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The effect of executive functions on early mathematical skills: a structural equation model

El efecto de las funciones ejecutivas sobre la competencia matemática temprana: un modelo de ecuaciones estructurales

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ABSTRACT

Although the role of executive functions in childhood mathematics learning has been extensively studied, there is no consensus on the specific contribution of each executive function in the development of early mathematical skills. This study aimed to determine the validity of a structural equation model of the executive functions of verbal working memory, behavioral inhibition, cognitive inhibition, cognitive flexibility, and planning to explain the variability in the level of development of early mathematical skills in children in kindergarten. We implemented a cross-sectional design of descriptive correlational cut, in which 130 students in the second cycle of early childhood education participated, 64 girls (49.2%; M=66.50 months, SD=7.95 months), 66 boys (50.8%; M=65.30 months, SD=8.10 months), belonging to four Chilean schools. We used five executive tasks and a test of early mathematical skills for the assessments. We performed descriptive analyses, correlations, and structural equation modeling to determine the combined statistical effect of executive functions on early mathematical skills. The results show that the five executive functions explain 57.3% of the variability of the scores achieved by children in early mathematical skills, highlighting the role of verbal working memory, cognitive flexibility, and planning. These results represent a significant contribution to current knowledge on the executive functions that may explain the differentiated performance in mathematics of children in early childhood education, providing relevant information to teachers regarding the executive demands necessary for each mathematical skill, which may favor the integration of teaching strategies that incorporate the stimulation of executive functions in classroom work, thus promoting improvements in the learning of this disciplinary area.

Keywords: working memory, inhibition, cognitive flexibility, planning, mathematical skills, childhood education

RESUMEN

Si bien el rol de las funciones ejecutivas en el aprendizaje de las matemáticas en la infancia ha sido largamente estudiado, no existe consenso respecto del aporte específico de los distintos componentes de las funciones ejecutivas en el desarrollo de las competencias matemáticas tempranas. El objetivo de este estudio fue determinar la validez de un modelo de ecuaciones estructurales de las funciones ejecutivas de memoria de trabajo verbal, inhibición conductual, inhibición cognitiva, flexibilidad cognitiva y planificación para explicar la variabilidad del nivel de desarrollo de las competencias matemáticas tempranas de niños y niñas de Educación Infantil. Se implementó un diseño transversal de corte descriptivo correlacional, en el cual participaron 130 estudiantes de segundo ciclo de Educación Infantil, 64 niñas (49.2%; M=66.50 meses, DT=7.95 meses), 66 niños (50.8%; M=65.30 meses, DT=8.10 meses), pertenecientes a cuatro centros educativos chilenos. Para las evaluaciones se utilizaron cinco tareas ejecutivas y un test de habilidades matemáticas tempranas. Se realizaron análisis descriptivos, correlaciones y modelos de ecuaciones estructurales, para determinar el efecto estadístico combinado de las funciones ejecutivas sobre las habilidades matemáticas tempranas. Los resultados evidencian que las cinco funciones ejecutivas explican el 57.3% de la variabilidad de las puntuaciones alcanzadas por los niños y niñas en las competencias matemáticas tempranas, destacando el rol de la memoria de trabajo verbal, la flexibilidad cognitiva y la planificación. Estos resultados suponen una importante contribución al conocimiento actual sobre las funciones ejecutivas que explican el desempeño diferenciado en matemáticas de niños y niñas de Educación Infantil, aportando información relevante a los docentes respecto a las demandas ejecutivas necesarias para cada habilidad matemática, lo que puede favorecer la integración de estrategias de enseñanza que incorporen la estimulación de las funciones ejecutivas en el trabajo de aula, promoviendo así mejoras en el aprendizaje de esta área disciplinar.

Palabras clave: memoria de trabajo, inhibición, flexibilidad cognitiva, planificación, habilidades matemáticas, educación infantil

INTRODUCTION

Mathematical performance is a basic instrumental skill for all educational systems. However, it is estimated that the rate of school-age children facing mathematical learning difficulties ranges between 1 and 7 % (Mammarella et al., 2021). These problems generally appear early, and continue over time (Chu et al., 2016) and despite this evidence, there is little identification for it within Early Childhood Education, meaning that learning difficulties are often undetected until after several years in school, increasing its persistence (Zhang et al., 2019).

