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When beliefs matter most: Examining children's math achievement in the context of parental math anxiety

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Abstract

A growing body of research suggests that parents' beliefs about and attitudes towards math predict their young children's math skills. However, limited research has examined these factors in conjunction with one another or explored potential mechanisms underlying these associations. In a sample of 114 preschool-aged children and their parents, we examined how parents' beliefs about math and math anxiety together relate to children's math achievement and how parents' practices to support math might explain these associations. We utilized a range of measures of parental math input, including survey measures of the home numeracy environment as well as observations of number talk. Parents with stronger beliefs about the importance of math tended to have children with more advanced math skills and parents with math anxiety tended to exacerbate the effects of these beliefs such that children whose math anxious parents held strong beliefs about math's importance performed best. Further, we found some evidence that parents' math practices may relate to this interaction or to children's math skills, but no single measure of math input mediated the effect of the interaction between parental math anxiety and math beliefs on children's math outcomes. Thus, parents' math anxiety differentially relates to children's math performance depending on parents' beliefs about math, but future research is needed to uncover the specific mechanisms through which these processes operate.

Keywords

math abilities; math anxiety; parental beliefs; home numeracy; math talk; early childhood

Introduction

Children's math skills vary widely in early childhood and are strongly predictive of later academic achievement (Duncan et al., 2007; Entwisle & Alexander, 1990; Jordan, Kaplan,

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Ola, & Locuniak, 2006; Starkey & Klein, 1992). Given the importance of these foundational math abilities for later math achievement, and the association between math achievement and outcomes including educational attainment, career choice, likelihood of full-time employment, income, and health and financial decision-making (e.g., Agarwal & Mazumder, 2013; Currie & Thomas, 1999; Reyna & Brainerd, 2007; Trusty, Robinson, Plata, & Ng, 2000), much work has examined factors related to these individual differences. Variability in these early math skills has been attributed to children's own domain-general and domain-specific cognitive factors (Chu, VanMarle, & Geary, 2016; Hart, Petrill, Thompson, & Plomin, 2009; Hyde, Khanum, & Spelke, 2014; Libertus, Feigenson, & Halberda, 2013) as well as many social and environmental factors. This is particularly salient in the case of parents, who are often the primary introduction to math for children before they begin formal schooling.

Many studies have examined the ways that parents support their children's early math learning and have found that parent math engagement typically predicts children's later math performance. Parents who report more frequently engaging in math activities such as playing board games or talking about money when shopping tend to have children with more advanced math skills (Elliott & Bachman, 2018a; LeFevre, Polyzoi, Skwarchuk, Fast, & Sowinski, 2010; LeFevre et al., 2009; Niklas & Schneider, 2014; Ramani & Siegler, 2008; Skwarchuk, 2009). Similarly, parents' use of mathematical language with their children, such as using number words in mealtime conversations or during play, is positively predictive of children's math abilities (Gunderson & Levine, 2011; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010; Ramani, Rowe, Eason, & Leech, 2015; Susperreguy & Davis-Kean, 2016). In addition to these direct opportunities for exposure to math content, some evidence suggests that parents also contribute to their children's math learning indirectly, such as through their beliefs or attitudes about math, but these findings are mixed (LeFevre et al., 2010; Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015; Missall, Hojnoski, Caskie, & Repasky, 2014; Skwarchuk, Sowinski, & LeFevre, 2014; Sonnenschein et al., 2012). Despite the growing body of research examining parents' practices to promote children's math learning, less is known about how parents' own characteristics, including not only their beliefs and attitudes about math, but also their own math abilities, relate to children's math skills.

In this study, we examine how parents' own cognitions and feelings about math, including their math anxiety and their beliefs about the importance of early math skills, may relate to children's math abilities in early childhood. Specifically, we investigate the extent to which these factors may interact to predict math achievement. Additionally, we explore how parents' engagement with their children may act as a mechanism to explain how these indirect parent factors relate to children's math outcomes.

Parental Beliefs about Children's Math Learning

Past research examining parents' beliefs about their children's learning has examined a wide range of beliefs, including parents' expectations (DeFlorio & Beliakoff, 2015; Fan & Chen, 2001; Jeynes, 2005; Kleemans, Peeters, Segers, & Verhoeven, 2012), their perceptions of their own role in their children's learning (DeFlorio & Beliakoff, 2015; Stipek, Milburn,

Clements, & Daniels, 1992), and their beliefs about the importance of specific academic subjects (Cannon & Ginsburg, 2008; Puccioni, 2015). In this study, we are particularly interested in examining parents' beliefs about math. Parents' beliefs about math may potentially be related to their child's math performance, though evidence is mixed (Fredricks & Eccles, 2002; Musun-Miller & Blevins-Knabe, 1998; Parsons, Adler, & Kaczala, 1982). On the one hand, Fredricks and Eccles (2002) found that parental beliefs about their child's math ability and expectations for their child's future math performance were strongly correlated with their elementary school child's math performance, as rated by the child's teacher. On the other hand, other work looking at associations between parental beliefs about the importance of math and children's math performance has not found relations. Specifically, Musun-Miller and Blevins-Knabe (1998) found that parents' beliefs about the importance of children's ability to do math in order to do well in first grade did not predict their kindergartners' math performance, though this was in a relatively small sample of children. Similarly, in a larger sample, LeFevre and colleagues (2009) found that parents' beliefs about the importance of children's ability to do math in order to do well in kindergarten did not relate to their early elementary school child's math performance. These previous studies have examined different types of parental beliefs surrounding math, from beliefs about math's importance to beliefs about their child's current ability and future in math, and have been inconclusive. Thus, one aim of the current work is to further examine the direct effect of parents' beliefs, specifically about math's importance, on their children's math performance in a larger sample with children prior to entering school, in the hopes of better understanding this potential association.

