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

Alex M. Silver *, Leanne Elliott, Melissa E. Libertus

Department of Psychology, Learning Research and Development Center, University of Pittsburgh, Pittsburgh, PA 15260, USA

A R T I C L E   I N F O

Article history:
Received 31 January 2020
Revised 19 August 2020

Keywords:
Math abilities
Math anxiety
Parental beliefs
Home numeracy
Math talk
Early childhood

A B S T R A C T

A growing body of research suggests that parents’ beliefs about and attitudes toward 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 used 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. Furthermore, 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 parental 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.

© 2020 Elsevier Inc. All rights reserved.

* Corresponding author.
E-mail address: ams645@pitt.edu (A.M. Silver).

https://doi.org/10.1016/j.jecp.2020.104992
0022-0965/© 2020 Elsevier Inc. All rights reserved.
Introduction

Children's math skills vary widely during early childhood and are strongly predictive of later academic achievement (Duncan et al., 2007; Entwisle & Alexander, 1990; Jordan, Kaplan, Ola, & Locuniak, 2006; Starkey & Klein, 1991). 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 in which parents support their children's early math learning and have found that parents' math engagement typically predicts children's later math performance. Parents who report more frequently engaging in math activities, such as playing board games and 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, Polyzoi, Skwarchuk, Fast, & Sowinski, 2010; Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015; Missall, Hojnoski, Caskie, & Repasky, 2015; 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 examined 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 during early childhood. Specifically, we investigated the extent to which these factors may interact to predict math achievement. In addition, we explored 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 & Belsiakoff, 2015; Fan & Chen, 2001; Jeynes, 2005; Kleemans, Peeters, Segers, & Verhoeven, 2012), their perceptions of their own role in their children's learning (DeFlorio & Belsiakoff, 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 were particularly interested in examining parents' beliefs about math. Parents' beliefs about math may potentially be related to their children's math performance, although 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 children's math ability and expectations for their children's future math performance were strongly correlated with their elementary school children's math performance, as rated by the children's teachers. 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, although this was in a relatively small sample of children. Similarly, in a larger sample, LeFevre et al. (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 children'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 children's current ability and future in math, and have been inconclusive. Thus, one aim of the current work was 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-related or STEM (science, technology, engineering, and math)-related field (Bleeker & Jacobs, 2004; Metzger, Sonnenschein, & Galindo, 2019; Parsons et al., 1982). In a sample of 5th to 11th graders, Parsons et al. (1982) found that parental beliefs about math significantly predicted their children's beliefs about and attitudes toward math. Parents who held stronger beliefs about their children'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 children. These findings are in line with expectancy-value theory (Wigfield & Eccles, 2000), where the value that individuals place on a task increases the likelihood of them choosing to do that task. In this case, believing that math is more important for their children 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 explored this hypothesis in the current study.

Parental math anxiety

In addition to varying beliefs about the importance of math, there is considerable variability among 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 needing 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). Not only is math anxiety associated with adults' own poor math performance (Ashcraft, 2002), but parents' math anxiety is also negatively associated with their elementary school children's math performance (Berkowitz et al., 2015; Maloney et al., 2015).

Maloney et al. (2015) found that the negative effect of parental math anxiety was particularly strong for school children whose math-anxious parents engaged 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 those of their peers. Thus, parents who are math anxious and spend more time helping their school-aged children with math content might actually do their children a disservice and have children who perform worse in math.

However, Berkowitz et al. (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, however, 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 on 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 affect their math engagement behavior. As such, in the current study we examined the main effects of math beliefs on children's math learning but also explored 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 explored potential mechanisms through which these effects may operate.

The current study

In sum, in this study we examined 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 hypothesized 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 explored potential mechanisms underlying these associations by using 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 expected 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 also controlled for other potentially confounding constructs, including children's general cognitive abilities. Specifically, we ensured that these potential parental effects on children's math performance held 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).
Method

