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Disassociating the Relation Between Parents' Math Anxiety and Children's Math Achievement: Long-Term Effects of a Math App Intervention

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Although parents' fears and worries about math—termed math anxiety—are negatively associated with their children's math achievement in early elementary school, access to an educational math app that 1st-grade children and parents use together can ameliorate this relation. Here we show that children of higher-math–anxious parents learn less math during 1st–3rd grades, but this is not the case when families are given a math app (even after app use markedly decreases). Reducing the link between parents' math anxiety and their positive attitudes about math for their children helped to explain the sustained benefit of the math app. These findings indicate that interventions involving parents and children together can have powerful lasting effects on children's academic achievement and suggest that changes in parents' expectations for their children's potential for success in math, and the value they place on this success, play a role in these sustained effects.

Keywords: math achievement, parent intervention, educational technology, academic motivation, early childhood intervention

Supplemental materials: http://dx.doi.org/10.1037/xge0000490.supp

Difficulty with math often begins early in life and carries long-term consequences for academic achievement. Children who start behind their peers in math at the beginning of schooling tend to stay behind in math throughout elementary, middle, and high school (Bailey, Siegler, & Geary, 2014; Jordan, Kaplan, Locuniak, & Ramineni, 2007; Pramling-Samuelsson, 2010; Siegler et al., 2012). Moreover, early math skills not only predict later math achievement, but also they are a better predictor of later reading achievement than early reading skills themselves (Duncan et al., 2007). Because success in math requires understanding mathematical principles and appropriately applying them across a variety of situations, developing early math skills likely enhances the development of higher-order thinking and reasoning abilities that contribute to success across academic areas (Duncan et al., 2007; Leinwand, Huinker, & Brahier, 2014; Watt et al., 2017).

Given the importance of early math skills, it is critical to understand why some children perform markedly worse in math than others and the levers that can be used to close early math achievement gaps. Some factors associated with poor math performance, such as inherited components of mathematical thinking, are relatively stable in nature (Davis et al., 2014; Lee, 2002; Reardon, 2011; Sirin, 2005). Other factors, such as parents' attitudes about math and the ways parents interact with their children around math, are more open to intervention (Lazarides, Harackiewicz, Canning, Pesu, & Viljaranta, 2015).

One attitude that has been shown to influence the way parents and children engage in math activities is parent math anxiety. Anxiety about mathematics (i.e., fear or apprehension about math) is prevalent in the United States as well as across the globe (Foley et al., 2017; Hembree, 1990). In the United States, 25% of 4-year college students and up to 80% of community college students report a moderate to high degree of math anxiety (Beilock & Willingham, 2014). Moreover, the math anxiety of important adults in children's lives, such as parents (Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015; Berkowitz et al., 2015) and teachers (Beilock, Gunderson, Ramirez, & Levine, 2010), is associated with lower child math achievement. For example, Berkowitz et al. (2015) found that children of higher-math–anxious parents learned less math during first grade than children of lower math–anxious parents. Furthermore, Maloney et al. (2015) found that the well-meaning homework help provided by math-anxious parents

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can backfire, leading first- and second-grade children to learn less math over the school year than their peers whose math-anxious parents help less, whereas this is not the case for homework help provided by non–math-anxious parents. If the relation between parents' math anxiety and children's math achievement is driven—at least in part—by the negative interactions parents have with their children around math (Maloney et al., 2015), then it follows that improving parent-child math interactions should reduce the negative association between parents' math anxiety and children's math achievement. And if positive parent-child math interactions not only boost children's math learning but also enhance parents' attitudes and beliefs about math, then this change in parents' math attitudes could carry long-lasting consequences for children's math achievement—perhaps by changing the way that parents interact with their children around math.

In a previously published report on a randomized field experiment, we investigated whether an intervention, in the form of a daily math story problem delivered via an app that parents and children engaged with together, could attenuate the relation between parents' math anxiety and their children's math achievement (Berkowitz et al., 2015). Families ($N = 587$) were given access to an iPad preloaded with either a math (intervention) or reading (control) app. The app consisted of a daily passage about an interesting, and often timely, topic and five corresponding questions ranging in difficulty from a preschool to late fifth-grade level (see online supplemental material for examples). The math intervention included word problems requiring children to use addition, subtraction, multiplication, and/or division as well as knowledge about shapes, measurement, and fractions. The reading control condition, although written about the same overall topic, provided little to no math content and asked reading comprehension questions that probed the child's ability to remember details of the passage, to make inferences based on the story as well as their vocabulary and spelling knowledge. Families were encouraged to use the app at least four times a week but were free to use it as much or as little as they wanted. We found that parents' math anxiety was negatively related to children's math achievement at the end of first grade in the control group, such that children with higher-math–anxious parents learned less math than their peers with lower-math–anxious parents. Strikingly, this was not the case in the math app intervention group, such that the math achievement of children in this group did not differ based on parents' math anxiety.

