EXECUTIVE FUNCTIONS, MATHEMATICS, AND PATTERNING

by

Mehreen Zehra Hassan
A Thesis
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of
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DEDICATION

This is dedicated to my wonderful parents, Muhammad and Ruqia Hassan.

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I would like to thank the many friends, relatives, and supporters who have made this happen. My loving parents who have supported me every step of the way. My siblings who have always encouraged me. Finally, thank you to Drs. Pasnak, Kornienko, and Rowe, who were of invaluable support and guidance throughout my graduate studies.

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LIST OF ABBREVIATIONS

Executive Function	EF
Head-Toes-Knees-Shoulder	HTKS
Multiple Classification Card Sorting Task	MCCST
Wechsler Intelligence Scale for Children	WISC

ABSTRACT

EXECUTIVE FUNCTIONS, MATHEMATICS, AND PATTERNING
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This paper presents a review of the role executive functioning abilities plays in patterning and mathematics achievement. A study is then reported that examines the relationship between measures of inhibition, working memory, cognitive flexibility, patterning, and mathematics achievement in kindergartners. Cognitive flexibility was found to be a significant predictor of patterning performance while working memory and inhibition were found to be significant predictors of mathematics achievement. Lastly, there were multiple significant correlations found between the measures of executive functions.

INTRODUCTION

Patterning is a key component of learning in early childhood. It is the ability to detect regularities and involves understanding abstract relationships while incorporating considerable amounts of reasoning that evolves from the age of preschool, to the thinking developed by early elementary children (Kidd et al., 2013). In kindergarten, teaching children to identify and complete patterns is considered to be an important part of the curriculum, as the National Council of Teachers of Mathematics (NCTM, 1993) recommended patterning to be a point of focus in preschool and kindergarten, and that teachers should help the students at this age understand the predictability of patterns and be able to generalize the ability to use known information to predict unknown information (Economopoulos, 1998). A child may be able to understand basic repetitions of two or three elements if they are aware of similarities and differences on dimensions, such as color or shape, and have sufficient previous knowledge about basic sequences to recognize when one item leads to or follows another.

Patterning skills are also thought to be good predictors of mathematic achievement as demonstrated by Kidd et al. (2013), where the researchers found that, compared to first graders given reading or mathematic instructions, those who received patterning instruction outperformed the other groups on mathematic achievement tests. These results were replicated by Kidd et al. (2014) and Pasnak et al. (2015), who also found improvements on reading measures to result from patterning instruction. However, some patterns can be quite complex and may involve more than one dimension and, as supported by previous literature, understanding new patterns requires effective executive functioning.

Executive functions or executive controls are a set of cognitive processes important for regulating and organizing behavior and other cognitive processes. They assist in the development of social and cognitive competence in young children and have been found to predict a child’s short term and long-term developmental outcome (Weiland, Barata, & Yoshikawa, 2014). There are three core executive functions that are often associated with patterning ability: cognitive flexibility, working memory, and inhibition. These functions are essential in novel tasks that require problem solving, planning, organizing, or overriding a strong internal or external pull (Diamond, 2006).

Inhibitory control is the ability to stop oneself from an automatic response or behavior to a stimulus. It is also necessary to block distraction and focus on a single task (Weiland et al., 2014). In relation to patterning, it is the ability to resist the urge to apply a rule of a previously presented pattern to a new pattern (Schmerold et al., 2017). Working memory allows children to hold information in their minds while they try to complete a task or solve a problem. This ability allows one to retain and manipulate information for learning and is necessary to dissect components of a task and to derive connections between deceptively unconnected items (Diamond, 2006). Working memory is necessary in patterning as it allows a child to compare different items while deciding on the pattern rule that they are to use.

According to Diamond (2013), inhibition and working memory support one another and are often required simultaneously. To keep one's mind focused on a task and to connect or recombine multiple items to create new ideas, one must be able to resist internal and external distractions. Similarly, to decide what is appropriate to inhibit, one must hold certain information and goals in mind to successfully block the inappropriate distractions. Furthermore, Diamond (2013) also notes that the third core executive function, cognitive flexibility, is developed later in childhood and requires effective inhibition and working memory.

Cognitive flexibility is the ability to smoothly switch perspective or attention to a different task or behavior. To change perspectives, one must be capable of inhibiting a previous perspective and retaining information about a new perspective (Diamond, 2013). In relation to patterning, cognitive flexibility allows a child to apply the same rules to multiple patterns that have different kinds of elements or to switch from one pattern rule to another when needed (Schmerold, et al., 2017).

