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RESEARCH ARTICLES

Predictive Capacity of Working Memory and Inhibition in Early Mathematical Skills

Capacidad predictiva de la memoria de trabajo e inhibición en las competencias matemáticas tempranas

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Summary

Early mathematical competencies have a great impact on academic performance and on the development of more complex mathematical skills, especially in early education. Several authors have highlighted the importance of working memory and inhibition in the development of these mathematical skills; however, there is no agreement regarding the explanatory capacity of these executive domains with respect to differentiated performance in mathematics. The aim of this research was to evaluate the predictive capacity of verbal and visuospatial working memory and of behavioral and cognitive inhibition in mathematical competencies of relational logic and numerical type in 106 Chilean children of early education between 4 and 6 years old, who were evaluated with four executive tasks and an early mathematical assessment test. For data analysis, correlations and multiple linear regressions were performed. The results showed that verbal working memory was a relevant predictor of both logical-relational and numerical mathematical competencies. These findings are relevant for the educational system, especially for early education, as they confirm that as children advance in their educational trajectory, their working memory is strengthened and with it their mathematical performance.

Keywords: Mathematical competencies; Executive functions; Working memory; Inhibition; Early education.

Resumen

Las competencias matemáticas tempranas tienen un gran impacto en el desempeño académico y en el desarrollo de habilidades matemáticas más complejas, especialmente en la educación inicial. Diversos autores han puesto de manifiesto la importancia de la memoria de trabajo e inhibición en el desarrollo de estas habilidades matemáticas, no obstante no existe un acuerdo respecto de la capacidad explicativa de estos dominios ejecutivos respecto al desempeño diferenciado en matemáticas. El objetivo de esta investigación fue evaluar la capacidad predictiva de la memoria de trabajo verbal y visoespacial y de la inhibición conductual y cognitiva en las competencias matemáticas de tipo lógico relacional y numéricas de 106 niños/as chilenos de educación inicial de entre 4 y 6 años, quienes fueron evaluados con cuatro tareas ejecutivas y un test de evaluación matemática temprana. Para el análisis de los datos se realizaron correlaciones y regresiones lineales múltiples. Los resultados mostraron que la memoria de trabajo verbal fue un predictor relevante tanto de las competencias matemáticas lógico-relacionales como de las numéricas. Estos hallazgos son relevantes para el sistema educativo, especialmente para la educación inicial, en tanto confirman que a medida que los/as niños/as avanzan en su trayectoria educativa, su memoria de trabajo se fortalece y con ello también su desempeño matemático.

Palabras claves: Competencias matemáticas; Funciones ejecutivas; Memoria de trabajo; Inhibición; Educación inicial.

INTRODUCTION

The importance of mathematics for any educational system is undeniable, since it is known that mathematical knowledge favors the understanding of reality and contributes to the choice of appropriate strategies for problem solving, and, in turn, favors the development of critical and autonomous thinking in students (Ministry of Education of Chile [MINEDUC], 2018). Hence, the importance of enhancing mathematical skills, since these are in constant development from the first years of life (Alsina, 2012) and stimulating them becomes fundamental if we want to reduce the prevalence of children with difficulties in learning mathematics, which, in the Latin American context, is of the order of 6 to 7% of the school-age population (Presentación et al., 2015).

In other words, good future mathematical performance can be developed and fostered from childhood, the so-called early mathematical skills (EMS), as there is evidence that they are an important predictor of academic performance at later educational levels (Duncan et al., 2007; Jordan et al., 2007). There is even evidence that they influence literacy performance and/or reading skills in school (Claessen et al., 2009; Claessens & Engel, 2013).

At a theoretical level, the EMSs integrate the abilities to understand and use mathematical procedures and concepts in the resolution of problems of various kinds, both intra- and extra-mathematical (Poma-Santivañez et al., 2021). In turn, this construct recognizes that logical operations and counting skills contribute significantly to mathematical development in childhood (Cerda et al., 2012) and therefore, eight domains are proposed that lay the foundation for early mathematics, such as: comparison, classification, correspondence, seriation, verbal counting, structured counting, resultant counting and general knowledge of numbers. The first four correspond to logical-relational skills (LRMS) and the following to numerical skills (NMC). Domains, which in turn, are homologous to the structure of the early mathematics assessment test used in this study (Cerda et al., 2012; Van de Rijt et al., 1999).