We have shown that increasing parents' interactions with their children around math with this particular math app reduced the relation between parents' math anxiety and children's math performance in the short term (Berkowitz et al., 2015). However, whether families continue to use the math app over time and whether the observed benefits of the math app in first grade persist, fade, or even disappear after subsequent years is unknown. This question is important because interventions that lead to long-term gains hold promise for yielding meaningful differences in terms of academic achievement and career opportunities.

Other studies have shown mixed long-term effects of educational interventions over time, with some effects persisting and others dissipating (Bailey, Duncan, Odgers, & Yu, 2017; Cohen, Garcia, Purdie-Vaughns, Apfel, & Brzustoski, 2009). Interestingly, interventions that fade often involve changing only behaviors (Bailey et al., 2017), whereas interventions that show persistent effects over multiple years often change attitudes in addition to behaviors in a recursive process in which changes in behaviors and attitudes predict improved outcomes over time (Beilock, Schaeffer, & Rozek, 2017; Cohen et al., 2009; Kenthirarajah & Walton, 2015; Wilson, 2011). For example, an intervention that encouraged parents to convey the importance and relevance of math and science to their high school students first changed parents' behaviors. These changes in behaviors resulted in a change in parents' and children's attitudes, which, in turn, led to sustained changes in children's educational outcomes 5 years after the start of the intervention (Harackiewicz, Rozek, Hulleman, & Hyde, 2012; Rozek, Hyde, Svoboda, Hulleman, & Harackiewicz, 2015; Rozek, Svoboda, Harackiewicz, Hulleman, & Hyde, 2017). Based on these findings, we predicted that long-term effects in our math app intervention study would depend, at least in part, on changing parents' attitudes about math.

Current Study

Given that many early childhood intervention studies either fail to track impact over time or show effects that diminish over time (Bailey et al., 2017), it is important to investigate the long-term effects of the previously described math app intervention because an intervention with lasting effects has greater implications for improving children's outcomes. First, we assessed whether families continued to use the math app when children were in second and third grades. Next, we tested whether, regardless of continued app usage, being assigned to the math app group was associated with less of a relation between parents' math anxiety and children's math achievement over the summer following first grade and through the end of third grade. Finally, we tested whether longer-term intervention effects depended on changes in parents' attitudes about math.

Given the demands of parenting and the possibility that parents and children are likely to seek novelty in their activities over time, we anticipated that family engagement with the intervention would decrease after a year of app use. To preview our findings, we indeed found that this was the case. However, we also found that—despite infrequent app usage after first grade—there were sustained effects of the math app on eliminating the negative association between parents' math anxiety and children's math achievement through the end of third grade. To address why this was the case, we focused on whether the intervention changed parents' attitudes about math.

One possibility is that the math app intervention might actually reduce parents' math anxiety. To test this possibility, parents completed a math anxiety questionnaire, which assessed their tendency to feel tension, apprehension, or fear in math-related situations (Alexander & Martray, 1989), at the beginning and end of their child's first-grade year.

Another possibility is that the math app intervention changes parents' attitudes about their children's potential for success in math and how much value they place on math for their children. Parents' expectations about their children's academic success and the value they place on this success (subsequently called parents' EV for expectations and value) have been shown to have a lasting positive effect on children's learning and motivation in school (Hill & Tyson, 2009; Pomerantz, Moorman, & Litwack, 2007; Rozek et al., 2015, 2017; Svoboda, Rozek,

Hyde, Harackiewicz, & Destin, 2016). We reasoned that because individuals with math anxiety tend to have negative math attitudes and low expectations for their own math success (Ahmed, Minnaert, Kuyper, & van der Werf, 2012; Hembree, 1990), higher-math–anxious parents might hold relatively low expectations for their children's math success and see little value in math for their children. We further reasoned that the math app intervention might improve higher-math–anxious parents' views about their children's potential in math as well as their value of math for their children, likely because they see that their children are able to productively engage in math problem solving and improve their math skills. In contrast, because lower math-anxious parents already likely hold higher EV, it may be difficult to raise these attitudes even further through an intervention. Higher-math–anxious parents' improved EV, in turn, could promote their children's math achievement despite parents' own math anxiety, decreasing the negative association between parents' math anxiety and children's math achievement. To address this second possibility, we also assessed parents' expectations for their children's success in math and the value they placed on their children's math learning at the beginning and end of their children's first grade year (Wigfield & Cambria, 2010).