In order to foresee these problems, there have been sizable efforts at the school level in recent decades to strengthen the so-called early mathematical skills of children in Early Education, since these are considered fundamental skills for learning the discipline and arise as a potent, stable predictor for academic achievement in both mathematics and other areas (Devlin et al., 2022).

From a theoretical standpoint, early mathematical skills include the abilities to understand, evaluate, and use mathematics in various intra- and extra-mathematical situations and contexts where they are needed (Cerda et al., 2012). Current theoretical positions about these mathematical skills broaden the reductionist focus of emphasizing only the development of relational logic skills as a basis for numbers acquisition (Piaget, 1965). Authors like Van de Rijt and Van Luit (1998) proposed an interactionist focus to explain the development of early mathematical skills, integrating logical thinking or Piaget operations into the development of numerical skills, such as subitization, counting experience, or general number knowledge (Barrouillet & Camos, 2003).

The present study intends to understand, conceptualize, and operationalize the early mathematical skill construct, with the skills to resolve a set of tasks in these two areas (Cerda et al., 2012). There will be a definition of eight elementary domains for early mathematics, namely comparison, classification, correspondence, seriation, verbal counting, structured counting, resultant counting, and general number knowledge, all of which are homologized to the structure of the early mathematical evolution scale used in this study (Van Luit & Van de Rijt, 2009).

Various authors have concluded that all these skills are developed at an early age, before entering school, and that they are a requirement to be able to follow a formal mathematical education (Aragón et al., 2015; Wongupparaj & Kadosh, 2022), since they are the basis for more advanced skills which help continue with acquiring more complex mathematical knowledge and skills in later school stages (Devlin et al., 2022; Purpura et al., 2017). This makes it important to evaluate children in Early Education, where the basis of future learning takes shape.

While there are authors who say that early mathematical skills predict future results, even more than the cognitive skills of the subject (Chu et al., 2016), others have centered on describing how the presence of higher cognitive processes at an early age can predict or at least explain differentiated mathematical performance (Cheung & Chan, 2022; Morgan et al., 2019), which has opened a fruitful line of research in order to examine possible precursor variables for early mathematical skills, especially within the realm of executive functions.

Executive functions and mathematical skills

Various studies have focused on determining the executive functions which can play a relevant role at an early age in acquiring and developing mathematical skills (Cheung & Chan, 2022; Wongupparaj & Kadosh, 2022), showing that children who begin Early Education with better executive skills have a mathematical performance advantage which can persist during their school years (Bernal-Ruiz et al., 2020).

Executive functions are higher-order cognitive processes which order and direct all cognitive and behavioral operations (Diamond, 2020) and are composed of at least three related, but distinct, cognitive domains. They allow individuals to exert greater control over information processing and behavior (Morgan et al., 2019). These are working memory, inhibition, and cognitive flexibility (Diamond, 2020; Miyake et al., 2000). Working memory implies simultaneous maintaining and manipulation of information during task execution (Allen et al., 2021); its content can be verbal or visuo-spatial (Diamond, 2020). Inhibition is the ability to annul a dominant or overwhelming response in favor of a more adaptable one (Diamond, 2020), and is itself divided into behavioral and cognitive inhibition, with the former related with impulse management and self-control and the second with selective attention (Diamond, 2020).

Finally, cognitive flexibility integrates focus, maintenance, and flexible adaptation to changing objectives or stimuli (Arán & Krumm, 2020). Planning and problem solving arise from these three components (Diamond, 2020).

On these grounds, various studies have indicated the significant role played by executive functions in developing mathematical skills, contributing empirical evidence on the close relation between both constructs (Cheung & Chan, 2022).