Several possible mechanisms underlying associations between parents' math importance beliefs and children's math skills have been proposed. On the one hand, parental beliefs about math may shape children's own beliefs about math, which in turn could relate to children's math performance. Among older children, parents' beliefs about math are related to their middle school and high school children's beliefs about math, as well as their children's likelihood of deciding to pursue a career in a math- or STEM-related field (Bleeker & Jacobs, 2004; Metzger, Sonnenschein, & Galindo, 2019; Parsons et al., 1982). In a sample of 5th to 11th graders, Parsons and colleagues (1982) found that parental beliefs about math significantly predicted their child's beliefs about and attitudes toward math. Parents who held stronger beliefs about their child's ability in math had children who held more positive attitudes toward math as well as more confidence to learn difficult math in the future. However, it is difficult to test this hypothesis in young children because of a lack of sensitive measures for children's beliefs and attitudes toward math before school entry.

On the other hand, parents' beliefs about math may shape their practices to support math, which may then relate to children's math skills. Past research suggests that parents' beliefs about the importance of math are related to the frequency with which parents engage in math activities with their preschool- and school-aged children (Cannon & Ginsburg, 2008; LeFevre et al., 2009; Muenks, Miele, Ramani, Stapleton, & Rowe, 2015; Musun-Miller & Blevins-Knabe, 1998; Sonnenschein et al., 2012; Zippert & Ramani, 2017). Parents who hold stronger math importance beliefs report engaging in more frequent math-related activities with their child. These findings are in line with Expectancy-Value Theory (Wigfield & Eccles, 2000), where the value an individual places on a task increases the

likelihood of them choosing to do that task. In this case, believing that math is more important for their child may lead parents to engage in more frequent math activities with them. This increased exposure to math activities may, in turn, lead to differences in children's math performance. We will explore this hypothesis in the current study.

Parental Math Anxiety

In addition to varying beliefs about the importance of math, there is considerable variability amongst adults in their level of math anxiety. Math anxiety is distinct from generalized anxiety and test anxiety and is defined as a feeling of tension or discomfort when having to solve math problems or work with numbers (Richardson & Suinn, 1972). Research estimates that at least 11% of adults have severe math anxiety, and there is considerable variability across adults in their level of math anxiety (Dowker, Sarkar, & Looi, 2016). Math anxiety is not only associated with adults' own poor math performance (Ashcraft, 2002), but parental math anxiety is also negatively associated with their elementary school child's math performance (Berkowitz et al., 2015; Maloney et al., 2015).

Maloney and colleagues (2015) found that the negative effect of parental math anxiety was particularly strong for school children whose math anxious parents engage with them in math activities and homework naturally. They found that parents who had low math anxiety had children who did well in math and had similar growth in math achievement across the school year, regardless of how much time their parents spent helping them with homework. In contrast, math performance for children whose parents had higher math anxiety was moderated by the amount of time their parents spent helping them with homework. When highly math anxious parents avoided helping their children with their math homework, children did well and exhibited just as much math learning during the school year as their peers whose parents had lower math anxiety. But for children whose parents were math anxious and tried to help them with homework, math scores across the school year were much worse and grew much slower than their peers'. Thus, parents who are math anxious and spend more time helping their school-aged child with math content might actually do their children a disservice and have children who perform worse in math.

However, Berkowitz and colleagues (2015) found that the relation between highly math anxious parents' math engagement and children's poor performance can be mitigated by training. They found that elementary school children whose parents had high math anxiety scored lower in math and had slower growth in their math achievement over the course of the school year than their peers whose parents reported low math anxiety. The effect of parental math anxiety on elementary school children's math achievement held even when controlling for parents' own math abilities. However, parents who were math anxious and were given explicit guidance on how to engage with their children through math story problems had children whose math performance increased as much as the math performance of children of low math anxious parents. This suggests that engaging in math content in particular ways may combat the effects of parental math anxiety.

These previous studies have examined the link between parental math anxiety and the math performance of their school-aged children. To date, though, no work has examined the effect of parental math anxiety on younger, preschool-aged children. Recently, Elliott and

colleagues (2020) found negative associations between parents' math anxiety and their engagement with math activities at home with their preschoolers, consistent with this past work, but child outcomes were not included in this study. However, qualitative analyses of interviews with parents in this study revealed potential heterogeneity among the practices of parents with high levels of math anxiety. In particular, several math anxious parents reported engaging in math activities very frequently with their young children in order to compensate for their own biases against math and avoid passing these negative attitudes to their children (Elliott, Bachman, & Henry, 2020). In these cases, parents' strong beliefs about the importance of math seem to interact with their level of math anxiety to impact their math engagement behavior. As such, in the present study we examine the main effects of math beliefs on children's math learning but also explore whether parents' math anxiety may moderate potential associations. Furthermore, given evidence that both parental beliefs about math and math anxiety may operate through parents' practices to support math, we also explore potential mechanisms through which these effects may operate.

The Current Study

In sum, in this study, we examine how parents' beliefs about math and math anxiety relate to preschool-aged children's math achievement and how parents' practices to support math may be related to these associations. We hypothesize that parents with stronger beliefs about the importance of math and less math anxiety will have children with more advanced math skills and that beliefs about math's importance will serve as a buffer for children with math anxious parents. Furthermore, we will explore potential mechanisms underlying these associations by utilizing a range of measures of parental math input, including survey measures of the home numeracy environment as well as observations of number talk in a laboratory setting. We expect that parents' math engagement with their children will mediate the effects of parental math beliefs and math anxiety on children's math performance. In addition to these measures of interest, we will also control for other potentially confounding constructs, including children's general cognitive abilities. Specifically, we will ensure that these potential parental effects on children's math performance hold above and beyond the influences of children's own inhibitory control and general vocabulary knowledge, both of which have been found to be related to children's math performance (see Allan, Hume, Allan, Farrington, & Lonigan, 2014; Purpura, Hume, Sims, & Lonigan, 2011).

Methods

Participants

Participants were 114 preschool-aged children (56 girls) and one of their parents. Children ranged in age from 3 years 8 months to 4 years 0 months (child *M* age = 3 years 11 months, *SD* = .77 months). Children were predominantly White, non-Hispanic (82%), while 8% of children were White, Hispanic/Latino, 3% were Black, non-Hispanic, 3% were Asian, non-Hispanic, and 4% were another race or multiple races. Parents were mostly mothers (95%) and were highly educated: 90% had earned a Bachelor's degree or higher, with level of education ranging from having completed high school to having completed a graduate degree. An additional 28 children (13 girls) participated but were dropped from analyses due to incomplete or missing data. Families were recruited from a mid-sized city in the United

States through a combination of flyers, online postings, and mailings, and were compensated $8 per hour for their time. Prior to any data collection, parents provided written informed consent as approved by the local Institutional Review Board.