Method

Participants

The objective of this study was to determine whether being randomly assigned to a math app (as compared with a reading control app) could eliminate the negative association between parents' math anxiety and children's math achievement in early elementary school over multiple school years. The sample consisted of 587 children from the greater Chicagoland area spread across 40 classrooms and included a 2:1 ratio of children in the math app to reading app group. Fifty-one percent of the children were female. This was a racially diverse sample: 45% of families were Caucasian, 30% were Hispanic, 14% were African American, and 9% were Asian. The remaining children (2%) reported being Native American, Pacific Islander, other, or selected multiple racial categories. Approximately 30% of the sample came from lower socioeconomic status households making less than $50,000 per year.

A subset of children (393) attended schools with classrooms assigned to both the math app intervention and reading app control group (referred to as matched schools). This subset provides a unique opportunity because these children who attend the same school likely have more in common (e.g., socioeconomic status, school and community resources) than children attending different schools (Berkowitz et al., 2016). We refer to children as either being in the full sample or the matched sample. Our primary sample is the matched sample, but we conduct all analyses on both the full and matched samples and see the same overall patterns of results.

In Berkowitz et al. (2015), the primary analytic sample (N = 278) differed from the full sample (N = 587) in the following ways: we removed families with (a) children missing math achievement scores in the fall or spring of first grade, (b) missing parent math anxiety scores, (c) not in matched schools, and (d) when participating children were twins (because twins could not be randomly assigned to condition, see online supplemental material for additional information). Finally, families that moved districts or asked to stop their participation in the study were removed (21 families). We used the same exclusion criteria in the current paper, except that because we were conducting a longitudinal analysis across time, we were able to include anyone who completed the initial time point (the fall of first grade) and any subsequent time point, which yielded a larger sample of 293 remaining families. We used the maximum likelihood methods to deal with missing data in Hierarchical Linear Modeling. Our primary sample included all families in the previous paper; however, if we focus on the group of families with all model predictor variables as well as end of third grade math achievement, we can assess what attrition looks like between the original group (N = 278) and this group still participating at the final time point (N = 195). Attrition did not significantly differ by condition ($\chi^2 = 2.05$, $p = .15$), children's math achievement, $F(1, 279) = .67$, $p = .41$, family income, $F(1, 238) = .12$, $p = .73$, or parents' math anxiety, $F(1, 279) = .39$, $p = .53$, suggesting that attrition has not led to a higher achieving, more advantaged, or less anxious sample.

Materials and Procedure

Families were recruited through their children's schools. In addition to sending home a recruitment letter and consent form through the school, research assistants attended back-to-school nights to answer questions about the study. Families received an iPad mini with either the intervention or control app preloaded onto it in the fall of first grade after children completed measures of their math and reading ability. Families had access to the app going forward and were helped to regain access if they deleted the app accidently or had problems with their iPad. When iPads were distributed, parents also received a survey to measure a variety of attitudes and behaviors related to math and reading (e.g., math anxiety) to complete and mail directly back to the university. Families were reminded via e-mail to complete the survey if they did not do so initially. At the end of first grade, parents completed a second survey to measure changes in their math attitudes. The families with parents who returned the survey at the end of the school year, as compared with families with parents who did not, did not significantly differ in terms of children's math achievement, $F(1, 276) = 3.27$, $p = .07$, family income, $F(1, 236) = .53$, $p = .47$, or parents' math anxiety, $F(1, 276) = .33$, $p = .57$, suggesting that parents who responded were representative of parents who did not complete the spring survey. The marginal findings on children's math achievement do raise the possibility that families who returned the survey are different in some way from families who did not. Even though this does not account for our interaction between the experimental group and parents' math anxiety, it is possible that our results concerning parents' EV are less applicable to families with lower-achieving children. In the spring of first grade and again in the fall and spring of second and third grades, children completed the same measures of their math and reading ability administered to individual children by research assistants. At testing, research assistants were blind to the group the classroom was assigned to and had no knowledge of parents' math anxiety levels.

Children were randomly assigned to app groups at the classroom level because parents often talk to each other within classrooms, and we wanted to minimize the chances that (a) families would

become aware of the multiple treatment groups and (b) that families would ask to change groups. We intentionally oversampled children in the math app intervention group (approximately two thirds of our sample), given our interest in math achievement.

Children's measures. Participants completed measures of their math achievement using the Applied Problems subtest of the Woodcock-Johnson III (Woodcock, McGrew, & Mather, 2001). The Woodcock-Johnson is a nationally normed, comprehensive test battery used to assess achievement skills of individuals between the ages of 2 and 90 years. The Applied Problems subtest consists of orally presented math word problems that involve arithmetic calculations of increasing difficulty. All analyses were performed on students' W scores, a transformation of the students' raw score into a Rasch-scaled score with equal intervals (a score of 500 is the approximate average performance of a 10-year-old). Because of its properties as an interval scale with a constant metric, the W score is recommended for use in studies of individual growth. On average, a 1-point increase on the W score could be very roughly associated with half a month more of math learned during a school year.