Within the components of executive function, Morgan et al. (2019) studied working memory, cognitive flexibility, and inhibition among kindergarteners as predictors for their academic achievements during second grade, concluding that the three components of the executive functions could significantly and positively predict achievements in reading, math, and science. In turn, Purpura et al. (2017) indicate that inhibition is widely related with emerging aspects of mathematics, and working memory is related with more complex aspects, while cognitive flexibility concerns the more conceptual or abstract components of this discipline. Simanowski & Krajewski (2019) concluded that working memory as a first factor and inhibition and cognitive flexibility as a combined factor showed a strong association with number base elements.

Amongst the executive function components, working memory stands out as a fundamental variable for mathematical problem solving and for developing skills in this area (Allen et al., 2021). In the study by Aragón et al. (2021) analyzing general and specific domain precursors of informal mathematical skills, working memory was the most relevant predictor. For Fung et al. (2020), verbal working memory is the executive function with the strongest direct relation with mathematical skills in early ages. Similarly, cognitive flexibility emerges as a predictive factor in longitudinal studies, as it explains a significant amount of mathematical performance variation during early primary school years (Magalhães et al., 2020).

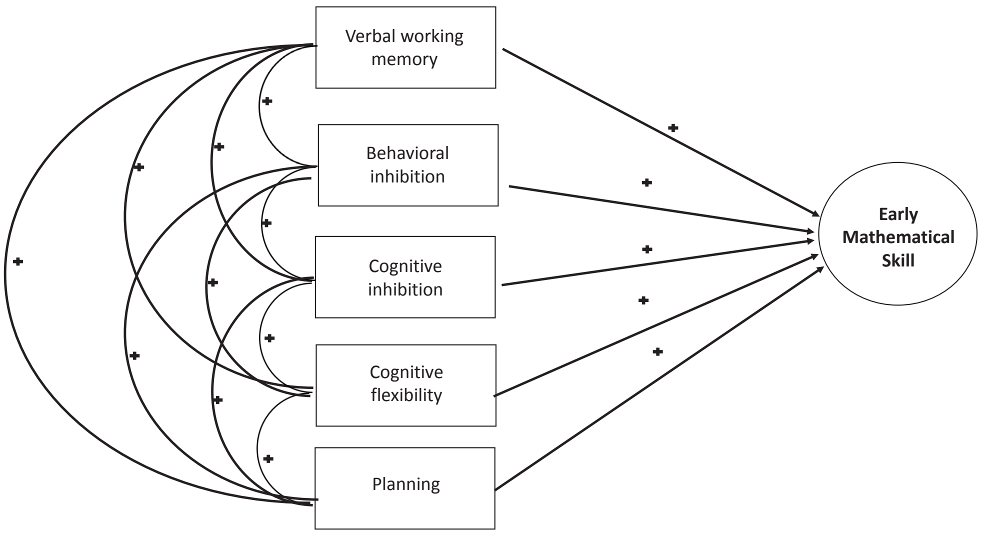
Despite the abundance of international studies about the relation between various components of executive functions and early mathematical skills, there is a limited body of evidence considering the specific role of executive function components in the specific domains of mathematics (Allen et al., 2021; Arán & Krumm, 2020). Most have examined relations between executive functions and general academic results in this discipline, using only a broad consideration of mathematics without considering that this discipline includes multiple components with varying cognitive complexity, making it fundamental to specifically know the underlying executive processes for each of them.

Considering this background, it is necessary to ask: Is it possible to establish a model where reciprocal interaction between executive function components (i.e. verbal working memory, behavioral inhibition, cognitive inhibition, cognitive flexibility, and planning) can explain varying development levels for early mathematical skills in the logico-relational and numerical dimensions, which examine tasks for comparison, classification, correspondence, seriation, verbal counting, structured counting, resultant counting, and general number knowledge, among children between 4 and 6 years old? Do any of these executive function components have a greater impact when explaining this variability?

The proposal is to examine the validity of a complex interaction model as a function of the aforementioned theoretical background, as illustrated in Figure 1. This model proposes that the variables for verbal working memory, behavioral inhibition, cognitive inhibition, cognitive flexibility, and planning are reciprocally, significantly, and positively interrelated, and that they in turn have a direct and positive relation with the scores achieved by children in early mathematical skills.

