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The Role of Cognitive Flexibility in Pattern Understanding

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Abstract

The ability to discover a regularity among an ordered set of units, termed patterning, is a crucial cognitive ability that precedes pre-algebraic mathematics skills and possibly reading. However, there is limited research on the cognitive underpinnings of patterning. There is some suggestion that there is a relation between cognitive flexibility, which is the ability to switch attention between two aspects of a stimulus, and patterning. However, no research has focused on this relation in children during early school years, which is when these skills are developing. The current study examined the relation between patterning, cognitive flexibility, and reading in first-grade children in the expectation that they would be related. Performance on the patterning and the card sorting cognitive flexibility measures were significantly related. However, reading and cognitive flexibility were not significantly related. This study is one of the first to show that cognitive flexibility may be an important underlying component of patterning ability.

Keywords: cognitive flexibility, patterning, executive function, reading, cognitive development

1. Introduction

Patterning, defined as the ability to discover a regularity among an ordered set of units, has been regularly taught within elementary school mathematics curricula for many years (Clements & Sarama, 2007a). Patterns that are taught include alternations in colors, letters, or numbers or increasing numbers, such as by two's or five's. Patterning ability has been deemed to be an important underlying cognitive process for pre-algebraic thinking (Papic & Mulligan, 2005).

Both the National Council of Teachers of Mathematics (National Council of Teachers of Mathematics, 2006) and the joint position statement of the National Association for Education of Young Children and the National Council of Teachers of Mathematics (2002/2010) posited that understanding patterns ensures that children are prepared for mathematical reasoning. This understanding includes learning about new properties of numbers inherent in patterning learning and the knowledge that there are rules that describe relationships between numbers. Patterning also advances the ability to count, understanding multiplicative concepts, and data exploration (Papic, 2007). There has also been evidence that patterning may be a precursor for reading skills although the process is not as clear (Kidd et al., 2014).

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Research on teaching patterning outside of the classroom has shown that there are substantial benefits to learning more complicated types of patterns (i.e., increasing, decreasing, symmetrical, etc.) with different types of stimuli (i.e., letters, number, clocks, and objects; Kidd et al.,2013; 2014). The children who were taught these patterning skills performed as well or significantly better on later measures of patterning, reading, and mathematics thanchildren who had state of the art instruction on reading or respectively. Therefore, patterning seems to be an important cognitive skill for children in learning mathematics and reading.

It has been theorized that patterning is a general cognitive ability that requires generalization skills as well as an abstract level of reasoning about the stimuli provided in the pattern (Clements & Sarama, 2007b). Children must be able to detect and generalize the apparent rule amongst the units. For example, children must determine that the set of numbers increase by fours in a pattern of numbers including: 3, 7, 11, 15, ?. Children must then use their abstraction skills to determine which item comes next in the sequence. Although patterning has been shown to be a crucial cognitive skill that will help with children's learning, there has been limited research examining the underlying cognitive components that may influence patterning.

It has been suggested that patterning requires covariational thinking, which is the general ability to detect relationships between two things (Warren & Cooper, 2006). When examining a pattern, children must use covariational thinking when making comparisons across the units within the pattern.

For example, children must examine each individual sets of units that precede and follow the units in order to determine the relationship. However, with more complex patterns, such as when the missing unit is in the middle of the pattern, children must use additional cognitive skills beyond simply detecting the co-varying relationships between the units. Children may also require the ability to shift thinking to different aspects of the pattern when attempting to solve the missing piece within it. For example, children must consider both the overall pattern and the individual locations of each of the units within the pattern and ultimately shift their thinking amongst these two aspects. This ability to shift one's thinking between two components of a set of stimuli is termed cognitive flexibility (Anderson, 2002).

There has been considerable research on the topic of cognitive flexibility. Cognitive flexibility has been identified as a component of executive functioning (EF), which is a set of abilities that aid in engaging in goal-directed behavior (Huizanga & van der Molen, 2007). The general cognitive ability of being flexible or switching one's thinking develops around the age of four or five years old. However, more complex cognitive flexibility, such as the ability to repeatedly switch one's thinking during a task or the ability to simultaneously consider multiple rules or dimensions of a task, develops later in childhood (Anderson, 2002; Cartwright, 2012; Cole, Duncan, & Blaye, 2014). Many types of measures have been used to assess cognitive flexibility, including simple card sorting tasks, categorizing of objects, and computerized puzzle tasks, all of which require shifting one's thinking between dimensions of the tasks (Cartwright, 2002; 2012; Smidts, Jacobs, & Anderson, 2004).However, there has been little or no research to test whether the measures are assessing similar constructs.