Parents' measures. Parents' math anxiety was measured using the 25-item short-Mathematical Anxiety Rating Scale (Alexander et al., 1989). Parents' responses were measured on a 5-point continuous scale in response to questions about how anxious different hypothetical situations would make them feel (e.g., "studying for a math test" or "opening a math text book"). Parents responded using a 1 (*not at all*) to 5 (*very much*) Likert rating scale. Math anxiety ranged from 1.00 to 4.48 with a mean of 2.20 ($SD = 0.80$), and parents' math anxiety was not significantly different between families in the intervention and control group.

Parents also completed measures of their EV, which were based on EV measures used in previous work in this area (Hyde et al., 2017; Wigfield & Cambria, 2010). Parents were asked how well their child does in math, how important math is for their child, and their expectations of their child's ability and for their child's future performance in math (see online supplemental material for specific items). Response options ranged from 1 to 5 with different anchors for each scale (e.g., for "How is your child doing in math?" the scale ranged from *not at all well* to *very well*). Scores ranged from 2.0 to 5.0 with a mean of 4.29 ($SD = 0.53$) in the fall and ranged from 2.75 to 5.00 with a mean 4.43 ($SD = 0.49$) in the spring. The Cronbach's alpha for the scale is .74.

Results

Overview of Analysis

In these subsequent analyses, we use the Raudenbush, Bryk, and Congdon (2004) hierarchical linear modeling program to account for the nested nature of our data. Children were assigned to group at the classroom level to minimize knowledge of the experiment, and thus, in subsequent models, the experimental group was accounted for in the model at the classroom level. Parents' math anxiety was z-scored and kept as a continuous variable. Group was analyzed as a centered contrast (coded +1 for math group and −1 for reading control group). Time was coded as 0–5, with 0 being the first time point (i.e., fall of first grade).

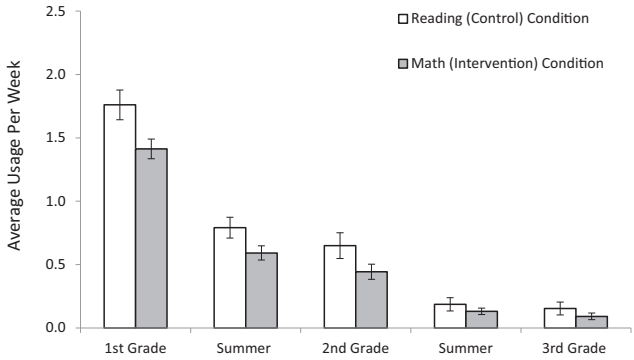

Figure 1. Average app usage per week over time. Trends in app usage show that usage declines after first grade and that the math app was used less than the reading app. Error bars represent ±1 *SE* of the mean. In first grade, 39% of families in the math app intervention condition and 37% in the reading control condition used the app less than once a week. However, during third grade, 97% of families in the math app intervention condition and 95% in the reading control condition used the app less than once a week. Error bars represent ±1 *SE* of the mean ($n = 283$).

What Does App Usage Look Like Over Time?

Families were encouraged to continue using the math app intervention (or the reading app control) after first grade, and we tested whether they did so. Our outcome of interest was average app usage per week over time. Using hierarchical linear modeling to account for the nested nature of our data (i.e., children within classrooms), we specified a three-level model, with the first level being time (app use during first grade, the summer after first grade, second grade, summer after second grade, and third grade), the second level being the child, and the third level being the classroom, to test whether app usage changed over time. The group the families were in (math intervention or reading control group) was included in the model to test whether the math and reading apps were differentially used over time. As seen in Figure 1, use of both apps dramatically and significantly decreased over time ($t = -15.78$, $p < .001$, $b = -0.33$, $SE = 0.02$). As reported previously (Berkowitz et al., 2015), families used the math app less than the reading app ($t = -2.10$, $p = .047$, $b = 0.02$, $SE = 0.02$).[1]

Are There Long-Term Benefits of the Intervention?