Figure 1

Hypothetical Structural Equation Model for Early Mathematical Skills



The following hypotheses are presented on the basis of the preceding paragraphs:

H1: There is a covariation between verbal working memory, behavioral inhibition, cognitive inhibition, cognitive flexibility, and planning as independent variables explaining much of the score variations in early mathematical skills.

H2: Verbal working memory is the most important predictor when explaining the percentage of variability explained by the set of executive function components regarding performance in early mathematical skills among children in Early Education.

H3: The five executive function components are positively and significantly related with performance in early mathematical skill among children in Early Education.

METHOD

Research design

As a function of the objectives and hypotheses, the research assumes a quantitative paradigm with a correlational descriptive character, and a cross-sectional design, since the fundamental intention is to establish a relational predictive model for the various executive function components regarding early mathematical skills among children in Early Education.

Participants

The present study involved 130 students in the second cycle of Early Education, 64 girls (49.2%; M=66.50 months, SD=7.95 months) and 66 boys (50.8%; M=65.30 months, SD=8.10 months), belonging to four urban educational centers in the region of Valparaíso, Chile, of which two were charter establishments (N=89; 68.5%) and two were public (N=41; 31.5%). The latter two are funded entirely by the State, and mainly receive students with high social vulnerability. To determine students' social vulnerability in Chile, information is gathered from databases available from various public organisms, and a student vulnerability index (SVI) is assigned to schools according to the vulnerability of the students which enter them, which is directly proportional to student poverty levels. Therefore, higher student poverty leads to a higher SVI for the educational center. This index includes 23 indicators, such as the students' geographical zone, poverty condition, school diet, crowding, parents' education level and occupation, dental aspects, and more.

The exclusion criteria were: (a) any neurodevelopmental disorder diagnosis, (b) receiving medical or psychopharmacological treatment which can affect performance in the tasks applied for executive function and early mathematical skills, and (c) families not authorizing study participation.

Instruments

To evaluate executive functions, a battery of five tasks was defined with adequate psychometric properties for scientific research (Kurgansky, 2022).

To evaluate Verbal Working Memory, we used the "*number inversion*" task from Batería IV COG by Woodcock-Muñoz (Woodcock et al., 2019), which is applied among children ages 2 and up. This task presents subjects with a series of 2 to 8 digits (5 tries each one), after which they must repeat the numerical sequence in inverse order. It lasts around 5 minutes and has a Cronbach's α of .84.

To evaluate Behavioral Inhibition, we used the *"Bzz! inhibition"* test from the TENI Neuropsychological Evaluation Test (Tenorio et al., 2012) for children ages 3 to 9. In this test, an electronic screen shows various bees which fly around making noise, which the child must squash during 1 minute by pressing them with a finger. After this, the subject is told that for a time (five minutes) they will be alone, and they must not touch the screen to squash the bees which continue making noise while flying across the screen. The child must then inhibit the desire to squash the bees and follow the instructions given. The result of this task is evaluated by whether or not the child was able to inhibit the bee-squashing action. If they could not stop, they are evaluated for how long they took to touch the screen again and how many times they did so. The test lasts 7 minutes, and has a Cronbach's α of .9.

To evaluate Cognitive Inhibition, we used the Stroop "Sun-Moon" task (Archibald & Kerns, 1999). This task includes two paper pages with images of suns and moons randomly placed into files and columns. The first page is the congruent condition, where children must say "sun" for images with suns and "moon" for images with moons during 45 seconds. The second page is the incongruent condition, where children must say the opposite of the drawing they say as quickly as possible, saying "moon" when they see a sun and "sun" when they see a moon. The inhibition measurement is the sum of correct run-throughs of the incongruent condition. Its duration is around 3 minutes. This task has a high reliability level, with test-retest scores of .91 for the incongruent condition.

To evaluate Cognitive Flexibility, we used the *"Dimensional Change Card Sort" (DCCS)* test (Zelazo, 2006). In this test, children have to classify bivalent cards according to different rules (shape or color). Afterwards, the classification rule changes as a function of a mark on the cards. The test measurement is the number of correctly classified cards. The DCCS lasts around 7 minutes and has a Cronbach's α of .94.

