Pre-print:

Ribeiro, L. A., Casey, B., Dearing, E., Nordahl, K. B., Aguiar, C., & Zachrisson, H. (2020). Early maternal spatial support for toddlers and math skills in second grade. *Journal of Cognition and Development*, *21*(2), 282-311.

Abstract

The aim of this study is to investigate whether maternal spatial support during two types of joint manipulative toy play with 2-year-old children was longitudinally associated with math screening test scores in second grade. The interaction between spatial support and maternal education was explored as well. We also investigated predictions of a teacher rating of math performance at second grade, although these effects were less robust. Data were drawn from [*name of the study removed for review*], a longitudinal study of Norwegian children and their families. Participants were a subsample of 932 mothers and their 2-year-olds. Mothers were asked to help their children solve both a puzzle task and a shape-color sorting task. Mothers' spatial support included spatial language, gestures, and placement of objects. Results showed that level of spatial support during mother-child interaction tasks at 2 years of age was significantly associated with math difficulties in second grade. This was the case for a puzzle task (a task associated with spatial visualization skills), but not for a shape-color sorting task (a task associated with shape and color feature discriminations). Conclusions are drawn with respect to the importance of identifying optimal parental spatial strategies associated with better math outcomes. These findings on parental facilitation of spatial skills during joint early play may be useful for future training interventions directed at parents of children at risk for poor math skills.

Keywords: spatial support, mathematics/number concepts, parent-child interaction

Early Maternal Spatial Support for Toddlers and Math Skills in Second Grade

There is increasing recognition of the importance of spatial skills in child development, and growing support for the link between spatial reasoning and mathematical ability (e.g., Hubbard, Piazza, Pinel, & Dehaene, 2005; Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2017). Indeed, more than a quarter of the variability in mathematics ability by age 4 may be predicted exclusively from spatial skills (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014). This relation may have important lasting consequences in terms of academic achievement. Consider, for example, that children who are capable of building relatively complex structures with toys like LEGO during the preschool years are more likely to be higher achievers in both middle and high school mathematics (Wolfgang, Stannard, & Jones, 2003).

Yet, unlike other domains such as language development, where several studies of naturalistic parent-child interactions have focused on predictors of language ability, less is known about what types of early experiences are associated with the development of good spatial skills (Levine, Ratliff, Huttenlocher, & Cannon, 2012). Moreover, little work has focused on identifying the types of early spatial learning supports that are associated with children's math achievement and later school performance (Mix & Cheng, 2012; Verdine, Golinkoff, et al., 2017). There are, however, reasons to suspect that the ways parents interact with their young children when playing with spatial toys may be associated with the development of spatial reasoning and lay the foundations for further development of spatial and mathematical ability (e.g., Levine et al., 2012).

Aiming to help grow this knowledge base and connect it to mathematics, in this study we examined the long-term associations between levels of maternal spatial support during mother-child interactions during puzzle and shape-sorting activities at age 2 and *mathematics performance 5 years later*. Specifically, we assessed whether maternal spatial language and gesture support during a joint puzzle task and a shape-sorting task at age 2 was associated with fewer math difficulties on a second-grade math screening test and with higher math ratings by second grade teachers. The goal was to examine maternal spatial support during play with two types of educational toys, which are likely to support the development of different types of math skills during early schooling. We were particularly interested in examining maternal support on the puzzle task, which is linked to spatial visualization skills and has been studied extensively as facilitating the development of early math (Levine et al., 2012; Mix & Cheng, 2012; Pruden et al., 2011). We also examined maternal support of the shape-sorting task since this is also a type of educational toy relating to early spatial and pre-math skills (Verdine et al., 2017).

Play-based Spatial Tasks

Puzzle tasks are considered a type of spatial visualization task, as they involve generating and holding a complex irregular mental image in mind and rotating it to fit onto an equally complex and irregular puzzle slot (Levine et al., 2012). Puzzle tasks depend on skills related to image generation, manipulation, and transformation. A number of studies have shown an association between experience with puzzles, parental spatial support, and other spatial skills (e.g., Pruden, Levine, & Huttenlocher, 2011). Levine et al. (2012) found that children aged 2 to 4, who spent more time playing with puzzles during home observations attained higher scores on a measure of spatial visualization transformation skills by the time they were 4.5 years old. Also, solving more difficult puzzles was associated with more spatial language exposure and with more parent engagement. Recently, Borriello and Liben (2017) found that informing mothers about spatial thinking and about ways to encourage it (e.g., telling mothers about the value of spatial thinking for daily activities and school subjects and how spatial play could be encouraged by giving examples from puzzle play), increased the level of spatial support they provided to their preschool children during joint block play (another type of play linked to spatial visualization skills).

Shape sorting tasks, which focus on shape and color feature discrimination, have also been associated with math reasoning, albeit less consistently. Shape sorting is not identified in the literature as a "pure" spatial visualization task, but as a spatial feature task that taps into other types of geometry skills besides spatial visualization (e.g., Mix & Cheng, 2012; National Council of Teachers of Mathematics Principles and Standards, 2000). The acquisition of the concept of geometric shapes is thought to be at the confluence of early spatial, math, and vocabulary knowledge (Verdine et al., 2017). Shape sorting tasks are focused on the categorization of spatial characteristics, such as shape identification (e.g., circle) and simple matching of shape attributes or features, such as discrimination of color, number of sides, sizes of angles, and symmetry (Verdine, Bunger, Athanasopoulou, Golinkoff, & Hirsh-Pasek, 2017). Shape knowledge is an important aspect of school readiness and part of mathematical learning, especially associated with establishing the foundations for geometric thinking (Cross et al., 2009; Fisher, Hirsh-Pasek, 2013). Geometric knowledge is also useful to learn arithmetical concepts and knowledge of informal geometry is required to teach and learn reading and writing (Aslan & Arnas, 2007), aspects also important in interpreting and solving math problems.

Parental Math/Spatial Talk There is evidence for the importance of the home environment for supporting children's developmental outcomes, including mathematical skills (Ma, Shen, Krenn, Hu, & Yuan, 2016; NICHD, Early Child Care Research Network, 2005). Home intervention studies aiming to increase the frequency of math-related home-based activities have shown positive effects on young children's outcomes (e.g., Berkowitz et al., 2015; Cheung & McBride, 2017; Starkey & Klein, 2000), and several studies have corroborated the predictive role of informal spatial and math activities in the home on later math achievement (LeFevre, et al., 2009; Lombardi, Casey, Thomson, Nguyen, & Dearing, 2017; Ramani, Rowe, Eason, & Leech, 2015). Many of these studies have adopted a naturalistic approach where parent-child dyads are observed during joint play (e.g., Casey, et al., 2018; Gunderson & Levine, 2011; Levine, Suriyakham, Rowe, Huttenlocher & Gunderson, 2010; Missall, Hojnoski, Caskie & Repasky, 2015; Pruden, et al., 2011; Susperreguy & Davis-Kean, 2016; Vandermaas-Peeler, Boomgarden, Finn, & Pittard, 2012; Vandermaas-Peeler, Ferretti, & Loving, 2012; Vandermaas-Peeler, Massey, & Kendall 2016). For example, Ramani et al. (2015) examined the effectiveness of support for spatial concept learning during a block building play task at age 3. Maternal support of children's planning skills during the task, were predictive of math achievement one and a half years later. Gunderson and Levine (2011) showed the importance of parents' use of counting and labeling sizes of objects as predictive of the emergence of mathematical concepts such as the cardinal principle. Similarly, the use of spatial words (as well as number words) in early parent-child interactions has been found to predict later spatial reasoning and math achievement. For example, Pruden, et al., (2011) examined the relation between parental spatial language input and both children's spatial language and later spatial skills. The frequent use of a particular subset of spatial words by parents, referring to spatial features of objects, such as dimension (e.g., big), shape (e.g., circle), and spatial properties (e.g., flat) was associated with children's talk about space, which in turn predicted later spatial thinking. This study found that variability in spatial language input, predicted the amount of spatial language children produced. Although one cannot infer causality, such longitudinal designs, controlling for a host of relevant covariates, can point to important associations between math/spatial support and later math achievement.

Other studies, using intervention designs and randomized control trials (e.g., Schmitt, Korucu, Napoli, Bryant, & Purpura, 2018) have also been carried out. For example, Young, Cartmill, Levine and Goldin-Meadow (2014) investigated the effects of spatial language in the context of puzzle play in improving preschool children's puzzle assembly ability. They independently manipulated the presence of spatial language (and the presence of gesture) in the context of four jigsaw puzzle training sessions. The study used a training paradigm in which each child assembled puzzles with an experimenter and he/she provided different input depending on the training condition to which the child was randomly assigned. Their findings show that providing quality spatial language is particularly effective in improving children's spatial abilities in puzzle solving. Further, exposure to parental spatial language, within other spatial tasks, has also been investigated. For example, block play in a guided play context (with photographs depicting the steps to build a completed block structure), seems to be particularly beneficial in terms of exposing children to spatial language. Parents randomly assigned to the guided play condition produced significantly higher proportions of spatial talk than parents assigned to other two play conditions (free play with blocks and preassembled structures) (Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, & Lam, 2011). In anoher study, Vandermaas-Peeler, Boomgarden, Finn, and Pittard (2012) randomly assigned parents to one condition where they received instructions to incorporate additional math talk into joint play cookery sessions in the home context. As compared to controls, these parents provided significantly more numeracy guidance and created more opportunities for their children to practice math skills, which translated into a higher number of correct responses in a child math assessment. These findings were corroborated by a similar study conducted by Vandermaas-Peeler, Ferretti, and Loving (2012), using a board game played in the home context.These studies illustrate the importance of guided/interactive play between parents and children as a way to facilitate spatial language exposure and emphasize the association between parental spatial support in the context of joint play and spatial skills.

Parental gesture support. In addition to parental spatial language, supportive gestures (like pointing to or placement of puzzle pieces) are also regarded as important elements in the communication between children and their caregivers. Preschoolers understand language best when accompanied by congruent gestures, which have a scaffolding role. For example, in a study by McNeil, Alibali, and Evans (2000), preschool children performed better at following verbally complex instructions with regards to location when these were accompanied by gestures, which reinforced a given spatial instruction (e.g., point up when the instruction included the word "up"), as opposed to being presented with non-congruent gestures. Levine, Gibson, and Berkowitz (2019) concluded that "*young children's spatial language is more highly predicted by parents' spatial language that is accompanied by gesture than by parents' spatial language that is unaccompanied by gesture* (Cartmill et al., 2010)" (p. 125). Levine's research team has also shown that spatial language that is accompanied by gesture is more effective in supporting preschoolers puzzle ability than spatial language not accompanied by co-speech gesture or by non-spatial language, either with or without co-speech gesture (Young et al., 2014). Given the important supportive role of gesture, in the present study we included maternal spatial support behaviors related to gesture as well as spatial language.