Mathematical skill is developed from the first years of life, since mathematical skills evolve towards greater complexity as cognitive development progresses (Alsina, 2012). Consequently, it is relevant to assess EMSs at an early age as they form the basis of the skills that enable the acquisition of more complex mathematical knowledge and skills in later school stages (Cerda et al., 2011) and, therefore, knowing its early development could favor the design of teaching strategies that favor the learning of this important disciplinary area.

However, multiple pieces of evidence link mathematics performance with students' executive functions (EF), demonstrating that the latter are a facilitating factor for learning this discipline (Blair & Razza, 2007; Presentación et al., 2015; Ruiz et al., 2019; ten Braak et al., 2022). For this reason, the study of the relationship between both variables constitutes an interesting objective, since there is evidence that EFs are significant predictors of mathematics in early education and may be fundamental for the development of early mathematical skills (Schmitt et al., 2017; ten Braak et al., 2022).

EFs defined as a set of mental processes that allow us to pay attention and stay focused, reason and solve problems, exercise the process of choice, discipline and self-control with the objective of avoiding impulsivity, and at the same time, adapt flexibly to changes or new information through which independent, purposeful and productive activities can be developed (Diamond & Lee, 2011; Muchiut et al., 2021). In this regard, they are higher order cognitive functions that allow us to adapt to changing contexts based on anticipation and prediction to reduce the uncertainty of the environment and favor our biological, individual and social adaptation (Tirapu-Ustárroz et al., 2018).

From a theoretical point of view, it is also known that EF is a multidimensional construct that includes at least three dimensions: inhibition (INH), cognitive flexibility (CF), and working memory (WM) (Diamond, 2013; Miyake et al., 2000). It should be noted that in this research we will focus specifically on the contribution of WM and INH in the development of EMS in early childhood education.

WM is defined as a system of limited capacity, whose function is to temporarily store and at the same time, manipulate information needed to perform tasks or carry out complex mental processes (Baddeley et al., 1986; Hernández-Torres et al., 2021; Rojas, 2017). These tasks refer to learning, reasoning, reading comprehension and mathematical skills. One of the main characteristics of this executive domain is active memory, since it transforms information and permanently updates its contents. Moreover, from Baddeley's (2012) model, WM has 4 components: the visuospatial agenda, which is responsible for maintaining and manipulating visual and spatial information; the phonological loop, whose function is the maintenance and manipulation of verbal and auditory information; the episodic buffer that stores temporal information from the phonological loop, the visuospatial agenda and the long-term memory; and the central executive that is in charge of performing control and strategy selection operations, integrating the information coming from the three previous components (González-Nieves et al., 2018; De Vita et al., 2022).

INH is defined as the ability to control impulsive responses and disregard distracting factors present in the environment, in other words, it involves the control of attention, behavior, and thoughts or emotions to override an internal predisposition or an attractive external stimulus (Canet-Juric et al., 2021; Diamond & Lee, 2011). Thus, INH has three main functions: (a) the suppression of actions that are inappropriate in a given context, (b) the omission of information that was relevant, but may not be currently relevant, and (c) the avoidance of interference of non-relevant information in WM while executing a task (Damasio et al., 2012; Hernández-Torres et al., 2021).

According to Diamond (2013), INH is divided into two types: behavioral INH (INHCon), related to self-control and resistance to temptations; and cognitive INH (INHCog), related to selective attention and interference control.

By virtue of the above, EFs are not only important for mathematical achievement, but also play a relevant role in learning to write (Altemeier et al., 2006; Arán & Richaud, 2015; Falabella et al., 2018), in literacy (Allan & Lonigan, 2011; Welsh et al., 2010) and in overall academic performance (Reyes et al., 2015). Therefore, knowing their evolution and stimulating them in early stages of development is key to successful school performance (Bernal-Ruiz et al., 2020; Fonseca et al., 2016; Hernández-Suárez et al., 2021).