To evaluate Planning, we used the Porteus Maze Test (Porteus, 1965), consisting of 12 labyrinths on paper with increasing difficulty. It lasts for 5 minutes and presents adequate internal consistency, with a Cronbach's α of .81 (Krikorian & Bartok, 1998).

Finally, to evaluate Early Math Skills we used the Early Numeracy Test (ENT) (Van Luit & Van de Rijt, 2009) previously adapted for Chile (Cerda et al., 2012), whose objective is evaluating early numerical knowledge, as well as detecting students with mathematical learning difficulties. It has 40 graphic items on paper, with a maximum score of 40 points – one for each correct item. The average test application time is 30 minutes, and it must be administered individually. The ENT evaluates 8 components of early mathematical education: comparison, classification, one-to-one correspondence, seriation, verbal counting, structured counting, resultant counting, and general number knowledge. The Cronbach's α of the Chilean version is .91.

The test application order begins with the cognitive flexibility test. The subsequent order is: verbal working memory, cognitive inhibition, early mathematical skill, planning test, and finally the behavioral inhibition test. This is done in order to facilitate motivation, since the longest test (the mathematical test) is in the middle, and the final test is on the electronic device, which gets the most attention from children.

Procedure

An informative letter was initially sent to 6 educational centers in the region of Valparaíso, Chile, which have an agreement with the professional practice/internship department of the sponsoring University, in order to request authorization to perform the study on their premises. In the 4 centers which agreed to participate, meetings were held with the families of Early Education students in order to explain the objective, characteristics, and scope of the study, as well as to obtain authorization to carry out the study with their children via signing informed consent.

Students who were authorized by their families to participate in the study and who gave their own assent were individually evaluated on their executive functions and their early math skills by two psychologists with cognitive evaluation experience, in two sessions of around 30 minutes each in a quiet room during the school day. Pauses took place between tests to avoid fatigue or tiredness affecting results.

The present study implemented all procedures in accordance with the guidelines from the Singapore Declaration on Research Integrity (World Conferences on Research Integrity, 2010). Authorization was also obtained from the Research Ethics Committee of the sponsoring University.

Data analysis

In order to establish the characteristics presented by each of the variables examined, we began with descriptive analyses, with determinations of central trend measurements, variability, maximums, minimums, and confidence intervals, along with kurtosis and asymmetry indices for the general sample. Correlation analyses were also determined between all variables via the Pearson coefficient. Finally, to represent the interaction between the five independent variables and early mathematical skill we opted to perform a structural equation model. To analyze the hypothetical model (see Figure 1), the maximum robust likelihood (RML) estimation model was used, due to the mainly ordinal nature of the analyzed data (Flora & Curran, 2004). Similarly, a set of various indices was analyzed to place the suitability of the proposed model in contrast, highlighting the χ^2 statistic, the comparative fit index (CFI), the non-normalized fit index (NNFI) and the root mean square error of approximation (RMSEA).

The data analysis software used was SPSS® along with EQS statistical software, version 6.2.

RESULTS

To begin, the study variables' univariant descriptive statistics were determined (see Table 1).

Table 1

Medians (M), standard deviations (SD), confidence Interval (C.I.), maximums and minimums, asymmetry, and kurtosis of variables

