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Preschoolers' strategies for solving visual pattern tasks

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ABSTRACT

This study examined preschoolers' ($N = 66$) strategies for solving a range of visual repeating pattern tasks. An analysis of the kinds of patterning tasks preschoolers encounter, such as duplicating, extending, and transferring patterns to superficially different materials, suggested the tasks could be solved using either a one-to-one appearance matching strategy or a relational similarity strategy. In the present study, preschoolers completed a series of patterning tasks and their strategies were examined by analyzing (1) accuracy, (2) errors, and (3) the relation of visuospatial short-term memory, working memory, and inhibitory control to accuracy and errors. The pattern of results indicated that preschoolers do use both kinds of strategies, but that the frequency with which they use each strategy depends on task complexity. Preschoolers tended to use an appearance matching strategy on duplicate and extend tasks and a relational similarity strategy on transfer tasks. Implications for understanding what patterning instruction is most likely to support relational reasoning are discussed.

Preschoolers' strategies for solving visual pattern tasks

Early experience with patterns is believed to be important for later algebraic reasoning because it provides opportunities for engaging in relational thinking, such as thinking about how elements within a particular problem relate to each other (Fuchs et al., 2012; Lee, Ng, Bull, Pe, & Ho, 2011; Mason, 1996; Mulligan & Mitchelmore, 2009; Orton & Orton, 1999; Warren & Cooper, 2006; Whitin & Whitin, 2011). Indeed, some recent studies have found that elementary school children's ability to solve patterning tasks is positively related to their performance on arithmetic word problems that involve algebraic concepts, such as the concept of equality and variable identification (Fuchs et al., 2012; Lee et al., 2011). Further, these links remain after controlling for a range of domain-general cognitive abilities. Fuchs and colleagues found nonverbal problem solving, including patterning abilities, to be uniquely predictive of arithmetic word problem skills in both first grade and third grade, even after controlling for processing speed, working memory, and language abilities (Fuchs et al., 2005, 2006, 2012).

Despite increasing evidence of a link between early pattern knowledge and later mathematics performance, little is known about the strategies children use to solve basic patterning tasks or the cognitive processes involved. A better understanding of these two aspects could help clarify which patterning tasks are most likely to benefit later mathematics performance and *why*. In the present study, we propose that early patterning tasks vary in the cognitive processes and strategies they require. More specifically, we propose that repeating patterning tasks can be solved using either a one-to-one appearance matching or relational similarity strategy and that only tasks that involve mental representation and manipulation of the repeating unit are likely to elicit use of a relational similarity strategy, which, in turn, might lead to better relational reasoning and support later mathematics learning.

Preschoolers' pattern knowledge

Patterns are sequences with a replicable regularity that can vary along a number of dimensions (Papic, Mulligan, & Mitchelmore, 2011; Warren & Cooper, 2006). Patterns can vary in their *structure*, such as whether they have a repeating unit (e.g., 1, 2 – 1, 2, with a unit of "1, 2"), a repeating rule (e.g., 1, 3, 5, 7, which has the rule of "+2"), or a growing relationship (e.g., 1, 2, 4, 7, in which each successive difference grows by 1). They also can vary in the *content* of the regularity, such as whether they consist of numbers (e.g., 1, 3, 9, 27), shapes, or colors. Finally, patterns can vary in the *complexity* of the regularity, ranging from simple regularities (e.g., AB-AB; 1, 3, 5, 7) to more complex ones, such as with more complicated units (e.g., ABCABB-ABCABB).

Repeating patterns comprised of visual content (e.g., colors/shapes) are a natural entry point for learning about patterns

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because they do not require any additional knowledge, such as skip counting or arithmetic operations, involved in later numerical patterns. By preschool, children are able to identify, create, and explain a variety of visual repeating patterns (Papic, 2007; Papic & Mulligan, 2007; Papic et al., 2011). For example, Rittle-Johnson, McLean, McEldoon, and Fyfe (2013) found the majority of the preschoolers they tested were able to duplicate a visual repeating pattern, even with a complex repeating unit (AABB). This facility with patterning extends beyond instructional interactions. Observational studies of preschool classrooms indicate that children spontaneously engage in pattern identification and pattern making using classroom materials (Fox, 2005; Ginsburg, Inoue, & Seo, 1999; Waters, 2004).

Preschoolers are not equally successful, however, on all tasks involving visual repeating patterns (Papic et al., 2011; Rittle-Johnson et al., 2013). Prior research has found that a majority of children (75%) between the ages of 3 and 5 years accurately complete pattern duplication tasks (i.e., reproduce a pattern using the same materials) and about half accurately complete pattern extension tasks (i.e., continue a pattern). On the other hand, fewer than a third of preschool-aged children accurately complete tasks that require them to isolate a repeating unit (i.e., produce one instance of the repeating unit) or transfer the pattern (i.e., create the same pattern using superficially different materials; Rittle-Johnson et al., 2013). This progression suggests that an analysis of the cognitive demands of different patterning tasks as well as the approaches children may use on them could provide information about how best to support preschoolers' emerging patterning knowledge.