We next examined whether the effects of the math app intervention in first grade extended through the end of third grade, despite infrequent app usage after first grade. Specifically, we focused on whether the negative relation between parents' math anxiety and children's math achievement seen in the control group was significantly reduced in the intervention group after first grade. Using maximum likelihood methods to deal with missing data and hierarchical linear modeling to account for the nested nature of our data (i.e., time within children within classrooms),

[1] In Berkowitz et al. (2015) we also looked children's use of the app (in the first year of the intervention). Note, however, that the sample depicted in the current graph is different than the 2015 study, given the longitudinal nature of the current study. To be included here, we followed the inclusion criteria for the time analysis and also required complete app usage data.

we found a significant three-way interaction between time (fall of first grade through spring of third grade), parents' math anxiety, and assignment to the math app intervention or control group on children's math achievement ($t = 2.40$, $p = .02$, $b = 0.46$, $SE = 0.19$, Figure 2). However, it should be noted that we do not see a main effect of the intervention. Parents' math anxiety became significantly negatively associated with children's math achievement over time in the control group, $t = -2.75$, $p = .01$ $b = -0.84$, $SE = 0.31$, but not in the intervention group, $t = 0.35$, $p = .73$, $b = 0.08$, $SE = 0.24$, from the end of first grade through the end of third grade (Figure 2 shows this effect over time; Figure 3 shows a scatterplot of these relations in the fall of first grade and spring of third grade, specifically). In other words, although there was a significant difference in the amount of math learned over the course of 3 years between children of higher- and lower-math–anxious parents who were randomly assigned to the reading control group, this was not the case for children randomly assigned to the math app intervention group, in which the level of math performance of children of higher-math–anxious parents did not significantly differ from the level of math performance of children with lower-math–anxious parents.

Why Does the Intervention Ameliorate the Negative Association Between Parents' Math Anxiety and Children's Math Achievement Over Time?

Using the same key predictors as in the previous analysis (children's fall of first grade math achievement, experimental group, parents' math anxiety, and the interaction between parents' math anxiety and experimental group), we examined the possibil-

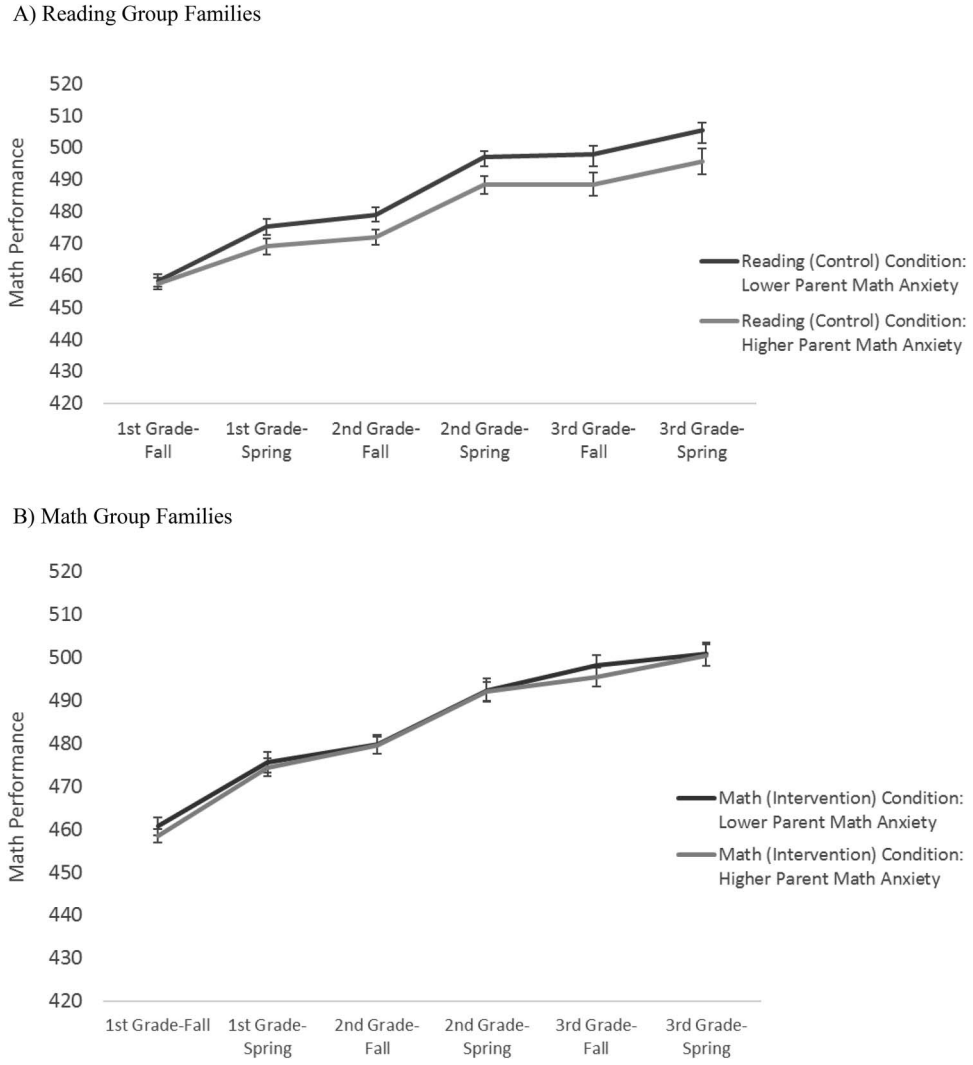

Figure 2. Math performance across time by group and parent math anxiety. For families in the reading (control) group, a gap in math performance (shown here in terms of Woodcock-Johnson standardized test w-scores) between children of lower- and higher-math–anxious parents emerged over the course of elementary (A). However, for families in the math (intervention) group, no such gap emerged (B). Graphs are plotted by doing a median split on parents' math anxiety, but in all analyses, math anxiety was a continuous variable.