Variables	M	SD	C.I.	MIN-MAX	Asymmetry	Kurtosis
Verbal Working Memory	2.17	2.83	1.68-2.67	0 – 10	1.011	-0.168
Behavioral Inhibition	10.80	6.58	9.66-11.95	2 - 19	-0.260	-1.694
Cognitive Inhibition	18.76	8.47	17.28-20.25	0 - 40	-0227	0.023
Cognitive Flexibility	8.59	5.54	7.62-9.56	0 - 16	-0.371	-1.023
Planning	132.49	39.69	124.52-138.46	59 - 171	-0.673	-1.108
EMS (*) Comparison	4.18	0.95	4.01-4.34	1 – 5	-1.129	0.907
EMS Classification	2.29	1.30	2.07-2.52	0 – 5	0.243	-0.243
EMS Correspondence	3.17	1.21	2.96-3.38	0 – 5	-0.410	-0.308
EMS Seriation	2.12	1.49	1.86-2.38	0 – 5	0.305	-0.801
EMS Verbal Counting	1.22	1.32	0.99-1.45	0 – 5	0.736	-0.514
EMS Resultant Counting	2.15	1.64	1.87-2.44	0 – 5	0.227	-1.158
EMS Structured Counting	1.96	1.39	1.72-2.20	0 – 5	0.279	-0.855
EMS General Number Knowledge	2.03	1.49	1.77-2.29	0 – 5	0.400	-0.759
EMS Total	19.12	7.94	17.74-20.50	4 - 38	0.223	-0.825

Note. (*) Early Mathematical Skills

In order to observe the type of relation between each of the five executive functions with the scores achieved in each of the mathematical skill dimensions, both logico-relational and numerical, we used the Pearson correlation coefficient. The correlation matrix, in turn, indicates that the five analyzed executive functions present significant positive associations with total early math skill scores, as well as with each of the specific dimensions and domains of this early mathematical skill. There is also a notable and significant positive relationship between the dimensions of the logico-relational and numerical skills with total early mathematical skill (see Table 2).

Table 2
Pearson correlation matrix for Executive Functions with Early Mathematical Skill

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Verbal Working Memory	1	.148	.280**	.399**	.277**	.221*	.313**	.393**	.562**	.568**	.497**	.625**	.535**	.656**
2. Behavioral Inhibition		1	.194*	.220*	.071	.209*	.233**	.175*	.128	.214*	.096	.141	.034	.203*
3. Cognitive Inhibition			1	.315**	.328**	.240**	.304**	.216*	.211*	.294**	.152	.308**	.297**	.347**
4. Cognitive Flexibility				1	.149	.198*	.333**	.307**	.360**	.379**	.280**	.392**	.386**	.459**
5. Planning					1	.209*	.264**	.416**	.350**	.201*	.180*	.277*	.266**	.370**
6. EMS (*) Comparison						1	.251**	.188*	.213*	.271**	.239**	.255**	.236**	.414**
7. EMS Classification							1	.539**	.487**	.474**	.410**	.537**	.400**	.706**
8. EMS Correspondence								1	.512**	.445**	.495**	.530**	.459**	.716**
9. EMS Seriation									1	.588**	.488**	.530**	.504**	.760**
10. EMS Verbal Counting										1	.593**	.626**	.585**	.799**
11. EMS Structured Counting											1	.655**	.477**	.761**
12. EMS Resultant Counting												1	.601**	.839**
13. EMS General Number Knowledge													1	.948**
14. EMS Total														1

Note. * $p < .05$; ** $p < .01$; (*) Early Mathematical Skill.

Finally, in order to respond to one of the study objectives and hypotheses, an analysis was done on the initial hypothetical structural equation model which examined the relations between the five executive functions considered as independent variables and early mathematical skill, considered as a dependent variable with a latent character (see Figure 2).

Figure 2

Structural Equation Model of Executive Functions related with components of Early Math Skill