Similar to patterning, cognitive flexibility is also highly linked to mathematics and reading achievement (Cartwright, 2002; Mayes, Calhoun, Bixler, & Zimmerman, 2009). Cognitive flexibility is especially important for reading such that children must repeatedly switch between the sound and meaning of words while they are reading texts (Cartwright, 2002). There is less evidence of a relation between cognitive flexibility and mathematics. However, Mayes et al., 2009 did find that cognitive flexibility significantly predicted mathematics performance better than other executive function measures. Therefore, cognitive flexibility also seems to be an important cognitive skill for learning how to read and complete math problems.

Although there has been much research on cognitive flexibility, few researchers have directly studied cognitive flexibility in relation to patterning ability. However, there are suggestions that patterning and cognitive flexibility are related. Hongwanishkul, Happaney, Lee, and Zelazo (2005) found that in preschoolers, a card sorting measure of cognitive flexibility was highly significantly related to a patterning measure within the Stanford-Binet Intelligence Scale. Another study showed that preschoolers' cognitive flexibility predicted knowledge of simple, repeating patterns (Miller, Rittle-Johnson, Loehr, & Fyfe, in press). Duan, Wei, Wang, and Shi (2010) showed that for children aged 11 and 12, a measure of cognitive flexibility was significantly related to the Raven's Progressive Matrices Test, which is a measure of pattern understanding. Therefore, cognitive flexibility and patterning seem to be related. However, no one has assessed these two constructs directly with complex patterns and cognitive flexibility measures for early elementary school children. The main goal of the present study was to examine the relation between patterning, cognitive flexibility, and the reading ability of such children. It was expected that patterning would be related to cognitive flexibility. Further, it was expected that both patterning and cognitive flexibility would be related to reading ability.

2. Method

2.1. Participants

Eight children from eleven first-grade classrooms in two public elementary schools in an urban Mid-Atlantic area were given permission to participate. The children were rated by their teachers as about average in academic ability and were not considered to have English as a second language nor have an Individual Education Plan (IEP). Eleven of the 88 children only completed three of the four assessments due to computer error during the puzzle cognitive flexibility task; however, their data were analyzed for the measures they did complete.

2.2. Measures

There was one assessment of reading ability, the Test of Early Reading Ability-3 (TERA), one assessment of patterning ability, and two assessments of cognitive flexibility –the Multiple Classification Card Sorting Task (MCCST) and the Cognitive Flexibility Puzzle Task (CFPT).

2.2.1. TERA

The reading measure focused on assessing children's early reading abilities, such as knowledge of conventions, alphabet, and meanings of passages. Children were shown pictures and/or passages with increasing difficulty and asked to label or explain what was presented. There were a total of 30 questions. Ceiling performance was reached after three consecutive wrong answers. The total number of correct responses were totaled and used in the analysis. The TERA has been shown to have high reliabilities, which range from .83 to .95 (Reid, Hresko, & Hammill, 2001). Additionally, the measure has shown strong concurrent validity by correlating with teacher ratings, the WRMT-NU/R, and SAT-9 ranging from .40 to .66.

2.2.2. Patterning Measure

The patterning measure focused on assessing children's ability to detect a pattern and select the next object within the pattern sequence. The patterns included shapes, numbers, and letters that either increased or decreased in size, value or position of the alphabet. The placement of the missing object within the sequence varied amongst the patterns; it was either first, middle, or last equally often. All patterns were presented horizontally and children were asked to choose from four possible options shown below the pattern sequence. There were a total of 18 patterns. The total number of correct responses were used in the analysis.

2.2.3. MCCST

The first cognitive flexibility measure was a card sorting task in which the children were asked to put cards into four piles based on two dimensions simultaneously: the color and type of object on the card (e.g., sorting by yellow and brown objects and also by tools and instruments) similar to the procedure by Cartwright (2002). There was a set of 12 training cards to familiarize the child with the task. For the test itself, there were four sets of 12 cards, which were presented to the children in a randomly selected order. Following each testing set, children were scored on whether they sorted the cards into the four piles correctly. Sorting time was also recorded with a stopwatch. The children were also subsequently asked to explain why they sorted the cards the way they did. If the sort was incorrect, the piles were corrected and the children were asked why the cards might be sorted the correct way. For each sort, a child received a score between 0 and 3 for level of sorting and a score between 0 and 2 for correction justification.