Procedure

Data for this study are drawn from the first and second time points of a longitudinal study. Parents and children visited the lab for their first visit, and then returned for a second visit two months later. During each two-hour visit to the lab, parents and children completed a short 10-minute free play interaction. Parents and children then individually completed a number of activities and assessments. Children completed a standardized math assessment and a measure of inhibitory control. Parents completed a standardized math assessment and filled out questionnaires about their own beliefs, attitudes and anxiety toward math and literacy, as well as a questionnaire about their child's vocabulary knowledge. In this study, predictors of interest (i.e., parental beliefs, math anxiety, and control variables) were drawn from the first lab visit, whereas outcomes of interest (i.e., children's math skills and vocabulary, in robustness analyses) were drawn from the second visit. Given that no middle time point was available for potential mechanism variables (i.e., those that were used as both predictors of math skills and outcomes in interaction models), composite variables were calculated for math activities and number talk variables.

In addition to the measures of interest described in detail below, children also completed assessments measuring their non-symbolic numerical comparison ability and number knowledge. Parents also completed standardized assessments of their reading skills and an assessment measuring their non-symbolic numerical comparison ability. These activities were not of interest to the current study and are thus not further described. Descriptive statistics and correlations for key study variables are shown in Table 1.

Measures

Parents' Beliefs—Parental beliefs about the importance of math and literacy for their child were measured at the first lab visit using the Benchmarks Survey from the Home Numeracy Questionnaire (LeFevre et al., 2009). Parents were asked "In your opinion, how important is it for children to reach the following benchmarks prior to entering kindergarten?" Responses ranged from 0 ("not at all important") to 4 ("very important") on a four-point scale. Items included parents' beliefs about the importance of four math skills and four literacy skills. Separate importance scores for math and literacy were calculated by averaging responses on the math items and literacy items respectively for each parent. These scales have acceptable internal consistency, with Cronbach's alpha of 0.75 and 0.84 for the math and literacy items, respectively.

Parents' Math Anxiety—Parents' math anxiety was measured at the first lab visit using the 30-item Math Anxiety Rating Scale, brief version (Suinn & Winston, 2003). Parents were asked to rate their anxiety in math-related situations. Parents were told "In the following, you will be presented with some everyday situations. Please rate each item in terms of how anxious you would feel during the event specified." Parents rated their anxiety on a five-point scale from 1 ("low anxiety") to 5 ("high anxiety"). Items included scenarios

including taking a final exam in a math class, totaling up a dinner bill, figuring out sales tax on a purchase, and being given a set of math problems to complete. An average math anxiety score was computed for each parent. This questionnaire demonstrates high internal reliability, with Cronbach's alpha reported to be 0.96, with strong test-retest reliability of 0.90 (Suinn & Winston, 2003).

Parents' Standardized Math Performance—Parental math performance was assessed using the Woodcock-Johnson Tests of Achievement III (WJ-III; Woodcock, McGrew, & Mather, 2001), which was completed at the first lab visit. Parents completed the Math Calculation subtest, which is untimed and asked them to solve as many problems as they could, including arithmetic, algebra and calculus. Then parents completed the Math Fluency subtest, a timed test where they were given simple arithmetic problems and instructed to complete as many problems as they could in three minutes. Parents' scores on the Math Calculation and Math Fluency subtests were then used to compute a normed Math Composite Score. The WJ-III is a standardized measure of achievement, with the Math Calculation Skills Composite Score showing excellent reliability with Cronbach's alpha of 0.94 (Woodcock et al., 2001).

Children's Inhibitory Control—Children's inhibitory control was assessed using a modified Day-Night Stroop task (Gerstadt, Hong, & Diamond, 1994) during children's first visit to the lab. In this assessment, children were shown images and instructed to say "day" when shown one image, and "night" when shown another image. The incongruent task asked children to say "night" when shown a sun image, and "day" when shown a moon image, requiring children to form a new association between the images and the words, as well as inhibit their prepotent association response. The control task showed children images of either a checkerboard or a squiggle pattern and required children to form the new association between the images and the words, without requiring the inhibition of a prepotent response. This control task requires the same formation of a new association between a word and picture as in the incongruent task but does not require inhibition. By including children's scores in the control task in models using the incongruent task, we can control for children's ability to form a new association and use this association to follow a rule in the incongruent task, such that performance on the incongruent task reflects only their ability to inhibit a prepotent response.

The order in which children were administered the incongruent and control tasks was counterbalanced across children. Children received 16 trials of the incongruent task and 16 trials of the control task, each of which had 8 trials of "day" and 8 trials of "night" correct responses. Children were not given any feedback after responding to a trial. In each trial, children could receive 0, 1 or 2 points for their response. Children received 2 points for every response that was correct on the first try, and 1 point for an incorrect response that they fixed spontaneously. Children received 0 points for any incorrect responses. Children's scores for all incongruent task trials were averaged to create their incongruent task score, and their scores for all control task trials were averaged to create their control task score. Past work demonstrates that the Day-Night Stroop task is a reliable measure of young

children's interference control that is highly correlated with other measures of inhibition, with correlation coefficients as high as 0.79 (Montgomery & Koeltzow, 2010).

Children's Standardized Math Performance—During both their first and second visits to the lab, children completed the Test of Early Mathematics Ability, 3rd edition (TEMA-3; Ginsburg & Baroody, 2003), a standardized math assessment that assesses numbering skills, number-comparison facility, numeral literacy, mastery of number facts, calculation skills, and understanding of concepts. The TEMA-3 was administered and scored by a trained experimenter. Raw TEMA-3 scores were used as the measure of children's math abilities. The TEMA-3 demonstrates high consistency and reliability with Cronbach's alpha of 0.94 and test-retest reliability of 0.82 (Ginsburg & Baroody, 2003).

