THE COGNITIVE COMPONENTS OF PATTERNING: THE RELATION BETWEEN EXECUTIVE FUNCTION AND PATTERNING

by

Allison M. Bock
A Dissertation
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Doctor of Philosophy
Psychology

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ACKNOWLEDGEMENTS

I would like to thank my friends and family who were supportive of me while completing this project. My committee members, Drs. Pasnak, Cartwright, Kidd, and Rojahn, always provided me with invaluable support and guidance. I would also like to thank my fellow lab members without whom this would not be possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABSTRACT

THE COGNITIVE COMPONENTS OF PATTERNING: THE RELATION BETWEEN EXECUTIVE FUNCTION AND PATTERNING

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The ability to detect a pattern within a sequence of ordered units, defined as patterning, is a skill that is central to learning mathematics and influential in reading. Although the importance of patterning has been demonstrated, there has been limited research investigating the cognitive components of patterning. Studies suggested that cognitive flexibility and working memory may underlie patterning. A construct similar to patterning, fluid intelligence, has also been linked to executive function, which includes working memory, inhibition, and cognitive flexibility. However, fluid intelligence seems to be most highly related to working memory. The main goal of the study was to examine the role of working memory, inhibition, and cognitive flexibility in first-grade children's patterning ability. We found that only cognitive flexibility was significantly related to patterning. This suggests that the ability to switch one's thinking is involved in understanding patterns. In addition, the study tested the relation between executive

function skills, patterning, reading fluency, and reading comprehension. We found that working memory was related to reading fluency and both working memory and inhibition were related to and uniquely predicted reading comprehension. Lastly, cognitive flexibility was significantly related to inhibition and working memory; however, inhibition and working memory were not related to one another.

INTRODUCTION

Detecting a pattern among a set of units is an underlying cognitive skill for children's pre-algebraic thinking (Papic & Mulligan, 2005). Patterning with numbers and blocks has been commonly taught within elementary school mathematics curricula for many years (Clements & Sarama, 2007a). 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) reported that understanding patterns helps to ensure that children are prepared for mathematical reasoning. However, recent research suggests that general understanding of patterns, which extends beyond simply determining a simple alternating pattern of sizes, colors, or shapes, influences more than just mathematics understanding. There is evidence that general patterning ability may be a precursor for reading skills, although this has been less researched (Herman, Trueblood, & Pasnak, 2006; Kidd et al., 2014). These patterning interventions have shown that there are benefits to learning more complicated and varied types of patterns, such as increasing, decreasing, or symmetrical patterns with letters, numbers, clocks, or objects, or with objects that rotate (Kidd et al., 2014). Following the interventions, children showed significant gains on patterning, mathematics, and reading achievement assessed by measures of word reading, reading fluency, and reading comprehension. Therefore, patterning appears to be a cognitive skill that is influential in learning mathematics and reading.

Patterning seems to be a general cognitive ability that requires generalization skills and abstract reasoning about the stimuli in the pattern (Clements & Sarama, 2007b). Children need to be able to detect and generalize the apparent rule amongst the units. Children must then use abstraction skills to determine which item comes next in the sequence. Although patterning has been shown to be an important cognitive skill that aids learning, there has been limited research explicitly examining the underlying cognitive components that may influence this understanding of patterns. One study showed that six- and seven-year-old children's patterning may be linked with cognitive flexibility, which is the ability to shift one's thinking based on rules or demands (Bock et al., 2015). Another study showed that ten-year-old children's patterning performance was predicted by working memory, or the ability to update one's thought processes (Lee, Ng, Bull, Pe, & Ho, 2011). Miller, Rittle-Johnson, Loehr, and Fyfe (in press) found that both working memory and cognitive flexibility significantly predicted the ability to understand repeating patterns in preschool. Together, these findings suggest that children must be able to cognitively shift between multiple aspects of a pattern as well as to maintain or manipulate these aspects in one's mind to be able to recognize what comes next in the pattern sequence. Due to the limited research in this field, literature on constructs similar to patterning may also provide insight into other cognitive underpinnings.