Several studies have shown the correlation between patterning and executive functions. Bock et al. (2015) studied the relationship between cognitive flexibility, complex patterning ability, and reading ability among first graders. With a sample of 88 first graders, the researchers assessed cognitive flexibility of the children using the Multiple Classification Card Sorting Task (MCCST), and the computer-based Cognitive Flexibility Puzzle Task (CFPT). The patterning measure assessed the children's ability to detect and complete a pattern by selecting the next object in a sequence from an array of possible choices. The researchers found a significant correlation between patterning and the MCCST measure of cognitive flexibility, but no significant relationship with the CFPT.

Schmerold et al. (2017) conducted research on the relationship between patterning, reading achievement, mathematics achievement, and executive functions in first graders who had a mean age of 6.5 years. To assess mathematic achievement, the Woodcock-Johnson Tests of Cognitive Abilities III was used while executive functioning abilities of cognitive flexibility, working memory, and inhibition were measured using the Multiple Classification Card Sorting Test, Wechsler Intelligence Scale for Children – Revised (WISC-R) Digit Span, and Stroop Color-Word Test, respectively. Similar to Bock et al. (2015), they found a significant correlation between patterning and cognitive flexibility, and between patterning and reading achievement. Patterning was also significantly correlated to mathematic achievement and working memory, but not to inhibition. Only cognitive flexibility was a significant predictor of patterning ability, and working memory correlated with mathematics achievement.

Schmerold et al. (2017) and Bock et al. (2015) produced similar results to those of Bock (2015). While the same measures of cognitive flexibility (MCCST) and working memory (WISC-R Digit Span) were used, Bock (2015) utilized the Day/Night test to measure inhibition instead of the Stroop Color-Word test. The significant relationship found between patterning and cognitive flexibility supported the other two studies. Bock (2015) also found that while cognitive flexibility was correlated to working memory and inhibition, the latter two were not related to one another.

These results were not replicated in a study in Singapore among a population that was mostly ethnically Chinese. Lee, Ng, Pe, Ang, Hasshim, & Bull (2012), studied the relationship between, patterning, executive functions, and numerical and arithmetic (NA) proficiency among children aged six-seven years enrolled in public schools in Singapore. They used the Flanker Task, Simon Task, and Picture-Symbol Task measures of executive functions and divided the components of these assessments to create different scores for tasks that measured inhibition and those that measured cognitive flexibility. Lee et al. (2012) found a low correlation between executive functions and NA proficiency and only a small correlation between inhibition and patterning. This contrast to results from previous studies could be due to the age of the children or to the different measures used to assess inhibition.

There have also been studies that examined the relationship between patterning and executive functions in preschoolers. Rittle-Johnson, Fyfe, McLean, and McEldoon (2013) assessed preschoolers on patterning and working memory using the WISC Forward and Backward Digit Span. The results from this study suggested that among four-year-old's, patterning knowledge was in part related to working memory capacity and that if working memory capability was high, so was patterning ability (Rittle-Johnson et al., 2013).

Collins and Laski (2015) used the same type of visual repeating patterning assessment as Rittle-Johnson et al. (2013) but employed the WISC Digit Span Backwards Recall Task and Corsi Blocks to assess working memory and the Head-Toes-Knees-Shoulders (HTKS) measure to assess inhibitory control in preschoolers. The authors found that like Rittle-Johnson et al. (2013), working memory was significantly correlated with the understanding of alternating patterns. However, unlike the results of Rittle-Johnson et al., inhibition also showed a strong correlation to patterning. Also utilizing the Rittle-Johnson et al. (2013) patterning assessment, Miller, Rittle-Johnson, Loehr, & Fyfe (2016) found that the WISC Digit Span assessment of working memory significantly predicted patterning ability while the Luria's Hand Game measure of inhibition did not.

From the above-mentioned studies, it can be inferred that while cognitive flexibility and working memory are correlated with successful patterning abilities, there is contrasting evidence about the role of inhibition.

Executive functions have also been studied to discover their relationship to mathematic achievement. The mechanisms through which executive functioning abilities may aid in successfully complete patterning tasks, may help in the same way to complete mathematic problems. While many studies have found that, from early childhood to adolescence, working memory has a strong relationship to mathematic achievement, the role of inhibition and cognitive flexibility are still unclear, as there are varying results.