Children's Vocabulary—Children's vocabulary was assessed at both lab visits using the Developmental Vocabulary Assessment for Parents, a parent-report measure of children's language development (DVAP; Libertus, Odic, Feigenson, & Halberda, 2015). This questionnaire has been validated as an alternative to a time-intensive, experimenter-administered test of vocabulary such as the Peabody Picture Vocabulary Test (Dunn & Dunn, 2007). Parents were asked to read through a representative list of 212 words and check off any words that they had heard their child say. Children's scores were calculated as the total number of words that parents reported their children to have used. The DVAP shows high concurrent validity and is highly correlated with other measures of children's vocabulary ability, including the Peabody Picture Vocabulary Test (with a coefficient of 0.69) and the MacArthur-Bates Communicative Development Inventories (with a coefficient of 0.79; Libertus et al., 2015).

Home Math Activities—Parents reported the frequency of home math activities using the home activities questionnaire from LeFevre and colleagues (2009) at both lab visits. Parents were asked to indicate how often in the past month they had participated in listed activities (e.g., "Identifying names of written numbers") with their child on a scale from 0 ("Did not occur") to 4 ("Almost daily"), and their responses for 23 math-related items were averaged to create a total score. This scale has acceptable internal consistency, with Cronbach's alpha of 0.80. In addition to the overall score of math activities, scores for two subdimensions of numeracy activities were calculated. Parents' reports of number skill (e.g., counting objects, printing numbers) and number book (e.g., using number activity books, reading number story books) activities were combined to form a formal math activities subdimension. Parents' reports of games (e.g., playing card games, playing board games with a die or spinner) and applications (e.g., using calendars and dates, talking about money when shopping) were combined to form an informal math activities subdimension. Parents' scores across the two visits were highly correlated for overall home math activities ($r = .61$, $p < .001$) as well as for formal and informal math activities ($r = .72$, $p < .001$, and $r = .76$, $p < .001$, respectively), and we aimed to have the most robust and stable observation of parents' typical math engagement with their child. As such, scores from the two timepoints were averaged to create composite home math activities scores.

Parents' Number Talk—For each lab visit, parent-child conversations during the 10-minute free play sessions were transcribed, which were used to code parent number talk during these interactions. Specifically, parents' use of number words (i.e., identifying only numerical uses of the word "one") as well as words that might elicit number talk (e.g., "count," "number," and "how many") were coded in line with past work (Elliott, Braham, & Libertus, 2017; Levine et al., 2010). The total number of number words and elicitations used by parents was tallied for each visit to form a single measure of parent number talk. Parents' number talk was correlated across the two visits ($r = .26$, $p = .002$), and we aimed to have the most robust and stable observation of parents' math input to their child, so counts for the two visits were averaged to create a composite parent number talk score.

Analysis Plan

To address whether parents' beliefs about math and math anxiety relate to children's math skills, we first regressed children's math performance on the TEMA-3 at the second visit on parents' ratings of the importance of math and reports of math anxiety from the first visit. In these analyses, we also controlled for children's vocabulary and inhibitory control as well as parents' math skills and beliefs about the importance of literacy skills from the first visit. To test our hypothesis that parents' math anxiety might moderate the effect of their beliefs about math importance on children's math performance, we then added an interaction between parents' beliefs about math and math anxiety from the first visit. All predictors were centered prior to analysis.

To examine the robustness of these associations, we then tested three alternative models. First, to test for specificity of these effects, we examined whether measures of parents' beliefs about math, math anxiety, or their interaction at the first visit predicted children's vocabulary at the second visit. Given the high autoregressive correlation of vocabulary scores across the two timepoints ($r = .80$, $p < .001$), vocabulary from the first visit was not included as a predictor, but TEMA-3 scores from the first timepoint were added to the model in addition to the other control variables. Next, we tested for specificity by including a model where we examined how parents' beliefs about the importance of literacy skills, parents' math anxiety, and their interaction at the first visit predicted children's math skills at the second visit. This model included a control for math beliefs at the first visit as well as the other control variables. Finally, we tested whether beliefs about math, math anxiety, and their interaction at the first visit predicted math ability at the second visit even when controlling for prior math performance, by including TEMA-3 scores from the first assessment as a predictor of later TEMA-3 scores. Autoregressive correlations were quite high, $r = .84$, $p < .001$, so this model serves as a particularly conservative test.

A final set of models aimed to explore potential mechanisms underlying the associations between parents' beliefs and math anxiety and children's math skills. We thus individually regressed overall home math activities, both formal and informal dimensions of home math activities, and parent number talk on parents' math beliefs, math anxiety, their interaction, and covariates at the first visit. Lastly, these potential mechanisms (overall home math activities, formal and informal home math activities, and parent number talk) were each included as predictors of math skills at the second visit.

Results

Interactions between Parental Math Anxiety and Math Beliefs

Children's math performance at the second visit was first regressed on parents' math beliefs and math anxiety, controlling for parents' math abilities and beliefs about literacy skills as well as children's vocabulary and inhibitory control at the first visit. This model was significant overall, $F(7, 106) = 3.45$, $p = .002$, and explained 19% of the variance in children's TEMA-3 outcomes at the second visit. As shown in Table 2, math beliefs at the first visit were significantly predictive of math abilities at the second visit, as a 1 SD increase in beliefs about the importance of math was associated with a 0.30 SD increase in children's math skills, a small effect with Cohen's f^2 of .05. However, parents' math anxiety at the first visit was not significantly related to their children's math skills at the second visit. We then added the interaction between parental math beliefs and parental math anxiety to this regression, $F(8, 105) = 4.28$, $p < .001$, see Table 2. This interaction term was highly significant and resulted in an additional 6% of variance explained in children's math skills at the second visit, a small to medium effect with Cohen's f^2 of .08. A plot of the interaction is shown in Figure 1.

Sensitivity Analyses

Domain-specificity—To examine whether the interaction between parental math beliefs and parental math anxiety was specific to math, we first regressed children's vocabulary scores from the second timepoint on the same set of predictors, with math achievement at the first visit included as a control. This model was not significant overall, $F(8,105) = 0.63$, $p = .75$, and neither the main effects of math beliefs and math anxiety nor the interaction was significantly related to children's vocabulary at the second visit.