Maternal education level

Maternal educational level is an important component of socio-economic status (SES), and has often been used as a proxy for SES composites of human, financial, and social capital within the family (Bornstein & Bradley, 2003). Not surprisingly, given shared genetic and environmental influences, maternal education has been shown to be a key predictor of children's school success (e.g., Magnuson, 2007). In large part, this is because more educated mothers provide higher quality cognitive support and stimulation to their children, on average, compared with less educated mothers, and the overall home environments of more educated parents contain more high-quality learning materials (e.g., Davis-Kean, 2005; Neitzel & Stright, 2004; Raviv, Kessenich, & Morrison, 2004; Suizzo & Stapelton, 2007; Zadeh, Farnia, & Ungerleader, 2010). For math achievement more specifically, associations with maternal education as well as SES composite indicators are well known, with differences attributed to experiences in the home learning environment (e.g., Burchinal, Nelson, Carlson, & Brooks-Gunn, 2008; Gustafsson, Hanse, & Roséen, 2011; Magnuson, 2007). Critical mechanisms explaining maternal education differences in math problem solving abilities at first grade, for example, include early childhood indicators of the quality of learning materials in the home, levels of learning stimulation from parents, and the extent to which children have a variety of learning experiences in and outside of the home (Zedah et al., 2010). When it comes to children's spatial skills, fewer studies have concentrated on maternal education per se, but differences between SES groups (e.g., in block building) are already apparent by age 3 (Verdine et al., 2014).

In addition to main effects, maternal education may also moderate the importance of parental supports for math achievement. Previous studies have found that children from low SES backgrounds (low parent income and/or education) tend to benefit the most from interventions to increase math skills (Schmitt, et al., 2018; Weiland & Yoshikawa 2013). We hypothesize that an overall scarcity of learning supports within the home may accentuate the positive consequences of learning resources and opportunities that are, in fact, provided. For example, to the extent that the home environments of less educated parents contain fewer spatial learning materials (e.g., fewer puzzles and other stimulating toys) compared with the homes of more educated parents, high-quality spatial learning support from parents may be of added importance. Conversely, the importance of high-quality support from parents may be less critical for children of more highly educated parents, if their home environments provide opportunities to compensate for that lack of support. While we are unaware of any evidence that directly supports this hypothesis, the added value of learning supports for children of less educated parents has been demonstrated in other domains. As two examples consider that family engagement in schooling and enriched child care environments have been shown to correlate particularly strongly and positively with the achievement of children with less educated parents (Dearing, Kreider, Simpkins, & Weiss, 2006; Votruba-Drzal et al., 2004).

Spatial Support, Spatial Skills, and Math Achievement

Our study is in line with the research on parental support of *spatial skills*. However, we were interested in examining the relation between parental spatial support on a puzzle task (and on a shape-sorting task) and later *math achievement*, an area that has been less studied up to this point. A detailed review of the literature on children across different ages has shown that spatial visualization skills, in particular, are typically found to relate to math skills (Mix & Cheng, 2012). Note that spatial visualization skills are not only associated with spatial mathematical abilities, such as those used in geometry, but are also important for other mathematical areas such as numerical and algebra problems and more general measures of mathematical achievement (e.g., Casey et al., 2015; Mix et al., 2016). This suggests that spatial visualization skills may be involved in different kinds of math reasoning, not just geometry and measurement. Consequently, in this study we examined predictors of math achievement with a screening measure incorporating a range of second grade math content areas.

Interventions to stimulate spatial reasoning may be particularly beneficial for children at risk for poor academic skills in relation to mathematics, given the larger body of research showing a strong link between spatial skills and math performance (Mix & Cheng, 2012). Providing spatial training to parents can contribute to compensating for the effects of a more deprived home environment (e.g., Starkey & Klein, 2000), although spatial training is likely helpful for all parents. In fact, providing middle-income parents with math/spatial training has proved helpful since they find it difficult to engage spontaneously in rich math/spatial talk during everyday leisure and household tasks, like for example playing board games and cooking (see e.g., Vandermaas-Peeler, Ferretti et al., 2012; Vandermaas-Peeler, Boomgarden et al., 2012). Encouraging parents to use spatial toys to stimulate the use of spatial language may be positively associated with the development of early spatial and math skills (Verdine et al., 2014). By using a screening measure for math difficulties as the math assessment tool, the current study is focused on possible implications for future intervention studies, especially for children at risk for poor math skills.

One study by Casey and colleagues (2014) offered evidence that maternal spatial support is associated with the acquisition of spatial skills. This study, using an origami task, showed that maternal spatial interactions were predictive of later arithmetic skills indirectly, with the child's spatial skills acting as a mediator that linked parent spatial language support with children's later mathematical reasoning (Casey, Dearing, Dulaney, Heyman, & Springer, 2014). In addition, maternal spatial supportive interactions during a mother-child origami task mediated the relation between mother's educational level and their 6-7-year-old daughters' spatial skills. Moreover, daughters' spatial skills mediated the relation between quality of maternal support in spatial interactions and daughters' arithmetic achievement (Casey, et al., 2014). Another study found that maternal support of spatial concept learning (through spatial language and gestures) at 3 years during a block building task predicted children's math ability at 4 ½ years and first grade (Lombardi, et al., 2017).

Teacher ratings of math achievement. Several studies have raised concerns with regard to teacher ratings, namely about the validity and biases in teachers' ratings of small children's abilities (e.g., Kilday, Kinzie, Mashburn, & Whittaker, 2012). Teacher ratings seem to be more reliable when it comes to assessments of specific and objective activities such as counting or number naming (important aspects of pre-math skills) than when it comes to more general assessments like vocabulary use (e.g., Mashburn & Henry, 2004). Teachers' ratings naturally somewhat deviate from objective assessments or test scores of academic abilities. Several child characteristics are predictive of these discrepancies, including child age, inattentive behavior, and social skills (Baker, Tichovolsky, Kupersmidt, Voegler-Lee, & Arnold, 2015). With regard to social skills in specific, for example a study using the Social Skills Rating System (SSRS; Gresham & Elliott, 1990), found that good social skills might protect against low teacher expectations for academic performance (Baker, et al, 2015). These results have been corroborated by other studies, which have linked competent profiles of school behaviour (e.g., high social skills, low inattentiveness) to ratings of higher academic performance (e.g., McWayne, Hahs-Vaughn, Cheung, & Wright, 2012). These findings also suggest that besides a direct relation to achievement, competent profiles of behaviour may also have an impact on child assessments and outcomes through teacher perceptions (e.g., Baker et al., 2015).

The Present Study

The focus of this study was on parental spatial support behavior with two types of play materials: a puzzle and a shape-color sorting toy. Our focus on these materials was justified by the fact that they are ubiquitous in the homes of young children and both have the potential for families to use as educational toys associated with later math skills. Both puzzle play and sorting activities are related to later school-based math activities (e.g., Pruden et al., 2011; Verdine et al., 2017). Puzzle play is linked to key math skills involving part-whole relations that are important for both geometry and arithmetic skills. Skill at sorting and classifying based on different dimensions, such as shape, color, size, etc., are critical for patterning and shape attribute discrimination skills. We chose both types of tasks because they may be considered natural play situations (a) in which math talk of different types are likely to emerge, and (b) which are closely aligned with manipulative play that is likely to occur in many children's home environments.

We examined support during puzzle play specifically because there is a clear literature linking skills in this area to skills in spatial visualization (Borriello & Liben, 2017; Casey, Erkut et al., 2008; Levine et al., 2012; Pruden et al., 2011), a type of spatial skill that has itself been extensively linked to math achievement (Mix & Cheng, 2012). The shape-color sorting task focuses more on shape discrimination along with verbal labeling and matching prototypical shapes involving circles, triangles, and squares, and colors, involving red, green, and yellow, than on spatial visualization and image generation and manipulation skills. The shape-color sorting task involves verbal categorization, and classification of shapes can be labeled based on their verbally identifiable features (e.g., curved vs. straight, or number of sides and corners) as well as the colors of each of the objects (Verdine, Bunger, et al., 2017). While these skills are strongly emphasized in the conceptual and theoretical early math learning literatures, they have been much less investigated as predictors of later math performance and have not been linked as extensively in the literature to spatial skills (but see recent article by Verdine, Bunger, et al., 2017). Consequently, there are less clear predictions relating to maternal support during the shape-color sorting task, although this is clearly an early activity similar to the types of math sorting tasks typically used in preschool and early elementary school. Consequently, we investigated early parent-child spatial interactions during toddlerhood on these two types of educational toys as a predictor of math skills five years later. Specifically, in this study, we investigated whether maternal spatial support (i.e., spatial talk, gestures, and placement of objects to facilitate child's spatial learning) during these activities at age 2 was associated with later math screening scores and teacher ratings in second grade.

We hypothesized that higher levels of maternal spatial support when the child was 2 years old on the spatial tasks would be associated with less math difficulties in second grade as assessed by the math screening test and on the teacher math rating scale (with the caveat that the teacher rating scale might be confounded by teacher halo-effects). We analyzed both support on the puzzle task and support on the shape-color sorting task – for which there were no clear predictions. We also investigated whether associations varied by maternal educational level, with the possibility that children of mothers with lower education children might be more affected by parental spatial support than children of mothers with higher education.

Note that spatial support occurring during the specific and brief period of the study tasks was, in and of itself, unlikely to have strong associations with later math achievement. Instead, in this article, we are proposing that assessment of spatial support during the joint manipulative play tasks enabled us to capture the type and quality of support that *mothers typically provided* during similar spatial play and learning interactions with their children in the home environment.

A unique feature of this study is that we isolated the specific effect of maternal spatial support, by controlling for general cognitive stimulation by mothers across the same mother-child interactions. We also controlled for total frequency of maternal talk to isolate the effect of maternal *spatial* talk on math achievement. Moreover, we investigated whether mothers' educational level moderated the relation between spatial support and math achievement. That is, whether this relation would be particularly strong for children of less educated mothers, compensating for fewer learning opportunities (in and out of the home). Furthermore, we carried out secondary analyses involving teacher-ratings as a complement to the screening math test. In order to rule out halo-effects where teachers would give higher mathematical achievement ratings to more likeable or socially competent students, we carried out an additional robustness check controlling for children's teacher-perceived social competence. Finally, we included a sensitivity analysis to address the robustness or fragility of results in light of potential unobserved selection effects.

Method

Participants

This study is based on data from the [*name of the study removed for review*], a longitudinal study of three cohorts of children and their families (N = 1157) from five municipalities in southeast Norway. Using a variety of methods, data on cognitive, social, and behavioral development were collected from 6 months onwards. Recruitment took place in three waves - in 2006 (n = 433), 2007 (n = 529), and 2008 (n = 195) - through public child health clinics attended by almost all families in Norway.

Parents of 1931 eligible children (at least one Norwegian-speaking parent) were informed about the study by a staff nurse, 1465 (76%) agreed to be contacted, and, subsequently, 1159 (60%) agreed to participate (two families later withdrew from the study and their data files were discarded). From the 1157 children, 80% were retained in second grade with a valid school identification number, giving us an analytical sample of 932, included in the present study. The remaining children were not included due to nesting issues (we had no information about which school they attended). The children included in our study sample did not differ from excluded children in any predictor or outcome variables. However, there were some differences in demographic variables and covariates as described in Appendix A. Informed written consent was obtained and the study was approved by the Norwegian Social Science Data Services and approved by the Regional Committee for Medical and Health Research Ethics (Protocol number: 2009/224. Study name: "[*Blinded for Review*] ").