In light of this background, multiple research studies have linked EF to mathematical performance in childhood (Blair & Razza, 2007; Cueli et al., 2020; Mazzoco et al., 2022; Presentation et al., 2015; Ruiz et al., 2019; ten Braak et al., 2022). For example, ten Braak et al. (2022), concluded that EFs are a factor facilitating the acquisition of mathematical knowledge and skills and at the same time, influence the prediction of academic achievement trajectories, through the self-regulatory behaviors linked to students' learning at the early education stage. Basically, these authors explain the differentiated performance in mathematics on the basis of a better development of EF in childhood.

Additionally, other research has concluded that both WM and INH are closely related to mathematical competencies at an early age, and specifically to mathematical learning and the emergence of difficulties in the area (Li & Geary, 2013; Presentación et al., 2015; Viterbori et al., 2015). For example, Viterbori et al. (2015), evidenced that WM is a significant predictor of mathematical performance and that it also has a relevant role in problem solving in early education. Similarly, other studies concluded that WM was strongly associated with the use of more sophisticated problem-solving strategies and consequently with good mathematical performance (Bull et al., 2008; Holmes & Adams, 2006; Ruiz et al., 2019).

In addition, recent research has shown that both verbal working memory (VWM), linked to the phonological loop, and visuospatial working memory (VSWM), linked to the agenda, are important executive domains in mathematical learning in childhood (Allen et al., 2021; Caviola et al., 2020; De Vita et al., 2022). However, there is no consensus on the specific contribution of these executive domains to the development of EMSs. For example, De Vita et al. (2022), concluded that visuospatial skills are the most closely related to mathematical knowledge at the preschool stage and that they play a fundamental role during the later stages of mathematical learning. Caviola et al. (2020) pointed out that VWM is a reliable and specific predictor of mathematics achievement. In contrast, Allen et al. (2020), concluded that VSWM is the domain that most contributes to the acquisition of mathematical skills during the early stages of schooling and the following year, these same authors pointed out that the relationship between VSWM and mathematics is stronger than that between VWM and mathematics (Allen et al., 2021). These results suggest that further research is needed on the contributions of WM subcomponents to the development of mathematical skills in childhood.

Some authors have highlighted the predictive power of INH in the area of mathematics over that of MT (Coulanges et al., 2021; Cueli et al., 2020), since they have emphasized that this executive domain would collaboratively influence children's ability to solve problems and simple mathematical operations at different stages of education (Agostino et al., 2010; Risso et al., 2015; Traverso et al., 2021), especially in the preschool stage, highlighting the important role of the INH for the execution of mathematical operations in pre-school education (Blair & Razza, 2007; Presentation et al., 2015). Indeed, Blair and Razza (2007) revealed that INH, at age 5, predicted mathematical performance the following year. Similarly, Presentation et al. (2015), highlighted that this executive domain as well as VWM are closely related to mathematical skills at early ages. Finally, Coulanges et al. (2021) found that INH contributes to the acquisition of fundamental mathematical content, which would explain the relationship between this executive domain and academic results in this area.

Ultimately, while there are numerous studies that have explored the role of EF in the development of mathematical skills in childhood, the results remain inconsistent and inconclusive (McClelland et al., 2014; De Vita et al., 2022). This points to the need to objectify the existing information by specifically investigating the predictive capacity of the VWM and VSWM and the INHCog and INHCon in the different dimensions of the EMS, to provide relevant information to educators on the specific cognitive demands of each mathematical competency and thus promote learning in this discipline.

Considering the multidimensionality of EF (Miyake et al., 2000) where each executive domain could predict in different ways the different mathematical skills (McClelland et al., 2014; Rosas et al., 2017), it is worth asking what is the predictive capacity of WM and INH on EMS of pre-school children?

In this regard, and considering recent research on this topic, we expect to observe a statistically significant predictive capacity of both executive domains on the development of children's EMS. Specifically, it is expected that WM will be a significant predictor of logical-relational and numerical mathematical skills and that INH will be a predictor only of numerical skills.

Based on the above-mentioned information, the main objective of this study was to determine the predictive capacity of WM, both verbal and visuospatial, and of INH, both behavioral and cognitive, in early mathematical skills of a logical-relational type (i.e., comparison, classification, seriation and correspondence) and of a numerical type (i.e., verbal counting, structured counting, resultant counting and general knowledge of numbers) in preschool children.