Additionally, we examined whether beliefs about children's literacy development interacted with math anxiety to predict children's math achievement, $F(8, 105) = 3.58$, $p = .001$. Although the interaction of math anxiety and literacy beliefs at the first visit was marginally related to children's math skills at the second visit, parents' beliefs about literacy and beliefs about math skills were highly correlated at the first visit, $r = .73$, $p < .001$. As such, it was unclear whether this interaction effect was truly driven by literacy beliefs or was an artifact of the strong association with math beliefs. To disentangle these explanations, both interaction terms were included in a single regression model, $F(9, 104) = 3.78$, $p < .001$. In this model, shown in Table 3, only the interaction between math beliefs and math anxiety reached statistical significance.

Controls for Prior Math—As a final robustness check, children's math scores at the first time point were added as a predictor of children's math scores at the second time point in addition to math beliefs, math anxiety, their interaction, and covariates from the first visit. This model explained 75% of the variance in math achievement at the second visit, $F(9, 104) = 35.30$, $p < .001$. As is shown in Table 4, math scores across the two timepoints were very highly correlated ($\beta = .82$). In this highly controlled model, the interaction term remained marginally significant and a small effect with Cohen's f^2 of 0.03, providing some evidence

for the moderation effect described above, even in this more stringent model. A plot of this interaction is shown in Figure 2.

Potential Mechanisms Linking Parent Math Anxiety and Math Beliefs to Children's Performance

Finally, to explore potential mechanisms of these associations, the scores for overall math activities, formal math activities, informal math activities, and number talk were regressed on beliefs about math, math anxiety, the interaction term, and covariates at the first visit. Results from these models are shown in Table 5. Although math beliefs were significantly predictive of math activities overall, this association was not moderated by math anxiety. However, formal math activities were reported more frequently by parents with stronger beliefs about the importance of math, and this association was marginally stronger for parents with higher levels of math anxiety. In contrast, no main effects or interactions were seen for informal math activities. Math beliefs and math anxiety also interacted to predict number talk, such that the positive links between beliefs about math and number talk were stronger among parents with higher levels of math anxiety.

Each of those composite parental engagement predictors was then included in the models shown in Table 2 to examine whether these potential mechanisms related to children's math outcomes at the second visit. Results of these models are shown in Table 6. The addition of overall math activities to these models resulted in a significant overall model, $F(9,104) = 4.61$, $p < .001$, and explained an additional 4% of variance in child math achievement at the second visit. Math activities were significantly related to children's math outcomes, as a 1 SD increase in overall math activities predicted a 0.21 SD increase in children's math skills, a small effect with Cohen's f^2 of .06. Similar associations were seen for formal math activities, $F(9,104) = 4.25$, $p < .001$, which explained an additional 2% of the variance in math achievement ($\beta = .16$), and informal math activities, $F(9,104) = 4.35$, $p < .001$, which explained an additional 3% of the variance ($\beta = .18$). However, number talk was not significantly related to children's math achievement at the second visit. Critically, in all of these models the interaction between math beliefs and math anxiety remained a significant predictor of children's math achievement.

Discussion

The goals of the present study were to evaluate how parents' math importance beliefs and math anxiety are related to their preschool-aged child's math achievement. We hypothesized that parents with higher math importance beliefs and lower math anxiety would have children who performed best in math but that high math importance beliefs would buffer the effects of high math anxiety. In line with this prediction, we found that math importance beliefs significantly predicted children's math performance above and beyond other predictors. However, math anxiety was not directly related to children's math abilities. Instead, math anxiety amplified the effects of math beliefs: in the context of high math anxiety, parents who believed math was particularly important had children with above average performance, whereas parents who rated math as less important had children with lower than average performance. In contrast, for parents with low math anxiety, beliefs about

math were not associated with children's math outcomes. As such, rather than strong beliefs about the importance of math simply buffering children from their parents' math anxiety, instead math anxiety may shape the way that parents' beliefs are transmitted into action and lead to better math outcomes. In this way, math anxiety may be faciliatory in encouraging parents to act on their strong beliefs.

Importantly, the relations between parental math anxiety and beliefs on children's math achievement held even when controlling for children's inhibitory control, their vocabulary knowledge, parents' own math abilities, and parents' beliefs about literacy importance. In addition, this set of parent- and child-level predictors that predicted children's math performance did not significantly predict children's vocabulary knowledge, and thus these effects appear to be somewhat domain-specific to math performance. Notably, the interaction between parental math anxiety and beliefs remained marginally significant, with a small effect size, even when controlling for children's math skills merely two months earlier. Finally, we had further hypothesized that the effects of parental math beliefs and math anxiety on children's math performance might operate through math activities or parental number talk to influence children's math performance, but in contrast to these expectations we found that none of these mediated the effects of parent math anxiety and math belief factors.

Predictors of Children's Math Performance

Here we found that parents' beliefs about the importance of math skills significantly predicted their preschool-aged child's math performance, even when controlling for all other predictors. Parents who had higher beliefs about math's importance and believed that it was more important for children to learn particular math skills prior to entering kindergarten had children who performed better on the math assessment. Although several studies have demonstrated that domain-general beliefs about the importance of academic skills predict achievement more generally (Elliott & Bachman, 2018b; Puccioni, 2015), past work examining math-specific beliefs found parental beliefs are often not associated with children's math outcomes (LeFevre et al., 2009; Musun-Miller & Blevins-Knabe, 1998; but see Fredricks & Eccles, 2002). Given the interaction between math anxiety and math beliefs observed in this study, these conflicted findings may be attributable to differences in the level of math anxiety among parents across studies.

