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Using block play to enhance preschool children's mathematics and executive functioning: A randomized controlled trial

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ABSTRACT

The current study investigated the extent to which a semi-structured block play intervention supported growth in mathematics and executive functioning for preschool children using a randomized controlled design. A secondary aim was to explore whether differential intervention effects emerged for children from various socioeconomic backgrounds, indicated by parental education level. Participants included 59 preschool children. Children ranged in age from 38 to 69 months ($M = 55.20$, $SD = 7.17$), and 56% were female. Results from regression models indicated that, although not statistically significant, children who participated in the intervention demonstrated greater gains in three mathematics skills (numeracy, shape recognition, and mathematical language) and two indicators of executive functioning (cognitive flexibility and a measure of global executive functioning) compared to children in a control group. Further, three significant interactions were found, suggesting that for numeracy, cognitive flexibility, and global executive functioning, children of parents with low educational attainment benefited the most from intervention participation. These findings provide preliminary evidence for the effectiveness of a semi-structured block play intervention for improving children's school readiness and have implications for including intentional instruction using blocks in preschool classrooms.

1. Introduction

Promoting children's readiness for kindergarten is a common and important goal of preschool. Engaging children in intentional and interactive play that capitalizes on existing materials in the classroom may be one way to develop two important school readiness skills: executive functioning and mathematics. Importantly, play has been identified as a core mechanism through which young children develop and learn (Kozulin, 2003; Vygotsky, 1986; Yelland, 2011). Block building, a form of construction play, is a common activity in early childhood classrooms (Hirsch, 1974; Yelland, 2011). In fact, many early childhood education classrooms include a dedicated space, or learning center, specifically for block play; likely the result of recommendations from the National Association for the Education of Young Children (NAEYC; Kersh, Casey, & Young, 2008; NAEYC, 2002). A growing body of correlational evidence has linked block play to mathematics, literacy, and spatial skills (Snow, Eslami, & Park, 2015; Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014; Wolfgang, Stannard, & Jones, 2001); however, no research to date has explored whether block play may be related to executive functioning (EF). Although some experimental work suggests that engaging in block play in preschool is related to gains in spatial skills (Casey et al., 2008), no previous research has explored a causal relation between block play and mathematics and EF.

As mathematics and EF skills are highly related during the preschool years (Allan, Hume, Allan, Farrington, & Lonigan, 2014; McClelland et al., 2007; Purpura, Schmitt, & Ganley, 2017), broadly malleable through intervention (Clements & Sarama, 2011; Diamond & Lee, 2011), and may specifically be promoted through block play activities, the central goal in this study was to evaluate the effects of a semi-structured block play intervention on preschool children's early mathematics and EF skills. A secondary goal was to explore whether differential intervention effects emerged for children from various socioeconomic backgrounds, as indicated by parental education level.

2. Block play as a context for learning

Block play in preschool provides a context where children can learn various skills (e.g., problem solving, perspective taking) through their interactions with both blocks and peers (Ginsburg, 2006). Engaging with blocks provides children with opportunities to reason and understand concepts of space and physical properties of objects (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe,

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2017). Further, block play is social, verbal, and facilitates shared play, thereby giving children an opportunity to exchange ideas with peers and work together. Research has shown that children engage in complex language interactions with their peers in classroom block play settings (Sluss & Stremmel, 2004). To date, most of the research on block play focuses on its relation to spatial skills (e.g., Casey et al., 2008), likely because building with blocks involves both spatial visualization and mental rotation skills. However, block play may also provide a context for children to learn mathematics and EF. It is possible that as children are gaining spatial awareness through block play (Casey et al., 2008), they are also practicing and sharpening mathematics skills and EF, particularly when manipulating the blocks and interacting with peers. Indeed, evidence suggests that participating in spatial learning interventions is predictive of young children's mathematics skills (Hawes, Moss, Caswell, Naqvi, & McKinnon, 2017).

3. Early mathematics and executive functioning in preschool

3.1. Mathematics

Children who enter school with strong mathematics skills have a greater likelihood of success in mathematics in kindergarten and in later grades (Byrnes & Wasik, 2009; Duncan et al., 2007). Further, strong early mathematics skills are related to positive outcomes in adulthood, such as socioeconomic success and higher levels of education (Ritchie & Bates, 2013). Specific mathematics skills that are particularly important for children's later mathematics achievement are numeracy-related and geometry skills (Nguyen et al., 2016). Numeracy includes counting, comparison, and operations (Purpura & Lonigan, 2013), and geometry includes shape recognition and knowledge of composition and decomposition of shapes and their structure (Sarama & Clements, 2009). Mathematical language, which consists of quantitative and spatial words related to early mathematics skills (e.g., many, few, near, far), also appears to be an important factor in the development of early mathematics skills (Purpura, Napoli, Wehrspann, & Gold, 2017).