Bull and Scerif (2001) tested a sample of 93 children aged 6-8 years, from schools in various regions of Scotland, on measures of executive functions and mathematic achievement. After an initial screening for mathematics, reading, and general intelligence, the children were tested on executive function measures in three sessions. In the first session, the Wisconsin Card Sorting Task (WCST) was given to the children to assess cognitive flexibility, followed by the Stroop task to measure inhibition and a Counting Span measure of working memory in the second and third sessions, respectively. The authors found a significant positive correlation between working memory and mathematics, and also found that those who had higher math scores were less distracted during the Stroop task measure of inhibitory control, which suggested a positive correlation between the two executive functions. A significant amount of variance in mathematics ability was predicted by each executive function measure, but only working memory continued to do so after taking the variance predicted by reading and IQ into account. While these results show that there is a relationship between mathematic achievement and executive functions, working memory seems to be the best predictor of mathematics ability for children in the first grade.

Harvey and Miller (2017) found a similar relationship between working memory and mathematic achievement from their data collected in Head Start preschool programs. Using the Flanker Inhibitory Control and Attention Test, the Dimensional Change Card Sort task, and the Self-Ordered Pointing Task to measure inhibition, cognitive flexibility, and spatial working memory, respectively, the researchers found that when the preschoolers were assessed on mathematic ability using the Child Math Assessment (CMA) measure, each executive functioning measure was significantly correlated with mathematic ability. Working memory and inhibition had the strongest correlations with and accounted for a significant portion of variance in mathematic achievement. However, the researchers also found that when all variables were accounted for, cognitive flexibility did not account for a significant portion of the variance in total mathematic achievement. The lack of evidence showing a relationship between cognitive flexibility and mathematics achievement is a recurring theme in literature as shown in studies such as Espy et al. (2004) and Blair and Rezza (2007). Furthermore, the researchers also found that the executive function measures were correlated to with each other, which highlights a challenge that arises in executive functioning studies. As there is a lot of overlap between the executive function abilities, it is difficult to precisely measure each ability independently.

Epsy et al. (2004) utilized two groups of preschool children in their study; one group of 66 typically developing preschoolers with mean age of 4.21 years; and another of 30 preschoolers who were born preterm at low neurobiological risk with a mean age of 3.76 years. While there were no differences found between typically developing preschoolers and those born preterm, the researchers found, like Harvey and Miller (2017), that all of the executive function measures were intercorrelated. Results showed that working memory and inhibition significantly contributed to mathematic achievement, while cognitive flexibility did not.

Furthermore, there have been several longitudinal studies that examined the role of executive functions in preschool in predicting mathematic achievement in later years. Blair and Razza (2007) recruited preschoolers from two Head Start programs and administered a peg-tapping measure of inhibition and an item-selection measure of cognitive flexibility. When the participants advanced to kindergarten, they were given academic achievement tests which included a mathematics knowledge section along with the same executive function measures they were given during the preschool year. The results showed that inhibition measured in preschool significantly predicted mathematics ability in kindergarten, while cognitive flexibility measured in those time-points did not produce the same longitudinal effect. The results of Clark, Pritchard, and Woodward (2010) paralleled those of Blair and Razza (2007) as they found that the cognitive flexibility measure did not correlate with later mathematics performance, while the children's performance on the inhibition condition task at preschool did predict performance of mathematics in later years. Similarly, Welsh, Nix, Blair, Bierman, and Nelson (2010) also found that the working memory and inhibition abilities assessed during the prekindergarten years significantly contributed to kindergarten mathematic achievement. These results provide significant evidence to show the importance of well-developed working memory and inhibition abilities and their capability of predicting mathematical achievement.

Bull, Espy, and Wiebe's (2008) study of how executive function in preschool predicted mathematic achievement in kindergarten yielded results that contrast with those of the previous studies discussed. The researchers found that that not only was working memory a good predictor of mathematic skills in preschool and later mathematic achievement, but that cognitive flexibility also predicted achievement in math at each individual timepoint. Though cognitive flexibility did not predict academic achievement over the course of the study, it is still interesting to see that it was found to predict achievement at each timepoint as previous studies failed to show a significant relationship between mathematic achievement and cognitive flexibility at single timepoints and longitudinally.

While the above studies showed the relationship between executive functions and mathematic achievement in preschool and kindergarten years, there have also been studies that explored the relationship in older children and produced similar results. For example, Lee et al. (2012) explored the relationship between executive functions, patterning abilities, and mathematics achievement in children aged six years and found that working memory had the highest significant correlation to mathematic achievement, as compared to inhibition and cognitive flexibility.

In a similar study, Van der Ven, Kroesbergen, Boom, and Leseman (2012) followed their sample from first grade to second grade and tested the children on multiple executive functioning measures in four waves, followed by mathematic achievement tests given three months after each wave. The study found that among the executive functions, only working memory significantly correlated with mathematic achievement in the second grade. A strange finding from the study was that inhibition was not found to predict mathematics abilities, which contrasts with other studies where inhibition was shown to significantly predict later mathematic achievement.