Procedure

We used information collected with parents via interviews and questionnaires about demographics, early child development, and maternal mental health. Within the larger longitudinal study, interviews with the parents where demographic data were collected took place when children were six months, one, two, three, and four years of age. At six months, both parents were invited to the interviews, at one and three years fathers were invited to participate, and at two and four years mothers were invited to take part in data collection. For this study, we used demographic data from interviews with the mothers when the child was 6 months and 2 years old. We also used observational data from video-recorded mother-child interactions conducted when the child was 2 years of age. Before the recording started, the interviewer gave mothers a short overview of the interaction tasks. Observational data were collected during a 6 minute *teaching activity* with two tasks. Mothers were presented first with a puzzle and subsequently with a shape-color sorter toy, and were asked to help their child as much as they thought necessary with one toy at a time (spending 3 minutes on each task). During the introduction to the *teaching* tasks, the interviewer spoke as little as possible directly to the child, since part of the assessment was to observe how the mother initiated the interactions. Mothers were repeatedly informed that they could choose to discontinue the tasks at any time. The interviewer left the room during the tasks and mother-child interactions were video recorded. After the interaction tasks were completed, the interviewer debriefed the participants and the child was given a small toy for his/her efforts.

Measures

Mothers' spatial support. To measure mothers' spatial support at age 2, we modified a rating scale for assessing parental spatial support based on the *Measure of Maternal Support of Spatial Concept Learning Using Spatial Materials* developed by Lombardi et al. (2017), at Boston College, (to fit the [*name of the study removed for review*] interaction tasks. Evidence suggests that behavior ratings may capture, to a greater extent, stable features of behavior (see Moskowitz & Schwarz, 1982), and have been used in prior studies of parental spatial support (Lombardi et al., 2017; Casey et al., 2014).

The current measure of spatial support assesses the extent to which the parent (i) verbally and (ii) through gestures and placement of objects supports the child's performance, exploration, and understanding of spatial visualization concepts. These features were all included in one single rating, which coders applied to the puzzle and the shape-color sorting tasks, respectively. In this study, a team of five coders were trained until reliability criteria were met (ICC above .70) before allowed to code study tapes. To measure inter-rater reliability, 20% of the tapes were double coded by two randomly selected coders every week during the entire coding period. Inter-rater reliability was monitored in bi-weekly meetings where disagreements were discussed and solved. Reliability among coders, as measured by Intra Class Correlations (ICC) was high (ICC = .84 for the puzzle task and ICC= .86 for the shape-color sorting task).

Broad categories of spatial language terms were taken from Cannon and colleagues (Cannon, Levine, & Huttenlocher, 2007). Categories of spatial language include words denoting orientations and transformations (e.g., upside down, flip), spatial dimensions (e.g., deep, small), positions and directions (e.g., underneath, behind), as well as shape labels (e.g., triangle), spatial features and properties (e.g., straight, flat). Non-verbal parental spatial support behaviors include the quality of parental gestures (e.g., pointing to key spatial locations), and placement of objects to facilitate the child's spatial learning (e.g., moving puzzle closer to the correct slots). Spatial support was coded from 1 (*none*) to 5 (*very high*) similar to Lombardi et al. (2017). (See Table 1 for descriptions and examples of the different codes.)

Insert Table 1 about here

A high quality spatial interaction for the puzzle task would involve statements/gestures like the following: (1) *"Try placing it next to that one, now it is upside-down, you need to turn it around, that's it, yes, great!";* (2) *"Try above the tractor, it's upside-down, try the other way."* The child fails; mom rotates the piece, and places it next to the puzzle. The child can now make the final move to fit the piece, and mom praises, *"Good job.*" For the shape-color sorting task, the following two high quality examples are provided: (1) *"And then you have to place them back again, remember, the red blocks were in the top row;"* (2) The child tries to fit another block (but not in the right hole) and mom says, *"No, that one doesn't fit, what's this then?"* and she points to the hole where the child tries to fit the block. *The child says, "Circle*", mom replies*, "Yes, it is".* Then mom points to the hole where the block will fit, and says*, "And what is this?"* The child answers *"Triangle,"* and is able to fit the block in the right hole. These examples were taken from our study tapes.

Math skills (screening test). In the spring of second grade, results from a screening math test were available for a subsample of 513 children. These children attended public schools in the five municipalities originally included. The screening test was designed nationally and was intended to help identify children who are underperforming and might need special attention from the teacher. The test assesses general ability to count, compare and rank numbers, work with number sequences, and perform addition, subtraction, and simple division operations. The test includes 15 problem sets with 1 to 4 math problems contained within each problem set. Examples of problems in the sets include identifying and counting geometrical forms, counting objects and placing the sum on a number line, identifying the greatest value out of three options, simple addition, and identifying half the value of a sum of coins (multiple-choice). In total, children complete 55 problems.

Every teacher was responsible for carrying out the test in her/his class and received an instruction manual; children completed the screening as a class. The teachers gave a general instruction at the start of the test, and then read out standardized instructions for each test page (each page contained a single problem set). Students took a break after the first 7 problem sets. The whole test took about 45 minutes to an hour to complete.

The number of correct answers within each of the 15 problem sets was summed. Because the test was designed to identify children with difficulties, test score distributions were skewed with about 11% of children in our sample attaining the top score (55 correct responses), while the 50^{th} percentile had 50 correct responses, and the 75^{th} percentile had 53 correct responses. In order to reduce measurement error in the math screening test, we fitted a measurement model based on the within problem set sums, using Confirmatory Factor Analysis with categorical indicators and a Weighted Least Squares Mean and Variance adjusted estimator. The measurement model fit the data well, $\chi 2$ (105, N = 513) 3394.55, p <.001; CFI = .99, TLI = .99, RMSEA = .03. It was correlated .88 with the sum of the 15 problem set sums, and .67 with the teacher rated math performance described below. We used the resulting latent measurement model as an outcome variable in further analyses.

Math skills (teacher rated). We also included another math assessment, a measure of math teacher ratings. Near the end of the Fall semester in second grade, children were assessed with the Social Skills Improvement System Rating Scales (SSIS-RS; Gresham & Elliott, 2008). The SSIS-RS are designed to assess *social skills*, *problem behaviors*, and *academic competence* in children/youth from 3 to 18 years. On the *academic competence scale*, teachers rate students in areas such as reading/writing, math, and motivation. For this study, we used the item covering children’s performance in math. Specifically, teachers were asked how a given child rated in terms of expectations for their grade level in math on a 5-point scale (1 = the lowest 10%, 2 = the next lowest 20%, 3 = the middle 40%, 4 = the next highest 20%, 5 = the highest 10%). High stability has previously been found in how teachers place children in these broad performance categories (Gresham & Elliott, 2008). The validity of teacher-rated performance can be inferred from a meta-analysis of 73 studies, which found an overall correlation of .63 between teachers' ratings of student performance and standardized test scores (Südkamp, Kaiser, & Möller, 2012).

Teachers' ratings of social competence. To control for teacher bias, in our robustness checks, we included second-grade teacher rating of children's social competence. We used the mean score of the full social competence scale from SSIS-RS (SSIS-RS; Gresham & Elliott, 2008). Internal consistency measured by Cronbach's Alpha was .96. As mentioned in the introduction, this scale has been previously used in studies about the validity of teacher reports of children's academic skills (e.g., Baker et al, 2015).

Covariates. Demographics collected at 6 months included child gender, maternal education, marital status, maternal age, and immigrant status. In second grade, data were also collected on child exact age at outcome testing.

We controlled for **maternal symptoms of depression and anxiety** by taking the mean score of the 13-item version of the Hopkins Symptom Check List (Strand, Dalgard, Tambs, & Rognerud, 2003). This measure was collected when the child was 2 years of age. Internal consistency measured by Cronbach's Alpha was .91.

To adjust for observed confounders related to **children's verbal ability**, we included also the communication scale of the Ages and Stages Questionnaire (ASQ; Bricker & Squires, 1999), which assesses the overall risk for delayed language development based on parent report. For the purpose of this study, we used the 24-month form of the Norwegian version (Janson & Smith, 2003).

Teaching activities, involving both the puzzle and shape-color sorting tasks, were also coded for the purpose of assessing mothers' **general cognitive support**, with global ratings assigned, using the NICHD's Study of Early Child Care and Youth

Development (SECCYD) scales *Qualitative Ratings for Parent-Child Interactions Ages 2-4 Years* (Owen et al., 2010). This observational rating system was designed to assess multiple maternal parenting dimensions including support of a wider range of cognitive concepts (not just those related to spatial visualization skills). This extensively-used rating system assessing general parental cognitive support that has been found to be predictive of children's cognitive development (NICHD Early Child Care Research Network (ECCRN), 2003; NICHD Early Child Care Research Network (ECCRN, 2008)). In this study, we used the rating of mothers' general cognitive stimulation during the *teaching activities* (available as a single score for both puzzle task and shape sorting task). This scale measures the degree to which the parent tries to foster the child's development by taking advantage of activities and engaging in a variety of actions that can facilitate learning. The focus is on the level of actions that may enhance perceptual, cognitive, linguistic, and/or physical development. Cognitive stimulation was rated on a Likert scale from 1 (*not at all characteristic*) to 5 (*highly characteristic*). In this general support measure, attempts to focus the child on an object or task, or simply labeling the attributes of objects (i.e., their colors), are regarded as stimulation, but of lower quality, whereas presenting activities step by step (e.g., "First we gather all the pieces, then we can see where they fit"), or encouraging child to use language (e.g., "Why don't you label the animals for me?") are regarded as better quality support. Five trained coders rated the mother-child interactions. Inter-coder reliability was monitored in bi-weekly meetings; 20% of the tapes were blindly assigned and double coded. Inter-rater reliability for the cognitive stimulation score as estimated by ICC was .79.

In addition, a covariate to control for **child independent task completion** during mother-child interactions was included in the analyses. The purpose of this control was to avoid penalizing mothers who might have provided effective support but who had children who solved the task on their own and did not need any spatial support. For that purpose, we created a dummy variable for each task resulting from combining level of spatial support (1-5) with task completion (1 = *not at all*; 2 = *to a little extent*; 3 = *to some extent*; 4 = *to a great extent*). If the child had received none or little spatial support (< 3) but managed to complete the task anyway (4), we assigned them a 1 (completes task without help) and otherwise a 0.

Finally, we controlled for **total frequency of maternal talk** during the puzzle task and the shape sorting task to isolate the specific effect of *spatial* maternal talk. The frequency of mothers' talk was derived from real time micro coding of the mother-child interaction (see Nordahl, Duckert, & Bjelland, 2007), where the number of verbal utterances was summarized. Reliability among coders was attained for the teaching activity as a whole (including both the puzzle task and the color-shape sorting task) with a total of 20% of the tapes coded by two different coders. Agreement among coders was .90. Overall inter-rater reliability, measured by Cohen's Kappa, was .75.

