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Research Article

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Mathematics, Reading, and Selected Cognitive Abilities at the Beginning of Kindergarten

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Abstract

Cognitive abilities, executive functions (EFs) and patterning, and simple measures of early literacy and mathematics were measured for 275 kindergartners during the second and third month of formal schooling. An exploratory factor analysis revealed four factors. The first was a literacy factor, to which a number series scale made a small contribution. The second was primarily a mathematics scale, but also reflected early literacy. The ability to recognize patterns, working memory, and inhibition also contributed to this factor. A third factor involved cognitive flexibility, patterning, and literacy. Finally, there was a factor that essentially involved phonics. These results indicate that two EFs and patterning are related to early mathematics at the beginning of kindergarten when children have experienced little formal schooling. In addition, very early in kindergarten, there is a general achievement factor that does not reflect any of the cognitive abilities tested here.

Keywords: executive functions, literacy, mathematics, patterning

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Since Miyake et al.'s seminal paper published in 2000, executive functions (EFs) have received increased attention in the research literature, including research examining relationships between EFs and academic achievement [1-5]. Diamond defines EFs as "a collection of top-down control processes used when going on automatic or relying on instinct or intuition would be ill-advised, insufficient, or impossible" (p. 136) [6]. Three core EFs include working memory, inhibition, and cognitive flexibility. Working memory consists of the ability to temporarily hold and manipulate things in one's mind. Cognitive flexibility, also known as shifting or set shifting, is the ability to shift responses from using one dimension or rule to another according to task demands. Inhibition is the ability to suppress favored or natural responses to other responses more appropriate to the task at hand. These EFs are identifiable in preschoolers although they continue to develop rapidly and the relations between them also change rapidly [7-12]. They share common variance, but become increasingly differentiated as children mature [13,14].

Another thinking ability that develops naturally is patterning, the ability to recognize a series of items. Patterning, as used by educators, refers to repeating series of items, usually objects, that alternate, such as large small large small large small or disc triangle square disc triangle square or red red tan tan red red tan tan, or (recently) to geometric figures that "grow" (e.g., •, ••, •••). Recent studies involved still more types of patterns, including growing patterns, like ABABBABBB, as well as repeating patterns [15,16]. Hendricks et al. studied children's ability to understand sequences of items as an extension of seriation and termed it sequentiation [17]. Seriation is the ability to understand a series of items that increase or decrease in one dimension, such as size, and to insert items appropriately into that series [18,19]. Hendricks et al. used many types of series, which might ascend or descend (e.g., a c f h j or 9 8 7 6 5), be symmetrical, involve time or be causal, involve the steps in going on a picnic, for example, or involve some other rule. Such series may or may not involve things that children have been taught. Given equal familiarity with the items in a sequence, the ability to understand an orderly series may indeed be the important cognitive ability that Hendricks et al. thought it to be [17].

Cognitive Abilities and Academic Achievement

Recent studies suggest there is a relationship between EFs and academic achievement [3,4,5,20]. Several studies of preschool children indicate that early mathematics is correlated with the development of EFs [21-24]. Espy et al. showed that two EFs, working memory and inhibition, correlated with emergent mathematics abilities in preschoolers [9]. McClelland et al. found that preschoolers' working memory and inhibition (especially inhibition) were correlated with later mathematics and literacy [25]. Bull et al. also found that, for preschool children, working memory and inhibition were associated with later mathematics and reading achievement [8]. Bull et al. reported that the same was true for cognitive flexibility. Research suggests that there is a predicative relationship between kindergarten children's EF and future academic achievement [2, 20]. The relationships were predictive; that is, EF in preschool predicted achievement in elementary school. Blair and Razza also found that preschoolers' EFs, specifically inhibition and cognitive flexibility, were correlated with subsequent achievement in both mathematics and literacy [7]. In a study of simultaneous relationships, Harvey showed that for preschool children who were English Language Learners, working memory, inhibition, and mathematics were associated but cognitive flexibility was not [26].

In yet another study of predictive relationships, but this time for kindergartners, EFs predicted later mathematics achievement [27]. Nguyen and Duncan found that kindergartners' EFs predicted third-grade achievement in mathematics and reading, with a stronger association between EFs and mathematics than EFs and reading. Specifically, they found that there was a stronger association between working memory and academic achievement than between inhibition and cognitive flexibility and academic achievement [3]. Similarly, Morgan, Farkas, Hillemeier, et al. found that kindergartners' EFs, including working memory, inhibition, and cognitive flexibility, predicted mathematics, reading, and science achievement in second grade [20]. After reviewing literature examining correlations between EFs and mathematics and reading across the span of ages 5 to 17, Clements et al. concluded that EFs "are general cognitive process that significantly support academic learning" (p. 82) [28].