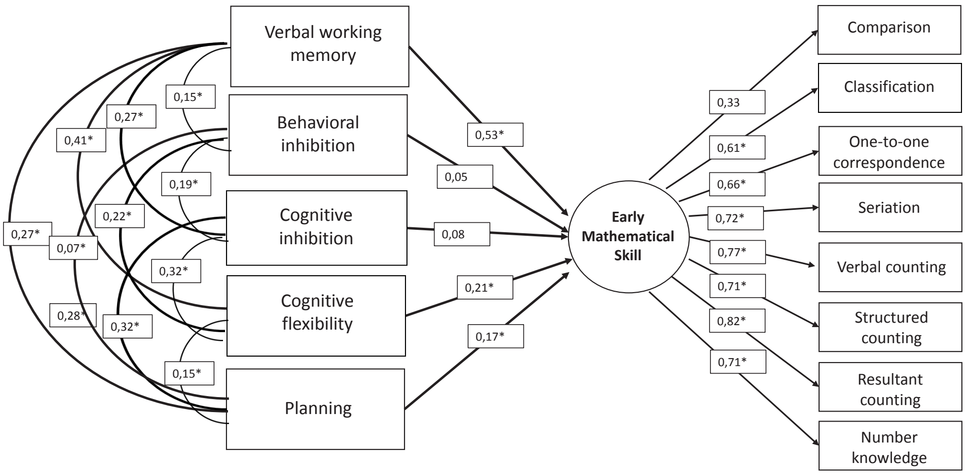


Figure 2 shows the graphic solution of this model where the five executive functions explain 57.3% of variability in the total scores achieved in early math skill (EMS). The model also shows adequate χ^2 fit indices (54) = 76.7; p <.05, CFI = .959; NNFI = .940, RMSEA = .058; IC (.022 - .085).

Based on the analysis of the standardized model regression coefficients, there is evidence of a significant positive relation between EMS and verbal working memory (β=.53; p<.05), cognitive flexibility (β=.21; p<.05), and planning (β=.17; p<.05). However, there is no observably significant relation between EMS and behavioral inhibition (β=.05; p>.05) or cognitive inhibition (β=.08; p>.05). Despite this latter point, there are observable positive covariations between the five executive functions examined.

Table 3 shows the relations between the executive functions analyzed and EMS, as well as the standardized beta values, standard error, and the variables' confidence intervals.

Table 3

Standardized coefficients, standard errors, and confidence intervals of the variables

			Standardized β	Standard Error	z	p-value	C.I.	
Verbal Working Memory	→	EMS	.532	0.064	8.293	.000***	0.40	0.65
Behavioral Inhibition	→	EMS	.049	0.067	0.72	.471	-0.08	0.18
Cognitive Inhibition	→	EMS	.075	0.073	1.03	.300	-0.06	0.21
Cognitive Flexibility	→	EMS	.213	0.073	2.91	.003**	0.06	0.35
Planning	→	EMS	.169	0.069	2.42	.015*	0.03	0.30
Comparison	←	EMS	.328	0.083	3.94	7.885e-05***	0.16	0.49
Classification	←	EMS	.606	0.059	10.20	.000***	0.48	0.72
Correspondence	←	EMS	.656	0.053	12.19	.000***	0.55	0.76
Seriation	←	EMS	.716	0.046	15.28	.000***	0.62	0.80
Verbal Counting	←	EMS	.773	0.039	19.41	.000***	0.69	0.85
Structured Counting	←	EMS	.717	0.046	15.34	.000***	0.62	0.80
Resultant Counting	←	EMS	.822	0.033	24.44	.000***	0.75	0.88
General # Knowledge	←	EMS	.711	0.047	15	.000***	0.61	0.80
Total EMS		EMS	.426	0.058	7.33	2.176e-13***	0.31	0.54

Note. *$p < .05$; ** $p < .01$; *** $p < .001$; EMS = Early Math Skill

DISCUSSION AND CONCLUSIONS

The objective and the principal hypothesis of this study was to generate a model of the complex interaction of five executive functions as predictors of variability in early mathematical skill among children in Early Education, via a structural equation model. This involved contrasting a hypothetical model as a function of theoretical understanding and empirical background about how verbal memory works, behavioral and cognitive inhibition, cognitive flexibility, and planning are all positively and significantly related with developing EMS in its relational and numerical logic domains. The evidence helped corroborate this background and consolidate the relevance of these cognitive skills in the subsequent development of more complex mathematical skills. These findings align with prior studies supporting the relation between executive functions, mainly working memory and cognitive flexibility, and mathematical performance among children in Early Education (Cheung & Chan, 2022).