Analytic Strategy

We tested our hypotheses with linear regression models. For analyses including the screening test, we ran structural models with a latent y-variable and observed x-variables. The analyses including teacher ratings, were specified with observed y- and x-variables. We estimated separate models for all outcomes. Our regression models were conditioned on a set of covariates listed in Table 2, in addition to municipality of recruitment (dummies for four out of five municipalities in Southeast Norway) and birth cohort (dummy coded). We accounted for school clustering in all our models (using the TYPE = COMPLEX command in MPLUS to account for nesting). To test the differential associations as a function of maternal education, we conducted a second set of analyses including interaction terms (the product of maternal education and spatial support ratings).

One feature of our analyses is of particular note. Our spatial tasks were designed to be too difficult for 2-year-olds to accomplish on their own, and thus require maternal support. Nevertheless, some children completed it without any support. Assuming that mothers were sensitive to their children's skills and their need for support, these mothers might have refrained from interrupting children who they knew were capable of completing the task independently. These children could potentially confound our estimates, having early advanced spatial skills and also subsequent good math skills. To account for this, and as mentioned above, we constructed a dummy variable, coded "1": children who completed the task with little or no spatial support from their mothers, and "0": otherwise. We conditioned all the main analyses (math outcomes) on this variable.

In all of our analyses, we controlled for all covariates described above. In addition, when estimating the predictive value of maternal support specific to spatial skills, we controlled for domain-general maternal cognitive stimulation. By controlling for this variable, we were able to distinguish the effect of domain-specific spatial support from the effect of overall cognitive support, similarly to what has been done in previous studies (e.g., Casey et al., 2014). This accounts for the global level of support, and allowed us to isolate the unique association between spatial support and math skills. At the same time, this is an indirect way to control for general maternal characteristics, which may confound the specific effect of maternal support of spatial skills. Likewise, we also controlled for total frequency of maternal talk in all analyses.

Missing Data

As we restricted our analyses to those children for whom we had a valid school identification number (*n* = 932), missing data was infrequent on the teacher-rated outcome and background variables. For spatial support in mother-child interaction tasks, about 17% of the data were missing, while as much as 45% of the data were missing on the math screening test. To handle missing data, we used the FIML (Full Information Maximum Likelihood) estimation in all analyses involving teacher-ratings.

Missing data on the math screen test (*n* = 419, or 45% of the analytical sample) were due either to children attending a school in a different municipality, not having taken the test, or attending a private school. For the analyses including the math screening test, the estimator used was the WLSMV (weighted least squares means and variance adjusted), which accounts for missing data in a substantively similar way. The FIML is a recommended approach for handling missing data, even when missingness rates are higher than those in the present study (Allison, 2002).Regarding the estimation of missing data on the outcome variable, this has been a topic of some debate. We do, however, follow recent best practice and estimate accounting for missing data also on the Y. (please see Little, Lang, Wu, & Rhemtulla, 2016, or https://modeling.uconn.edu/wp-content/uploads/sites/1188/2016/05/Don't-be-Fancy.-Impute-Your-Dependent-Variables.pdf) for an argument. This approach is consistent with recommendations by Graham (2009) and Allison (2002).

Moreover, we have conducted comparisons between those participants for whom we had math test scores with the remaining participants. Participants with available test score data where less likely to have a non-western immigrant background, received higher levels of general cognitive stimulation, had mothers who were older, more educated, more likely married/partnered and with lower levels of depression. No differences were found for levels of support received on the puzzle or shape sorting task, child verbal ability at age 2, exact age at math testing or mothers' talk frequency (see Appendices B e C).

As a very last step, we used sensitivity analyses to address the robustness or fragility of results in light of potential unobserved selection effects (Dearing & Zachrisson, 2019). To do so, we used the coefficient of proportionality method (Oster, 2019). This method provides an indication of how large the impact of unobserved selection factors would need to be relative to unobserved variables to nullify results. For our sensitivity analyses, we assume a maximum R square of .7 for the math outcomes (see Dearing & Zachrisson, 2019).

Results

Descriptives

Demographic characteristics, as well as maternal spatial support and math achievement descriptive data, are displayed in Table 2. Spatial support in the puzzle task, as well as the general cognitive stimulation rating, had mean scores close to the median category on the rating scale (i.e., 3), and were approximately normally distributed. Moreover, teacher rated math achievement was slightly negatively skewed, while the math screening test was strongly negatively skewed, as can be seen from the descriptives for the raw sum score. Given that the focus in the present study was to use a screening measure to assess children at risk for math problems, this skewed bias was likely. For a full correlation matrix, see Appendix D.

Insert Table 2 about here

Regression Analyses

In our main set of models, we estimated the association between maternal spatial support and math screening scores at the end of second grade. We used latent outcomes in a SEM framework, as mentioned in the analytic strategy section and including all the covariates. We found that mothers who provided a higher level of spatial support in the puzzle task had children who scored significantly higher on the math screening test with effect size r_p =.08, p =.03. In contrast, for the shape-color sorting task, a feature discrimination task, for which parental predictions were not clear, we found no significant effects of maternal support on later math ability. For both tasks, there were no significant interactions by maternal education (see Table 3; full models with covariates can be found in Appendices E and F).

Insert Table 3 about here

Additionally, we ran some analyses including teacher-ratings as a measure of math skills. We estimated the association between maternal spatial support at age 2 and teacher-ratings of math achievement in second grade. Spatial support from mothers on the puzzle task did not significantly predict teacher-rated math. There was a statistically significant (negative) interaction with maternal education (see Table 4). The association between mothers´ spatial support and teachers´ math ratings was strongest for children of mothers with lower education. Nevertheless, this result did not hold up when we conducted a robustness check to help address potential teacher-report biases, that is, teachers rating students who are more socially competent (e.g., more attentive, smiling, agreeable) as having higher mathematical abilities (see Table 4, Model 3; full models with covariates can be found in Appendices G-I). When controlling for teacher ratings of social competence, the interaction between spatial support and maternal education was no longer statistically significant for teacher ratings.

Neither main effects nor interaction effects were found when spatial support on the shape-sorting task was used as predictor of teacher-rated math achievement.

Insert Table 4 about here

Sensitivity Analyses

In the analyses described above, there is one association, which is statistically significant, between maternal stimulation in the puzzle task, and the math screening measure. We therefore focus our sensitivity analysis on this association. This analysis indicated that in order to nullify the association, unobserved covariates would need to explain more than 3 times the amount of variance explained by our observed covariate set. Juxtaposed with published benchmarks for robustness (Oster, 2019), our results appear highly robust to potential omitted variable bias.

Discussion

In this study, we added to the limited literature on how mother-child interactions in early childhood are associated with long-term mathematical outcomes. Our main aim was to investigate whether the quality of maternal spatial support during interactions at age 2 was associated with reduction in math difficulties in second grade. We analyzed mother-child puzzle play interactions, found in the literature to be related to spatial visualization skills (Casey, Erkut et al., 2008; Levine et al., 2012; Pruden et al. 2011), and mother-child play with a shape-color sorting task, which is more associated with shape and color feature discriminations than spatial visualization skills. Moreover, we investigated whether the relation between early maternal spatial support and math skills was moderated by maternal education. We used ratings of maternal spatial support including language, gestures, and object placement used when helping children complete manipulative play toys with the aim of capturing the quality of spatial support that mothers may be providing in the home environment.

Early Maternal Spatial Support and Math Screening Scores in Second Grade

Our main finding was that higher maternal spatial support during early mother-child interactions on a puzzle play task was significantly associated with fewer math difficulties in the children on a math screening test in second grade - a test designed to identify children at risk for poorer math skills. This is important because these are children vulnerable to failure in math, and researchers have found that math experiences and competencies prior to school entry are one of the most powerful predictors of later math and life successes, even stronger than reading skills (Duncan et al., 2007). In fact, it has been found that low levels of early math knowledge negatively impact the odds of graduating from high school and attending college, as well as income and health outcomes during adulthood (Currie & Duncan, 2000; Feinstein & Bynner, 2004; Geary, Hoard, Nugent, & Bailey, 2013). Thus, it is meaningful and relevant that maternal spatial support on a puzzle task as early as 2 years of age was positively associated with math scores assessed five years later. This finding establishes a longer-term association between early maternal spatial support and math achievement, in the lower range, than has been found before. Note, however, that this finding does not imply cause and effect because these are only correlational data.

These findings on puzzle play with toddlers are consistent with the prior research study showing an association between early parental support of *block building* skills at 3 years of age and math assessed at ages 4 to 5 (Lombardi et al., 2017). Our findings contribute to the field by showing that maternal spatial support during yet another type of joint spatial visualization activity (a *puzzle* task) contributes to later math skills.

Further, we also investigated the effect of maternal spatial stimulation with another type of math-related lay toy usually found in homes, a shape-color sorting toy, for which we had no clear predictions based on the literature. This type of play toy focuses more on labeling and matching prototypical shapes involving circles, triangles, and squares, which could be labeled based on their verbally identifiable features (e.g., number of sides and corners) as well as color (Verdine, Bunger, et al., 2017). In fact, no effects of maternal spatial support on later math scores were found for this task.

Puzzle tasks involve spatial visualization skills because they depend upon the ability to visualize, mentally manipulate, and rotate *irregular* shapes (without easily identifiable verbal labels). Puzzle tasks might therefore depend more on skills relating to image generation, manipulation and transformation, as opposed to shape-color sorting tasks. Puzzle tasks may give an advantage in providing a context for eliciting maternal spatial support with the potential to predict solving math problems because, in contrast to spatial feature tasks, they draw on another type of cognitive process involving use of images rather than just verbal categorization and logical deductive reasoning. In contrast, skill on shape-color sorting tasks may be more dependent on learning feature discrimination and classification. Both puzzle tasks and shape-color sorting tasks are considered to involve pre-math skills, and math skills prior to schooling have been found to be associated with both later math and reading (Duncan et al., 2007). However, a review of the literature across ages has shown that the type of spatial activities that tap spatial visualization abilities are the types of spatial activities that are most likely to predict math skills (Mix & Cheng, 2012). Thus, the present findings are consistent with the literature on the specificity of visualization skills in predicting math.

These results also contribute to the field because they extend these predictive associations over a longer time-span, from experiences in toddlerhood all the way to math performance in the second grade of elementary school. This study thus adds to the literature by providing one of the first empirical examinations of maternal spatial support as early as 24 months of age as predictors of fewer math difficulties five years later. These findings suggest that mother-child spatial interactions may potentially provide an avenue for designing future parental interventions in children's early math development.

Another major advantage of this study on parental support specific to spatial skills is that both general maternal cognitive support and total frequency of maternal language during the videotaped teaching activities were statistically controlled. These controls help reduce the likelihood that the maternal support measure on the puzzle task was simply assessing mothers' general level of cognitive support on joint play activities, as well as the possibility that the maternal spatial support measure was just assessing total amount of language stimulation provided by the mothers across the two teaching activities.