Although never explicitly defined as "patterning," similar constructs have been incorporated into theories of intelligence. For example, Cattell defined intelligence as being composed of two intelligence factors, fluid and crystallized reasoning (Daleo et al., 1999). Fluid intelligence, defined as the ability to use one's reasoning skills to solve novel problems, is linked to general patterning ability (Daleo et al., 1999). Induction, which is the component of fluid reasoning that involves the ability to detect underlying rules when observing a phenomenon, is likely to be involved in learning and understanding pattern rules (Schneider & McGrew, 2012). Additionally, the Raven's Progressive Matrices test (RPM), which is a commonly used measure of reasoning that employs matrix patterns, has been identified as explicitly measuring fluid intelligence. In the RPM, children are provided with a 2x2 or 3x3 matrix of stimuli with one missing piece. The goal is to detect the pattern amongst the rows and columns of stimuli and determine the missing stimulus. Although never directly identified as a measure of patterning, the skills required to complete the RPM and other similar matrices intelligence tests seem to be similar to those involved in understanding general patterning. Therefore, studies that have focused on fluid intelligence can help to inform of possible underlying cognitive skills required for successful patterning.

Fluid intelligence, often measured by the RPM, has repeatedly been linked to a set of cognitive skills called executive functions (Brydges, Reid, Fox, & Anderson, 2012; Diamond; 2013; Duan, Wei, Wang, & Shi, 2010; Friedman et al. 2006). Executive function is an umbrella term for skills that regulate and control one's thought and behavior (Miyake et al., 2000). Executive function is usually further broken into three components: inhibition, which is the ability to disregard irrelevant stimuli; working memory, as previously mentioned, is the ability to update one's thought processes; and cognitive flexibility, the ability to shift one's thinking based on context (Miyake, et al., 2000). These three components of executive function have repeatedly been shown to be separate and distinct; however, they are consistently highly significantly related to one another (Duan et al., 2010; Miyake et al., 2000).

Findings on the relation between fluid intelligence and executive function have been mixed depending on the age of the participants tested. A majority of the current research examining executive function and fluid intelligence has used adult participants. The results have predominately shown that working memory is related to and significantly predictive of performance on fluid intelligence measures, particularly those using matrices tests (Borella, Carretti, & Mammarella, 2006; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Friedman et al., 2006; Martinez & Colom, 2006; Wiley, Jarosz, Cushen, & Colflesh, 2011). Further, fluid intelligence has been more highly related to working memory than to cognitive flexibility, inhibition, or processing speed (Borella et al., 2006; Conway et al., 2002; Friedman et al., 2006). These findings suggest that the ability to update and control one's thinking during problem solving is important for solving complex matrix patterning problems, especially during adulthood. There is some evidence of significant relationships between fluid intelligence and the other executive functions, inhibition and cognitive flexibility (Naglieri & Goldstein, 2014; Schweizer, Moosbrugger, & Goldhammer, 2005; Withoft, Sander, Sub, & Wittman, 2009). However, Schweizer et al. (2005) did not measure working memory and Naglieri and Goldstein (2014) and Withoft et al. (2009) did not account for unique relationships between variables. Therefore, it is possible that these findings may be driven by the role that working memory plays in these other executive functions.

Only two studies have directly examined the relation between executive function and fluid intelligence with children. Duan et al. (2010) found that working memory was the most important factor for performance on the RPM. Inhibition and cognitive flexibility were significantly related to performance, but these factors were less influential than working memory. In contrast, Brydges et al. (2012) found that a single executive function composite variable, which included working memory, inhibition, and cognitive flexibility, predicted fluid intelligence better than using these separate variables as predictors. This composite “latent” executive function variable was the best predictor of fluid intelligence performance. This suggests that performance on the matrix reasoning requires all three capabilities to complete the task successfully.

The findings of Duan et al. (2010) and Brydges et al. (2012) are in line with the recent findings on the relation between children’s cognitive flexibility, working memory, and patterning (Bock et al., 2015; Lee et al., 2011). However, more research is needed to determine whether these other executive functions relate to patterning and fluid reasoning in similar ways in first-grade children. As previously noted, reasoning skills required to complete fluid intelligence matrices tests, such as the RPM, seem to be similar to those required to complete linear patterning tests. For both tests, deduction of the pattern and abstraction of the rule to determine the appropriately missing piece is required. Therefore, it would be expected that performance on patterning measures would be linked to working memory most closely. However, patterning should also be significantly related to other executive functions as well.