Overall, previous research has supported the claims that executive functions are the building blocks of thinking that are required for efficient problem solving, whether they be patterning or mathematics problems. However, the precise relationships between the variables are unclear and have not been examined extensively in kindergarten. The goal of this study was to directly examine the relationship between executive functions, patterning, and mathematic achievement in kindergartners. It was hypothesized that cognitive flexibility, working memory, and inhibition would correlate to and be significant predictors of patterning; the three executive functions (EF) would be related to mathematic achievement, with working memory having the strongest relationship; and all the measures of EF would be related to each other.

METHOD

Participants

Sixty kindergartners, 32 boys and 28 girls, were selected from elementary schools in the mid-Atlantic region. The schools' demographics were that around 71% were eligible for free or reduced cost lunches and ethnicities included around 2% American Indian/Alaskan, 8% Asian/Pacific Islander, 35% African-American, 31% Hispanic/Latino, 22% White, and 2% other. All kindergarten classrooms were included from the schools (13 total classrooms), except one. The children selected from testing were determined by their teachers to be proficient in English and did not have an Individualized Education Plan. Parental consent was obtained for the sample.

Materials and procedures

Testing was conducted during April-May. All participants were tested individually by research assistants during the school day in multiple sessions across the two months. The measures were given to the participants in random order. All testing was completed in a quiet location within the classroom or in a quiet hallway. Each of the sessions lasted approximately 10-15 minutes, depending on individual performances.

Patterning test.

A 24-problem patterning test was used to assess the ability of the participants to detect and complete patterns. The patterning test included six of each type of pattern:

ABAB, AABAAB, ABABBABBB, and symmetric patterns. Every participant was shown the patterns, one by one, and asked to choose what shape or object was to go in the blank, either in the beginning or the end, to complete the pattern. Each pattern was presented horizontally to the participants and they were asked to choose from four possible options below the sequence. Each response was recorded, and a correct response was given one score.

Kaufman Test of Educational Achievement, Third Edition (KTEA-3).

The Numeracy subtest of the KTEA-3 test was used to measure mathematical knowledge for participants. The Numeration subtest measures an individual's understanding of whole and rational numbers. It covers topics such as identifying, representing, comparing numbers. The subtest is grouped into three general areas of skills consisting of basic concepts (conceptual knowledge), operations .(computational skills), and applications (problem solving). The first 22 items of the Math Concepts and Applications subset where the participants applied math concepts, principles, and procedures to real-life situations was used along with 23 items from the Math Computation subset where the participants wrote solutions to addition and subtraction problems. Ceiling on the individual subsets was reached after four consecutive incorrect responses to the questions. Raw scores on the subsets of the KTEA-3 were used to compare math abilities to the other variables.

Day/Night Test.

This test is a measure of inhibition. Each participant was shown a total of 16 pictures of suns and moons in a counterbalanced order. Before beginning the task, the participants were instructed to say “day” when they saw the moon and say “night” when they saw the sun. The accuracy of their responses was divided by the total time it took to complete the test was calculated for the Day/Night inhibition score used in the analyses. The internal reliability of this measure is reportedly high with a Kuder-Richardson reliability of .93 (Chasiotis, Kiessling, Hofer, & Campos, 2006).

Head-Toes-Knees-Shoulders (HTKS).

This test is also a measure of inhibition. The participants were asked to play a game in which they were told to do the opposite of what the researcher said (e.g. touch their toes when the researcher said to touch their head). There were two parts to this measure. First, when the researcher instructed them to touch their heads, the participants were to do the opposite and touch their toes, and vice versa. After four practice trials and ten trials of testing, the researcher began the second part of the assessment by first coaching the participants to touch their shoulders when instructed touch their knees, and vice versa, which concluded with four practice trials. Lastly, ten trials were then administered and included all four instructions, i.e., head, toes, shoulders, and knees. Responses on every trial was recorded and two points were given to a correct response, 1 for self-corrected, and 0 for incorrect. Inter-rater reliability for this measure with preschool children is reportedly high (r = 0.95–0.98; Ponitz et al.,2008).

The Multiple Classification Card Sorting Task (MCCST).