Supplemental analyses including teacher-ratings

A statistically significant interaction between spatial support and maternal education was initially found when children's math skills were assessed through teacher ratings. Spatial support during the puzzle task was more strongly associated with later math skills, as rated by teachers, for children of mothers with lower education. This result is in line with previous studies, emphasizing the importance of improving spatial support from parents during joint play, especially for parents from lower-SES backgrounds, whose children are at risk for lower math achievement (e.g., Borriello & Liben, 2017).

However, it is important to note that this interaction was no longer statistically significant in robustness checks when controlling for teacher-ratings of social competence, a proxy for teacher biases in possibly giving higher math scores to more likeable students. Because we were careful to include measures of teachers' ratings of children's social competence as well as math competence, we found that the teacher ratings of math competence were confounded by their view of children's social skills. Thus, in future research using teacher ratings of academic performance, it will be important to control for the more general effect of teachers' biases as a potential confounding factor in their ratings of school achievement. For example, Kilday et al. (2012) found a concordance of .50 between teacher ratings of math achievement and direct assessments of math skills. The results were interpreted by the authors as moderate usefulness of teacher ratings, that is, they are useful in determining whether children are above or below the mean, but they may lack accuracy in terms of appropriate rating of the students. This could be related to the lack of familiarity with specific behavioural markers for the demonstration of general math skills. For example, teachers are slightly better at rating children in terms of their number sense than their skills in geometry and measurement. This could be because teachers are more familiar with recognizing children's number-sense skills than those in geometry and measurement (Kilday et al., 2012). It is important to note that our measure of social competence is not a measure of social desirability, but of halo effects where students who are perceived as more socially competent would be rated as having higher academic skills. Future studies should address social desirability issues and their role in teachers' self-reports.

Limitations and strengths

It should also be noted that our spatial support ratings were based on only two 3-minute observation with 2-year-olds. This may have introduced measurement error into the maternal support ratings, and consequently, these results need to be replicated using maternal-child interactions of a longer duration. However, other parent-child research involving similarly brief interactions has also successfully shown predictive relations between early parental behavior and later cognitive performance. While a number of these studies have used interactions of 10-15 minutes (Martin, et al., 2007; NICHD Early Child Care Research Network, 2008), others have used shorter time intervals of 5 minutes during interactions with 3-year- olds (Devine, Bignardi, & Hughes, 2016; Lombardi et al., 2017). Importantly, the short duration of the observation

should weaken (not strengthen) our attempt to detect associations with later math outcomes, underscoring the potential importance of the associations that we did detect. In addition, we also point out as a limitation that we have not counterbalanced the order of presentation of the puzzle and the shape sorting tasks, i.e., all dyads completed the puzzle task in the first place. These interactions were initially devised as a common teaching task in the original NICHD SECCYD global ratings but for spatial ratings, there was the *a priori* need to analyze the two tasks separately, since, as explained in the introduction, they tap very different spatial and pre-math skills. It is possible that mothers and children were less engaged in the second task (shape sorting task) and that this might have affected the levels of spatial support provided.

Although the observational nature of this study is an advantage in relation to other studies using parent self-report of stimulating activities (e.g., Kroll & Borck, 2013), we acknowledge that we have, as in many observational studies, captured a sample of mother-child interaction behaviors, which might have been influenced by the artificial context or specific isolated factors like mood, amount of sleep and so on. Thus, we assumed maternal spatial support during the puzzle and shape sorting tasks would reflect the amount of spatial talk children would typically be exposed to daily in the home context. Exposure to spatial talk, in turn, would be associated with facilitation of spatial thinking and spatial reasoning ability, which would relate to development of pre-math skills. In fact, previous studies have provided evidence that variations in spatial language children hear, which directs their attention to important aspects of the spatial environment, may be one of the mechanisms contributing to differences in spatial skills (e.g., Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, & Lam, 2011). Moreover, variability in spatial language input has been found to predict the amount of spatial language children produce, even when controlling for overall parent language input (Pruden et al., 2011). We should also point out as a limitation that our study lacked a measure of children’s spatial skills, which would enable us to further corroborate this link between spatial language inputs from the parents and children’s spatial language and reasoning.

Another limitation in terms of the generalizability of our study concerns our math outcome measure. The use of a national math screening test provided a precise estimate of math difficulties, but addressed variability within a more restricted range of children, as it was designed to detect students who may be at risk for math problems. Therefore, our results cannot be generalized to findings relating to wider measures of math skills. We have included also an additional measure of teacher ratings of wider math ability, for which we had a wider coverage. Teacher ratings are less precise estimates of ability, despite the advantage of presenting a more normal distribution and including a larger range from very low to very high achievement. However, in this study, teacher-ratings were found to be prone to social desirability biases. Thus, our key findings can be most likely generalized to children who are having math difficulties. Future research is necessary to determine whether this association is relevant across a wider range of math abilities, and whether the findings relate specifically to math skills or are predictive of academic performance more generally. Another limitation of our study is the lack of a direct measure of general intelligence or verbal skills, beyond the ASQ, which assesses parental report of the overall risk for delayed language development at age 2.

Finally, we acknowledge as a critical limitation of our study the fact that we did not control for quality of math instruction in the classroom. Although these students were exposed to formal math teaching for only one and a half years, it is possible that the effect of math instruction would have overshadow the effect of spatial and pre-math experiences in the home prior to school entry.

The use of a very large longitudinal sample and rich observational data coded for spatial support while controlling for a series of child and maternal variables that have been associated with children’s math achievement are critical strengths of this work. The fact that we were able to control for general cognitive support and frequency of talk in all analyses enabled us to distinguish the contributions of spatial support from overall cognitive support (e.g., Casey et al., 2014). In other words, the key stimulation that matters is likely to be spatial - not just general cognitive stimulation. Although cause and effect conclusions cannot be made from correlational findings, these results suggest a direction for designing future interventions that explore the use of parental spatial support involving puzzles, which provide a good context for spatial support, as a potential route for improving the math skills of children who are at risk for poor math skills.

Conclusions and Implications

This study supports the association of maternal spatial support during a puzzle task with toddlers with a screening test identifying children at risk for poor math skills as late as second grade. Spatial visualization tasks, such as puzzles, may provide the context to stimulate spatial thinking and reasoning abilities that are associated with math ability in the long-term. We are certain that we have not accidentally just captured “good parenting” in the form of general cognitive stimulation or high frequency of talk directed to the child, as these factors were controlled in the study. Further, while maternal spatial support of children’s interactions with a puzzle toy predicted later math skills, support with shape-color sorting tasks did not. These findings establish preliminary evidence of the long-term association between spatial visualization support in toddlerhood and reduced math difficulties in second grade. The findings raise awareness of the potential for fostering spatial skills in play activities at home, encouraging parents to facilitate spatial concept development during joint puzzle play.

Table 1: *Ratings of maternal level of spatial support for the puzzle and shape-color sorting tasks*

Rating	**Maternal spatial support**	**Examples**	
		Puzzle task	Shape-sorting task
(1) None	Does not support the child's spatial learning and may focus		

	on other aspects of the tasks such as colors instead of shapes, or may be silent or withdrawn and not provide any kind of support.	-	-
(2) Low	Provides very occasional and infrequent spatial language or gestures and does not explain the purpose of the task.	Mom places a puzzle piece near the correct slot or matching puzzle piece but does not direct the child's attention to it or explain why.	The parent refers to the different shapes but does not explain how the shapes have to be put into the sorting tray.
(3) Moderate	Sometimes uses spatial language or gestures to support the child. Mom may also explain the purpose of task by modelling or use of language.	"That one was too big."	"That's a square, and there you have a triangle. Maybe you should try it in the triangle [hole]."
(4) High	Frequently uses clear spatial language and/or gestures; gives good suggestions and strategies for approaching spatial task effectively.	"The space for this puzzle piece has an animal with a tall head. Can you find a puzzle hole that has a tall part?"	"The piece you are holding has a circle at the bottom. Here is the circle on the board. Can you put your circle here?"
(5) Very High	Similar to "High" rating, but mom is clearly seeking to stimulate a higher level of mastery or sophistication in the child's spatial concepts.	"If you hold the piece like this and place it over each of the holes (*demonstrates over different holes*), you can see where it goes."	"It needs to be in the same row as the blue block, where does the blue circle go?" Mom points, and says, "There, right next to the red circle".

Table 2

Summary of demographic characteristics, maternal support, and math achievement (N = 932)

	% Missing	*% / M(range)*	*SD*
Child, family & maternal characteristics			
Boy	.00	50.60	-
Maternal education (years)	.90	14.47(9-18)	2.51
Maternal age	.23	31.26(19-42)	4.64
Verbal ability (age 2)	1.02	2.31(.55-3.00)	0.39
Western immigrant	1.02	6.27	-
Non-Western immigrant	1.02	5.25	-
Single mother	3.61	6.44	-
Maternal depression	4.83	1.33(1-3.62)	0.41
Maternal support			
Spatial support on puzzle task	16.20	2.79(1-5)	0.80
Spatial support on shape-color sorting task	16.74	2.86(1-5)	0.83
Talk frequency	21.59	49.57(14-88)	9.95
General cognitive stimulation	16.20	2.90(1-5)	0.67
Math – Outcome Measures			
Teacher-ratings second grade	7.62	3.59(1-5)	1.10
Test screening scores second grade (latent)	49.12	-.15	0.31
Test screening scores second grade (raw)	44.95	47.81 (11-55)	8.01

Table 3

Regression model for the association between maternal spatial support at age 2 and the ***math screening measure*** *in second grade (n = 932)*

		Model 1		Model 2 (interaction)	
Puzzle task		*Coeff (SE)*	*p*	*Coeff (SE)*	*p*
	Spatial Support	.08(.04)	**.03**	.09(.04)	**.02**
	SS x Maternal Ed.	-	-	-.03(.06)	.56
Shape sorting task					
	Spatial Support	.03(.04)	.42	.03(.05)	.52
	SS x Maternal Ed.	-	-	-.02(.07)	.83

Note. SS = Spatial Support. The following covariates were included in the model: child gender, child exact age at outcome testing, child verbal ability (age 2), maternal education, maternal age, maternal marital status, maternal immigrant background, maternal depression, maternal frequency of talk, maternal general cognitive stimulation, cohort.

Table 4

Regression model for the association between maternal spatial support at age 2 and ***teacher ratings of math achievement*** *in second grade (n = 932)*

	Model 1		Model 2 (interaction)		Model 3 (interaction *)	
	Coeff (SE)	*p*	*Coeff (SE)*	*p*	*Coeff(SE)*	*p*

Puzzle task							
	Spatial Support	.05(.04)	.20	.07(.04)	.06	.06(.04)	.08
	SS x Maternal Ed.	-	-	-.07(.04)	**.04**	-.05(.03)	.13
Shape sorting task							
	Spatial Support	.07(.04)	.10	.07(.04)	.10	-	-
	SS x Maternal Ed.	-	-	-.01(.04)	.75	-	-

* Robustness check controlling for teacher ratings of social competence

Note. SS = Spatial Support. The following covariates were included in the model: child gender, child exact age at outcome testing, child verbal ability (age 2), maternal education, maternal age, maternal marital status, maternal immigrant background, maternal depression, maternal frequency of talk, maternal general cognitive stimulation, cohort.