Researchers have also examined the relationship between children's patterning abilities and academic achievement. Hendricks et al. found in a randomized active control design that teaching patterning to first-grade children, who have a working knowledge of letters and numbers, produced substantial gains in mathematics and written language [17]. Subsequent research confirmed these findings with first graders on a variety of standardized tests [29-31]. In these studies, the results were more robust for early mathematics than for early literacy and depended to some extent on which standardized test was used. In their longitudinal study, Rittle-Johnson et al. found that patterning knowledge in preschool predicted mathematical achievement in fifth grade [32].

Executive Functions, Patterning, and Academic Achievement

In recent years, researchers have also begun to examine the relationship among EFs, children's patterning abilities, and academic achievement [33-35]. Strauss et al. evaluated the relationship between patterning and EFs at the end of kindergarten [36]. The children had been instructed on a mix of repeating patterns and sequential (growing or symmetrical) patterns or received control instruction in mathematics, literacy, or social studies for several months in a randomized design. There were no differences in achievement in literacy or mathematics. All EFs were intercorrelated and also correlated with literacy, mathematics, and patterning. The latter correlated with both literacy and mathematics. A factor analysis showed that working memory, one inhibition measure, patterning, mathematics, and two literacy measures involving knowledge of initial sounds loaded on the same factor. The other three literacy measures (phonemes and word recognition) and a second inhibition measure constituted a second factor, and four cognitive flexibility measures comprised a third factor.

For first-grade children, there is also evidence of simultaneous relationships between EFs and academic achievement. Bock et al. showed that inhibition correlated with a reading comprehension measure, whereas working memory correlated with both reading comprehension and fluency [34]. Bock also measured first graders' patterning ability and found that it was correlated with cognitive flexibility and working memory. The relationship between patterning and cognitive flexibility supported findings from their earlier study [37]. Schmerold et al. pursued the relationship between patterning, EF, and both reading and mathematics for first graders [35]. Patterning at the end of first grade was related to cognitive flexibility, working memory, reading, and mathematics. Regression analyses and structural equation modeling showed that the effect of cognitive flexibility was entirely mediated by patterning, while working memory had independent effects as well as effects moderated by patterning.

Purpose of Present Study

The missing evidence concerns the relations between EFs, patterning, and early literacy and mathematics at the *beginning* of kindergarten. Ascertaining these relations between the naturally developing cognitive abilities expressed in EFs and patterning and emergent literacy and mathematics before the children have received formal instruction in the public schools was the goal of the present study. These relations between the cognitive abilities children first bring to the classroom and their level of mathematics and reading achievement may be particularly important in informing classroom practices. Clements and Sarama note that because of the rapid development of EFs in the early years, "educators need to use research to provide environments, curricula, and experiences that develop these processes, especially for children at risk due to developmental delays or low entering competencies" (p. 765) [38]. Therefore, the purpose of this present study was to examine the relationships among the three core EFs (i.e., working memory, inhibition, and cognitive flexibility), patterning ability, literacy achievement, and mathematics achievement at the beginning of kindergarten.

The hypotheses tested were as follows:

1. At the beginning of kindergarten, working memory, inhibition, cognitive flexibility and patterning all comprise a common factor denoting cognitive ability.
2. Working memory, inhibition, cognitive flexibility, and patterning are related to early literacy.
3. Working memory, inhibition, cognitive flexibility, and patterning are related to early mathematics.
4. Early literacy and early mathematics are related to each other only through their relationship to cognitive ability.

Method

Participants and Setting

Participants were kindergarten students from 23 kindergarten classrooms in five public elementary schools in the mid-Atlantic region. Informed consent was obtained from parents of 275 children, 116 males and 159 females. If a child had an Individualized Education Program, they were excluded from the study. The school district website provided the following demographics for the students enrolled: 5.25% Asian, 25.78% Black, 37.29% Hispanic, 28.31% White, <1% Native Hawaiian/Pacific Islander, <1% Native American, and 3.04% Multi-racial. The website also states that 56% of students were eligible for free or reduced-price meals. These confidential data were not available for individual children.

The academic year in the cooperating school system began after Labor Day. Kindergarten teachers spent the first month of kindergarten helping the children become accustomed to the school environment, learning classroom rules and appropriate behavior, and building rapport.