There is also a well-documented overlap between both patterning and executive function skills with academic achievement, particularly in the areas of mathematics and reading. Patterning is significantly linked to mathematics achievement, early reading ability, and reading achievement as measured by word reading, reading fluency, and reading comprehension (Bock et al., 2015; Herman et al., 2006; Kidd et al., 2014). Executive function has also been shown to be important for mathematics (Bull & Scerif, 2001; Espy et al., 2004) and reading fluency and reading comprehension (Cartwright, 2012; de Beni & Palladino, 2000; Sesma, Mahone, Levine, Eason, & Cutting, 2009; van der Sluis, de Jong, & van der Leij, 2007). All three executive function components seem to be influential in learning mathematics, particularly when children struggle in this area (Bull & Scerif, 2001). One study showed that inhibition contributes unique variance to mathematics performance (Espy et al., 2004). However, the majority of findings show that working memory, or updating one's thoughts, is the most important cognitive skill for mathematics (Bull & Lee, 2014; Lee et al., 2011; Mazzocco & Kover, 2007; Raghubar, Barnes, & Hecht, 2010). Similarly, executive function skills are linked to multiple aspects of reading achievement. All three executive function components are related to reading comprehension, which is the ability to understand while reading (Cain, 2006; Cartwright, 2002; de Beni & Palladino, 2000). However, working memory seems to be the most influential factor for reading fluency, which is the ability to correctly and quickly read text aloud (Jacobson et al., 2011; Locascio, Mahone, Eason, & Cutting, 2010).

The goal of the proposed study was to directly examine the relation between patterning and the three executive function components, working memory, inhibition, and cognitive flexibility. It was hypothesized that patterning would be related to all three measures, with working memory having the strongest relationship. Additionally, the study examined the relation between reading fluency and reading comprehension and these four cognitive measures. Reading comprehension was expected to be related to patterning and the three executive function variables, whereas reading fluency was expected to be related to patterning and working memory. Lastly, the study evaluated the interrelations between the three executive function variables. It was expected that the variables would be significantly related to one another.

METHOD

Participants

Eighty-four children who were judged by their teachers to be of average ability were chosen from 11 first-grade classrooms in two public elementary schools in an urban Mid-Atlantic area. Children were restricted from involvement in the study if they had an Individualized Education Plan or were considered by their teachers to not be proficient in English. This sampling yielded an approximately equal number of first-grade boys (N = 40) and girls (N = 44) who were 6-7 years old. The Gray Oral Reading Test data from eight children were removed from the analyses due to experimenter error.

Measures

Children completed an assessment of reading ability, the Gray Oral Reading Test, an assessment of patterning ability used by Bock et al. (2015), and three assessments of executive function skills. These included the Day/Night inhibition test; the Multiple Classification Card Sorting Test, which assessed cognitive flexibility; and the Wechsler Intelligence Scale for Children digit span, which assessed working memory. The order in which children received the measures were counterbalanced across the classrooms.

Gray Oral Reading Test 4 (GORT)

The GORT is an assessment of reading ability. Children were required to read aloud five passages. Before reading each passage, the research assistant directed the children to read for comprehension. While reading aloud, research assistants marked any deviations from the passages. Time to read each passage was also measured. After each passage, the research assistant asked the children to answer five comprehension questions. Ceiling was reached after three incorrect responses to the comprehension questions on any one passage. The total number of deviations from print, time to complete the passages, and correct responses to comprehension questions were totaled. Children received a fluency score, which was calculated by totaling words correctly read per minute. Children also received an average comprehension score, which included the average number of correct responses to the comprehension questions across each passage. Lastly, the number of stories completed was counted. Children's reading fluency score, average comprehension score, and number of stories read were used in the analyses. The reliability and validity of the GORT is high, ranging from .85 to .95 on test–retest comparisons and a median correlation coefficient of .63 with six other standardized measures (Wiederholt, 2001).

Patterning Measure

The patterning measure assessed children's ability to detect a pattern and fill in a missing piece within the pattern sequence. The 18 patterns included a line of numbers, letters, and shapes that either increased or decreased in value, position of the alphabet, or size or were symmetrical (See Figure 1 for example). The missing item was presented in the last position in the sequence. All patterns were presented horizontally and children were asked to choose from four possible options shown below the sequence. The total number of correct responses was used in the analyses.

