stewart, M. A. (1996). The developmental interface between nature and nurture: A mutual influence model of child antisocial behavior and parent behaviors. *Developmental Psychology*, *32*, 574–589.

Ge, X., Natsuaki, M. N., Martin, D., Leve, L. D., Neiderhiser, J. M., Shaw, D. S., … Reiss, D. (2008). Bridging the divide: Openness in adoption and post-adoption psychosocial adjustment among birth and adoptive parents. *Journal of Family Psychology*, *22*, 529–540.

Geary, D. C. (1995). Reflections of evolution and culture in children's cognition: Implications for mathematical development and instruction. *American Psychologist*, *50*, 24–37.

Gottfredson, L. S. (2004). Intelligence: Is it the epidemiologists' elusive "fundamental cause" of social class inequalities in health? *Journal of Personality and Social Psychology*, *86*, 174–199.

Gottlieb, G. (1998). Normally occurring environmental and behavioral influences on gene activity: From central dogma to probabilistic epigenesis. *Psychological Review*, *105*(4), 792–802.

Gottlieb, G., & Lickliter, R. (2007). Probabilistic epigenesis. *Developmental Science*, *10*, 1–11.

Groot, A. S., de Sonneville, L. M. J., Stins, J. F., & Boomsma, D. I. (2004). Familial influences on sustained attention and inhibition in preschoolers. *Journal of Child Psychology and Psychiatry*, *45*, 306–314.

Grossmann, K., Grossmann, K. E., Kindler, H., & Zimmermann, P. (2008). A wider view of attachment and exploration. In J. Cassidy & P. R. Shaver (Eds.), *Handbook of* *attachment: Theory, research, and clinical applications* (2nd ed., pp. 857-879). New York, NY: Guildford Press.

Gunderson, E. A., & Levine, S. C. (2011). Some types of parent number talk count more than others: Relations between parents' input and children's cardinal-number knowledge. *Developmental Science, 14,* 1021–1032.

Hammond, S. I., Müller, U., Carpendale, J. I. M., Bibok, M. B., & Liebermann-Finestone, D. P. (2012). The effects of parental scaffolding on preschoolers' executive function. *Developmental Psychology*, *48,* 271–281.

Hart, S. A., Ganley, C. M., & Purpura, D. J. (2016). Understanding the home math environment and its role in predicting parent report of children's math skills. *PLoS ONE*, *11*, 1–30.

Hart, S. A., Petrill, S. A., & Thompson, L. A. (2010). A factorial analysis of timed and untimed measures of mathematics and reading abilities in school aged twins. *Learning and Individual Differences*, *20*, 63–69.

Hart, S. A., Petrill, S. A., Thompson, L. A., & 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*, 388–402.

Heineck, G., & Riphahn, R. T. (2009). Intergenerational transmission of educational attainment in Germany: The last five decades. *Jahrbücher Für Nationalökonomie Und Statistik*, *229*, 36–60.

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*, 36–60.

Holmes, J., & Adams, J. W. (2006). Working memory and children's mathematical skills: Implications for mathematical development and mathematics curricula. *Educational Psychology*, *26*, 339–366.

Horwitz, B. N., & Neiderhiser, J. M. (2015). *Gene-environment interplay in interpersonal relationships across the lifespan*. (J. M. Neiderhiser & B. N. Horwitz, Eds.), *Advances in Behavior Genetics*. New York, NY: Springer.

Hughes, C., Ensor, R., Wilson, A., & Graham, A. (2010). Tracking executive function across the transition to school: A latent variable approach. *Developmental Neuropsychology*, *35*, 20–36.

Huntsinger, C. S., Jose, P. E., & Larson, S. L. (1998). Do parent practices to encourage academic competence influence the social adjustment of young European American and Chinese American children? *Developmental Psychology*, *34*, 747–756.

Jacob, R., & Parkinson, J. (2015). The potential for school-based interventions that target executive function to improve academic achievement: A review. *Review of Educational Research*, *85*, 512–552.

Jacobs, J. E., Davis-Kean, P., Bleeker, M., Eccles, J. S., & Malanchuk, O. (2005). *"I can, but I don't want to": The impact of parents, interests, and activities on gender differences in math*. *Gender differences in Mathematics: An Integrative Psychological Approach*.