Measures

Mathematics Tests

Mathematics was measured by the Woodcock-Johnson III Math Concepts Scales 10, 18A and 18B (WJ 10, WJ 18A and WJ 18B). The WJ-III has convergent validity coefficients of 62–.66 with the Kaufman Test of Educational Achievement and 68–.70 with the Wechsler Individual Achievement Test [39-41].

Early Literacy Tests

Literacy skills were measured with the DIBELS Letter Naming Fluency (LNF) and Initial Sound Fluency (ISF) scales and with the Test of Early Reading Ability-3 (TERA). For LNF children had one minute to name as many letters as they knew from a list. They were scored on the number of letters they tried and the number they got correct. For ISF children had to identify which picture from sets of pictures began with a certain sound. They received two scores: the number of correct responses and the number correct per second. The average predictive validity of kindergarten ISF for the Woodcock-Johnson Broad Reading Cluster was .36 [42]. Validity coefficients for the DIBELS were .34 (December) and .44 (April) with the Woodcock Johnson Readiness Cluster Score.

At the beginning level of the TERA children are to read words that label pictures or to select words that have been read to them from among an array of alternatives. The test-retest reliability for this test is .88-.92 [43].

Working Memory Test

The Corsi Blocks test was used to assess students' visuospatial short-term memory. The researcher tapped a series of blocks in a particular order and then the students were instructed to tap the blocks in the same order. Orsini reported correlations ranging from .70-.79 with the Wechsler Intelligence Scale for Children-R Digit Span scale [44].

Patterning Test

The patterning test could be administered in about 15 minutes. Each of the 30 pages presented a pattern horizontally, with the pattern displaying at the top and four answer choices below it. There was a total of 30 patterns; 6 patterns were ABABA?, 6 patterns were ABBAB?, 6 patterns were ACEFH? (skip-one), 6 patterns were ABCCB? (symmetric), and 6 patterns were ABABBABB? (growing). The patterns were comprised of pictures of objects, shapes, letters, numbers, and clocks, and the missing element was at the beginning or end equally often. See Figure 1 for examples.

Figure 1: Examples of Patterning from the Patterning Test

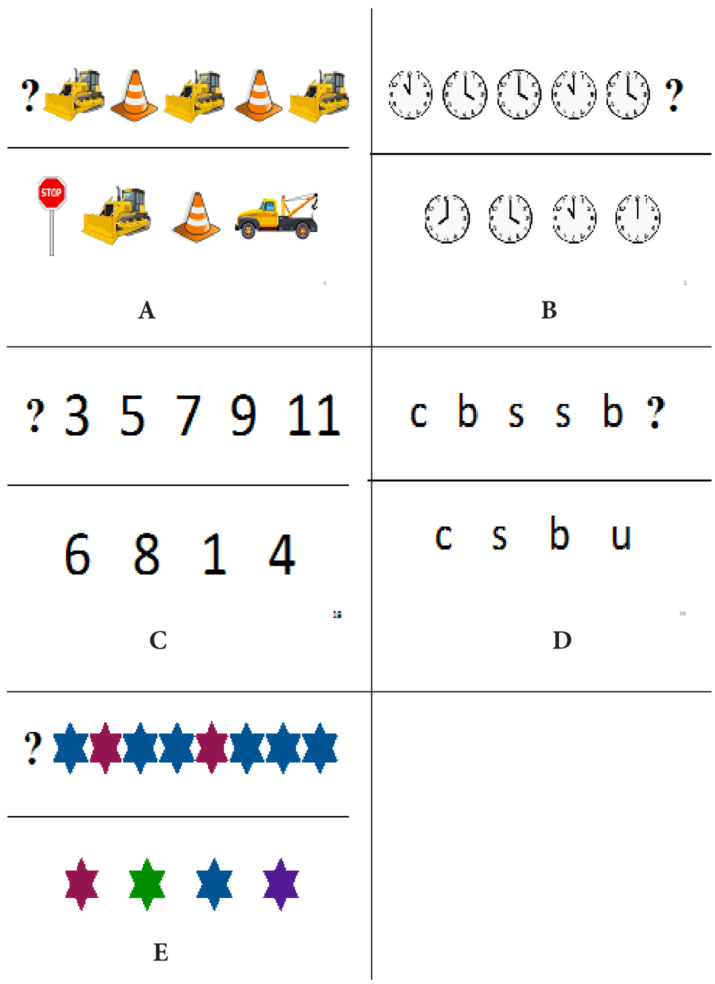

Figure 1: This figure gives examples of patterns that were used in the patterning test. (A) An ABAB pattern presented with objects. (B) An AABBABB pattern presented with pictures of clocks. (C) A skip-one pattern presented with numbers. (D) An ABCCBA (symmetric) pattern presented with letters. (E) An ABABBABBB

(growing) pattern presented with colored shapes.