References

Allison, P. D. (2002). *Missing data*. Thousand Oaks, CA: Sage publications. doi.org/10.4135/9781412985079

Aslan, D., & Arnas, Y. A. (2007). Three to six year old children's recognition of geometric shapes. *International Journal of Early Years Education*, *15*, 83-104.

Baker, C. N., Tichovolsky, M. H., Kupersmidt, J. B., Voegler-Lee, M. E., & Arnold, D. H. (2015). Teacher (mis) perceptions of preschoolers' academic skills: Predictors and associations with longitudinal outcomes. *Journal of Educational Psychology*, *107*, 805.

Berkowitz, T., Schaeffer, M. W., Maloney, E. A., Peterson, L., Gregor, C., Levine, S. C., & Beilock, S. L. (2015). Math at home adds up to achievement in school. *Science, 350,* 196–198. doi:10.1126/science.aac7427

Bricker, D., & Squires, J. (1999). Ages and Stages Questionnaires: A Parent-Completed, Child-Monitoring system. Baltimore, Md.:Paul H. Brookes.

Bornstein, M. H., & Bradley, R. H. (2003). Socioeconomic Status. *Parenting, and Child Development. Lawrence Erlbaum*.

Borriello, G. A., & Liben, L. S. (2018). Encouraging maternal guidance of preschoolers' spatial thinking during block play. *Child Development*, *89*, 1209-1222. doi:10.1111/cdev.12779

Burchinal, M., Nelson, L., Carlson, M., & Brooks-Gunn, J. (2008). Neighborhood characteristics, and child care type and quality. *Early Education and Development*, *19*, 702-725. doi:10.1080/10409280802375273

Cannon, J., Levine, S. C., & Huttenlocher, J. (2007). *A system for analyzing children and caregivers' language about space in structured and unstructured contexts*. Spatial Intelligence and Learning Center (SILC) Technical Report. http://doi.org/2007

Cartmill, E., Pruden, S. M., Levine, S. C., Goldin-Meadow, S., & Center, S. I. L. (2010). The role of parent gesture in children's spatial language development. In *Proceedings of the 34th annual boston university conference on language development* (pp. 70-77). Somerville, MA: Cascadilla Press.

Casey, B. M., Andrews, N., Schindler, Kersh, J., Samper, A., & Copley, J. (2008). The development of spatial skills through interventions involving block building activities. *Cognition and Instruction, 26*, 269-309. doi: 10.1080/07370000802177177

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

Casey, B., Erkut, S., Ceder, I., & Young, J. M. (2008). Use of a storytelling context to improve girls' and boys' geometry skills in kindergarten. *Journal of Applied Developmental Psychology*, *29*, 29-48. doi:10.1016/j.appdev.2007.10.005

Casey, B. M., Lombardi, C. M., Thomson, D., Nguyen, H. N., Paz, M., Theriault, C. A., & Dearing, E. (2018). Maternal support of children's early numerical concept learning predicts preschool and first grade math achievement. *Child development*, *89*, 156-173.

Casey, B.M., Pezaris, E., Fineman, B., Pollock, A., Demers, L., & Dearing, E. (2015). A longitudinal analysis of early spatial skills compared to arithmetic and verbal skills as predictors of fifth-grade girls' math reasoning. *Learning and Individual Differences, 40*, 90-100. doi: 10.1016/j.lindif.2015.03.028

Casey, M.B., Nuttal, R., Pezaris, E., & Benbow, C.P. (1995). The influence of spatial ability on gender differences in mathematics college entrance test scores across diverse samples. *Developmental Psychology, 31*, 697-705. doi:10.1037/0012-1649.31.4.697

Cheung, S. K., & McBride, C. (2017). Effectiveness of parent–child number board game playing in promoting Chinese kindergarteners' numeracy skills and mathematics interest. *Early Education and Development*, *28*, 572-589.

Cross, C. T., Woods, T. A., & Schweingruber, H. (2009). *Mathematics learning in early childhood*. Washington, DC: National Academies Press.

Currie, J., & Duncan, T. (2000). School quality and the longer-term effects of Head Start*. The Journal of Human Resources*, 35, 755-774. doi: 10.2307/146372

Davis-Kean, P. E. (2005). The influence of parent education and family income on child achievement: the indirect role of parental expectations and the home environment. *Journal of family psychology*, *19*, 294.

Dearing, E., Kreider, H., Simpkins, S., & Weiss, H. B. (2006). Family involvement in school and low-income children's literacy: Longitudinal associations between and within families. *Journal of Educational Psychology*, *98*, 653.

Dearing, E., & Zachrisson, H.D. (In press). Taking selection seriously in correlational studies of child development: A call for sensitivity analyses. *Child Development Perspectives.* doi:10.1111/cdep.12343

Devine, R.T., Bignardi, G., & Hughes, C. (2016). Executive function mediates the relations between parental behaviors and children's early academic ability. *Frontiers in Psychology, 7*, 1-15. doi:10.3389/fpsyg.2016.01902

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engle, M., Brooks-Gunn, J. Sexton, H., Duckworth, K. & Japel, C. & (2007). School readiness and later achievement. *Developmental Psychology*, *43*, 1428-1446. doi: 10.1037/0012-1649.43.6.1428

Feinstein, L., & Bynner, J. (2004). The importance of cognitive development in middle childhood for adulthood socioeconomic status, mental health, and problem behavior. *Child Development, 75,* 1329-1339. doi:10.1111/j.1467-8624.2004.00743.x

Ferrara, K., Hirsh-Pasek, K., Newcombe, N. S., Golinkoff, R. M., & Lam, W. S. (2011). Block talk: Spatial language during block play. *Mind, Brain, and Education*, *5*, 143-151. doi: 10.1111/j.1751-228X.2011.01122.x

Fisher, K. R., Hirsh-Pasek, K., Newcombe, N., & Golinkoff, R. M. (2013). Taking shape: Supporting preschoolers' acquisition of geometric knowledge through guided play. *Child development*, *84*, 1872-1878.

Geary, D.C., Hoard, M.K., Nugent, L. & Bailey, D.H. (2013). Adolescents' functional numeracy is predicted by their school entry number system knowledge. *PLoS ONE 8*, e54651. doi:10.1371/journal.pone.0054651

Graham, J. W. (2009). Missing data analysis: Making it work in the real world. *Annual review of psychology*, *60*, 549-576.

Gresham, F., & Elliott, S. N. (2008). *Social Skills Improvement System (SSIS) Rating Scales.* Bloomington, MN: Pearson Assessments.

Gunderson, E. A., & Levine, S. C. (2011). Some types of parent number talk count more than others: Relations between parents' input and children's cardinal-number knowledge. *Developmental Science, 14*, 1021–1032. doi:10.1111/j.1467-7687.2011.01050.x

Gustafsson, J. E., Hansen, K. Y., & Rosén, M. (2011). Effects of home background on student achievement in reading, mathematics, and science at the fourth grade. *TIMSS and PIRLS*, 181-287.

Hubbard, E. M., Piazza, M., Pinel, P., & Dehaene, S. (2005). Interactions between number and space in parietal cortex. *Nature Reviews Neuroscience*, *6*, 435-448. doi:10.1038/nrn1684

Janson, H. & Smith, L. (2003). *Norsk Manual Supplement til Ages and Stages Questionnaires [Norwegian Manual Supplement for the Ages and Stages Questionnaire].* Oslo, Norway: Regional Center for Child and Adolescent Mental Health, Health Region East/South.

Kilday, C. R., Kinzie, M. B., Mashburn, A. J., & Whittaker, J. V. (2012). Accuracy of teacher judgments of preschoolers' math skills. *Journal of Psychoeducational Assessment*, *30*, 148-159.

Kröll, A., & Borck, R. (2013). The influence of child care on maternal health and mother-child interaction.

LeFevre, J., Skwarchuk, S. L., Smith-Chant, B. L., Fast, L., Kamawar, D., & Bisanz, J. (2009). Home numeracy experiences and children's math performance in the early school years. *Canadian Journal of Behavioural Science/Revue Canadienne Des Sciences Du Comportement, 41*, 55–66. doi:10.1037/a0014532

Levine, S. C., Gibson, D. J., & Berkowitz, T. (2019). Mathematical Development in the Early Home Environment. In *Cognitive Foundations for Improving Mathematical Learning* (pp. 107-142). Academic Press.

Levine, S. C., Ratliff, K. R., Huttenlocher, J., & Cannon, J. (2012). Early puzzle play: A predictor of preschoolers' spatial transformation skill. *Developmental Psychology*, *48*, 530-542. doi: 10.1037/a0025913

Levine, S. C., Suriyakham, L. W., Rowe, M. L., Huttenlocher, J., & Gunderson, E. A. (2010). What counts in the development of young children's number knowledge?. *Developmental psychology*, *46*(5), 1309.

Little, T. D., Lang, K. M., Wu, W., & Rhemtulla, M. (2016). Missing data. *Developmental psychopathology*, 1-3. doi: 10.1002/9781119125556.devpsy117

Lombardi, C. M., Casey, B. M., Thomson, D., Nguyen, H. N., & Dearing, E. (2017). Maternal support of young children’s planning and spatial concept learning as predictors of later math (and reading) achievement. *Early Childhood Research Quarterly*, *41*, 114-125. doi:10.1016/j.ecresq.2017.07.004

Ma, X., Shen, J., Krenn, H. Y., Hu, S., & Yuan, J. (2016). A meta-analysis of the relationship between learning outcomes and parental involvement during early childhood education and early elementary education. *Educational Psychology Review*, *28*, 771-801. doi:10.1007/s10648-015-9351-1

Magnuson, K. (2007). Maternal education and children's academic achievement during middle childhood. *Developmental psychology*, *43*(6), 1497.

Martin, A., Ryan, R. M., & Brooks-Gunn, J. (2007). The joint influence of mother and father parenting on child cognitive outcomes at age 5. *Early Childhood Research Quarterly, 22*, 423-439. doi: 10.1016/j.ecresq.2007.07.001

Mashburn, A. J., Hamre, B. K., Downer, J. T., & Pianta, R. C. (2006). Teacher and classroom characteristics associated with teachers' ratings of pre-kindergartners' relationships and behaviors. *Journal of Psychoeducational* n*Assessment, 24*, 367 -380.

Mashburn, A. J., & Henry, G. T. (2004). Assessing school readiness: Validity and bias in preschool and kindergarten teachers' ratings. *Educational Measurement: Issues and Practice*, *23*(4), 16-30.

McWayne, C. M., Hahs-Vaughn, D. L., Cheung, K., & Wright, L. E. G. (2012). National profiles of school readiness skills for Head Start children: An investigation of stability and change. *Early Childhood Research Quarterly*, *27*, 668-683.

McNeil, N. M., Alibali, M. W., & Evans, J. L. (2000). The role of gesture in children's comprehension of spoken language: Now they need it, now they don't. *Journal of Nonverbal Behavior*, *24*, 131-150.

Missall, K., Hojnoski, R. L., Caskie, G. I., & Repasky, P. (2015). Home numeracy environments of preschoolers: Examining relations among mathematical activities, parent mathematical beliefs, and early mathematical skills. *Early Education and Development*, *26*, 356-376.