John, A., Halliburton, A., & Humphrey, J. (2013). Child-mother and child-father play interaction patterns with preschoolers. *Early Child Development and Care*, *183*, 483–497.

Jordan, N. C., Kaplan, D., Olah, L. N., & Locuniak, M. N. (2006). Number sense growth in kindergarten: A longitudinal investigation of children at-risk for mathematics difficulties. *Child Development*, *77*, 153–175.

Kleemans, T., Peeters, M., Segers, E., & Verhoeven, L. (2012). Child and home predictors of early numeracy skills in kindergarten. *Early Childhood Research Quarterly*, *27,* 471–477.

Kleemans, T., Segers, E., & Verhoeven, L. (2013). Relations between home numeracy experiences and basic calculation skills of children with and without specific language impairment. *Early Childhood Research Quarterly*, *28,* 415–423.

Kovas, Y., Harlaar, N., Petrill, S. A., & Plomin, R. (2005). “Generalist genes” and mathematics in 7-year-old twins. *Intelligence*, *33*, 473–489.

Kovas, Y., Haworth, C. M. A., Petrill, S. A., & Plomin, R. (2007). Mathematical ability of 10-year-old boys and girls: Genetic and environmental etiology of typical and low performance. *Journal of Learning Disabilities, 40,* 554–567.

Kovas, Y., Voronin, I., Kaydalov, A., Malykh, S. B., Dale, P. S., & Plomin, R. (2013). Literacy and numeracy are more heritable than intelligence in primary school. *Psychological Science*, *24*, 2048–2056.

Lamb, M. E. (Ed.). (2004). The role of the father in child development (4th ed.). Hoboken, NJ: Wiley.

Larson, K., Russ, S. A., Nelson, B. B., Olson, L. M., & Halfon, N. (2015). Cognitive ability at kindergarten entry and socioeconomic status. *Pediatrics*, *135*, e440–e448.

Leaper, C., Anderson, K. J., & Sanders, P. (1998). Moderators of gender effects on parents' talk to their children: A meta-analysis. *Developmental Psychology*, *34*, 3–27.

LeFevre, J.-A., Clarke, T., & Stringer, A. P. (2002). Influences of language and parental involvement on the development of counting skills: Comparisons of French- and English-speaking Canadian children. *Early Child Development and Care*, *172*, 283–300.

LeFevre, J.-A., Kwarchuk, S.-L., Smith-Chant, B. L., 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*, 55–66.

LeFevre, J.-A., Polyzoi, E., Skwarchuk, S.-L., Fast, L., & Sowinski, C. (2010). Do home numeracy and literacy practices of Greek and Canadian parents predict the numeracy skills of kindergarten children? *International Journal of Early Years Education*, *18*, 55–70.

Lemelin, J.-P., Boivin, M., Forget-Dubois, N., Dionne, G., Séguin, J. R., Brendgen, M., … Pérusse, D. (2007). The genetic-environmental etiology of cognitive school readiness and later academic achievement in early childhood. *Child Development*, *78*, 1855–1869.

Lemery-Chalfant, K., Doelger, L., & Goldsmith, H. H. (2008). Genetic relations between effortful and attentional control and symptoms of psychopathology in middle childhood. *Infant and Child Development*, *17*, 365–385.

Leve, L. D., DeGarmo, D. S., Bridgett, D. J., Neiderhiser, J. M., Shaw, D. S., Harold, G. T., … Reiss, D. (2013). Using an adoption design to separate genetic, prenatal, and temperament influences on toddler executive function. *Developmental Psychology*, *49*, 1045–1057.

Leve, L. D., Neiderhiser, J. M., Shaw, D. S., Ganiban, J. M., Natsuaki, M. N., & Reiss, D. (2013). The Early Growth and Development Study: a prospective adoption study from birth through middle childhood. *Twin Research and Human Genetics*, *16*, 412–423.

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*, 207–227.

Levine, S. C., Suriyakham, L. W., Rowe, M. L., Huttenlocher, J., & Gunderson, E. A. (2010). What counts in the development of young children's number knowledge? *Developmental Psychology*, *46*, 1309–1319.