This is a measure of cognitive flexibility. Participants were presented with 8 cards and each has an image of a different combination of color, shape, and size, e.g., a green apple, a red apple, a red flower, a green flower (Podjarny, Kamawar, Andrews, 2017). A researcher gave an example of sorting a practice set of cards on a 2x2 matrix so that same shapes and same colors were lying next to each other. After answering any questions, a shuffled deck of cards was handed to the participants and was instructed to sort the cards into four different piles, just as the researcher had demonstrated. The researcher started the timer as soon as the participant put the first card on the matrix and stopped the timer after the child put the last card down. After sorting, the participant was then asked for a reason for why he or she placed the cards in the manner they did. This was repeated with four sets of cards. The number of seconds the participants utilized for the whole task, the accuracy of the sorting on the matrix, and the justification given for the sorting task were recorded. The composite score for this measure was the sum of the sorting accuracy and justification score divided by the total time in seconds it took for all four sets, and then multiplied by 100. Reliability for this measure is high, with a Cronbach's alpha of .86 (Cartwright, Marshall, Dandy, & Isaac, 2010).

Corsi Blocks backwards.

This test was used as a measure of working memory. This assessment utilized nine numbered blocks randomly arranged on a board so that only the researcher could see the numbers on the blocks. Initially beginning with two blocks, the researcher tapped the blocks and the participants were instructed to tap blocks in the opposite order. Two trials were given per level, where 1 level is defined by the number of blocks in the sequence. The sequence length extended up to nine blocks until the participant failed to correctly tap the order on two consecutive trials on the same level. The responses for each trial was also recorded. The score for the task was the largest sequence that the child was able to reproduce. This task was successfully used to measure working memory in prior research with preschoolers (Collins & Laski, 2015, Bull et al., 2008) and the test-retest reliability for older children, aged 11–16, is r = 0.70–0.79 (Orsini, 1994).

Wechsler Intelligence Scale for Children- Revised (WISC-R) Digit Span.

This is a measure of working memory. The WISC-R Digit Span consists of two parts: Digits Forwards and Digits Backward. Only the Digits Backward was used for this study. After ensuring the participant understood the meaning of backwards, the researcher read aloud a string of numbers and the participants were instructed to repeat the numbers spoken by the researcher in the backwards order. This assessed the child's ability to retain and manipulate information received, utilizing the working memory. The assessment began with a two-digit sequence and extended to nine-digit sequences until the participant gave two consecutively incorrect responses in the same sequence length. Each correct response was given a point. The test-retest reliability for children aged 6–16 is r = 0.83 (Williams, Weiss, & Rolfhus, 2003).

RESULTS

Descriptive statistics were conducted on all the variables of interest (see Table 1). All variables were normally distributed except for math concepts and application which had a high kurtosis value. For all analyses, a sample of 60 kindergartners was used.

Bivariate Correlations

Pearson- product correlations were calculated among all the variables (see Table 2).

Patterning

There were a significant, positive correlations between patterning and the two mathematic measures, Math Concepts and Application, r(59) = .447, $p < .01$, and Math Computation ,r(59) = .410, $p < .01$. Patterning was also positively correlated to the measures of working memory, Digit Span, r(59) = .260, $p < .05$, and Corsi Block, r(59) = .389, $p < .01$, and the MCCST task which measured cognitive flexibility, r(59) = .416, $p < .01$. Among the two measures of inhibition, results found patterning to be significantly correlated to the HTKS, r(59) = .360, $p < .01$, but found no significant correlation between patterning and the Day/Night task, r(59) = .117, $p > .50$.

As the correlation coefficients are the effect size, defined as small, medium, and large by .10, .30, and .50, respectively (Cohen, 1992), the relationship between patterning and the two mathematic measures were medium effects. Further, the relationships between patterning and both the MCCST measure of cognitive flexibility and the HTKS inhibition task were also medium effects. The correlation between patterning and the Corsi Blocks measure of working memory was also a medium effect while the correlation with the digit span working memory measure and patterning was a small effect.

Executive Function Measures

Amongst the two measures of inhibition, Day/Night and HTKS, Day/Night was only significantly, positively correlated to Math Computation, r(59) = .275, $p < .05$, and the HTKS task, r(59) = .316, $p < .05$, both with medium effect sizes. The HTKS task was significantly correlated to both measures of mathematic achievement, Math Computation, r(59)= .530 $p < .01$, and Math Concepts and Applications, r(59) = .485, $p < .01$, with large and medium effect sizes, respectively. The HTKS was also significantly correlated to the Digit Span test, r(59) =.304, $p < .05$, the Corsi Block, r(59) =.632, $p < .01$, and the MCCST, r(59) =.480, $p < .01$. The Digit Span was positively correlated to Math Concepts and Application, r(59) =.290, $p < .05$, Math Computation, r(59) =.403, $p < .01$, and the Corsi Block, r(59) =.260, $p < .05$. The Digit span and the MCCST measures were not found to be significantly correlated to one another, r(59) =.179, $p > .05$. The Corsi Block was significantly correlated to the MCCST, r (59) =.550, $p < .01$, and Math Computation, r(59) =.548, $p < .01$, with large effect sizes, and also related to Math Concepts and Application, r(59) =.442, $p < .01$, with medium effect. Lastly, there were significant, positive correlations between the MCCST and the two measures of mathematic achievement, Math Concepts and Application, r(59) =.424, $p < .01$, and Math Computation, r(59) =.472, $p < .01$, with medium effect sizes.