2.2.4. CFPT

The second cognitive flexibility measure was a computer-based puzzle task presented in Adobe® Flash® similar to Gonzalez, Figueroa, Bellows, Rhodes, and Youmans, (2013). The puzzle was made of a 6 x 6 grid divided into 36 squares. Each square had an object with a specific shape, shape color, and background color. Children were to select one of the squares next to the square with the cursor that matched by either shape or color or background. If they selected a tile that matched in one of these characteristics their cursor would move to that square.In this way, by a series of correct selections, they could move the cursor from the upper left corner of the grid to the lower right corner, their goal. However, their choices were limited: they could only choose a square below, to the right, or diagonally below and to the right of the one on which the cursor rested, so that moves always brought them closer to the lower right corner of the grid. This limitation was made obvious by graying out the squares not eligible for selection (those to the left or top, or diagonally to the left or top). Further, there was only one correct move for each individual turn. If children selected the wrong square a noise would alert them to the error, and they were allowed to make another choice. To correctly make this move to the next square, children needed to match the current square to one of the three options based on shape, shape color, or background color. Each time, only one of these characteristics permitted the correct choice, and throughout the task, which characteristic permitted a correct choice switched, and the children had to switch the basis of their choice accordingly. The children were not directly instructed to make any switches; they needed to discover this need to switch due to the squares not matching based on a characteristic they had just used. For example, a child might make two moves successfully by matching by shape, then on the third move, no squares would match the shape of the current square, forcing the child to switch from matching by shape and choose a new characteristic based on the squares available i.e. matching by either background color or shape color.

Each puzzle was randomly generated, with switch moves and order of presentation randomized. Children completed six puzzle trials, each containing between one and six switches.

The time to make each selection and errors made were recorded for each trial. Switch and non-switch times were calculated as well as a switch cost, which was the direct measure of cognitive flexibility.

2.3. Procedure

All of the selected children were tested individually on the TERA, MCCST, patterning test, and CFPT in four separate sessions in the fall semester by trained research assistants.Each of the four sessions lasted approximately 5-10 minutes depending on individual performance. Children were told that they were going to be asked some questions and then were provided with instructions for each of the assessments corresponding to that session. Children were given the opportunity to discontinue testing if desired.

For the TERA-3, children were told that they would be shown some pictures or some short passages and they would be asked some questions. Research assistants asked standardized questions consistent with the protocol for each question.

The patterning instructions included telling the children that they would be shown some letters, numbers, or shapes and that one of them would be missing. The children were then told that they would need to choose the letter, number, or shape that was missing.

For the MCCST, the researcher introduced the task by telling children that they would be placing cards into four different piles based on two dimensions, by color and kind of object on the card. The research assistants then showed the children how to sort the cards by sorting a training set of cards. The sorting was explained for each card in the training sort. For example, the researcher explained that the card was yellow and a musical instrument so it would go in a specific pile, whereas the next card was brown and a tool so it would go in another pile. Following the training sort, children were asked if they had any questions. Children were reminded that they were to place the cards into four different piles by color and kind of object prior to each of the four test sorts.

For the puzzle task, participants were told that they would be playing a game on the computer. They viewed a simple training PowerPoint that showed an example of the puzzle screen, introduced the rules by which they would be matching, and described how the squares differed in shape, shape color, and background color.

The children then watched the researcher complete three practice puzzles to ensure they fully understood how to navigate the puzzle properly. The children were then told to try to complete to puzzle as fast as they can but to do it correctly. They then asked if they had any questions prior to completing the task.Thereafter, they completed six puzzles, without feedback.

3. Results

There was some consistency in cognitive flexibility measures. Puzzle switch and non-switch times were highly correlated with one another and with switch costs. Card sorting errors, justifications, and sorting time correlated with time spent on puzzle problems, both those that required switches and those that did not (see Table 1). However, they were not correlated with the switch costs on the puzzle. Card sorting errors were correlated with card sorting times and verbal justifications, but the correlation between the latter two measures was not significant.