Loehlin, J. C., Horn, J. M., & Willerman, L. (1989). Modeling IQ change: Evidence from the Texas Adoption Project. *Child Development*, *60*, 993–1004.

Lowe, J., Erickson, S. J., MacLean, P., Duvall, S. W., Ohls, R. K., & Duncan, A. F. (2014). Associations between maternal scaffolding and executive functioning in 3 and 4 year olds born very low birth weight and normal birth weight. *Early Human Development*, *90*, 587–593.

Lucassen, N., Kok, R., Bakermans-Kranenburg, M. J., Van Ijzendoorn, M. H., Jaddoe, V. W. V., Hofman, A., … Tiemeier, H. (2015). Executive functions in early childhood:

The role of maternal and paternal parenting practices. *British Journal of Developmental Psychology*, *33*, 489–505.

Lugo-Gil, J., & Tamis-LeMonda, C. S. (2008). Family resources and parenting quality: Links to children's cognitive development across the first 3 years. *Child Development*, *79*, 1065–1085.

Lukowski, S. L., Soden, B., Hart, S. A., Thompson, L. A., Kovas, Y., & Petrill, S. A. (2015). Etiological distinction of working memory components in relation to mathematics. *Intelligence*, *47*, 54–62.

Luo, D., Petrill, S. A., & Thompson, L. A. (1994). An exploration of genetic g: Hierarchical factor analysis of cognitive data from the Western Reserve Twin Project. *Intelligence*, *18*, 335–347.

Mabbott, D. J., & Bisanz, J. (2008). Computational skills, working memory, and conceptual knowledge in older children with mathematics learning disabilities. *Journal of Learning Disabilities*, *41*, 15–28.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin*, *109*, 163–203.

Maloney, E. A., Ramirez, G., Gunderson, E. A., Levine, S. C., & Beilock, S. L. (2015). Intergenerational effects of parents' math anxiety on children's math achievement and anxiety. *Psychological Science*, *26*, 1480–1488.

Marceau, K., De Araujo-Greecher, M., Miller, E. S., Massey, S. H., Mayes, L. C., Ganiban, J. M., … Neiderhiser, J. M. (2016). The perinatal risk index: Early risks experienced by domestic adoptees in the United States. *PLoS ONE*, *11*, 1–11.

Marceau, K., Hajal, N., Leve, L. D., Reiss, D., Shaw, D. S., Ganiban, J. M., … Neiderhiser, J. M. (2013). Measurement and associations of pregnancy risk factors with genetic influences, postnatal environmental influences, and toddler behavior. *International Journal of Behavioral Development*, *37,* 366–375.

Martin, A., Ryan, R. M., & Brooks-Gunn, J. (2007). The joint influence of mother and father parenting on child cognitive outcomes at age 5. *Early Childhood Research Quarterly*, *22*, 423–439.

Martin, A., Ryan, R. M., & Brooks-Gunn, J. (2010). When fathers' supportiveness matters most: Maternal and paternal parenting and children's school readiness. *Journal of Family Psychology*, *24*, 145–155.

Mazzocco, M. M. M., Devlin, K. T., & McKenney, S. J. (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*, 318–344.

Mazzocco, M. M. M., & Kover, S. T. (2007). A longitudinal assessment of executive function skills and their association with math performance. *Child Neuropsychology*, *13*, 18–45.

McBride, B. A., Dyer, W. J., Liu, Y., Brown, G. L., & Hong, S. (2009). The differential impact of early father and mother involvement on later student achievement. *Journal of Educational Psychology, 101*, 498–508.

McClelland, M. M., Acock, A. C., Piccinin, A., Rhea, S. A., & Stallings, M. C. (2013). Relations between preschool attention span-persistence and age 25 educational outcomes. *Early Child Research Quarterly, 28,* 314–324.

McClelland, M. M., Cameron, C. E., Connor, C. M. D., Farris, C. L., Jewkes, A. M., & Morrison, F. J. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology, 43*, 947–959.