In contrast to prior work with elementary school students that found that higher parental math anxiety was associated with children's worse math performance (Berkowitz et al., 2015; Maloney et al., 2015), here we found that parental math anxiety was not a significant predictor of preschool-aged children's math performance. This unexpected finding could be attributable to the younger age of children in this study, particularly if the effects of parental math anxiety increase as they need to explain more complex math concepts to their children, if children become better able to pick up on or notice their parents' math anxiety with age, or if parents increase their engagement in children's math learning once children enter school. This last possibility is consistent with the results of Maloney and colleagues (2015), who found that negative effects of parental math anxiety were only seen for elementary school children whose parents helped them with homework. More longitudinal work

exploring the developmental progression of parental math anxiety, including when in development parental math anxiety begins to negatively relate to children's skills and why this association seems to change across time as children's skills develop and math learning transitions outside of the home, is needed to gain a fuller picture of these complex processes. Although we posit that parental math anxiety is a fairly static construct for parents, understanding how this anxiety manifests and how it relates to parents' behaviors in drastically changing environments (e.g., discussing basic number concepts as a primary educator of your young child compared to helping with more complex assignments chosen by a teacher for your older child) is a novel area for future research. However, it is also notable that for parents in the present study with low ratings of the importance of math, math anxiety was indeed predictive of lower math achievement for children. This negative relation was offset by a positive association between parents' math anxiety and children's achievement among parents with high ratings of the importance of math.

Further evidence for the notion that parental math anxiety may affect preschool-aged children's math achievement differently than elementary school-aged children comes from our model predicting children's math achievement when controlling for prior math skills. Here we found that parental math anxiety was overall positively related to children's math achievement. This change in the association may indicate that math anxiety is particularly related to change in math skills, such that children of parents with high math anxiety may initially have had below average math skills but throughout the course of this study show more growth than children of parents with low math anxiety (e.g., participating in a study where parents are asked about their engagement in math activities may change parents' behaviors in some way, and parents with math anxiety may be particularly prone to change their behavior). More research is needed to unpack these complex associations between parents' math anxiety and children's math achievement over time.

Potential Mechanisms Linking Parent Math Anxiety and Math Beliefs to Children's Performance

In this study we also examined potential mechanisms that might explain the association between parent beliefs and math anxiety and their children's math performance. We hypothesized that parents' behaviors to support math at home might explain why beliefs about the importance of math were particularly strongly related to children's math skills among parents with high levels of math anxiety. Parents who are math anxious yet still value the importance of math may attempt to compensate for their own anxiety by engaging in math learning activities at home, thus giving their child more opportunities to learn math and develop their math skills. In contrast, math anxious parents who do not find math to be important may avoid these types of activities.

Several measures of math activities and number talk were utilized in this study to test these claims but none of the measures mediated the interaction effect on children's math abilities. We found that parents' beliefs about the importance of math did predict their frequency of engaging in math activities and was particularly related to their use of formal activities, like flashcards and workbooks, but not their use of informal math activities, like board games. This relation was marginally stronger for parents with higher math anxiety. However, the

frequency of these math activities was a unique predictor of children's math performance and did not mediate the relation between the beliefs and anxiety interaction and children's performance.

We further predicted that the amount of number talk that parents engaged in with their child might mediate the effects of the interaction between math beliefs and math anxiety on children's math performance. Although the interaction between math beliefs and math anxiety did predict parents' use of number talk with their child, such that parents with high math anxiety and strong beliefs about the importance of math tended to use more number talk than any of the other parents, number talk did not predict children's math performance. In contrast to prior work (Elliott et al., 2017; Levine et al., 2010), here we did not observe an association between parents' use of number talk and their child's math performance. These differences may be in part due to the different age of the children in our study compared to previous studies, the context in which number talk was measured (i.e., lab vs home setting), or the way in which it was measured in these studies (e.g., number words only, a restricted range of number words, or a broader range of math-related words).

In sum, the interaction of parents' math beliefs and math anxiety was related to several independent measures of math input, but the interaction remained a significant predictor of math skills even when controlling for these potential mechanisms. This pattern may have been partially attributable to the fact that many of the measures of math input were not significantly predictive of children's math abilities. These findings underscore a larger concern in this body of research regarding how best to measure the home numeracy environment in a way that is ecologically valid and captures the most critical components of these interactions (see Elliott & Bachman, 2018). To date, most research relies on frequency-based measures, such as how often activities occur or number words are used (e.g., LeFevre et al., 2009; Levine et al., 2010). As such, we may overlook factors such as the quality of the interactions, the developmental match between math content and children's math skills, the emotional valence of parents and children in these activities, and the extent of these interactions. It is possible that the interaction of parents' math beliefs and math anxiety may also relate to some of these unmeasured factors, such that parents with high math anxiety who believe math is important engage in interactions that are more tailored to children's skill levels and/or are more positive whereas math anxious parents who do not believe math is important may not tailor their activities to their child as much or may engage in less positive interactions. As such, we suspect that parents' behaviors likely mediate associations between parents' beliefs and anxiety and their children's math skills, but additional work is needed to develop more sensitive measures of the home numeracy environment to detect this mediation.

Limitations, Conclusions and Future Directions

We found that parents' math importance beliefs may only matter in the context of parental math anxiety. Further, we found that although parents' beliefs and math anxiety were related to their math engagement with their child, these engagement factors did not explain the differences in children's math performance. As such, we extend past work by demonstrating that parent math anxiety and math importance beliefs are important constructs for future

study as predictors of children's math (e.g., Maloney et al., 2015; Fredricks & Eccles, 2002), and critically, that they do not operate through the math engagement practices currently studied in the literature.

Several limitations of the current study warrant discussion. As noted above, more nuanced measures of parental engagement in math content with their children would help determine the association between these predictors and children's math performance. Additionally, we have looked at these relations assuming that parent factors produce effects on child outcomes and have largely ignored the role of children in this story. It is quite likely that children's own cognitive abilities, beliefs, and affect toward math impact their own math performance and shape the way their parents engage in math with them. Future work should evaluate how children's own propensities toward math influence how their parents engage in math with them, and how this may impact how much benefit children receive from their parents' math input. Finally, our sample consisted of primarily highly educated, White mothers and their children, which limits the generalizability of these findings to a broader population. Some work suggests that math anxiety is present cross-culturally (see Foley et al., 2017, for review), though future research should examine whether parental math anxiety and math beliefs relate to children's math achievement similarly across different demographic and ethnic backgrounds.