Table 1: Intercorrelations between Cognitive Flexibility Measures

	Puzzle Non-switch	Puzzle Switch	Puzzle Switch Cost	CS Errors	CS Justif	CS Time
Puzzle Non-switch	-	.726**	-.308**	.326**	.202+	.248*
Puzzle Switch		-	.431**	.241*	.283*	.278*
Puzzle Switch Cost			-	.094	-.126	.059
CS Errors				-	-.405**	.196+
CS Justification					-	-.146
CS Time						-

Note: ** $p < .01$, * $p < .05$, + $p < .10$

Patterning and TERA scores were correlated, $r(86) = .285$, $p < .01$, and some aspects of cognitive flexibility were correlated with both (see Table 2). In the case of patterning, it was the children's errors on the card sort that were reflected in their errors on patterning. Correlations with the pattern task for the children's verbal justification, time spent on sorting, and composite cognitive flexibility card sorting measures were small and non-significant.

TERA scores did not correlate with any card sorting measures of cognitive flexibility but did correlate with the times on puzzle patterns that did not require a switch.

Table 2: Correlations between Cognitive Flexibility Measures with TERA and Patterning

	Puzzle Non-switch	Puzzle Switch	Puzzle Switch Cost	CS Errors	CS Justification	CS Time
TERA	-.198+	-.101	.120	-.070	.090	-.011
Patterning	-.126	-.185	-.091	-.251*	.157	.089

Note: * $p < .05$, + $p < .10$

4. Discussion

The main goal of the current study was to examine the relation between patterning and cognitive flexibility. The results indicated that cognitive flexibility may be an ability that supports patterning, because of the significant relation between performance on the patterning measure and the card sorting task. This finding suggests that patterning may require the ability to repeatedly switch between focusing on the multiple aspects of the pattern when determining a missing piece of the sequence. This significant outcome replicates previous findings that these two constructs are related using other cognitive flexibility and patterning measures with other age ranges (Duan et al., 2010; Hongwanishkul et al., 2005; Miller et al., in press).

Although patterning was related to the card sorting task, patterning was not significantly related to the other measure of cognitive flexibility, the puzzle task. Further, performance on the two cognitive flexibility tasks were not significantly related beyond overall time to complete the tasks. However, the puzzle task has solely been used to assess cognitive flexibility in adults. Therefore, there is a possibility that this measure of cognitive flexibility may not be accurately measuring a similar construct in adulthood as it is measuring in childhood. Previous studies have alluded that assessing children with adult measures of executive function may not be valid measurements (Anderson, 2002).

The results confirmed that patterning was significantly related to reading ability, which provides more support that patterning may be important for learning reading skills (Kidd et al., 2013; 2014). However, cognitive flexibility was not significantly related to reading, which is inconsistent with previous research (Cartwright, 2002; Cole et al., 2014). This could be due to the measure of early reading ability used in the current study which assessed the child's knowledge of the alphabet, conventions, and understanding of print. Previous studies showing the relation between cognitive flexibility using this card sorting task and reading have utilized measures of reading comprehension, such as the Woodcock-Johnson Reading Mastery Test, which require children to solely read passages for understanding (Cartwright, 2002; Cole et al., 2014). Reading comprehension has been theorized to involve shifting attention between aspects of print, which may drive this relation. However, as the results suggest, knowledge of the alphabet, conventions, and understanding of print may not require this same flexibility in thought.

Additionally, research showing a relation between cognitive flexibility and reading has been shown with only children in the middle childhood age range, primarily between the age of 7 and 11 years old (Cartwright, 2002; Cole et al., 2014), whereas children from the current study were slightly younger, between the age of 6 and 7 years old. As noted, cognitive flexibility has been theorized to precede reading ability; therefore, although there is a significant relation at the older age ranges, the significant relation may not exist for these younger children. Future studies should examine this relation further to tease apart whether the lack of a relation in the present experiment may be due to the difference in measures or age.

Discovering the underlying cognitive components of patterning will help researchers and educators theorize about the abilities required to learn mathematics and reading skills. Overall, the findings from the study provide evidence that patterning may require cognitive flexibility. Future research could elaborate by examining the role of other executive functions, such as inhibition and working memory (Huizanga & van der Molen, 2007). Upon knowing the underlying cognitive skills, interventions for math and reading could focus on these cognitive abilities as a whole.

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