McClelland, M. M., Cameron, C. E., Duncan, R., Bowles, R. P., Acock, A. C., Miao, A., & Pratt, M. E. (2014). Predictors of early growth in academic achievement: The head-toes-knees-shoulders task. *Frontiers in Psychology, 5*, 1–14.

McGue, M., Keyes, M., Sharma, A., Elkins, I., Legrand, L., Johnson, W., & Iacono, W. G. (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.

McKenzie, B., Bull, R., & Gray, C. (2003). The effects of phonological and visual-spatial interference on children's arithmetical performance. *Educational and Child Psychology*, *20*, 93–108.

McLean, J. F., & Hitch, G. J. (1999). Working memory impairments in children with specific arithmetic learning difficulties. *Journal of Experimental Child Psychology, 74*, 240–260.

Melhuish, E. C., Sylva, K., Sammons, P., Siraj-Blatchford, I., Taggart, B., Phan, M. B., & Malin, A. (2008). Preschool influences on mathematics achievement. *Science, 321*, 1161–1162.

Merz, E. C., Landry, S. H., Montroy, J. J., & Williams, J. M. (2017). Bidirectional associations between parental responsiveness and executive function during early childhood. *Social Development*, *26*, 591–609. https://doi.org/10.1111/sode.12204

Meuwissen, A. S., & Carlson, S. M. (2015). Fathers matter: The role of father autonomy support and control in preschoolers' executive function development. *Journal of Experimental Child Psychology*, *140*, 1–15.

Missall, K., Hojnoski, R. L., Caskie, G. I. L., & 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*, 356–376.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49–100.

Müller, U., Baker, L., & Yeung, E. (2013). *A developmental systems approach to executive function*. *Advances in Child Development and Behavior* (Vol. 45). Elsevier Inc.

Murnane, R. J., Willett, J. B., & Levy, F. (1995). The growing importance of cognitive skills in wage determination. *The Review of Economics and Statistics*, *77*, 251–266.

Nath, S., & Szücs, D. (2014). Construction play and cognitive skills associated with the development of mathematical abilities in 7-year-old children. *Learning and Instruction*, *32*, 73–80.

National Assessment of Educational Progress. (2015). 2015 mathematics results. Retrieved from http://www.nationsreportcard.gov/reading_math_2015/ - mathematics?grade=4.

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010).

Navarro, M. G., Braham, E. J., & Libertus, M. E. (2018). Intergenerational associations of the approximate number system in toddlers and their parents. *British Journal of Developmental Psychology,* Advance online publication.

Ng, F. F.-Y., Tamis-Lemonda, C., Yoshikawa, H., & Sze, I. N.-L. (2015). Inhibitory control in preschool predicts early math skills in first grade: Evidence from an ethnically diverse sample. *International Journal of Behavioral Development*, *39*, 139–149.

O'Connor, T. G., Deater-Deckard, K., Fulker, D., Rutter, M., & Plomin, R. (1998). Genotype-environment correlations in late childhood and early adolescence: Antisocial behavioral problems and coercive parenting. *Developmental Psychology*, *34*, 970–981.

Oliver, B. R., Dale, P. S., & Plomin, R. (2005). Predicting literacy at age 7 from preliteracy at age 4: A longitudinal genetic analysis. *Psychological Science*, *16*, 861–865.

Oliver, B. R., Harlaar, N., Thomas, M. E. H., Kovas, Y., Walker, S. O., Petrill, S. A., … Plomin, R. (2004). A twin study of teacher-reported mathematics performance and low performance in 7-year-olds. *Journal of Educational Psychology*, *96*, 504–517.

Pan, Y., Gauvain, M., Liu, Z., & Cheng, L. (2006). American and Chinese parental involvement in young children's mathematics learning. *Cognitive Development*, *21*, 17–35.

Passolunghi, M. C., Mammarella, I. C., & Altoè, G. (2008). Cognitive abilities as precursors of the early acquisition of mathematical skills during first through second grades. *Developmental Neuropsychology*, *33*, 229–250.

Passolunghi, M. C., Vercelloni, B., & Schadee, H. (2007). The precursors of mathematics learning: Working memory, phonological ability and numerical competence. *Cognitive Development*, *22*, 165–184.