METHOD

Type of Study

A non-experimental ex-post-facto design was used. In this type of design there is no manipulation of the independent variables, since the results have been obtained when the data are collected, both for the dependent and independent variables. In addition, the prospective nature is added to the design by incorporating a predictive study, which requires the definition of the role of both dependent and independent variables (Bruna & Gil, 2017). In this case, the predictive capacity of WM and INH in the EMSs of children in the early stage was established.

Participants

The sample included 106 pre-school children, of whom 50 were from pre-kindergarten (47.2%) (males N= 22, mean age= 5.01, DE 0.31; females N= 28; mean age = 4.89, SD 0.42) and 56 were from kindergarten (52.8%) (males N= 25, mean age = 6. 05, SD 0.48; females N= 31; mean age = 5.96, DE 0.33), belonging to public (N= 20, 18.9%), private (N=14, 13.2%) and subsidized (N=72, 67.9%) Educational Establishments (EE) of the Valparaíso region, Chile (See Table 1).

Table 1.
Description of participants

Course		Public EE		Subsidized EE		Private EE	
		Participants (N = 20 (18,9%))		Participants (N = 72 (67,9%))		Participants (N = 14 (13,2%))	
Prekinder	Sex	Men	Women	Men	Women	Men	Women
N=50 (47,2%)		*N*=3 (2.8%)	*N*=5 (4.7%)	*N*=17 (16%)	*N*=18 (17%)	*N*=2 (1.9%)	*N*=5 (4.5%)
	Age	5.08 (0.38)	4.96 (0.41)	5.01 (0.32)	4.82 (0.35)	4.87 (0.17)	5.03 (0.67)
Kinder	Sex	Men	Woman	Men	Woman	Men	Woman
N=56 (52,8%)		*N*=6 (5.7%)	*N*=6 (5.7%)	*N*=13 (12.3%)	*N*=24 (22.6%)	*N*=6 (5.7%)	*N*=1 (0.9%)
	Age	6.19 (0.34)	6.11 (0.33)	5.89 (0.50)	5.93 (0.33)	6.26 (0.49)	6.19 (0.34)

Note. Children (N = 106).
Source. Elaborated by the author.

The exclusion criteria were, first, to present a neurodevelopmental disorder (i.e., ASD, ADHD, language disorders, among others). Secondly, to be taking medications that affect performance in the variables evaluated. Finally, they did not want to participate in the research work, or their family members had not authorized them to do so.

Instruments

To assess mathematical skills, the Chilean version (Cerda et al., 2012) of the Early Numeracy Test (ENT) by Van Luit and Van de Rijt (2009), which focuses on the assessment of mathematical skills in their logical-relational and numerical dimensions, was used (Cerda et al., 2012). This test can be applied from 4 to 7 years of age, it has 40 items, and its application lasts an average of 30 minutes. Its Cronbach's alpha is .91 (Cerda et al., 2012).

Four tasks were used for the assessment of EF. VWM was assessed using the "number reversal" test of the Woodcock-Muñoz IV Battery of Cognitive Skills (Woodcock et al., 2019). This test is administered from the age of 2 years and involves the repetition of number sequences in reverse order to that in which they were presented. Its Cronbach's alpha is .87 (Woodcock et al., 2019).

Por su parte, The VSWM was evaluated with the subtest "Torpo el Topo Torpe" of the TENI (Child Neuropsychological Assessment Test) (Tenorio et al., 2012), which is applied to children between 3 and 9 years of age, who must remember the sequence in which a mole appeared in a grid of tunnels arranged on the screen of an electronic device that increases in complexity every two correct guesses. Its reliability coefficient is .9 (Tenorio et al., 2012).

The INHCog was assessed with the Sun-Moon Stroop task (Archibald & Kerns, 1999). This test consists of two pages of stimuli, both with rows and columns of color pictures of moons and suns. On the first page, the evaluee is asked to say as fast as he/she can each of the images, saying "sun" for the sun pictures and "moon" for the moon pictures (congruent condition) for 45 seconds. On the second page, the subject is asked to say as fast as he/she can, the opposite of the picture he/she sees, i.e., "sun" when he/she sees a "moon" and "moon" when he/she sees a "sun" (incongruent condition). The inhibition measure is calculated based on the sum of the items completed correctly in the incongruent condition within a time limit of 45 seconds. This task has a good level of reliability, with test-retest scores of .91 in the incongruent condition (Archibald & Kerns, 1999).