Despite these limitations, we find that parents' beliefs and math anxiety impact their child's math performance and their engagement in math with their child. However, many important questions remain, including determining the mechanism by which parental math beliefs and anxiety impact children's performance. Finally, examining the impact of these parental factors on their math engagement with their child is critical, particularly given the potential links between parental math engagement and children's math performance.

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Research Highlights

- Parents' beliefs about math and math anxiety interact to predict child math skills
- Beliefs about math do not relate to child math for parents with low math anxiety
- Math importance beliefs predict math skills when parents have high math anxiety
- Parental engagement does not mediate this interaction

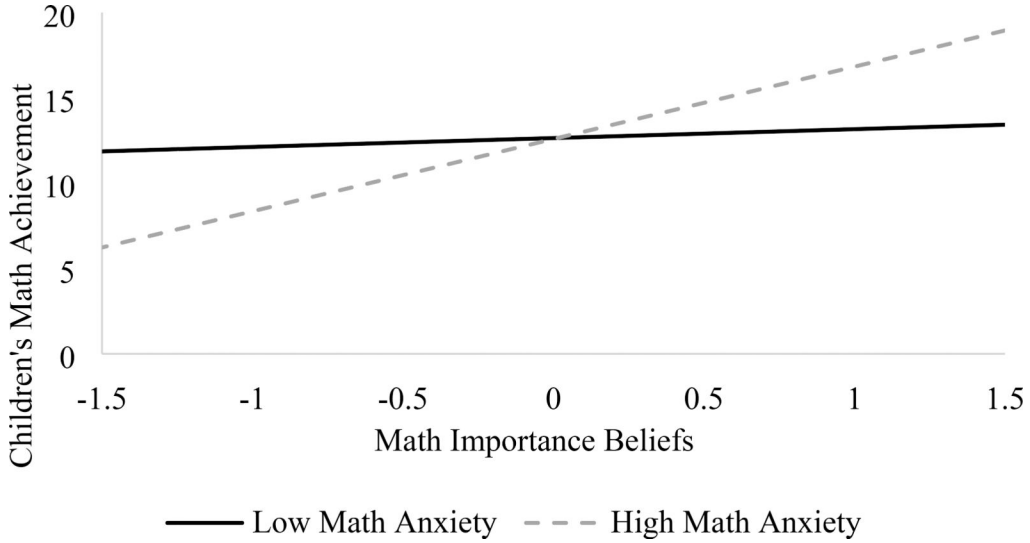

Figure 1.
Parents' math anxiety and math importance beliefs interaction predicting children's math achievement.

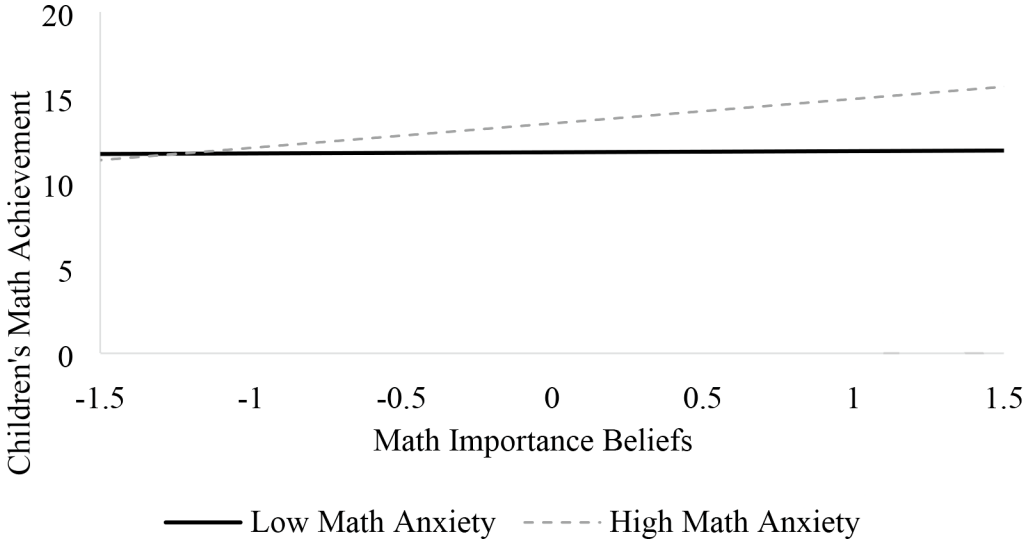

Figure 2.
Interaction between parents' math anxiety and math importance beliefs predicting children's math achievement, controlling for prior math skills.

Table 1

Descriptive statistics and bivariate correlations for all study variables, N = 114

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Math Beliefs	1													
2. Math Anxiety	.001	1												
3. Home Math Activities: All	.29**	.08	1											
4. Home Math Activities: Formal	.28**	−.02	.86***	1										
5. Home Math Activities: Informal	.28**	.07	.85***	.62***	1									
6. Parent Number Talk	.11	−.09	.23*	.22*	.25**	1								
7. Parent Math Abilities	−.06	−.60***	−.13	−.08	−.17†	.06	1							
8. Literacy Beliefs	.73***	.01	.17†	.15	.12	.002	−.09	1						
9. Child Vocabulary (Visit 1)	.06	.08	.22*	.07	.29**	.05	−.06	.01	1					
10. Child Vocabulary (Visit 2)	.15	.01	.31***	.25**	.37***	.04	−.06	.12	.80***	1				
11. Day-Night Stroop: Incongruent	−.02	−.18†	−.07	−.03	−.14	−.02	.15	.05	.02	.06	1			
12. Day-Night Stroop: Control	−.15†	.02	−.09	−.09	−.20	.04	.04	.0002	.04	.04	.31***	1		
13. Child Math Abilities (Visit 1)	.20*	−.26**	.18*	.24**	.11	.03	.19*	.16†	.002	.05	.31***	.19*	1	
14. Child Math Abilities (Visit 2)	.18†	−.10	.21*	.21*	.13	.06	.11	.13	−.06	.02	.31***	.24**	.84***	1
M	2.87	2.37	1.70	1.60	1.73	13.54	104.33	3.32	96.61	104.01	1.32	1.53	10.75	12.61
SD	0.76	0.70	0.53	0.68	0.66	10.23	12.73	0.73	26.02	28.80	0.55	0.48	5.57	5.77
Min	1.00	1.10	0.60	0.17	0.50	2.00	79.00	1.00	32.00	44.00	0.00	0.00	0.00	1.00
Max	4.00	4.53	3.08	3.17	3.43	72.00	134.00	4.00	162.00	182.00	2.00	2.00	27.00	31.00