Passolunghi, M. C., & Cornoldi, C. (2008). Working memory failures in children with arithmetical difficulties. *Child Neuropsychology*, *14*, 387–400.

Petrill, S. A., Logan, J., Hart, S. A., Vincent, P., Thompson, L. A., 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*, 371–381.

Plomin, R., & Kovas, Y. (2005). Generalist genes and learning disabilities. *Psychological Bulletin*, *131*, 592–617.

Plomin, R., DeFries, J. C., & Loehlin, J. C. (1977). Genotype-environment interaction and correlation in the analysis of human behavior. *Psychological Bulletin*, *84*, 309–322.

Plug, E., & Vijverberg, W. (2003). Schooling, family background, and adoption: Is it nature or is it nurture? *Journal of Political Economy. ETLA Discussion Papers*, *111*, 611–641.

Polderman, T. J. C., Derks, E. M., Hudziak, J. J., Verhulst, F. C., Posthuma, D., & Boomsma, D. I. (2007). Across the continuum of attention skills: A twin study of the SWAN ADHD rating scale. *Journal of Child Psychology and Psychiatry*, *48*, 1080–1087.

Raghubar, K. P., Barnes, M. A., & Hecht, S. A. (2010). Working memory and mathematics: A review of developmental, individual difference, and cognitive approaches. *Learning and Individual Differences*, *20*, 110–122.

Ramani, G. B., & Siegler, R. S. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child Development*, *79*, 375–394.

Reyna, V. F., Nelson, W. L., Han, P. K., & Dieckmann, N. F. (2009). How numeracy influences risk comprehension and medical decision making. *Psychological Bulletin*, *135*, 943–973.

Rhoades, B. L., Greenberg, M. T., & Blair, C. (2012). Demographic and familial predictors of early executive function development: Contribution of a person-centered perspective. *Journal of Experimental Child Psychology*, *108*, 638–662.

Rivera-Batiz, F. L. (1992). Quantitative literacy and the likelihood of employment among young adults in the United States. *The Journal of Human Resources*, *27*, 313–328.

Roskam, I., Stievenart, M., Meunier, J.-C., & Noël, M.-P. (2014). The development of children's inhibition: Does parenting matter? *Journal of Experimental Child Psychology*, *122*, 166–182.

Ryan, R. M., Martin, A., & Brooks-Gunn, J. (2006). Is one good parent good enough? Patterns of mother and father parenting and child cognitive outcomes at 24 and 36 months. *Parenting, 6*, 211–228.

Sabol, T. J., & Pianta, R. C. (2012). Patterns of school readiness forecast achievement and socioemotional development at the end of elementary school. *Child Development*, *83*, 282–299.

Sacerdote, B. I. (2002). The nature and nurture of economic outcomes. *American Economic Review*, *92*, 344–348.

Saracho, O. N., & Spodek, B. (2008). Fathers: The "invisible" parents. *Early Child Development and Care*, *178*, 821–836.

Saxe, G. B., Guberman, S. R., Gearhart, M., Gelman, R., Massey, C. M., & Rogoff, B. (1987). Social processes in early number development. *Monographs of the Society for Research in Child Development*, *52*, vii-160.

Scarr, S., & McCartney, K. (1983). How people make their own environments: A theory of genotype → environment effects. *Child Development*, *54*, 424–435.

Scarr, S., & Weinberg, R. A. (1983). The Minnesota adoption studies: Genetic differences and malleability. *Child Development*, *54*, 260–267.

Scarr, S., & Weinberg, R. A. (1976). IQ test performance of Black children adopted by White families. *American Psychologist*, *31*, 726–739.

Schuchardt, K., Maehler, C., & Hasselhorn, M. (2008). Working memory deficits in children with specific learning disorders. *Journal of Learning Disabilities*, *41*, 514–523.

Seidman, L. J., Buka, S. L., Goldstein, J. M., Horton, N. J., Rieder, R. O., & Tsuang, M. T. (2000). The relationship of prenatal and perinatal complications to cognitive functioning at age 7 in the New England cohorts of the National Collaborative Perinatal Project. *Schizophrenia Bulletin*, *26*, 309–321.