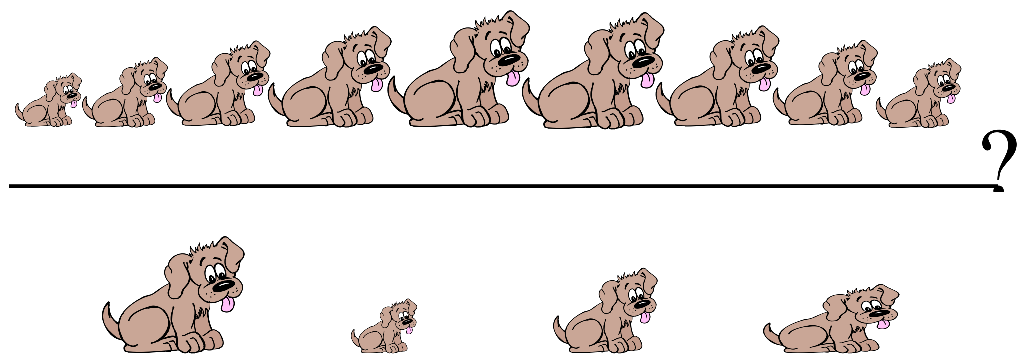

Figure 1 Example of a symmetrical pattern within patterning measure

Day-Night

The day-night inhibition test was an assessment of the child's ability to inhibit an initial, automatic response. A flip book contained eight pictures of suns and eight pictures of moons in a counterbalanced order. Children were asked to say night in response to seeing a sun and to say day in response to seeing a moon. The accuracy of their responses as well as the total time to complete the task were calculated. The total number of correct responses were used in the analyses. The internal reliability of the measure has been reported to be high with a Kuder-Richardson reliability of .93 (Chastiotis, Kiessling, Hofer, & Campos, 2006).

Multiple Classification Card Sorting Test (MCCST)

This cognitive flexibility measure required children to sort 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 tools and instruments) similar to the procedure by Cartwright (2002). A set of 12 training cards were used to familiarize the child with the task. For the test, four sets of 12 cards were presented in a random order. Children were scored on accuracy of sorting (one point for correct sort), and the time of sort was recorded with a stopwatch. The children were also asked to explain the reasoning for sorting the cards in the way that 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. Children received two points for correct justification (similar to Cartwright, 2002). A flexibility composite score was calculated by adding the sorting score and justification score and dividing by the sorting time. Reliability for this measure is high with a Cronbach's alpha of .86 (Cartwright, Marshall, Dandy, & Isaac, 2010).

Wechsler Intelligence Scale for Children (WISC) Digit Span

The WISC digit span was used to assess children's working memory. Children were provided with series of digits and asked to say them back to the researcher. First, children were asked to recall the digits provided to them exactly as recited (forwards), which assesses children's memory capacity. Then, children were asked to recall the digits provided to them backwards, which assesses children's working memory. The forwards digit span had 14 sets of three numbers to nine numbers, with two trials for each. The backwards digit span recall had 12 sets of two to eight numbers, with two trials for each. Testing was discontinued if a child was incorrect on both trials for any given amount of numbers. The total number of correct trials was counted for the backwards task and used in the analyses.

Procedure

All of the selected children were tested individually in five separate sessions by one of the 24 trained research assistants. Prior to testing, the research assistants were provided with sheets detailing the instructions to follow for administering each measure as well as opportunities to practice each measure with the experimenters. The experimenters randomly observed the research assistants while testing to ensure the research assistants were adhering to standardized protocol.

All testing was completed in a quiet location within the classroom or in a quiet hallway. Each of the sessions lasted approximately 5-10 minutes depending on individual performance on the measures. Children were provided with instructions for each of the assessments corresponding to the session and were given the opportunity to discontinue testing if desired.

For the GORT, children were told they would be reading some stories and then would be asked some questions. Each of the five stories were introduced and questions were asked consistent with the standardized protocol. The patterning instructions involved 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 asked to choose the letter, number, or shape that was missing. Before the day/night task, children were told that they would be playing a silly game. The first page shown to the children had both a sun and a moon. The research assistant introduced the task by telling the child the rules of the game in which they must say night in response to the sun and day in response to the moon. The assistant pointed to the sun and moon during instruction. To check their understanding of the instructions, the children were asked what they should say for the sun and for the moon. If incorrect, they were corrected at this point. Next, the children were shown the 16 trial pages in a flip book.

For the MCCST, the researcher introduced the task by telling children that they would be placing cards into four different piles according to the 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 and explaining the reasoning for each card's placement in the training sort. Following the training sort, children were asked if they had any questions. Children were reminded that they would need to place the cards into four different piles by color and kind of object prior to each of the four test sorts.