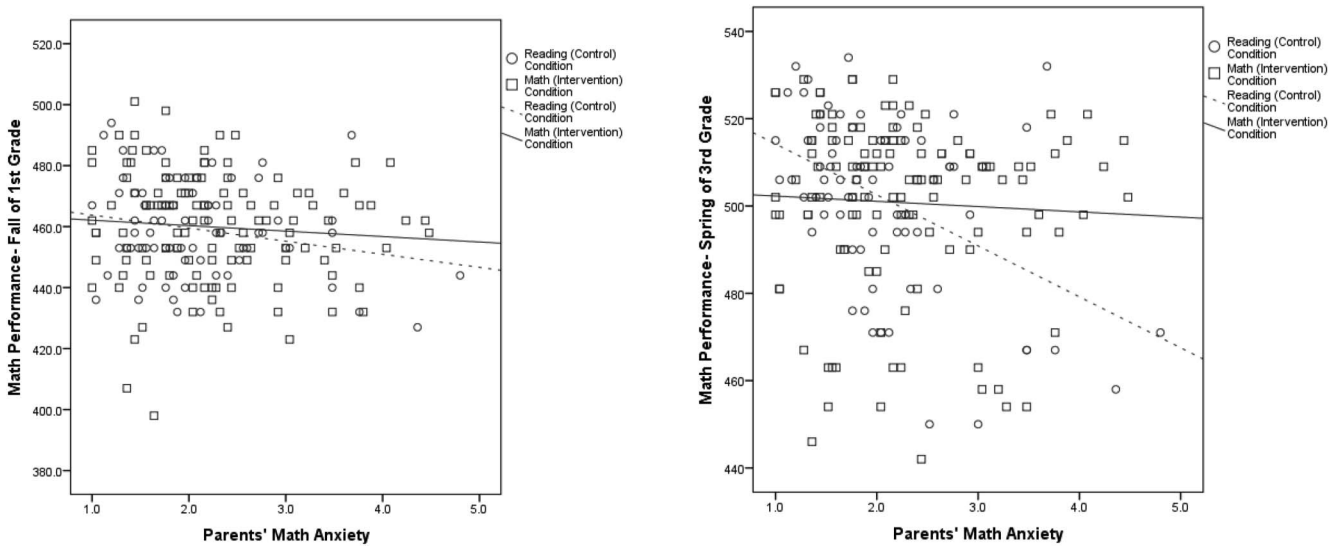

Figure 3. The relation between parents' math anxiety and children's math performance. In the fall of first grade (left graph), in both groups, parents' math anxiety did not relate to children's math performance (shown here in terms of Woodcock-Johnson standardized test scores). By the end of third grade, there was a significant negative relation between parents' math anxiety and their children's math performance in the reading group. However, for families in the math app group, there was no relation between parents' math anxiety and children's math performance at the end of third grade.

ity that the math app improved parents' personal attitudes about math (i.e., their math anxiety) and their attitudes about math for their children.

The intervention did not alter parents' own math anxiety: At the end of first grade, there was a nonsignificant group effect, $t = 0.31$, $p = .76$, $b = .02$, $SE = .08$, and a nonsignificant interaction of group by parent math-anxiety, $t = 1.10$, $p = .29$, $b = .10$, $SE = .09$. Because math anxiety is a stable characteristic that forms early in schooling (Hembree, 1990), it is perhaps unsurprising that it is difficult to change in adulthood.

The intervention did, however, undo the negative association between parents' math anxiety and parents' EV for children, as shown by a significant group by parent math-anxiety interaction on parents' EV (measured at the end of first grade), $t = 2.50$, $p = .01$, $b = .08$, $SE = .03$, Figure 4. Furthermore, in the control group, the higher parents' math anxiety, the lower their EV at the end of first grade ($r = -.49$; $t = -2.07$, $p = .04$, $b = -0.12$, $SE = .06$), even when controlling for their children's prior math achievement. However, in the intervention group, by the end of first grade, this relation was reduced; specifically, there was no significant difference in parents' EV as a function of parents' math anxiety ($r = -.16$; $t = 1.31$, $p = .19$, $b = 0.05$, $SE = 0.04$).