Mix, K. S., & Cheng, Y. L. (2012). The relation between space and math: Developmental and educational implications. In J. B. Benson (Ed.), *Advances in child development and behavior* (Vol. 42, pp. 197-243). San Diego: Elsevier.

Mix, K. S., Levine, S. C., Cheng, Y. L., Young, C., Hambrick, D. Z., Ping, R., & Konstantopoulos, S. (2016). Separate but correlated: The latent structure of space and mathematics across development. *Journal of Experimental Psychology: General*, *145*, 1206-1227. doi: 10.1037/xge0000182

Moskowitz, D. S., & Schwarz, C. J. (1982). Validity comparison of behavior counts and ratings by knowledgeable informants. *Journal of Personality and Social Psychology, 42,* 518-528. doi: 10.1037/0022-3514.42.3.518.

National Council of Teachers of Mathematics (NCTM). 2000. *Principles and standards for school mathematics*, Reston, VA: NCTM.

Neitzel, C., & Stright, A. D. (2004). Parenting behaviours during child problem solving: The roles of child temperament, mother education and personality, and the problem-solving context. *International Journal of Behavioral Development*, *28*, 166-179. doi:10.1080/01650250344000370

NICHD Early Child Care Research Network (2003). Do children's attention processes mediate the link between family predictors and school readiness? *Developmental Psychology, 39*, 581–593.

NICHD Early Child Care Research Network (Ed.). (2005). *Child care and child development: Results from the NICHD study of early child care and youth development.* Guilford Press.

NICHD Early Child Care Research Network (2008). Mothers' and fathers' support for child autonomy and early school achievement. *Developmental Psychology, 44*, 895-907. doi:10.1037/0012-1649.44.4.895

Nordahl, K., Duckert, M., & Bjelland, I. (2007). *Toddler and Parent Interaction Coding System.* [Unpublished coding manual]. Oslo, Norway: The Norwegian Center for Child Behavioral Development.

Oster, E. (2019). Unobservable selection and coefficient stability: Theory and evidence. *Journal of Business & Economic Statistics*, *37,* 187-204. doi:10.1080/07350015.2016.1227711

Owen, M. T., Amos, M. L., Bondurant, L., Hasanizadeh, N., Hurst, J. R., & Villa, A. (2010). *Qualitative ratings for parent-child interactions: Ages 2–4 years*. Unpublished manual. The University of Texas at Dallas.

Pruden, S. M., Levine, S. C., & Huttenlocher, J. (2011). Children's spatial thinking: does talk about the spatial world matter? *Developmental Science*, *14*, 1417-1430. doi: 10.1111/j.1467-7687.2011.01088.x

Ramani, G. B., Rowe, M. L., Eason, S. H., & Leech, K. A. (2015). Math talk during informal learning activities in Head Start families. *Cognitive Development*, *35*, 15-33.

Razza, R. A., & Raymond, K. (2013). Associations among maternal behavior, delay of gratification, and school readiness across the early childhood years. *Social Development, 22*(1). 180–196. doi: 10.1111/j.1467-9507.2012.00665.x

Raviv, T., Kessenich, M., & Morrison, F. J. (2004). A mediational model of the association between socioeconomic status and three-year-old language abilities: The role of parenting factors. *Early Childhood Research Quarterly*, *19*(4), 528-547.

Schmitt, S. A., Korucu, I., Napoli, A. R., Bryant, L. M., & Purpura, D. J. (2018). Using block play to enhance preschool children's mathematics and executive functioning: A randomized controlled trial. *Early Childhood Research Quarterly*, *44*, 181-191.

Starkey, P., & Klein, A. (2000). Fostering parental support for children's mathematical development: An intervention with Head Start families. *Early Education and Development*, *11*, 659-680.

Strand, B. H., Dalgard, O. S., Tambs, K., & Rognerud, M. (2003). Measuring the mental health status of the Norwegian population: A comparison of the instruments SCL-25, SCL-10, SCL-5 and MHI-5 (SF-36). *Nordic Journal of Psychiatry, 57*, 113–118. doi:10.1080/08039480310000932

Südkamp, A., Kaiser, J., & Möller, J. (2012). Accuracy of teachers' judgments of students' academic achievement: A meta-analysis. *Journal of Educational Psychology, 104*, 743-762. doi: 10.1037/a0027627

Suizzo, M. A., & Stapleton, L. M. (2007). Home-based parental involvement in young children's education: Examining the effects of maternal education across US ethnic groups. *Educational Psychology*, *27*, 533-556.

Susperreguy, M. I., & Davis-Kean, P. E. (2016). Maternal math talk in the home and math skills in preschool children. *Early Education and Development*, *27*, 841-857.

Vandermaas-Peeler, M., Boomgarden, E., Finn, L., & Pittard, C. (2012). Parental support of numeracy during a cooking activity with four-year-olds. *International Journal of Early Years Education*, *20*, 78-93.

Vandermaas-Peeler, M., Ferretti, L., & Loving, S. (2012). Playing the ladybug game: Parent guidance of young children's numeracy activities. *Early Child Development and Care*, *182*, 1289-1307.

Vandermaas-Peeler, M., Massey, K., & Kendall, A. (2016). Parent guidance of young children's scientific and mathematical reasoning in a science museum. *Early Childhood Education Journal*, *44*, 217-224.

Verdine, B. N., Bunger, A., Athanasopoulou, A., Golinkoff, R. M., & Hirsh-Pasek, K. (2017). Shape up: An eye-tracking study of preschoolers' shape name processing and spatial development. *Developmental Psychology, 53*, 1869-1880. doi:10.1037/dev0000384

Verdine, B. N., Golinkoff, R. M., Hirsh-Pasek, K., & Newcombe, N. S. (2014). Finding the missing piece: Blocks, puzzles, and shapes fuel school readiness. *Trends in Neuroscience and Education*, *3*, 7-13. doi:10.1016/j.tine.2014.02.005

Verdine, B., Golinkoff, R. M., Hirsh-Pasek, K., & Newcombe, N. (2017). Links between spatial and mathematical skills across the preschool years. *Society for Research in Child Development Monograph*, *82*.

Votruba-Drzal, E., Levine Coley, R., & Lindsay Chase-Lansdale, P. (2004). Child care and low-income children's development: Direct and moderated effects. *Child development*, *75*, 296-312.

Weiland, C., & Yoshikawa, H. (2013). Impacts of a prekindergarten program on children's mathematics, language, literacy, executive function, and emotional skills. *Child Development*, *84*(6), 2112-2130.

Wolfgang, C., Stannard, L., & Jones, I. (2003). Advanced constructional play with LEGOs among preschoolers as a predictor of later school achievement in mathematics.
Early Child Development and Care, *173*, 467-475. doi:10.1080/03004430320000

Young, C., Cartmill, E., Levine, S., & Goldin-Meadow, S. (2014). Gesture and speech input are interlocking pieces: The development of children’s Jigsaw Puzzle Assembly ability. In *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 36, No. 36).

Zedah, Z. Y., Farnia, F., & Ungerleider, C. (2010). How home enrichment mediates the relationship between maternal education and children's achievement in reading and math. *Early Education and Development*, *21*(4), 568-594.

Appendices

Appendix H: Regression model for the association between maternal spatial support at age 2 and teacher ratings of math achievement in second grade (*n* = 692, Listwise)

Appendix I: Regression model for the association between maternal spatial support at age 2 on the **puzzle task** and teacher ratings of math achievement in second grade, **controlling for teacher rated social competence**

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Appendix A: Comparison of sample included and excluded

Children included in our study sample did not differ from children for whom we had no school id (*n* = 225) in predictors or outcome variables. There were no differences in term of spatial support in the puzzle (t = -.64, p > .05) or in the shape sorting task (t = -1.20, p > .05), nor for the outcome variables math screening test (t =-1.02, p > .05) or teacher-rated math achievement (t =.44, p > .05). Moreover, no differences were found in terms of child variables like gender (χ^2 = .006, p > .05), overall risk for delayed language development (t = 1.90, p > .05), western immigrant status (vs. Norwegian) (χ^2 = 1.70, p > .05). However, significant differences were found for maternal education (t =-4.63, p < .01), with lower levels of education among those excluded. Also, excluded mothers were younger than mothers retained in our sample (t =-4.82, p < .01), and more likely to be single (χ^2 = 7.45, p < .01) and to have higher levels of anxiety and depression (t = 2.95, p < .01). Moreover, excluded families were more likely to have non-western immigrant status (vs. Norwegian) (χ^2 = 4.79, p < .05) and mothers who provided less general cognitive stimulation (t = -2.84, p < .01).

Appendix B: Chi-square test differences between the full sample and the sample with Math test scores

	$\chi 2$	*d.f..*	*p*
West immigrant	2.20	1	0.14
Non-west immig.	9.10	1	.003
Single	13.79	1	.00
gender	1.09	1	.30
Cohort 1	6.70	1	.01
Cohort 2	1.15	1	.28

Table C: *t*-test differences between the full sample and the sample with math test scores

	t-value	*d..f..*	*p*
Support puzzle task	-1.08	901	.28
Shape sorting task	-1.44	899	.15
Maternal Ed	-5.69	1142	.00
Maternal age	-6.66	1148	.00
General cognitive stim	-3.43	906	.00
Verbal ability (age 2)	-1.45	1059	.15

Maternal depression	3.93	1046	.00
Exact at testing	-1.48	890	.14
Talk frequency	-1.63	906	.10

Appendix D: Correlation matrix for predictors, covariates, and outcomes.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Teacher rated math	1												
2. Math test screening[a]	.67	1											
3. SS on Puzzle task[b]	.07	.09	1										
4. SS on Shape-color sorting task[b]	.08	.05	.42	1									
5. Gender	.03	.14	-.05	-.06	1								
6. Verbal ability (age 2)	.17	.09	.15	.16	-.19	1							
7. Maternal ed.	.15	.24	.03	.10	-.02	-.06	1						
8. Maternal age	-.03	.03	.08	.10	.01	.04	.26	1					
9. Single mother	-.02	-.07	-.00	-.04	.01	.01	-.19	-.17	1				
10. West immigrant	.08	.05	-.04	-.02	-.06	-.02	.07	.04	.00	1			
11. Non-west immig.	.01	-.06	-.05	.00	-.02	-.02	-.02	.03	-.00	-.04	1		
12. Maternal depression	-.04	-.14	-.02	.02	-.00	-.04	-.14	-.15	.21	-.06	.04	1	
13. Talk frequency	.06	.06	.40	.31	.01	.04	.04	.12	.01	-.00	.00	.01	1
14. General cog. stim.	.03	-.02	.25	.28	-.07	.15	.11	.05	-.04	-.02	-.05	-.00	.24

Notes:SS: Spatial Support. [a]Correlations with latent variable. [b]Partial correlations conditioning on whether the child completed the task without support.