Siegler, R. S., & Ramani, G. B. (2008). Playing linear numerical board games promotes low-income children's numerical development. *Developmental Science*, *11*, 655–661.

Skwarchuk, S.-L. (2009). How do parents support preschoolers' numeracy learning experiences at home? *Early Childhood Education Journal*, *37*, 189–197.

Skwarchuk, S.-L., Sowinski, C., & LeFevre, J.-A. (2014). Formal and informal home learning activities in relation to children's early numeracy and literacy skills: The development of a home numeracy model. *Journal of Experimental Child Psychology*, *121*, 63–84.

Sluis, S. van der, Leij, A. van der, & Jong, P. F. de. (2005). Working memory in Dutch children with reading- and arithmetic-related LD. *Journal of Learning Disabilities*, *38*, 207–221.

Smith, K. E., Landry, S. H., & Swank, P. R. (2000). The influence of early patterns of positive parenting on children's preschool outcomes. *Early Education and Development*, *11*, 147–169.

Son, S.-H., & Morrison, F. J. (2010). The nature and impact of changes in home learning environment on development of language and academic skills in preschool children. *Developmental Psychology*, *46*, 1103–1118.

Sorariutta, A., & Silvèn, M. (2018). Quality of both parents' cognitive guidance and quantity of early childhood education: Influences on pre-mathematical development. *The British Journal of Educational Psychology, 88*, 192–215.

Spinath, B., Spinath, F. M., Harlaar, N., & Plomin, R. (2006). Predicting school achievement from general cognitive ability, self-perceived ability, and intrinsic value. *Intelligence, 34*, 363–374.

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *Quarterly Journal of Experimental Psychology, 59*, 745–759.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643–662.

Stuss, D. T. & Benson, D. S. (1986). *The frontal lobes.* New York: Raven Press.

Thompson, L. A., Detterman, D. K., & Plomin, R. (1991). Associations between cognitive abilities and scholastic achievement: Genetic overlap but environmental differences. *Psychological Science, 2*, 158–165.

Totsika, V., & Sylva, K. (2004). The home observation for measurement of the environment revisited. *Child and Adolescent Mental Health, 9*, 25–35.

Towe-Goodman, N. R., Willoughby, M., Blair, C., Gustafsson, H. C., Mills-Koonce, W. R., Cox, M. J., & The Family Life Investigative Group. (2014). Fathers' sensitive parenting and the development of early executive functioning. *Journal of Family Psychology, 28*, 867–876.

Tracey, D. H., & Young, J. W. (2002). Mothers' helping behaviors during children's at-home oral reading practice: Effects of children's reading ability, children's sex, and mother's educational level. *Journal of Educational Psychology, 94,* 729–737.

Tucker-Drob, E. M., & Harden, K. P. (2012). Early childhood cognitive development and parental cognitive stimulation: Evidence for reciprocal gene-environment transactions. *Developmental Science, 15,* 250–259.

van der Sluis, S., de Jong, P. F., & van der Leij, A. (2004). Inhibition and shifting in children with learning deficits in arithmetic and reading. *Journal of Experimental Child Psychology, 87,* 239–266.

van der Sluis, S., de Jong, P. F., & van der Leij, A. (2007). Executive functioning in children, and its relations with reasoning, reading, and arithmetic. *Intelligence, 35,* 427–449.

van der Ven, S. (2011). *The structure of executive functions and relations with early math learning*.

Verdine, B. N., Golinkoff, R. M., Hirsh-Pasek, K., Newcombe, N. S., Flipowicz, A. T., & Chang, A. (2014). Deconstructing building blocks: Preschoolers' spatial assembly performance relates to early mathematics skills. *Child Development, 85,* 1062–1076.

Verdine, B. N., Irwin, C. M., Golinkoff, R. M., & Hirsh-Pasek, K. (2014). Contributions of executive function and spatial skills to preschool mathematics achievement. *Journal of Experimental Child Psychology, 126,* 37–51.

Vukovic, R. K., & Siegel, L. S. (2010). Academic and cognitive characteristics of persistent mathematics difficulty from first through fourth grade. *Learning Disabilities Research & Practice*, *25*, 25–38.