A mediated moderation analysis suggested that the intervention eliminated the negative relation between parents' math anxiety and children's math achievement, in part because it changed the negative association between parents' math anxiety and parents' EV (mediated moderation 95% CI [.45, 4.12]). That is, there was a significant indirect effect of parents' math anxiety through parents' EV on children's subsequent math performance, measured in fall of second grade, in the control group, 95% CI [−4.24, −.63], but not the intervention group, 95% CI [−1.15, .56]). Higher performance in the fall of second grade, in turn, predicted higher math achievement at the end of third grade, $t = 8.21$, $p < .001$ (see online supplemental material for model details). These results are consistent with other findings on the recursive effects of psychological-based interventions, which show that changes in behavior resulted in

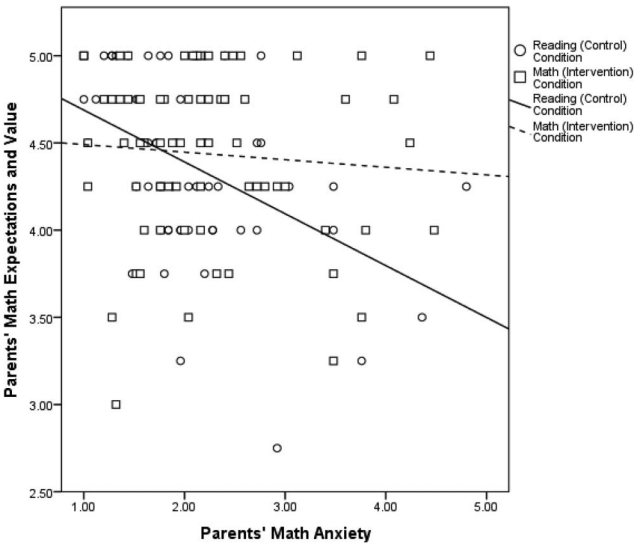

Figure 4. The relation between parents' math anxiety and parents' EV for their children in math. Parents' math expectations and value were measured at the end of first grade. In the reading control group, there was a significant negative relation between parents' math anxiety and parents' EV. This negative relation between parent math anxiety and parents' EV was eliminated in the math intervention group.

changes in attitudes, which in turn altered behavior (Cohen et al., 2009; Rozek et al., 2017; Shrout & Bolger, 2002).

Discussion

Parents' math anxiety is associated with how much math their children learn from first through third grade. For families in the control group, who did not have access to the math app intervention, we found a continuing (through the end of third grade) negative relation between parents' math anxiety and children's math achievement. That is, children of higher-math–anxious parents learned less math in early elementary school than children of lower-math–anxious parents. And this impact is not small: by the end of third grade, children of higher-math–anxious parents have learned the equivalent of approximately 5 fewer months of math (more than half of a school year) than children of lower-math–anxious parents, according to standardized test scores.

To change the negative relation between parents' math anxiety and their children's math achievement, we randomly assigned some families to receive a math app that promoted parent-child engagement in structured math interactions. Because prior research has suggested that higher-math–anxious parents have negative math interactions with their children and it is these interactions that undermine children's math learning (Maloney et al., 2015), we hypothesized that giving families a math app that engaged parents and children in productive math interactions could lessen the negative link between parents' math anxiety and children's math achievement. In our prior paper on the effects of giving parents access to a math app in first grade, we found that the math app intervention ameliorated the short-term negative relation between parents' math anxiety and children's math achievement over the course of first grade (Berkowitz et al., 2015).

In this study, we asked whether the early benefits of using the math app persist over time, even after 2 years when parents and children infrequently use the math app. And, if so, why? Results showed that whereas families decreased their use of the math app after first grade, the intervention led to a lasting change in the association between parents' math anxiety and children's math achievement through the end of third grade. Specifically, the math learning gains of children of higher- and lower-math–anxious parents did not differ for those in the intervention group. These lasting effects were partially explained by changes in parents' attitudes about math in relation to their children. Eliminating the negative association between parents' math anxiety and parents expectations and value (parents' EV) for their children accounted for, in part, the sustained beneficial effect of the math app involving children's math achievement.

Apps are a relatively recent addition to children's lives, but parents frequently turn to technology to support their children's learning (Radesky & Christakis, 2016). Although many apps are advertised as being able to develop children's academic skills and abilities, there is a dearth of evidence about the effectiveness of these apps and their impact on children's learning and even fewer studies that look at the lasting effects on learning. Additionally, all apps are not created equal (Hirsh-Pasek et al., 2015), and the math app intervention examined in this study differs from many traditional apps in several potentially significant ways. Most notably, parents were encouraged to use this app with their children, as compared with many other apps, which typically involve children engaging with apps independently. Our results show that the decreased negative association between parents' math anxiety and children's math learning was partly because of a change in parents' attitudes, suggesting that an important route through which educational apps can have a positive effect on children's learning is by supporting high-quality parent-child interactions. These findings indicate that apps that children and parents engage in together may hold greater potential to support children's learning than apps children engage with alone. This is because the coengagement of parents and children in app use opens up a route that can change parents' interactions and attitudes—a route that seems less feasible when children engage with apps on their own.