Strategies for solving visual repeating pattern tasks

It has been posited that early patterning tasks lay a foundation for later algebraic reasoning because they provide opportunities for children to practice relational thinking and rule deduction (Charles, 2005; Fuchs et al., 2012; Lee et al., 2011; Mason, 1996; Mulligan & Mitchelmore, 2009; Orton & Orton, 1999; Warren & Cooper, 2006; Whitin & Whitin, 2011). Relational thinking is broadly defined as the process of making comparisons and recognizing similarities and differences to discern meaningful structure and patterns underlying information (Dumas, Alexander, & Grossnickle, 2013). It has been posited to be important for mathematics in a number of ways, including understanding the equal sign (McNeil & Alibali, 2005), arithmetic concepts such as commutativity (Farrington-Flint, Canobi, Wood, & Faulkner, 2007), and algebraic problem solving (English & Sharry, 1996). In the early learning context of visual repeating patterns, thinking about relational similarities would include considering how individual pattern components combine to create units (i.e., understanding that in an AB-AB pattern, A and B, together, comprise the unit), how two units within a pattern possess the same underlying structure (i.e., that an AB-AB pattern consists of instances of identical "AB" units), and how the same unit can be represented using superficially different materials (i.e., "circle, square – circle, square" and "blue, red – blue, red" are both AB-AB patterns). While the value of early patterning activities is believed to lie in their promotion of relational thinking, however, it remains to be tested whether the kinds of patterning tasks children are exposed to in early childhood actually lead them to focus on relational similarities.

An analysis of the kinds of patterning tasks preschoolers encounter suggests that while the tasks could be solved using relational strategies as described above, the majority also can be solved successfully, and perhaps more easily, using a one-to-one appearance matching strategy, or matching superficial features without considering underlying structure. Patterning tasks vary in the extent to which they require mental representation and manipulation of the repeating unit. As illustrated in Fig. 1, some patterning tasks ask children to duplicate or extend a pattern, while others ask children to isolate and transfer the underlying structure of a pattern to new materials (Rittle-Johnson et al., 2013; Warren & Cooper, 2007). Duplication and extension tasks may be less difficult for preschool children because they can be completed using appearance matching. For example, a child could duplicate a pattern by matching the color or shape of each item in the pattern, one at a time. On the other hand, unit isolation and transfer tasks may be more difficult because they require children to use relational similarity strategies to mentally represent, abstract, and manipulate the unit of repeat (Rittle-Johnson et al., 2013; Warren & Cooper, 2006).

Children often possess multiple strategies for solving problems and select among them based on task demands as well as their proficiency in executing the strategies available to them (Chen & Siegler, 2000; Siegler, 1996). In the case of visual repeating pattern tasks, we hypothesize that preschoolers are likely to use a one-to-one appearance matching strategy, unless the task complexity requires a relational similarity strategy for accuracy. Even as toddlers, children are able to engage in one-to-one reasoning and superficial appearance matching (Gelman & Meck, 1983; Izard, Streri, & Spelke, 2014; Mix, 2002; Sophian, 1988). On the other hand, reasoning based on relational similarity, particularly when the relations are unknown, develops later between the ages of 3 and 5 years (Gentner, 1989; Goswami, 1991, 2013; Rattermann & Gentner, 1998; Singer-Freeman, 2005). Because children are more capable of one-to-one appearance matching and it can yield a high accuracy on many patterning tasks, it seems likely that this would be preschoolers' predominant approach to solving patterning tasks.

Research on children's relational reasoning provides support for the hypothesis that children may tend to use an appearance matching strategy on patterning tasks. When presented with the opportunity to use either appearance matching or relational similarity, even 5-year-olds are more likely to use appearance matching (Gentner & Rattermann, 1991; Paik & Mix, 2008). Gentner and Rattermann (1991), for example, found that in a task in which children could search for a sticker under objects based on relational similarity (same relative size as in the example search task) or appearance matching (same object type as in the example task), three- and four-year-olds consistently searched based on appearance matching. Further, children over-rely on surface features even when they are irrelevant for solving the task (Kotovsky & Gentner, 1996). For example, children have greater difficulty comparing set sizes when two sets are comprised of dissimilar objects or when objects within sets are heterogeneous than when both sets are homogenous and contain similar objects (Mix, 2008). Thus, unless patterning tasks are carefully structured so that a relational similarity strategy is required or more likely to lead to an accurate response, children may not use it. Only patterning tasks that require children to isolate and transfer the repeating unit, such as asking children to make the "same pattern" using superficially different materials (another color, shape, or both), may push children to attempt a relational similarity strategy. Further, because children are being forced to use a strategy with which they are less accustomed, we would expect lower accuracy on these types of tasks.

Memory and inhibition in solving patterning tasks

Given our analysis of the kinds of strategies that could be used on early patterning tasks, we propose that memory and inhibition are involved and that exploring the involvement of these processes could provide insight into children's strategy choice. Some earlier work has implicated verbal working memory in children's performance on patterning tasks (Holzman, Pellegrino, & Glaser, 1983; Rittle-Johnson et al., 2013). For example, Rittle-Johnson et al. (2013) found verbal working memory was related to ability estimates of four-year-olds' patterning performance on a patterning