The instructions for the digit span included telling the children that the researcher would read some numbers and that they must remember them and tell them back to the researcher. For the digit span backwards, children were asked whether they understood what backwards meant. If they did not, an example of giving the list backwards was provided to them.

RESULTS

Descriptive statistics were conducted on the variables of interest (see Table 1). All variables were normally distributed, except for inhibition accuracy, which had high negative skewness and high positive kurtosis values (see Table 1). Pearson correlation coefficients between the executive function variables, patterning, and reading achievement variables were calculated. Examining the inter-correlations between the executive function variables showed that cognitive flexibility was significantly related to inhibition and working memory. However, inhibition and working memory were not significantly related (see Table 2). Patterning was related only to cognitive flexibility. For reading achievement, working memory and inhibition were significantly related to reading comprehension, while only working memory was significantly related to reading fluency (see Table 2). Additionally, cognitive flexibility and working memory were related to overall reading performance, which was measured by the total number of stories completed. Patterning was not related to reading achievement. The effect sizes of the correlations between cognitive flexibility and the executive function and patterning variables are considered to be medium effects (Cohen, 1992). Additionally, the relation between working memory and reading fluency was a medium effect.

Table 1 Descriptive statistics for variables

	Mean	SD	Min	Max	Skew	Kurtosis
Working memory	2.69	1.27	0	6.00	-0.31	0.17
Inhibition	14.65	3.15	0	16.00	-3.41	12.02
Cognitive flexibility	0.05	0.03	0	0.16	0.53	0.15
Patterning	7.94	3.51	0	16.00	0.37	-0.21
GORT – Fluency	56.82	37.28	3.74	151.28	0.72	-0.39
GORT – Comp	2.69	0.87	1.00	4.8	0.45	-0.14
GORT – Stories	2.66	1.46	1.00	5.00	0.28	-1.45

Table 2 Correlations among variables

	WM	Inhibition	CF	Pattern	Fluency	Comp	Stories
Working memory	-	.02	.34**	.14	.30**	.27*	.25*
Inhibition		-	.02	-.01	-.15	.23+	.18
Cognitive flexibility			-	.31**	.09	.15	.20+
Patterning				-	.08	.09	.05
GORT – Fluency					-	.44**	.36**
GORT – Comp						-	.78**
GORT – Stories							-

Note: +$p < .1$, *$p < .05$, **$p < .01$.

Regression analyses were run to examine which variables predicted patterning performance, reading fluency, and reading comprehension. All assumptions for regression analyses were met. Although the inhibition accuracy variable showed high skewness and kurtosis, for all regression analyses, the variance of the inhibition errors were constant and the scores were not correlated with the errors. For patterning, a hierarchical linear regression was run with working memory, inhibition, and cognitive flexibility as predictor variables. Cognitive flexibility contributed significant and unique variance over the other two executive function variables, inhibition and working memory (see Table 2). A total of 7.4% of the variance in patterning performance was explained by cognitive flexibility. For reading fluency and reading comprehension, hierarchical linear regressions were conducted with working memory, inhibition, cognitive flexibility, and patterning as predictor variables. Working memory contributed the only significant variance for reading fluency with a total of 11% of the variance explained (see Table 3). However, both working memory and inhibition performance significantly predicted unique variance for reading comprehension (see Table 4). These variables explained 12% of the variance in reading comprehension.

Table 2 Hierarchical linear regression predicting patterning from working memory, inhibition, and cognitive flexibility

Predictors	R^2	Adj R^2	*B*	*t*
Model 1	.04	.03		
Working Memory			.21+	1.92
Model 2	.05	.03		
Working Memory			.21+	1.92
Inhibition			-.04	-.32
Model 3	.12	.09		
Working Memory			.13	1.13
Inhibition			-.10	-.87
Cognitive Flexibility			.29*	2.56*

Note: +$p < .1$, *$p < .05$.

Table 3 Hierarchical linear regression predicting reading fluency from working memory, inhibition, cognitive flexibility, and patterning

Predictors	R^2	Adj R^2	*B*	*t*
Model 1	.09	.07		
Working Memory			.30*	2.58
Model 2	.11	.09		
Working Memory			.30*	2.59
Inhibition			-.16	-1.37
Model 3	.11	.07		
Working Memory			.28*	2.33
Inhibition			-.17	-1.43
Cognitive Flexibility			.06	.44
Model 4	.11	.06		
Working Memory			.28*	2.29
Inhibition			-.17	-1.42
Cognitive Flexibility			.05	.37
Patterning			.02	.13

Note: +$p < .1$, *$p < .05$.