Cognitive Flexibility Test
The Multiple Classification Card Sorting Task (MCCST) was used to measure cognitive flexibility. There are five sets of 12 cards: one set is an example set and the other four sets are used for the test. The task includes sorting the 12 cards into four categories in a 2X2 matrix. The two dimensions include the type of object pictured on the card and the color of the object pictured on the card. The colors and objects pictured differ for each set. For example, one card may have a brown saw, another card may have a yellow trumpet, another card may have brown flute, and another card may have a yellow hammer. All of the brown tools are placed into one pile, yellow tools are placed in another pile, brown instruments placed in another pile, and yellow instruments placed in the last pile. After the first set was demonstrated for the students and any questions were answered, the students were asked to sort each set of cards. The they were asked to justify why they sorted their cards that way. Each students score was determined by their accuracy, the time they took to complete the sets, and how they justified their sorting. Cronbach's alpha reliability for this measure is .86 [45].

Inhibition Test
The Day-Night task is an executive functioning test used as a measurement of interference control. The students were instructed to say "day" when presented with a card that had a picture of the moon on it. They were also told to say "night" when presented with a card that had a picture of the sun. The time it took for a child to answer correctly was the child's score. Chasiotis et al. reported a Kuder-Richardson internal reliability of .93 for the Day-Night test [46].

Procedure
The tests were administered in a counterbalanced order from late September through early October. No child took more than one test per day.

Analysis and Results
An exploratory factor analysis (EFA) was conducted using oblique rotation and minimal residual estimation algorithm for all baseline measures to determine the latent structure of the measures. The goal was to determine whether all measures were related to a common factor. Allowing for oblique rotation provided the most stringent assessment of the covariance structure for a single factor model. All analyses were conducted in R (version 4.0.4) using the psych package (version 1.9.12.31). Additionally, a test for simple structure was conducted to see if a single factor solution would be likely.

Four factors were extracted (see Tables 1 and 2). These results indicate that a single factor solution was not likely given the complexity of the correlations between the measures. Further, despite the failure to find a single factor, a factor solution was found that fit well (non-significant Chi-square and sufficiently low error with RMSE below 0.05).

Table 1: Exploratory Factor Analysis: Standardized Loadings

Exploratory	Factor		Analysis		Standardized		Loadings
	MR1	MR2	MR3	MR4	h2	u2	com
Pattern	0.02	0.35	0.29	-0.02	0.28	0.72227	2.0
TERA	0.29	0.36	-0.06	0.08	0.39	0.61477	2.1
DIBELS 1st Sounds	0.16	0.38	-0.02	0.46	0.70	0.30118	2.2
DIB_RightPerMin	-0.01	-0.02	0.02	1.01	1.00	0.00416	1.0
DIB LettersNamed	0.98	0.02	-0.01	0.02	1.00	0.00051	1.0
DIB LettersTried	0.96	-0.02	0.03	-0.01	0.90	0.09797	1.0
WJ10 Applied Math	-0.07	0.83	0.03	0.03	0.67	0.33460	1.0
WJ18A Concepts	0.12	0.73	0.00	0.02	0.67	0.32704	1.1
WJ18B NumberSeries	0.28	0.47	0.04	-0.02	0.47	0.52605	1.6
Inhibition Time	0.10	-0.30	-0.21	-0.04	0.16	0.83769	2.0
Flex_Sort_Accuracy	0.00	0.00	0.76	-0.01	0.58	0.42377	1.0
Flex_Sort_Justify	-0.03	0.14	0.60	0.00	0.43	0.56945	1.1
Flex_Sort_Ratio	0.02	-0.03	0.97	0.02	0.93	0.06779	1.0
Corsi Memory	-0.05	0.36	0.15	-0.05	0.15	0.85255	1.4

Note: A high score on the inhibition time measure is a poor score, so significant inhibition correlations are negative.

Table 2: EFA Model Fit Summary Statistics

	MR1	MR2	MR3	MR4
SS loadings	2.32	2.47	2.13	1.39
Proportion Variance	0.17	0.18	0.15	0.10
Cumulative Variance	0.17	0.34	0.49	0.59
Proportion Explained	0.28	0.30	0.26	0.17
Cumulative Proportion	0.28	0.58	0.83	1.00

Correlations between the four factors ranged from .21 to .62. These are shown in Table 3

Table 3 : Correlations Between the Factors Extracted from the EFA

	MR1	MR2	MR3	MR4
MR1	1.00	0.62	0.21	0.49
MR2	0.62	1.00	0.38	0.53
MR3	0.21	0.38	1.00	0.28
MR4	0.49	0.53	0.28	1.00

In sum, four factors emerged. Factor MR 1 is primarily a literacy factor, reflecting the TERA and DIBELS Letter Naming scales, with some contribution from the WJ number series scale. Factor MR 2 is primarily mathematics, but also reflects the other two literacy scales and patterning, inhibition, and working memory. The third factor consists of inhibition, cognitive flexibility, and patterning. The fourth reflects two DIBELS first sounds literacy scales.