Participants

Participants were 114 preschool-aged children (56 girls) and one parent of each child. Children ranged in age from 3 years 8 months to 4 years 0 months ($M_{age} = 3$ years 11 months, $SD = 0.77$ month). Children were predominantly White non-Hispanic (82%), whereas 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% of all parents had earned a bachelor’s degree or higher, with levels 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 they 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 2 months later. During each 2-h visit to the lab, parents and children completed a short 10-min 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 children’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 nonsymbolic numerical comparison ability and number knowledge. Parents also completed standardized assessments of their reading skills and an assessment measuring their nonsymbolic numerical comparison ability. These activities were not of interest to the current study and thus are 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 children 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 5-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 alphas of .75 and .84 for the math and literacy items, respectively.
<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Math beliefs</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Math anxiety</td>
<td>.001</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Home math activities: All</td>
<td>.29</td>
<td>.08</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Home math activities: Formal</td>
<td>.28</td>
<td>-.02</td>
<td>.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Home math activities: Informal</td>
<td>.28</td>
<td>.07</td>
<td>.85</td>
<td>.62</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Parents’ number talk</td>
<td>.11</td>
<td>-.09</td>
<td>.23</td>
<td>.22</td>
<td>.25</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Parents’ math abilities</td>
<td>-.06</td>
<td>-.60</td>
<td>-.13</td>
<td>-.08</td>
<td>-.17</td>
<td>.06</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Literacy beliefs</td>
<td>.73</td>
<td>.01</td>
<td>.17</td>
<td>.15</td>
<td>.12</td>
<td>.002</td>
<td>-.09</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Children’s vocabulary (Visit 1)</td>
<td>.08</td>
<td>.22</td>
<td>.29</td>
<td>.05</td>
<td>-.06</td>
<td>.01</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Children’s vocabulary (Visit 2)</td>
<td>.15</td>
<td>.01</td>
<td>.31</td>
<td>.25</td>
<td>.37</td>
<td>.04</td>
<td>-.06</td>
<td>.12</td>
<td>.80</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Day–Night Stroop: Incongruent</td>
<td>-.02</td>
<td>-.18</td>
<td>-.07</td>
<td>-.03</td>
<td>-.14</td>
<td>-.02</td>
<td>.15</td>
<td>.05</td>
<td>.02</td>
<td>.06</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Day–Night Stroop: Control</td>
<td>-.15</td>
<td>.02</td>
<td>-.09</td>
<td>-.09</td>
<td>-.20</td>
<td>.04</td>
<td>.04</td>
<td>.002</td>
<td>.04</td>
<td>.04</td>
<td>.31</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Children’s math abilities (Visit 1)</td>
<td>.20</td>
<td>-.26</td>
<td>.18</td>
<td>.24</td>
<td>.11</td>
<td>.03</td>
<td>.19</td>
<td>.16</td>
<td>.002</td>
<td>.05</td>
<td>.31</td>
<td>.19</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>14. Children’s math abilities (Visit 2)</td>
<td>.18</td>
<td>-.10</td>
<td>.21</td>
<td>.21</td>
<td>.13</td>
<td>.06</td>
<td>.11</td>
<td>.13</td>
<td>-.06</td>
<td>.02</td>
<td>.31</td>
<td>.24</td>
<td>.84</td>
<td>1</td>
</tr>
<tr>
<td>M</td>
<td>2.87</td>
<td>2.37</td>
<td>1.70</td>
<td>1.60</td>
<td>1.73</td>
<td>13.54</td>
<td>104.33</td>
<td>3.32</td>
<td>96.61</td>
<td>104.01</td>
<td>1.32</td>
<td>1.53</td>
<td>10.75</td>
<td>12.61</td>
</tr>
<tr>
<td>SD</td>
<td>0.76</td>
<td>0.70</td>
<td>0.53</td>
<td>0.68</td>
<td>0.66</td>
<td>10.23</td>
<td>12.73</td>
<td>0.73</td>
<td>26.02</td>
<td>28.80</td>
<td>0.55</td>
<td>0.48</td>
<td>5.57</td>
<td>5.77</td>
</tr>
<tr>
<td>Min</td>
<td>1.00</td>
<td>1.10</td>
<td>0.60</td>
<td>0.17</td>
<td>0.50</td>
<td>2.00</td>
<td>79.00</td>
<td>1.00</td>
<td>32.00</td>
<td>44.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Max</td>
<td>4.00</td>
<td>4.53</td>
<td>3.08</td>
<td>3.17</td>
<td>3.43</td>
<td>72.00</td>
<td>134.00</td>
<td>4.00</td>
<td>162.00</td>
<td>182.00</td>
<td>2.00</td>
<td>2.00</td>
<td>27.00</td>
<td>31.00</td>
</tr>
</tbody>
</table>

*p < .10.

*p < .05.

*p < .01.

*p < .001.
Parents' math anxiety

Parents’ math anxiety was measured at the first lab visit using the 30-item Math Anxiety Rating Scale (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 5-point scale from 1 (low anxiety) to 5 (high anxiety). Items included scenarios such as 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 .96, and strong test–retest reliability of .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 within 3 min. Parents’ scores on the Math Calculation and Math Fluency subtests were then used to compute a normed 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 .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 children’s 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” correct responses 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 points, 1 point, 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 response. 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 being as high as .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–Third 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 .94 and test–retest reliability of .82 (Ginsburg & Baroody, 2003).