Vygotsky, L. S. (1978). *Mind in Society. The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

Wadsworth, S. J., DeFries, J. C., Fulker, D. W., & Plomin, R. (1995). Cognitive ability and academic achievement in the Colorado Adoption Project: A multivariate genetic analysis of parent-offspring and sibling data. *Behavior Genetics*, *25*, 1–15.

Walker, S. O., Petrill, S. A., Spinath, F. M., & Plomin, R. (2004). Nature, nurture and academic achievement: A twin study of teacher assessments of 7-year-olds. *British Journal of Educational Psychology*, *74*, 323–342.

Watts, T. W., Duncan, G. J., Chen, M., Claessens, A., Davis-Kean, P. E., Duckworth, K., … Susperreguy, M. I. (2015). The role of mediators in the development of longitudinal mathematics achievement associations. *Child Development*, *86*, 1892–1907.

Watts, T. W., Duncan, G. J., Siegler, R. S., & Davis-Kean, P. E. (2014). What's past is prologue: Relations between early mathematics knowledge and high school achievement. *Educational Researcher*, *43*, 352–360.

Wechsler, D. (1997). WAIS-III administration and scoring manual. San Antonio, TX: The Psychological Corporation.

Wechsler, D. WPPSI-III administration and scoring manual. San Antonio, TX: Psychological Corp; 2002.

Welsh, J. A., Nix, R. L., Blair, C., Bierman, K. L., & Nelson, K. E. (2010). The development of cognitive skills and gains in academic and school readiness for children from low-income families. *Journal of Educational Psychology, 102,* 43–53.

Whitehurst, Grover, J., & Lonigan, Christopher, J. (1998). Child development and emergent literacy. *Child Development, 69,* 848–872.

Whyte, J. C., & Bull, R. (2008). Number games, magnitude representation, and basic number skills in preschoolers. *Developmental Psychology, 44,* 588–596.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson Tests of Achievement* (3rd ed.). Itasca, IL: Riverside Publishing Company.

Yeung, W. J., Sandberg, J. F., Davis-Kean, P. E., & Hofferth, S. L. (2001). Children's time with fathers in intact families. *Journal of Marriage and Family*, *63*, 136–154.

Young-Loveridge, J. M. (2004). Effects on early numeracy of a program using number books and games. *Early Childhood Research Quarterly*, *19*, 82–98.

Zamarian, L., Visani, P., Delazer, M., Seppi, K., Mair, K. J., Diem, A., … Benke, T. (2006). Parkinson's disease and arithmetics: The role of executive functions. *Journal of the Neurological Sciences, 248,* 124–130.

Zelazo, P. D., & Müller, U. (2002). Executive function in typical and atypical development. In U. Goswami, (Ed.), *Blackwell handbook of childhood cognitive development* (pp. 445–469). Malden, MA: Blackwell Publishing.

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GRANTS, AWARDS, AND HONORS

Strumpf Endowment, Travel Grant ($350 - $800 each) — 2014-2017
NSF Application Incentive Award ($500 each) — 2012-2013
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RESEARCH INTERESTS

Math skills, spatial skills, parenting and other early life experiential factors, gene-environment interplay and other individual difference factors

PUBLICATIONS

Peer-Reviewed Journal Articles

Borriello, G. A., Ramos, A.M., Neiderhiser, J. M., Natsuaki, M. N., Shaw, D., Reiss, D., Leve, L. D, & Neiderhiser, J. M. (in preparation). Investigating the etiology of mathematics abilities using a prospective-adoption design.

Borriello, G. A. & Liben, L. S. (2018). Encouraging Maternal Guidance of Preschoolers' Spatial Thinking during Block Play. *Child Development*. *89*(4), 1209-1222.

Evans, D., **Borriello, G. A.,** & Field, Andy (2018). The psychological impact of the primary-secondary school transition. *Frontiers in Psychology*. *9*(1482), 1 – 18.

Book Chapters

Liben, L. S., Schroeder, K. M., **Borriello, G. A.,** & Weisgram, E. S. (in press). Cognitive development in the context of gendered toy play. In E. S. Weisgram & L. M. Dinella (Eds.), *Gender-typing of children's toys*. Washington, D.C.: American Psychological Association.