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Young girls' spatial and arithmetic performance: The mediating role of maternal supportive interactions during joint spatial problem solving☆

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ABSTRACT

The present study addresses girls' (6–7-year-olds; $N = 162$) early spatial and arithmetic skills within the context of learning environments provided by their mothers. The study was designed to determine the relationship between maternal supportive interactions on a joint origami spatial problem-solving task and their first grade daughters' spatial and arithmetic skills. During home visits the mothers and daughters were videotaped jointly solving origami tasks with maternal supportive interactions assessed through ratings of maternal stimulation of cognitive development and maternal quality of assistance; the girls were separately assessed in school on spatial and arithmetic skills. Using structural equation modeling, the main findings were (1) maternal supportive interactions on a mother–child origami task mediated the relation between mothers' spatial skills/educational level and their daughters' spatial skills and (2) their daughters' spatial skills in turn mediated the relation between quality of maternal supportive spatial interactions and the daughters' arithmetic achievement. The present findings indicate the importance of early maternal supportive interactions relating to spatial problem solving for girls' spatial and arithmetic achievement. Furthermore, all pathways linking girls' home environments and *arithmetic* skills were mediated through the girls' *spatial* skills, suggesting that for young girls, development of early spatial skills may be important for effective arithmetic learning.

Introduction

Understanding the development of girls' spatial skills is critical, due to extensive research showing that girls as a group are at a disadvantage compared to boys when solving the types of spatial problems that relate to mathematics performance (Linn & Petersen, 1985; Uttal et al., 2013; Voyer, Voyer, & Bryden, 1995). The present study on first grade girls is a follow-up of a prior study using a different sample of girls. In the first study, we found a significant pathway between maternal spatial skills and their daughters' spatial skills (Dearing et al., 2012). In the present study, we are interested in investigating potential home environment mediators linking mothers' and daughters' spatial skills.

In our prior data set (Dearing et al., 2012), we found that the association between the general home learning environment and young girls' spatial skills was *not* mediated by the amount of spatial activities experienced in the home. Being exposed to more spatial toys and games did not appear to be associated with girls' level of spatial skills. These findings suggest that girls need more than moderate amounts of exposure to spatial materials in order to acquire competitive spatial skills. One optimal condition for the development of young girls' spatial skills may be to provide some type of external support to develop these skills. One of the few studies examining the effect of the early home environment on spatial skills found that for girls (but not for boys), degree of parental support and parent spatial language at ages 2–3 were influential in predicting spatial performance at age 4½ (Levine, Ratliff, Huttenlocher, & Cannon, 2012). These findings suggest that for girls, it may take focused experiences through parental guidance (rather than simple exposure to spatial activities) in order to develop spatial skills.

One key research objective addressed in the present study was to determine whether maternal support during spatial skill-specific maternal–child interactions might mediate the association

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between mothers' and daughters' spatial skills. Although inherited factors may be involved in this relation, the present study is not designed to address this issue. Our hypothesis was that mothers with high spatial skills would provide spatial-specific environments for their daughters through maternal supportive interactions during joint spatial activities. These interactions may be one mediating factor linking maternal spatial skills with their daughters' skills. Consequently, this new research study was designed to investigate evidence for this mediating pathway through maternal supportive spatial interactions.

A related research objective in the present study was to determine whether maternal support during maternal–child spatial interactions mediates the relation between *maternal education* and their daughters' spatial skills. Maternal education has been studied extensively in relation to quality of mother–child interactions and children's cognitive behaviors. There is consistent evidence that education level is strongly related to mothers' cognitive support skills during joint problem solving (Neitzel & Stright, 2004; Richman, Miller, & LeVine, 1992). From their review of the literature and their own research, Neitzel and Stright conclude that educated parents may have more well-developed repertoires for providing cognitive support to their children as well as more training and practice in the use of a variety of strategies for solving problems.

Finally, the last research objective addressed in the study was to determine whether young girls' spatial skills provide a proximal link to their arithmetic skills, serving as a mediator with the more distal environmental factors in the home. Spatial skills involve the ability to think and reason through the comparison, manipulation, and transformation of mental pictures. In young children, spatial processing has been shown to predict early arithmetic achievement (Gunderson, Ramirez, Beilock, & Levine, 2012; Laski et al., 2012; LeFevre et al., 2010; Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014; Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014). We chose to study arithmetic in first grade at the start of elementary school as our measure of early mathematics because being underprepared at this age in arithmetic may have long-term consequences for children's life chances in terms of persistent underachievement, decreased odds of graduating from high school, and reduced earnings in adulthood (Duncan et al., 2007).