Table 4 Hierarchical linear regression predicting reading comprehension from working memory, inhibition, cognitive flexibility, and patterning

Predictors	R^2	Adj R^2	*B*	*t*
Model 1	.06	.05		
Working Memory			.24*	2.06
Model 2	.12	.09		
Working Memory			.24*	2.07
Inhibition			.24*	2.06
Model 3	.12	.08		
Working Memory			.23+	1.80
Inhibition			.23+	1.89
Cognitive Flexibility			.04	.33
Model 4	.12	.06		
Working Memory			.22+	1.76
Inhibition			.23+	1.90
Cognitive Flexibility			.03	.21
Patterning			.04	.33

Note: +$p < .1$, *$p < .05$.

DISCUSSION

The primary goal of the study was to examine whether executive function skills were related to patterning performance. Patterning only correlated significantly with cognitive flexibility, but not to the other two executive function skills, inhibition and working memory. The results replicate previous findings that cognitive flexibility and patterning are significantly related (Bock et al., 2015). This suggests that cognitive flexibility is a distinctive executive function skill that is needed to understand patterns. Patterning may involve cognitively switching one's thinking from one possible pattern to another while completing patterning tasks, or it may also involve switching between elements within a particular pattern. The relation of patterning to cognitive flexibility deserves further investigation to better understand the precise relations between these variables.

Interestingly, neither working memory nor inhibition were related to patterning performance. This finding contradicted the findings of Borella et al. (2006) and Friedman et al. (2006) that working memory was strongly linked to patterning performance. However, Borella et al. (2006) and Friedman et al. (2006) used matrix reasoning problems in their research. Hence, there may be a flaw in the assumption that the cognition used to complete the linear patterns used in the current study is similar to the cognition used to complete more complex matrix reasoning problems, where there are two or three columns of stimuli involved. Although both types of problems involve detecting patterns and filling in a missing part of the pattern, there has been no research testing whether there is an overlap between these types of measures. The current research suggests that there is little overlap. Additionally, these results contradict the findings of Miller et al. (in press) and Lee et al. (2011) that suggest that working memory predicts patterning performance. However, preschool-aged children and 10-11 year old children were tested in those studies and different types of patterns were used (simple repeating patterns and solely numeric patterns respectively). In any event, the current findings show that for first graders, completing linear patterns does not involve the cognitive skills of working memory or inhibition.

A secondary goal was to examine the role of patterning and executive function skills in reading fluency and reading comprehension. Previous research indicated that all of these cognitive skills were related to reading comprehension (Cartwright, 2002, 2012; Hendricks, et al., et al. 2006; Kidd et al., 2014). Additionally, it was expected that inhibition, cognitive flexibility, and patterning would be related to reading fluency (Jacobson et al., 2011; Kidd et al., 2014; Locascio et al., 2010; van der Sluis, de Jong, & van der Leij, 2007). However, the results of the study showed that only working memory and inhibition were significantly related to both reading fluency and reading comprehension, whereas cognitive flexibility and patterning were not significantly related to either variable.

Previous research has shown that the ability to shift one’s attention and be cognitively flexible is related to multiple aspects of reading achievement, including pre-reading skills, word-reading efficiency, and reading comprehension (Cartwright, 2012; van der Sluis et al., 2007; Welsh, Nix, & Blair, 2010). However, it has also been shown that, especially with first-grade children, a general flexibility task may not be significantly related to reading comprehension (Cartwright et al., 2010). It was previously found that reading comprehension is more related to a reading-specific flexibility task that involves switching between thinking about sound and meaning of words than to a general flexibility measure that involves switching between thinking about color and shape of objects, such as the measure used in this study (Cartwright et al., 2010). The results of the current study seem to further support the position that the general ability to switch one's thinking does not strongly relate to reading achievement at this age.

Working memory significantly and uniquely predicted both reading fluency and reading comprehension. This replicates previous demonstrations that have shown a strong relationship between working memory and multiple reading achievement variables, including reading fluency and reading comprehension (Cartwright, 2012; Jacobson et al., 2011; Locascio et al., 2010; Semsa et al., 2009). The earlier findings show that working memory is involved at multiple levels of reading, especially reading aloud and understanding while reading. It has been posited that children with better working memory skills may have more cognitive resources to engage in the multiple processes required for reading (Sesma et al., 2009). However, more research is needed to evaluate the reason for this strong relationship.