† $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$

Table 2

Parents' beliefs about math and math anxiety predicting children's math achievement

Variable	B (S.E.)	B (S.E.)
Beliefs about Math	2.30 * (1.00)	2.38 * (0.97)
Math Anxiety	−0.13 (0.91)	−0.04 (0.88)
Beliefs about Math X Math Anxiety		2.64 ** (0.91)
Parent Math Achievement	0.03 (0.05)	0.02 (0.05)
Literacy Beliefs	−0.80 (1.04)	−0.76 (1.01)
Child Vocabulary	−0.02 (0.02)	−0.01 (0.02)
Day-Night Stroop: Incongruent	2.55 * (0.99)	2.57 ** (0.95)
Day-Night Stroop: Control	2.63 (1.15)	2.50 (1.11)
Constant	12.61 *** (0.50)	12.61 *** (0.49)

† $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$

Table 3

Sensitivity analyses comparing parents' beliefs about math and literacy interactions with math anxiety predicting children's math achievement

Variable	B (S.E.)
Beliefs about Math	2.35 * (0.98)
Math Anxiety	−0.04 (0.98)
Beliefs about Math X Math Anxiety	2.85 * (1.36)
Parent Math Achievement	0.02 (0.05)
Literacy Beliefs	−0.72 (1.02)
Beliefs about Literacy X Math Anxiety	−0.32 (1.47)
Child Vocabulary	−0.01 (0.02)
Day-Night Stroop: Incongruent	2.56 ** (0.96)
Day-Night Stroop: Control	2.49 * (1.12)
Constant	12.61 *** (0.49)

† $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$

Table 4

Sensitivity analyses of interaction between parents' math anxiety and math importance beliefs predicting children's math achievement, controlling for prior math skills

Variable	B (S.E.)
Beliefs about Math	0.75 (0.57)
Math Anxiety	1.20 * (0.51)
Beliefs about Math X Math Anxiety	0.97 † (0.53)
Parent Math Achievement	0.01 (0.03)
Literacy Beliefs	−0.56 (0.58)
Child Vocabulary	−0.02 (0.01)
Day-Night Stroop: Incongruent	0.61 (0.56)
Day-Night Stroop: Control	1.01 (0.65)
Lagged TEMA-3 Scores	0.85 *** (0.06)
Constant	12.61 *** (0.28)

$^{\dagger}p < .10$

$^{*}p < .05$

$^{**}p < .01$

$^{***}p < .001$

Table 5

Parents' beliefs about math and math anxiety predicting math input

	Overall Math Activities	Formal Math Activities	Informal Math Activities	Number Talk
Variable	**B (S.E.)**	**B (S.E.)**	**B (S.E.)**	**B (S.E.)**
Beliefs about Math	0.23 * (0.09)	0.31 * (0.12)	0.11 (0.11)	3.47 † (1.86)
Math Anxiety	0.00 (0.09)	−0.09 (0.11)	−0.06 (0.1)	−1.36 (1.69)
Beliefs about Math X Math Anxiety	0.09 (0.09)	0.19 † (0.11)	0.13 (0.11)	5.20 ** (1.74)
Parent Math Achievement	0.00 (0.00)	−0.01 (0.01)	−0.01 (0.01)	−0.02 (0.09)
Literacy Beliefs	−0.05 (0.10)	−0.10 (0.13)	0.01 (0.12)	−2.40 (1.93)
Child Vocabulary	0.00 (0.00)	0.00 (0.00)	0.01 ** (0.00)	0.03 (0.04)
Day-Night Stroop: Incongruent	−0.04 (0.09)	0.00 (0.12)	−0.12 (0.11)	−0.85 (1.82)
Day-Night Stroop: Control	−0.03 (0.11)	−0.06 (0.14)	−0.10 (0.13)	1.81 (2.13)
Constant	1.70 *** (0.05)	1.62 *** (0.06)	1.75 *** (0.06)	13.54 *** (0.93)

† $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$

Table 6

Parents' beliefs about math, math anxiety and different types of math input predicting children's math achievement

Variable	B (S.E.)	B (S.E.)	B (S.E.)	B (S.E.)
Beliefs about Math	1.85 † (0.97)	1.95 † (0.99)	2.20 * (0.96)	2.48 * (0.99)
Math Anxiety	−0.03 (0.86)	0.08 (0.87)	0.07 (0.87)	−0.08 (0.89)
Beliefs about Math X Math Anxiety	2.44 ** (0.89)	2.37 * (0.91)	2.42 ** (0.9)	2.79 *** (0.95)
Overall Home Math Activities	2.33 * (0.97)			
Formal Math Activities		1.39 † (0.77)		
Informal Math Activities			1.62 * (0.82)	
Number Talk				−0.03 (0.05)
Parent Math Achievement	0.03 (0.05)	0.03 (0.05)	0.03 (0.05)	0.02 (0.05)
Literacy Beliefs	−0.64 (0.99)	−0.62 (1)	−0.78 (0.99)	−0.83 (1.02)
Child Vocabulary	−0.02 (0.02)	−0.02 (0.02)	−0.03 (0.02)	−0.01 (0.02)
Day-Night Stroop: Incongruent	2.67 ** (0.93)	2.58 ** (0.94)	2.77 ** (0.95)	2.55 ** (0.96)
Day-Night Stroop: Control	2.58 * (1.09)	2.58 * (1.1)	2.67 * (1.1)	2.55 * (1.12)
Constant	8.64 *** (1.72)	10.37 *** (1.34)	9.77 *** (1.51)	13.01 *** (0.85)

Note. Each column displays results from a model with the addition of only one potential mediator as a predictor of early math

† $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$