Children’s vocabulary
Children’s vocabulary was assessed at both lab visits using the Developmental Vocabulary Assessment for Parents (DVAP), a parent-report measure of children’s language development (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 children 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 .69) and the MacArthur–Bates Communicative Development Inventories (with a coefficient of .79) (Libertus et al., 2015).

Home math activities
Parents reported the frequency of home math activities using the home activities questionnaire from LeFevre et al. (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 children 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 .80. In addition to the overall score of math activities, scores for two subdimensions of numeracy activities were calculated. Parents’ reports of number skill activities (e.g., counting objects, printing numbers) and number book activities (e.g., using number activity books, reading number story books) 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 children. As such, scores from the two time points were averaged to create composite home math activities scores.

Parents’ number talk
For each lab visit, parent–child conversations during the 10-min free play sessions were transcribed, and these transcriptions were used to code parents’ 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,” “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 parents’ 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 children, so counts for the two visits were averaged to create a composite parents’ 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 parents’ 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, parents' 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 time points \((r = .80, p < .001)\), vocabulary from the first visit was not included as a predictor, but TEMA-3 scores from the first time point 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. Thus, we individually regressed overall home math activities, both formal and informal dimensions of home math activities, and parents' number talk on parents' math beliefs, parents' 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 parents' number talk) each were included as predictors of math skills at the second visit.

Results

Interactions between parental math anxiety and parental 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, with an increase of 1 standard deviation in beliefs about the importance of math being associated with an increase of 0.30 standard deviation 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

<table>
<thead>
<tr>
<th>Variable</th>
<th>(B) (SE)</th>
<th>(B) (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beliefs about math</td>
<td>2.30*(1.00)</td>
<td>2.38*(0.97)</td>
</tr>
<tr>
<td>Math anxiety</td>
<td>−0.13 (0.91)</td>
<td>−0.04 (0.88)</td>
</tr>
<tr>
<td>Beliefs about Math × Math Anxiety</td>
<td></td>
<td>2.64*(0.91)</td>
</tr>
<tr>
<td>Parents' math achievement</td>
<td>0.03 (0.05)</td>
<td>0.02 (0.05)</td>
</tr>
<tr>
<td>Literacy beliefs</td>
<td>−0.80 (1.04)</td>
<td>−0.76 (1.01)</td>
</tr>
<tr>
<td>Children's vocabulary</td>
<td>−0.02 (0.02)</td>
<td>−0.01 (0.02)</td>
</tr>
<tr>
<td>Day–Night Stroop: Incongruent</td>
<td>2.55*(0.99)</td>
<td>2.57*(0.95)</td>
</tr>
<tr>
<td>Day–Night Stroop: Control</td>
<td>2.63 (1.15)</td>
<td>2.50 (1.11)</td>
</tr>
<tr>
<td>Constant</td>
<td>12.61** (0.50)</td>
<td>12.61** (0.49)</td>
</tr>
</tbody>
</table>

* \(p < .05\).
** \(p < .01\).
*** \(p < .001\).
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 Fig. 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 time point 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.

In addition, 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 shown in Table 4, math scores across the two time points 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 .03, providing some evidence for the moderation effect described above even in this more stringent model. A plot of this interaction is shown in Fig. 2.

Potential mechanisms linking parents' 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,
Table 3
Sensitivity analyses comparing parents’ beliefs about math and literacy interactions with math anxiety predicting children’s math achievement.

<table>
<thead>
<tr>
<th>Variable</th>
<th>B (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beliefs about math</td>
<td>2.35* (0.98)</td>
</tr>
<tr>
<td>Math anxiety</td>
<td>-0.04 (0.98)</td>
</tr>
<tr>
<td>Beliefs about Math × Math Anxiety</td>
<td>2.85* (1.36)</td>
</tr>
<tr>
<td>Parents’ math achievement</td>
<td>0.02 (0.05)</td>
</tr>
<tr>
<td>Literacy beliefs</td>
<td>-0.72 (1.02)</td>
</tr>
<tr>
<td>Beliefs about Literacy × Math Anxiety</td>
<td>-0.32 (1.47)</td>
</tr>
<tr>
<td>Children’s vocabulary</td>
<td>-0.01 (0.02)</td>
</tr>
<tr>
<td>Day–Night Stroop: Incongruent</td>
<td>2.56** (0.96)</td>
</tr>
<tr>
<td>Day–Night Stroop: Control</td>
<td>2.49* (1.12)</td>
</tr>
<tr>
<td>Constant</td>
<td>12.61*** (0.49)</td>
</tr>
</tbody>
</table>

* p < .05.  
** p < .01.  
*** p < .001.

Table 4
Sensitivity analyses of interaction between parents’ math anxiety and parents’ math importance beliefs predicting children’s math achievement, controlling for prior math skills.