Discussion

The hypothesis that the EF and patterning comprised a common factor was not verified. Working memory loaded only on factor 2, and cognitive flexibility loaded only on factor 3. Both inhibition and patterning did load on both factors 2 and 3 and inhibition cognitive flexibility and patterning on factor 3, indicating some degree of commonality at the outset of kindergarten.

The data also show that early literacy and mathematics are related. The first factor is essentially an early academic achievement factor, reflecting primarily literacy but also mathematics, that is relatively independent of the thinking abilities represented by EF and patterning. Hence, they are probably the products of other kinds of cognitive abilities, and probably affected in some cases by parental and/or preschool instruction in numbers and the alphabet.

The WJ 18B mathematics scale consists of series of numbers that follow increasingly complex rules. The scale has previously been shown to be affected by instruction on complex patterns and might be expected to be related to the patterning measure used here [30,47]. However, the scale's loading on factor 2, which does reflect the current patterning measure, is not much more than half that of the other mathematics scales, and it makes an independent contribution to Factor 1, which reflects literacy but not patterning. Possibly the commonality the scale shares with literacy reflects the hypothesis of Manning et al. that kindergartners feel that there are predictable sequences in sentences [48]. This possibility awaits future investigations.

Factor 2 involved both literacy measures (DIBELS and TERA) and, mathematics (all three scales). Hence, the relation of EF to the early literacy and mathematics of beginning kindergartners is primarily the ability to refrain from natural but inappropriate responding when required to do so and the ability to hold and manipulate information in their minds. The ability to recognize patterns in sequences of a variety of items also contributes to both literacy and mathematics. This finding supports the ideas advanced by Sarama and Clements regarding early literacy and by many researchers regarding mathematics [38, 49].

Cognitive flexibility was not found to be an important part of any factor involving literacy or mathematics. In this, the findings are similar to those of Strauss et al. for a different sample of children at the end of their kindergarten year [36]. They also support the analysis of Schmerold et al. for first graders [35]. Those researchers found that cognitive flexibility played no role in literacy or mathematics once its relation to patterning was accounted for statistically.

There is also a phonics factor, as represented by the DIBELS first sounds measures that is also relatively independent of EF and patterning. There is really no evidence of its origination in these data, but it is not related to the natural abilities measured here. This factor probably reflects another instruction effect, again resulting from efforts by some parents or preschool teachers to teach phonics.

Limitations and Conclusions

The generalizability of this research is limited by the sample of children from whom measurements were obtained. The sample was very diverse ethnically and largely from families with low socioeconomic status (SES). More than half of the children were eligible for subsidized lunches. A sample from schools serving children from primarily middle-class families might yield different results. Offsetting this in part is the fact that because the measures were taken early in the kindergarten year, these children did not reflect the impacts of formal schooling. However, children from higher SES might be more likely to have experienced preschool, which could not be assessed here.

Another limitation is the measures used. Although the WJ, TERA, and DIBELS are respected and commonly used instruments, different measures could produce different results [29,30]. These measures are a limitation of virtually all research in early education.

The diversity of EF measures that researchers employ is a particular problem. There are many different measures of working memory and of inhibition, and they have produced different results in previous research by other investigator [12,50,51]. There are also different measures of cognitive flexibility, although most involve a card sort of items varying in two dimensions [52].

Finally, each team of researchers has used its own set of patterns. Those used in the present research include most types that other researchers have used, but it is a truism that different measures can produce different results.

Despite these limitations, which are inherent in any research in early education the present research has produced some important findings. It is the only research showing relations between EF, patterning, literacy, and mathematics at the very beginning of formal schooling. The most striking finding is that there is a general achievement factor which does not reflect EF or patterning. Second, there is a second factor that reflects mathematics, two EF (inhibition and working memory), and patterning. Third, cognitive flexibility as measured by a card sort and patterning load on a factor that does not involve literacy or mathematics. Finally, it is of some interest that phonics loaded on a factor which did not involve other literacy measures or any cognitive measure.

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