Mathematics Measures

The two measures of mathematics achievement were significantly correlated with one another, r(59) =.797, *p* < .01, with a large effect size (see Table 2).

Table 1. Descriptive Statistics for Variables

	N	Mean	SD	Min	Max	Skew	Kurtosis
Patterning	60	13.37	5.56	3.00	22.00	-.265	-1.26
Math Concepts & Application	60	19.03	3.50	7.00	22.00	-1.77	2.99
Math Computation	60	14.70	5.68	.00	23.00	-.84	.197
Day/Night	60	.25	.12	.00	.52	-.08	-.068
HTKS	60	43.42	14.57	.00	59.00	-1.19	1.03
Digit Span	60	2.13	1.94	.00	7.00	-.56	-.39
Corsi Block	60	2.58	1.36	.00	5.00	-.54	.01
MCCST	60	7.42	4.54	1.09	20.21	1.11	.65

Table 2. Correlations Among Variables

	P	MCA	MC	D/N	HTKS	DS	CB	MCCST
Patterning	--	.447**	.410**	.117	.360**	.260*	.389**	.416**
Math Concepts & Application		--	.80**	.230	.490**	.290*	.440**	.424**
Math Computation			--	.28*	.53**	.40**	.55**	.472**
Day/Night				--	.32*	.10	.23	.225
HTKS					--	.30*	.63**	.480**
Digit Span						--	.26*	.179

Corsi Block	--	.550**
MCCST		--

*p<0.05 **p<0.01

Regression Analysis

Hierarchical linear regression analyses were conducted to examine which variables predicted patterning, and mathematic achievement. Composite variables were created for working memory and inhibition. The scores on the Digit Span and the Corsi Blocks tasks were averaged to form a composite Working Memory variable. The z-scores of the Day/Night and the HTKS tasks scores were averaged to create a composite Inhibition variable.

Preliminary analysis showed that all assumptions for regression were met, including tests of multicollinearity that found low levels of multicollinearity between the variables (VIF= 1.360 for inhibition, 1.389 for working memory, and 1.330 for cognitive flexibility).

Patterning and EF

Hierarchical multiple regression was performed to investigate the ability of executive functions (working memory, inhibition, and cognitive flexibility) to predict patterning performance. In the first step of hierarchical multiple regression, working memory was entered as a predictor. This model was statistically significant, $F(1, 58) = 10.848$, $p < .0,1$ and explained 15.3% of variance in patterning performance. After entry of inhibition at step 2, the total variance explained by the model as a whole increased to 17%, $F(2,57) = 5.841$, $p < .01$, however, inhibition explained an insignificant 1.7% of variance in patterning performance ($p > .05$). In step 3, cognitive flexibility was entered and contributed a significant 6.3% of variance ($p < .05$), which increased the total variance explained by the model to 23.3%, $F(3,56) = 5.67$, $p < .01$. In the final adjusted model, only cognitive flexibility was a significant predictor of patterning performance ($p < .04$; see Table 3).

Mathematics Achievement and EF

The ability of executive functions (working memory, inhibition, and cognitive flexibility) to predict math achievement was examined. A math composite variable was created by averaging the math computation and math concepts and application variables. This math composite variable was used as the dependent variable.

In the first step of hierarchical multiple regression, working memory was entered as a predictor. This model was statistically significant, $F(1,58) = 25.486$, $p < 0.001$, and explained 30.5% of variance in mathematic achievement. After entry of inhibition at step 2, the total variance explained by the model as a whole was 38.2%, $F(2, 57) = 17.653$, $p < 0.001$. The introduction of inhibition explained an additional 7.7% of variance in mathematic achievement, R^2 change= .077, $F(1,57) = 7.128$, $p < .05$. In step 3, cognitive flexibility was entered and contributed 4% of variance ($p > .05$), which increased the total variance explained by the model to 42.2%, $F(3,56) = 13.601$, $p < .01$. In the final adjusted model, only working memory and inhibition were significant predictors of mathematic achievement (see Table 4).