The rationale for studying the relation between spatial and arithmetic skills in girls

Gender differences in some types of spatial skills have been found to occur at an early age; children as young as 3–6 years of age show a male advantage on 2- and 3-dimensional mental rotation and mental transformation tasks (Casey, Andrews, et al., 2008; Casey, Erkut, Ceder, & Young, 2008; Levine, Huttenlocher, Taylor, & Langrock, 1999; Tzuriel & Egozi, 2010; Vasilyeva & Bowers, 2006). An early male advantage has also been found on spatial visualization tasks, mazes, part–whole relations puzzles, and map reading (Levine et al., 1999). In middle school, researchers have found that the association between spatial skill and mathematics performance is more robust in females than in males (Casey, Nuttall, & Pezaris, 1997; Fennema & Tartre, 1985; Friedman, 1995). A major longitudinal study of 400,000 students found that spatial skills in high school were predictive of choice of majors and careers in science, technology, engineering, and mathematics (STEM), above and beyond the effects of verbal and mathematics abilities (Wai, Lubinski, & Benbow, 2009). Further, these skills are related to employment in a range of STEM careers in which women are underrepresented. Thus, for girls in particular, it is important to understand the early factors that contribute to the development of their spatial skills. A goal of the present study was to identify within-gender proximal mechanisms that account for why some young girls perform better than others as a means for identifying future targets for early intervention.

Addressing the spatial/math association in young learners

A large number of studies have shown the key role of spatial skills for success in mathematics and science, and in a recent 2012 review in *Advances in Child Development and Behavior*, Mix and Cheng reported that the connection between space and math may be one of the most robust and well-established findings in cognitive psychology. However, these researchers (2012) also concluded that while this spatial-mathematics "relation is well established in older children and adults, its emergence in early development and subsequent developmental interactions are not well documented" (pp. 197–198).

Interestingly, some very recent evidence has emerged indicating that a spatial/arithmetic relationship is present in young learners. Several intervention studies have found that spatial interventions with block building, pattern blocks, mental rotations, and drawing shapes can improve early arithmetic accuracy (Cheng & Mix, 2014; Grissmer et al., 2013). Other studies found an association between 3-year-old's spatial skills on 2-D and 3-D spatial assembly tasks and their counting and number skills at both 3- and 4-years-of age (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014; Verdine, Irwin, et al., 2014; Verdine, Golinkoff, Hirsh-Pasek, Newcombe, Filipowicz, et al., 2014).

In recent reviews, both Mix and Cheng (2012) and Verdine, Golinkoff, Hirsh-Pasek, and Newcombe (2014) propose that spatial representations help in children's ability to develop mental models of number. In fact, Gunderson and associates (Gunderson et al., 2012) found that mental rotation and mental transformation skills predicted the quality of young children's number line representations as well as later arithmetic accuracy. Cheng and Mix (2014) conducted 2-D mental rotation training with first and second graders, and found that practice solving these spatial problems directly improved children's arithmetic accuracy. This success was largely due to their dramatic improvement on missing terms problems, such as 4 + __ = 12. Cheng and Mix (2014) concluded that the mental rotation problems improved the cognitive processes needed to mentally manipulate these symbols into a more conventional spatial format. Thus, there are a variety of ways that effective spatial skills may benefit children's ability to understand the spatial layout of numerical and counting problems and to accurately solve arithmetic problems.

In our prior research, the relation between home factors and girls' spatial skills (block design and mental rotation) formed a separate pathway from the relation between home factors and girls' arithmetic skills (Dearing et al., 2012). In this prior data set, spatial skills did show a small, but significant correlation with arithmetic skills (Dearing et al., 2012). Moreover, with this sample of girls, spatial skills were found to be strongly associated with girls' use of higher-level mental arithmetic strategies (Laski et al., 2012). Higher-level mental arithmetic strategies included use of retrieval and decomposition rather than concrete strategies such as counting on fingers or counters. One purpose of the present study is (1) to further investigate the relation between spatial skills and arithmetic in young girls and (2) to understand better the factors in the home environment contributing to this relationship through more closely examining maternal–child spatial interactions.

Literature on the effects of maternal supportive interactions during children's problem solving

In order to understand the development of spatial skills, it is important to consider it within the context of the home