Inhibition also yielded a unique prediction of reading comprehension, but not reading fluency. This finding is compatible with research that has found that inhibition relates to aspects of reading, including pre-reading skills, word-reading proficiency, and reading comprehension (Cartwright, 2012). Cain (2006) and de Beni and Palladino (2000) also found that inhibition was related to reading comprehension and Jacobson et al. (2012) found that inhibition was not related to reading fluency. This suggests that inhibition may be a necessary skill for understanding what you are reading but less important for other aspects of the process. Because their predictions of reading comprehension are unique, it appears that working memory and inhibition are explaining different aspects of reading comprehension.

There was no relationship between patterning and both reading fluency and reading comprehension in this study. Although the relationship between patterning and reading has been understudied overall, some previous findings have shown that patterning and early reading skills were significantly related (Bock et al., 2015) and that reading achievement, as measured by multiple measures of word reading, reading fluency, and reading comprehension, has increased following patterning instruction (Herman et al., 2006; Kidd et al., 2014). The studies showing a significant relationship have assessed early reading skills and used a composite reading measure rather than individual measures of reading fluency and reading comprehension (Bock et al., 2015; Kidd et al., 2014). Further, findings on reading and patterning have been inconsistent as Kidd et al. (2013) found that patterning instruction did not specifically increase reading fluency and comprehension. Together, these findings suggests that patterning may be most closely related to reading in the early stages of learning rather than directly related to reading fluency and comprehension for first-grade children. Additionally, the findings from Kidd et al. (2013; 2014) used patterning measures with more varied types of patterns, including rotating patterns and clock faces with changing times, which were presented both horizontally and vertically. Future research should examine whether the types of patterns included in the measure are influential in the relation to reading achievement variables.

A final goal was to examine the interrelations between the executive function variables of working memory, inhibition, and cognitive flexibility. Although research shows that these three variables are separate, they are consistently significantly related to one another (Best & Miller, 2010; Miyake et al., 2000). The current study showed that cognitive flexibility was significantly related to the other two executive function variables; however, working memory and inhibition were not significantly related. There has been some suggestion that cognitive flexibility may be comprised of these other two components and that working memory and inhibition may combine with each other to create cognitive flexibility (Best & Miller, 2010; Garon, Bryson, & Smith, 2008). The results of this study suggest some support for this theory. Due to the lack of relationship amongst working memory and inhibition, cognitive flexibility may be a function of the two variables, which may independent of each other.

Limitations of the study include utilizing multiple research assistants for data collection and lack of measurement of control variables. Although there was a standardized protocol for data collection, there may have been slight variations across research assistants. Additionally, the study did not include measures of variables that may have influenced the results of the study. For example, there was not a measure of phonological processing. Locascio et al. (2010) found that phonological processing mediates the relationship between working memory and reading fluency. Therefore, future research should include this as a variable of interest. Additionally, there was no information about bilingual status or socioeconomic status of the children. The sample of participants was obtained from a diverse metropolitan area with children who were likely to come from families who were in a low socioeconomic status or who spoke more than one language. Future research should include these variables to account for the possibility that they may influence the findings of the study.

Because patterning contributes so strongly to mathematics skills, a sensible next step may be to extend these findings to examine the overlap of cognitive flexibility and patterning with mathematics skills. Some research has suggested that executive function skills, particularly working memory, are related to mathematics skills (Jerman, Reynolds, & Swanson, 2012; Lee et al., 2011; Mazzocco & Kover, 2007). However, more research is needed within this area.

The finding that cognitive flexibility may be an underlying factor for patterning performance may influence future work on patterning interventions. It is known that patterning facilitates later mathematics performance and is related to some early reading skills (Hendricks et al., 2006; Kidd et al., 2014). Elementary school curricula already place emphasis on detecting patterns. The present results suggest that teachers may find it beneficial to place emphasis on the switching component of completing the patterning tasks.

Additionally, the results highlight the variables that are important for reading fluency and reading comprehension. In particular, it is important to note that both inhibition and working memory are related to reading comprehension; whereas, working memory is related to reading fluency. Therefore, teachers may wish to focus on these cognitive skills when working with children who struggle with reading.

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