Table 3. Hierarchical Linear Regression Predicting Patterning from Inhibition, Working Memory, and Cognitive Flexibility

	R^2	Adj R^2	*B*	t
Model 1	.153	.138		
Working Memory			.391*	3.238
Model 2	.170	.141		
Working Memory			.325*	2.395
Inhibition			.146	1.081
Model 3	.233	.192		
Working Memory			.246	1.800
Inhibition			.057	.410
Cognitive Flexibility			.289*	2.143

$^*p<0.05$

Table 4. Hierarchical Linear Regression Predicting Mathematic Achievement from Inhibition, Working Memory, and Cognitive Flexibility

	R^2	Adj R^2	*B*	t
Model 1	.305	.293		
Working Memory			.553*	5.048
Model 2	.382	.361		
Working Memory			.410*	3.512
Inhibition			.312*	2.670
Model 3	.422	.391		
Working Memory			.348*	2.939
Inhibition			.241*	2.014
Cognitive Flexibility			.228	1.943

$^*p<0.05$

DISCUSSION

The results of this study somewhat supported the hypotheses. While the measures of cognitive flexibility, inhibition, and working memory were correlated to patterning, cognitive flexibility was found to be the only significant predictor of patterning performance while controlling for the effects of working memory and inhibition. The three EF's were also related to mathematic achievement, however only working memory and inhibition were significant predictors. Lastly, all the measures of EF's were correlated to each other, except the Day/Night measure of inhibition which was only significantly correlated to the HTKS measure of inhibition, and the Digit Span measure of working memory which was not correlated to the MCCST measure of cognitive flexibility.

The primary goal of this study was to examine the relationship between the executive function abilities of kindergartners and their performance on the patterning task. Though there were several significant correlations found between patterning performance and the executive functioning measures, when accounting for all three executive functions in a regression analysis, only cognitive flexibility significantly predicted patterning performance. This finding is similar to the results found in first grade studies relating cognitive flexibility and patterning performance (Schmerold et al., 2017, Bock et al., 2015, Bock et al., 2018), further providing support for the notion that the ability to smoothly switch perspective or attention from one pattern rule to another is vital in understanding and completing patterns.

The current study also found that unlike the Head-Toes-Knees-Shoulder measure of inhibition, which was significantly correlated to patterning performance, the Day/Night test of inhibition was not. This replicates Collins and Laski (2015) results which found HTKS to be related to patterning performance in preschoolers. Other studies that used different measures of inhibition such as Stroop Color-Word Test (Schmerold et al.,2017), Day/Night Test (Bock, 2015, Bock et al., 2018), Luria's Hand Game (Miller et al., 2016), and The Flanker Inhibitory Control and Attention Test (Harvey & Miller, 2017) also found no relationship between inhibition and patterning performance in preschoolers (Miller et al., 2016, Harvey & Miller, 2017) and first graders (Schmerold et al.,2017, Bock, 2015, Bock et al., 2018). This is a rather interesting finding that could be explained by the cognitive abilities of the different age groups and the relative difficulty of the inhibition measures. The Day/Night test was not correlated with patterning in the current study with kindergartners, nor in the studies with first graders. This leads to the assumption that the inhibition demands of the Day/Night test were not taxing enough for children aged five-seven. On the other hand, the HTKS test was significantly related to patterning performance among kindergartners and preschoolers. This not only indicates that the task demands of the HTKS were sufficient to produce an effect, but also highlights the sensitivity of the HTKS task in measuring inhibition. The current findings indicate that the inhibitory control required for the HTKS task was an essential ability needed to complete the various types of patterns utilized in the study.

Furthermore, patterning performance was significantly correlated to the two working memory measures, the Corsi Block and the Digit Span Backwards. When added to the regression model, working memory predicted a significant portion of the variance in patterning performance, until cognitive flexibility was entered into the model. Upon that, only cognitive flexibility significantly predicted patterning performance when controlling for the effects of working memory and inhibition. This contrasts with previous studies (Rittle-Johnson et al., 2013, Miller et al., 2016, Collins & Laski, 2015) where working memory was found to be a significant predictor of patterning performance in preschoolers. This dissimilarity could be accounted for by the age of the participants and the difficulty level of the patterning tasks. The three studies mentioned all utilized similar patterning measurements that required the preschoolers to duplicate, extend, and create simple repeating patterns with blocks, which would rely greatly on the ability of the preschoolers to retain and manipulate information while completing the patterning assessment. Given the complex patterns in the present study and the variety of the types of patterns, there were more demands on cognitive flexibility. Thus, it is viable to suggest that, when patterns are very complex, working memory has no effect independent of cognitive flexibility. Therefore, with the patterns of the present measure, differences in children's working memories made no difference in patterning performance independent of its relation to cognitive flexibility.