Although many school districts encourage parents to be more involved in their children's academic work, a recommendation that on the face of it seems as though it would have positive effects on children's achievement, when parents are left to their own devices to help their children, they may actually undermine children's learning (Hill et al., 2009; Maloney et al., 2015; Pomerantz et al., 2007). Therefore, simply promoting parental involvement without providing adequate structure and support can lead to undesired results. Providing structured ways for higher-math–anxious parents to share math with their children, such as a math app that prompts engaging math interactions, can help ensure that parental involvement actually reaps positive outcomes for children. By facilitating positive parent-child interactions, educational interventions can have powerful effects on children's academic achievement because these interventions can change parents' attitudes about their children's potential for success. These attitude changes, in turn, may play an important role in realizing lasting benefits on children's learning.

Limitations and Future Directions

This study reveals promising findings about the sustainability of the effects of a math app intervention. However, there are also limitations of our study and important future directions to pursue. Although a study involving more than 1,000 individuals (parents and children) and 20 schools with students followed up for 3 years is a large undertaking, future studies should increase the sample size to allow for greater statistical precision and power. Related to the size of our sample, we note that a larger sample would be ideal for mediation analysis within a multilevel framework, and future studies should examine mediation in more detail to address this shortcoming. A final note about the sample involves attrition over time. We do not find that individuals leaving the study over time differ on key study variables, including children's math achievement, family income, or parents' math anxiety. However, attrition analysis on parent survey completion showed a marginal difference on children's math achievement, such that the higher children's math achievement, the marginally more likely parents were to complete the survey. This raises the possibility that the families of parents who did not complete the survey differed in some way, and thus, our results concerning those survey measures may not generalize for families whose children are at lower levels of achievement in math.

Additionally, to conduct a stringent test of our hypothesis, we assessed the effect of the math app in comparison with an active control group (a reading app that similarly increased parental involvement, based on our app usage numbers), but it is possible

that the reading app could contribute to the effects seen in this paper. Specifically, it is possible (although we argue unlikely) that the reading app exacerbates the link between parents' math anxiety and children's math achievement instead of the math app alleviating this relation or that both contribute to our findings. Given that previous observational research involving no apps shows a similar negative association between parents' math anxiety and their children's math achievement as we see in our reading control group families (Maloney et al., 2015), we believe our reading condition is likely to be similar to a business as usual condition and not driving our effects.

We show that a particular math app can lead to sustained changes in the association between parents' math anxiety and children's math achievement, and in future research, we hope to identify the specific factors that make this app successful. Future research is needed to examine the kinds of math apps that can increase children's math achievement as well as parents' expectancies and value in large samples. In this research, it will be important to identify critical features of math apps that do and do not work—for example, is engaging parents and children together a critical element of sustaining gains in children's math achievement or are math apps that children use alone, which is the typical case, also effective?

Conclusion

Children's math learning in elementary school plays an important part in children's long-term academic success. However, in early elementary school, children with math-anxious parents begin to fall behind their peers with less math-anxious parents. Our research suggests that it is possible to shift this relationship by providing families with a low-cost math intervention that involves parents and children interacting, closing the gap between children from higher- and lower-math–anxious families. We find that changes in parents' expectations and value can help drive these sustained changes. Furthermore, our research suggests that interventions that involve families can have lasting impacts—and, given this finding, practitioners and policymakers can fruitfully widen their focus beyond the classroom setting to help all children achieve.

Context of Research

Previous research highlights the fact that parents' math talk predicts and promotes children's math learning. However, research also demonstrates that parents' math anxiety negatively relates to children's math learning, especially when they frequently interact with their children around math. This negative relation can be ameliorated when parents are provided with supports to facilitate math interactions with their children. The findings reported in this paper add to the existing literature by showing that a math app provided to families at the beginning of first grade reduces the enduring negative association between parents' math anxiety and children's math achievement, even 3 years after the app was introduced, when families are rarely if ever using the app. We also test two proposed mechanisms that could explain this effect—changes in parent math anxiety and changes in parent expectations and value for their children's math achievement. Our findings show that in the math app condition, there is no longer a negative relation between the math anxiety of parents and children's math achievement and that this is partially due to changes in parents' expectations of and value for their children's math achievement. In future work, we plan to explore other contributing factors to sustained effects, including whether supportive math apps change parents' support of their children's math learning through increased and higher-quality math talk and/or higher-quality homework help.

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