3.2. Executive functioning

EF is defined as goal-oriented behaviors used to control automatic thoughts and responses (Miyake et al., 2000). EF has three components: working memory, inhibitory control, and cognitive flexibility (Garon, Bryson, & Smith, 2008) and can be thought of as a global skill that includes the integration of these components (McClelland & Cameron, 2012). Working memory is the ability to hold and manipulate information in mind, inhibitory control is the capacity to override a dominant behavior in favor of a more adaptive one, and cognitive flexibility is the ability to shift attention and focus on changing goals or stimuli (Baddeley, Logie, Bressi, Sala, & Spinnler, 1986; Bull & Scerif, 2001; Garon et al., 2008). Between the ages of 3 and 5, there are dramatic structural changes in the prefrontal cortex that contribute to EF development (Clohessy, Posner, & Rothbart, 2001; Garon et al., 2008). As such, many consider the preschool stage a sensitive period for the development of EF. Early EF predicts a number of important child and adult outcomes, including academic achievement and overall well-being (Duckworth & Carlson, 2013; McClelland et al., 2007; McClelland, Acock, Piccinin, Rhea, & Stallings, 2014; Miller & Hinshaw, 2010; Moffitt et al., 2011; Wrosch, Miller, Schulz, & Carver, 2003). The association between EF and mathematics is particularly robust (Blair & Raver, 2014), and recent research suggests this relation is bidirectional (Fuhs & McNeill, 2013; Schmitt, Geldhof, Purpura, Duncan, & McClelland, 2017).

3.3. Block play as an opportunity to enhance mathematics and EF

NAEYC and the National Council of Teachers of Mathematics emphasize the importance of shared play as an opportunity for children to exchange ideas, and these groups recognize that block play in particular is a valuable way for children to engage in shared mathematical learning (NAEYC, 2002). In early childhood, block play is thought to provide children with opportunities to engage in many mathematical activities, such as counting, sorting, measuring, and classifying (Wolfgang et al., 2001; Yelland, 2011), all of which are important for learning mathematical concepts, including numerical skills and geometry. Correlational research suggests that complexity of block play is related to early mathematics skills (Trawick-Smith et al., 2016) and that early block play performance is associated with later standardized mathematics scores (Wolfgang et al., 2001). Further, young children's ability to complete a task of assembling interlocking blocks is predictive of their short- and long-term mathematics performance (Pirrone & Di Nuovo, 2014; Verdine et al., 2014; Wolfgang, Stannard, & Jones, 2003).

In addition to associations between block play and skills like numeracy and geometry, block play may also support children's mathematical language skills. Compared to other types of play, engaging with blocks tends to promote more complex language in early childhood classrooms (O'Brien & Bi, 1995). Ramani et al. (2014) observed that children playing with blocks in dyads talk about math-related ideas (e.g., numbers and spatial relations). Given the causal relation between mathematical language and numeracy (Purpura et al., 2017), block play may improve children's mathematical skills by providing a context for engaging in conversations that are rich in mathematical language and enhance hands-on engagement with numeracy concepts. For example, children may make comparisons (e.g., "Your tower has more blocks than mine."), perform simple number combinations (e.g., "Let's add three more to make it taller."), and discuss concepts of geometry (e.g., "Line the triangles up with the squares to make the roof.").

Block play in preschool may also facilitate the development of EF skills. Block play provides a context for planning, problem solving, and negotiating with peers (Yelland, 2011), which are important components of EF (Miyake et al., 2000). For example, when two children are engaging in collaborative block play, they must plan the structure (e.g., "Let's build a house."), negotiate the rules (e.g., "How about I build the garage and you build the bedroom?"), and problem solve in the face of challenges (e.g., "The long block is too big for the garage. Let's try the short one."). Thus, children may practice their EF skills during block play activities by paying attention to their peers and the materials they are playing with, remembering plans, inhibiting impulses to knock a structure down or give up, and adapting to new plans and goals. Block play is also thought to provide children with opportunities to practice mental representations of objects and products (Wolfgang et al., 2001) that lay the foundation for cognitive development (Kamii, 1972; Piaget, 1962). As children practice these mental representations, they learn to substitute and combine these representations internally which may support the development of EF because it promotes children's ability to direct their own activity and sustain attention (Case et al., 1996; Christakis, Zimmerman, & Garrison, 2007; Hoffman & Russ, 2012).

4. Prior intervention work

Given robust associations between early mathematics and EF, scholars are beginning to develop interventions that seek to promote both domains simultaneously. Although some interventions have been effective in supporting growth in one of these con-