The overall results showed that mathematics achievement was significantly correlated to the measures of working memory, inhibition, and cognitive flexibility. In a regression, when accounting for all three EF's, mathematic achievement was only significantly predicted by working memory and inhibition. These finding are supported by research conducted in preschool (Epsy et al., 2004, Welsh et al., 2010, Bull et al., 2008, Harvey & Miller, 2017), first grade (Bull & Scerif, 2001, Lee et al.,2012), and second grade (Van der Ven et al., 2012**)**, who all found a significant relationship between working memory and mathematic achievement. This supports the idea that, for young children, the ability to hold and manipulate information in the mind while solving problems is important for satisfactory mathematic performance. The finding that inhibition was related mathematic achievement is also consistent with previous studies (Blair & Razza, 2007, Clark et al., 2010, Bull et al., 2008, Epsy et al., 2004, Harvey & Miller 2017). These studies examined the relationship of executive functions to mathematical proficiency in preschoolers (Epsy et al., 2004, Miller, 2017), as well as the relationship between developing executive functions in preschool to later mathematic achievement in kindergarten (Blair & Razza, 2007) and first grade (Clark et al., 2010, Bull et al., 2008). Given the similarity of the results found on the relationship of working memory and inhibition to mathematic achievement among studies where the age of the samples ranged from 4-7 years, it can be inferred that proficiency in mathematics in young children not only requires the ability to retain information in the working memory, but also demands the ability to inhibit impulses to answer a question based on guesswork.

Lastly, examining the correlations between the executive function measures found that the Day/Night measure of inhibition was uncorrelated to all the measures of executive function except the HTKS task measure of inhibition, which is similar to

Bock's (2015) finding that the Day/Night task was uncorrelated to working memory and cognitive flexibility. The MCCST measure of cognitive flexibility was not significantly correlated to the Day/Night test and the Digit Span backward test of working memory. This is similar to the results of Schmerold et al. (2017), who found that none of their executive function measures- MCCST, Digit Span, and Stroop color word test- were correlated to each other for first graders. On the other hand, the HTKS task significantly related to all the measures of executive function and the Corsi Block measure of working memory was significantly correlated to all the measures of executive function except the Day/Night test. This could suggest that the HTKS and the Corsi Block are more sensitive measures of inhibition and working memory, respectively, particularly for the younger age group.

These results have clear implications for classroom practice. The finding that working memory and inhibition are essential for mathematic achievement suggests that teachers may find it beneficial for students to focus on developing these cognitive abilities in order to improve mathematic performance.

Further, the results of this study suggest that a well-developed cognitive flexibility may be fundamental in successfully completing complex patterning tasks. Previous studies have shown that performance on complex patterns is related to mathematics (Schmerold, 2017) and that improving performance on complex patterns improves later mathematic performance (Kidd et al., 2013, Kidd et al., 2014, Pasnak et al., 2015). Therefore, young children who struggle in mathematics would further benefit from a curriculum that not only emphasizes understanding complex patterns but stresses the switching aspects of completing patterning tasks.

Limitations and Future Directions

As the Corsi Block and the HTKS were found to be more sensitive measures of working memory and inhibition, respectively, for this age group, future studies should incorporate these measures in upcoming work on the role of executive functions in patterning and mathematic achievement for kindergartners. Likewise, there was not a lot of variability found in the scores on the mathematic measures which could can affect the generalizability of the mathematics achievements results. Future research would benefit from a mathematics measure that tests the kindergartners on material that goes beyond what is taught in their class curriculum.

A limitation of this study is that the data on the socioeconomic and ethnicity status of the participants were not collected. Though the participants were from schools in the Northern Virginia area where many low-income and immigrant families from a large variety of cultures and ethnicities reside, the results may not generalize to other populations. Further, the effects, if any, of the gender of the participants was not included in the analysis, as the differences between genders was not a focus of this study. Looking at the gender differences, however, would provide more information on individual differences that may influence results, and is a direction that executive function and patterning research could go towards. Lastly, it is possible that some statistical power may have been lost due to the small sample size ($n = 60$). Future studies can incorporate a larger sample of kindergartners to study the role of executive functions in predicting patterning and mathematic achievement.

Conclusion

This is the first study to extensively examine the relationship that the executive functioning abilities have with patterning and mathematic achievement in kindergarten utilizing five different measures of executive functions. This study provides evidence that cognitive flexibility does predict patterning performance, and working memory and inhibition predict mathematic achievement. The results have implications for a classroom curriculum that emphasizes the development of these executive function abilities which would benefit elementary school children to excel in mathematics.

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