<table>
<thead>
<tr>
<th>Variable</th>
<th>B (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beliefs about math</td>
<td>0.75 (0.57)</td>
</tr>
<tr>
<td>Math anxiety</td>
<td>1.20* (0.51)</td>
</tr>
<tr>
<td>Beliefs about Math × Math Anxiety</td>
<td>0.97 (0.53)</td>
</tr>
<tr>
<td>Parents’ math achievement</td>
<td>0.01 (0.03)</td>
</tr>
<tr>
<td>Literacy beliefs</td>
<td>-0.56 (0.58)</td>
</tr>
<tr>
<td>Children’s vocabulary</td>
<td>-0.02 (0.01)</td>
</tr>
<tr>
<td>Day–Night Stroop: Incongruent</td>
<td>0.61 (0.56)</td>
</tr>
<tr>
<td>Day–Night Stroop: Control</td>
<td>1.01 (0.65)</td>
</tr>
<tr>
<td>Lagged TEMA-3 scores</td>
<td>0.85*** (0.06)</td>
</tr>
<tr>
<td>Constant</td>
<td>12.61*** (0.28)</td>
</tr>
</tbody>
</table>

† p < .10.  
* p < .05.  
** p < .01.  
*** p < .001.

Fig. 2. Interaction between parents’ math anxiety and parents’ math importance beliefs predicting children’s math achievement, controlling for prior math skills.
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 model shown in Table 2 to examine whether these potential mechanisms were 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 this model 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, with an increase of 1 standard deviation in overall math activities predicting an increase of 0.21 standard deviation in children’s math skills, a small effect with Cohen’s
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 these models, the interaction between math beliefs and math anxiety remained a significant predictor of children's math achievement.

**Discussion**

The goals of the current study were to evaluate how parents' math importance beliefs and math anxiety are related to their preschool-aged children'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 that 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, math anxiety may shape the way in which parents' beliefs are transmitted into action and lead to better math outcomes. In this way, math anxiety may be facilitatory in encouraging parents to act on their strong beliefs.

Importantly, the effects of the relations between parental math anxiety and parental math 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 parental math beliefs remained marginally significant, with a small effect size, even when controlling for children's math skills merely 2 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 parents' 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 children'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 that 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 finding 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 parents 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 et al. (2015), who found that negative effects of parental math anxiety were seen only 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 to 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 one’s young child vs. helping with more complex assignments chosen by a teacher for one’s older child) is a novel area for future research. However, it is also notable that for parents in the current 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’s math achievement 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 showed more growth than children of parents with low math anxiety; for example, 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 parents’ math anxiety and math beliefs to children’s performance

In this study, we also examined potential mechanisms that might explain the association between parents’ 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, thereby giving their children 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 used 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, such as flashcards and workbooks, but not their use of informal math activities, such as 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 children 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 children, 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 children's math performance. These differences may be in part due to the different age of the children in our study compared with previous studies, the context in which number talk was measured (i.e., lab vs. home setting), or the way in which number talk was measured in these studies (e.g., number words only, a restricted range of number words, 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 and Bachman, 2018a). To date, most research relies on frequency-based measures such as how often activities occur and how often 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 that 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 that math is important might not tailor their activities to their children 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 matter only in the context of parental math anxiety. Furthermore, we found that although parents' beliefs and math anxiety were related to their math engagement with their children, these engagement factors did not explain the differences in children's math performance. In addition, we looked at these relations assuming that parent factors produce effects on child outcomes and largely ignored the role of children in this story. It is quite likely that children's own cognitive abilities, beliefs, and attitudes toward math affect their own math performance and shape the way in which 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 affect 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 a review), although 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 affect their children's math performance and parents' engagement in math with their children. However, many important questions remain, including determining the mechanism by which parental math beliefs and anxiety affect children's performance. Finally, examining the impact of these parental factors on parents' math engagement with their children is critical, particularly given the potential links between parental math engagement and children's math performance.
CRediT authorship contribution statement

Alex M. Silver: Conceptualization, Investigation, Data curation, Formal analysis, Writing - original draft. Leanne Elliott: Investigation, Data curation, Formal analysis, Writing - original draft. Melissa E. Libertus: Writing - review & editing, Supervision, Funding acquisition.

Acknowledgments

This work was supported by the National Science Foundation (Grant DUE1534830 to M.E.L.), the James S. McDonnell Foundation Scholar Award (to M.E.L.), and the National Institutes of Health (Grant T32GM081760 to A.M.S.). We thank Abigail Haslinger, Jamie Patronick, Chelsea MacNeil, Amy Veasey, Erinn Hanner, Lauren Krawczyk, and the research assistants in the Kids’ Thinking Lab for help with data collection and data entry. We especially thank the families who participated.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2020.104992.

References


