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Contributions of executive function and spatial skills to preschool mathematics achievement

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ABSTRACT

Early mathematics achievement is highly predictive of later mathematics performance. Here we investigated the influence of executive function (EF) and spatial skills, two generalizable skills often overlooked in mathematics curricula, on mathematics performance in preschoolers. Children ($N = 44$) of varying socioeconomic status (SES) levels were assessed at 3 years of age on a new assessment of spatial skill (Test of Spatial Assembly, TOSA) and a vocabulary measure (Peabody Picture Vocabulary Test, PPVT). The same children were tested at 4 years of age on the Beery Test of Visual–Motor Integration (VMI) as well as on measures of EF and mathematics. The TOSA was created specifically as an assessment for 3-year-olds, allowing the investigation of links among spatial, EF, and mathematical skills earlier than previously possible. Results of a hierarchical regression indicate that EF and spatial skills predict 70% of the variance in mathematics performance without an explicit math test, EF is an important predictor of math performance as prior research suggested, and spatial skills uniquely predict 27% of the variance in mathematics skills. Additional research is needed to understand whether EF is truly malleable and whether EF and spatial skills may be leveraged to support early mathematics skills, especially for lower SES children who are already falling behind in these skill areas by 3 and 4 years of age.

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These findings indicate that both skills are part of an important foundation for mathematics performance and may represent pathways for improving school readiness for mathematics.

Introduction

Early mathematics achievement is highly predictive of later mathematics skill (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Duncan et al., 2007; Jordan, Glutting, & Ramineni, 2010; Morgan, Farkas, & Wu, 2009). However, with a few notable exceptions (Clements & Sarama, 2011; Gunderson, Ramirez, Beilock, & Levine, 2012; Wai, Lubinski, & Benbow, 2009; Webb, Lubinski, & Benbow, 2007), previous investigations of early mathematics skill focused solely on number recognition, cardinality, counting, and number magnitude. Likewise, many mathematics curricula for preschoolers focus exclusively on building these skills. Although they are important (e.g., Jordan, Kaplan, Ramineni, & Locuniak, 2009), a growing body of research demonstrates that other abilities not traditionally viewed as "mathematics skills," such as spatial skills (Grissmer et al., 2013; Gunderson et al., 2012; Verdine et al., 2014) and executive function (EF) skills (Blair & Razza, 2007; Clark, Pritchard, & Woodward, 2010; Espy et al., 2004; Geary, 2005; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Geary, Hoard, Nugent, & Byrd-Craven, 2008; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; Monette, Bigras, & Guay, 2011), make significant contributions to young learners' overall mathematics performance. Just how these skills together are related to mathematical achievement is not entirely clear, especially the extent to which spatial skills influence mathematics performance once one takes into account that some EF skills are required to successfully complete most mathematics and spatial tests. Here we focused on evaluating the contribution that EF and spatial skills make to the prediction of mathematics skill in preschoolers of diverse social classes.

EF and mathematics

Executive function refers to higher order cognitive abilities used in planning, information processing, and problem solving for goal-directed behaviors in novel or challenging settings (Beck, Schaefer, Pang, & Carlson, 2011; Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Blair, 2010). Components of EF that may be important in mathematics include set shifting, inhibition, cognitive flexibility, working memory, planning, and updating (Blair & Razza, 2007; Herbers et al., 2011; Miyake, 2000). Rather than enter the theoretical debate about which specific skills constitute EF and can be isolated from one another, here we opted to assess two areas of EF with established histories. Although not a complete list of EF skills, these generally agreed-on components of EF—inhibition and cognitive flexibility—would appear to have applications in the mathematical domain.

Children from low-SES (socioeconomic status) backgrounds often perform below their middle-income peers on measures of EF (Blair, 2010), and the relationship between EF and early mathematics performance appears to be influenced, at least in part, by experiential factors associated with SES (Aunola et al., 2004; Diamond, 2011; Riggs, Jahromi, Razza, Dillworth-Bart, & Mueller, 2006). Some research suggests that these skills can be improved with targeted intervention (Barnett et al., 2008; Bierman et al., 2008; Diamond, Barnett, Thomas, & Munro, 2007) and adaptive training (Holmes, Gathercole, & Dunning, 2009), but positive effects are not always found (e.g., Farran, Wilson, Lipsey, & Turner, 2012) and the extent to which effects last or generalize beyond the trained stimuli is hotly debated (Egeland, Aarlien, & Saunes, 2013; Melby-Lervåg & Hulme, 2013). Regardless of the ability to train EF, however, there is little debate over whether these skills are generally useful in academic settings or for mathematics. Regardless, EF skills are only part of a broader skill set that affects mathematics achievement.