Appendix E: Regression model for the association between maternal spatial support at age 2 and the **math screening measure** in second grade (*n* = 932)

	Puzzle task				Shape-Color Sorting task			
	Model 1		Model 2 (interaction)		Model 1		Model 2 (interaction)	
	Coeff (SE)	*p*	Coeff (SE)	*p*	Coeff (SE)	*p*	Coeff (SE)	*p*
Spatial support (SS)	.08(.04)	**.03**	.09(.04)	**.02**	.03(.04)	.42	.03(.05)	.52
SS x Maternal ed.	-	-	-.03(.06)	.56	-	-	-.02(.07)	.83

Covariates								
Gender	.16(.05)	**.002**	.16(.05)	**.002**	.14(.05)	**.005**	.14(.04)	**.001**
Verbal ability (age 2)	.11(.04)	**.01**	.09(.04)	**.02**	.11(.04)	**.01**	.09(.04)	**.02**
Maternal ed.	.18(.06)	**.001**	.19(.05)	**.00**	.18(.06)	**.001**	.22(.06)	**.00**
Maternal age	.02(.06)	.73	.02(.06)	.72	.02(.06)	.75	-.02(.06)	.78
Single mother	-.002(.06)	.98	-.01(.06)	.94	.002(.06)	.98	-.005(.05)	.92
West immigrant	.03(.04)	.44	.03(.04)	.53	.04(.05)	.44	.04(.05)	.42
Non-west immig.	-.02(.05)	.74	-.01(.05)	.85	-.02(.04)	.70	-.02(.04)	.59
Maternal depression	-.10(.04)	**.02**	-.09(.04)	**.03**	.06(.05)	.20	-.10(.04)	**.01**
Talk frequency	.05(.05)	.30	.05(.05)	.33	.07(.05)	.18	.07(.05)	.16
General cog. stim.	-.11(.04)	**.01**	-.11(.04)	**.01**	-.10(.04)	**.02**	-.10(.05)	.05
Exact age at testing	.11(.04)	**.01**	.10(.04)	**.02**	.12(.04)	**.004**	.11(.04)	**.005**
Cohort 1	-.21(.08)	**.01**	-.19(.08)	**.02**	-.21(.08)	**.007**	-.18(.08)	.12
Cohort 2	-.12(.07)	.09	-.12(.07)	.09	-.12(.07)	**.08**	-.11(.07)	.12

Note.1 Results are based on standardized coefficients and adjusted for small age differences at test date (second grade). General cognitive stimulation was not a significant negative predictor until amount of maternal talk was also included as a control variable in the analysis, suggesting that this is a suppression effect due to two highly related covariate

Appendix F: Regression model for the association between maternal spatial support at age 2 and the **math screening measure** in second grade (*n* = 416, Listwise)

	Puzzle task				Shape-Color Sorting task			
	Model 1		Model 2 (interaction)		Model 1		Model 2 (interaction)	
	Coeff (SE)	*p*	Coeff (SE)	*p*	Coeff (SE)	*p*	Coeff (SE)	*p*
Spatial support (SS)	.11(.05)	**.03**	.12(.05)	**.02**	.03(.06)	.59	.03(.05)	.56
SS x Maternal ed.	-	-	-.03(.05)	.62	-	-	-.05(.07)	.49
Covariates								
Gender	.21(.05)	**.000**	.21(.05)	**.000**	.19(.04)	**.000**	.19(.04)	**.000**
Verbal ability (age 2)	.09(.06)	.15	.08(.06)	.20	.10(.06)	.11	.10(.06)	.10
Maternal ed.	.24(.07)	**.001**	.25(.08)	**.001**	.24(.07)	**.001**	.25(.07)	**.001**
Maternal age	-.05(.06)	.45	-.05(.06)	.44	-.05(.06)	.44	-.05(.06)	.44
Single mother	.04(.05)	.39	.04(.05)	.43	.04(.05)	.41	.04(.05)	.39
West immigrant	.06(.05)	.22	.06(.05)	.28	.07(.05)	.21	.07(.05)	.49
Non-west immig.	-.02(.04)	.65	-.01(.04)	.78	-.03(.04)	.47	-.03(.04)	.39
Maternal depression	-.09(.05)	.05	-.08(.05)	.09	-.09(.05)	.05	-.09(.05)	**.04**
Talk frequency	.01(.06)	.84	.009(.06)	.88	.05(.06)	.39	.05(.06)	.41
General cog. stim.	-.05(.05)	.33	-.05(.05)	.35	-.04(.06)	.43	-.04(.06)	.44

Exact age at testing	.12(.06)	.05	.11(.06)	.07	.12(.06)	**.03**	.12(.06)	**.03**
Cohort 1	-.10(.10)	.30	-.10(.10)	.33	-.10(.10)	.30	-.10(.10)	.31
Cohort 2	-.006(.07)	.93	-.01(.07)	.90	-.006(.08)	.94	-.004(.08)	.96

Note.1 Results are based on standardized coefficients and adjusted for small age differences at test date (second grade)

Appendix G: Regression model for the association between maternal spatial support at age 2 and **teacher ratings of math achievement** in second grade (n = 932)

	Puzzle task				Shape-Color Sorting Task			
	Model 1		Model 2 (interaction)		Model 1		Model 2 (interaction)	
	Coeff (SE)	*p*	Coeff (SE)	*p*	Coeff (SE)	*p*	Coeff (SE)	*p*
Spatial support (SS)	.05(04)	.20	.07(.04)	.06	.07(04)	.10	.07(04)	.10
SS x Maternal ed.	-	-	-.07(.04)	**.04**	-	-	-.01(.04)	.75
Covariates								
Gender	.07(.04)	.10	.07(.04)	.10	.07(.04)	.12	.07(.04)	.12
Verbal ability (age 2)	.15(.04)	**.00**	.14(.04)	**.00**	.15(.04)	**.00**	.15(.04)	**.00**
Maternal ed.	.17(.03)	**.00**	.17(.03)	**.00**	.17(.04)	**.00**	.17(.04)	**.00**
Maternal age	-.07(.03)	**.01**	-.07(.03)	**.01**	-.08(.03)	**.009**	-.08(.03)	**.009**
Single mother	-.04(.03)	.17	-.04 (.03)	.16	-.04(.03)	.17	-.04(.03)	.17
West immigrant	.08(.04)	.06	.08(.04)	.07	.08(.04)	.06	.08(.04)	.07
Non-west immig.	-.01(.04)	.73	-.004(.04)	.92	-.02(.04)	.62	-.02(.04)	.65
Maternal depression	-.03(.04)	.45	-.03(.04)	.43	-.04(.04)	.39	-.04(.04)	.39
Talk frequency	.06(.04)	.11	.06(.04)	.14	.06(.04)	.13	.06(.04)	.13
General cog. stim.	.006(.03)	.83	.003(.03)	.91	-.002(.03)	.96	-.002(.03)	.96
Exact age at testing	.16(.03)	**.00**	.16(.03)	**.00**	.17(.03)	**.00**	.17(.03)	**.00**
Cohort 1	-.11(.05)	.05	-.11(.05)	.05	-.10(.05)	.05	-.10(.05)	.06
Cohort 2	-.05(.06)	.36	-.05(.06)	.36	-.05(.06)	.35	-.05(.06)	.35

Note. Results are based on standardized coefficients and adjusted for small age differences at test date (second grade)

Appendix H: Regression model of the association between maternal spatial support at age 2 and **teacher ratings of math achievement** in second grade (n = 692, Listwise)

Puzzle task	Shape-Color Sorting Task

	Model 1		Model 2 (interaction)		Model 1		Model 2 (interaction)	
	Coeff (SE)	*p*	Coeff (SE)	*p*	Coeff (SE)	*p*	Coeff (SE)	*p*
Spatial support (SS)	.05(04)	.12	.08(.04)	**.04**	.07(04)	.09	.07(04)	.09
SS x Maternal ed.	-	-	-.06(.04)	.10	-	-	-.01(.03)	.77
Covariates								
Gender	.09(.04)	**.02**	.10(.04)	.02	.09(.04)	**.03**	.09(.04)	**.03**
Verbal ability (age 2)	.14(.05)	**.004**	.14(.05)	**.005**	.15(.05)	**.002**	.14(.04)	**.003**
Maternal ed.	.16(.04)	**.00**	.16(.04)	**.00**	.16(.04)	**.00**	.16(.04)	**.00**
Maternal age	-.07(.03)	**.02**	-.08(.03)	**.02**	-.08(.03)	**.02**	-.08(.03)	**.02**
Single mother	.004(.03)	.90	.004 (.03)	.91	.003(.03)	.93	-.003(.03)	.92
West immigrant	.09(.05)	.07	.08(.05)	.08	.09(.05)	.07	.08(.05)	.07
Non-west immig.	.03(.03)	.40	.03(.03)	.32	.02(.03)	.51	.02(.03)	.50
Maternal depression	-.02(.04)	.72	-.02(.04)	.69	-.02(.04)	.63	-.02(.04)	.63
Talk frequency	.04(.04)	.33	.04(.04)	.38	.04(.04)	.37	.04(.04)	.37
General cog. stim.	.008(.03)	.80	.005(.03)	.88	.003(.04)	.94	.003(.04)	.94
Exact age at testing	.14(.04)	**.00**	.14(.04)	**.00**	.15(.04)	**.00**	.15(.04)	**.00**
Cohort 1	-.10(.06)	.10	-.10(.06)	.09	-.10(.06)	.11	-.10(.06)	.11
Cohort 2	-.02(.06)	.71	-.02(.06)	.71	-.02(.06)	.73	-.02(.06)	.73

Note. Results are based on standardized coefficients and adjusted for small age differences at test date (second grade)

Appendix I: Regression model of the association between maternal spatial support at age 2 on **puzzle task** and teacher ratings of math achievement in second grade, **controlling for teacher rated social competence**

	Imputed data (*n* =930)		Listwise (*n* = 647)	
	Model 2 (interaction)		Model 2 (interaction)	
	Coeff (SE)	*p*	Coeff (SE)	*p*
Spatial support (SS)	.06(.04)	.08	.08(.04)	**.04**
SS x Maternal ed.	-.05(.03)	.13	-.05(.03)	.16
Covariates				
Gender	.14(.04)	**.00**	.18(.04)	**.00**
Verbal ability (age 2)	.12(.04)	**.001**	.12(.05)	**.02**
Maternal ed.	.13(.04)	**.00**	.12(.04)	**.00**
Maternal age	-.07(.03)	**.01**	-.07(.04)	.07
Single mother	-.01(.02)	.67	.02(.03)	.46
West immigrant	.06(.04)	.12	.06(.05)	.23
Non-west immig.	.009(.04)	.82	.05(.04)	.21
Maternal depression	-.03(.04)	.46	-.009(.04)	.81

Talk frequency	.04(.04)	.22	.02(.04)	.64
General cog. stim.	.02(.03)	.48	.04(.04)	.34
Exact age at testing	.14(.03)	**.00**	.13(.04)	**.001**
Cohort 1	-.09(.05)	.08	-.08(.06)	.18
Cohort 2	-.04(.05)	.38	.005(.05)	.92
Social competence	.29(.03)	**.00**	.29(.04)	**.00**

Note.1 Results are based on standardized coefficients and adjusted for small age differences at test date (second grade)