It was confirmed that a relevant percentage of variability in the variability of scores achieved due to the successful resolution of the comparison, classification, one-to-one correspondence, seriation, verbal counting, structured counting, resultant counting, and general number knowledge tasks can be attributed to the covariation of the five executive functions analyzed. Furthermore, each one of them in particular presents relations with a bivariate positive and significant character, partially confirming our first hypothesis. In other words, successfully resolving tasks linked with these executive functions, especially those tied with verbal working memory, cognitive flexibility and planning, help to secure and achieve better comparative performance in logico-relational and numerical tasks for mathematical skills in Early Education.

In particular, the initially hypothesized model showed adequate fit indices and an explained variability percentage, with a relevant role for verbal working memory (confirming our second hypothesis) followed by cognitive flexibility and planning. In this sense, verbal working memory has been recognized as an important predictor for childhood mathematical performance (Allen et al., 2021; Cheung & Chan, 2022). Studies such as the one by Cheung & Chan (2022) concluded that verbal working memory is closely tied with mental calculations and problem solving among children in Early Education. Similarly, Purpura et al. (2017) found that verbal working memory among Early Education students was associated with performance on complex math tasks involving multiple steps, such as comparing numbers and problem-solving. Passolunghi et al. (2008) concluded clearly that the main mathematical predictor in first grade was the phonological loop. This predictive role of verbal working memory is probably grounded in the fact that students have to store, recover, and integrate variegated information when performing mathematical activities (Bull & Lee, 2014).

Cognitive flexibility also arose as an important EMS predictor, in line with prior studies supporting the relation between this executive function component and math performance among children in Early Education. These include Yeniad et al. (2013), who reported that cognitive flexibility can significantly predict math performance in children between 4 and 13 years old, and González-Castro et al. (2014), who reported differences among primary school children with ADHD when comparing quantities and informal calculations which could be associated with working memory and executive function deficits, and not with specific math learning problems. Buttelmann & Karbach (2017) also indicated that cognitive flexibility training based on task changing can be a key factor for math performance as well as in improving other executive functioning components in childhood. Stad et al. (2018) concluded that cognitive flexibility is closely tied with childhood math performance, since math requires changes between different arithmetical task aspects.

Our findings also present planning as a good mathematical predictor, confirming that math studies require managing the steps to achieve specific objectives and solve problems (Purpura et al., 2017). Studies in Latin American contexts confirm our finding, such as Arroyo et al. (2014), who concluded that planning skills are significantly related with math problem solving in Argentinean students; and Agudelo et al. (2016), who showed that planning has a fundamental role in mathematical task performance for Uruguayan students.

Finally, neither cognitive or behavioral inhibition appeared to be significant EMS predictors in the hypothetical model. However, the background of the positive and significant bivariate relations between each of them and the scores achieved by students for EMS allows us to conjecture that its effect could not be captured by the small sample size, particularly when the confidence intervals for the standardized β values are broad. Studies have also confirmed that these two executive function components are not only associated with incremental working memory performance, given that they act as a filter for relevant information (Cueli et al., 2020); there is also support for their significant relation with various types of early mathematical tasks such as counting, subitizing, correspondence and numerical sets, among others (Cheung & Chan, 2022; Purpura et al., 2017).

Together with the prior elements, the bivariate correlation matrix allowed us to verify the significant and positive relation of each of the five executive function components with EMS and verify the validity of the third hypothesis, as other studies have shown before (Cheung & Chan, 2022).

While this study offers interesting results, there are some limitations worth indicating, such as sample size and selection. This took place as a function of accessibility, considering the issues with doing tests in a pandemic context after long lockdown periods, which according to some authors negatively affects both cognitive and social development (Arantes de Araújo et al., 2021).

The conclusions which we have reached must be analyzed based on the limitation imposed by using measurements and tasks which do not always coincide in various studies, which can explain some differences observed in the specific contribution of each executive function component in EMS (Peres & Vargas, 2021).

Despite these limitations, we believe that this study will contribute to future research seeking to strengthen mathematical learning, using strategies which help stimulate executive functions which have been shown to predict performance in this area from an early age, including verbal working memory, cognitive flexibility, and planning. We hope to contribute in this way to pertinent interventions to approach problems in developing math skills in Early Education, providing teachers with relevant data about the executive demands needed for each math skill, thus helping promote better learning of this material.

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