For the INHCon, the subtest "Bzz! - Inhibition" subtest of the TENI (Tenorio et al, 2012). This task assesses the ability to self-regulate behavior and delay gratification, since the screen of the electronic device shows a series of bees that fly producing noise, which the child, for 1 minute, must kill by pressing them with his/her finger, then the child is informed that for five minutes he/she will be left alone and must not touch the screen to kill the bees. During those five minutes the bees continue to fly around the screen and beep. The child must then inhibit his/her desire to play with the device and control his/her behavior to respond to the given instruction. The result of this task shows whether the child was able to inhibit the urge to touch the screen. And if not, the system records how long it took him/her to play this one and how many times he/she manipulated it. It has a Cronbach's alpha of .9 (Tenorio et al., 2012).

Procedure

In the six schools that agreed to be part of the study, the research team participated in parents meetings in each school, where both teachers and families were informed of the objective and details of the study. Likewise, they were asked for their authorization by signing the informed consent form for their children to participate in the study. Then, the children whose families authorized their participation were evaluated individually in a session of approximately 40 minutes during their school day. All evaluations were conducted between September and October 2022.

Data Analysis

To systematize the demographic information of the sample, descriptive analyses were performed. Correlation analyses were then used to determine the presence of associations between the executive domains VWM, VSWM, INHCog, INHCon and the children's mathematical skills. Finally, hierarchical multiple linear regression analyses were performed to evaluate the predictive capacity of each of the studied EFs on the EMS dimensions of the participants. Analyses were performed with the open access program Jamovi, version 2.2.5 (The Jamovi Project, 2021).

Ethical Considerations

Each of the research steps were implemented according to the guidelines of the Singapore Declaration on Research Integrity (World Conferences on Research Integrity, 2010). For this reason, an informed consent protocol was implemented and signed by the families of the participants, who in turn gave their consent to be part of the study. Likewise, the research was approved by the Ethics Committee of the University.

RESULTS

Correlation between working memory, inhibition and mathematical skills

First, the univariate normality assumption for Pearson's correlation analysis was examined and met. The correlation matrix was then obtained between the EMSs, both logical-relational and numerical, and the participants' VWM, VSWM, INHCog, INHCon EFs.

As shown in Table 2, the VWM shows moderate to high significant correlations with the LRMS (0.593) and NMS (0.700). VSWM presents significant correlations with the NMS (0.350) correlations are low, and with the LRMS, correlation is significant (*p*=.022). Regarding INH, it can be observed that INHCon does not present significant correlations with any of the EMS, while INHCog presents a significant and moderate correlation with both LRMS (0.405) and NMS (0.415).

Table 2.
Correlation matrix of mathematical skills with executive functions

		Executive Functions			
		Verbal Working Memory	Visuospatial Working Memory	Behavioral Inhibition	Cognitive Inhibition
Logical-Relational MS (LRMS)	Pearson's r	0.593***	0.226*	-0.117 *n.s*	0.405***
	p value	<.001	0.022	0.231	< .001
Numerical MS (NMS)	Pearson's r	0.700***	0.350***	0.018 *n.s*	0.415***
	p value	<.001	<.001	0.854	< .001

Note. * $p < .05$, *** $p < .001$, *n.s.* = no significativo
Source. Elaborated by the author.

WM and INH as predictors of mathematical performance: hierarchical multiple linear regression models

Finally, for the evaluation of the predictive capacity of the VWM, VSWM and INHCon, INHCog on the logical-relational and numerical EMS of the participants, hierarchical multiple linear regression models were performed, including as the first predictor the EF with the highest correlation coefficient with the criterion (i.e., LRMS, NMS).

It should be noted that the regression models complied with the assumptions of autocorrelation and collinearity.

The results indicate that VWM was the best predictor of participants' EMS (LRMS = 0.559, p =.001; NMS = 0.640, p <.001) relative to the other predictors.

Specifically, a one predictor model integrated by the VWM, significantly predicts the LRMS, R2= .351, F (1, 104) = 56.2, p <.001. Thus, this model manages to explain 35.1% of the variability of the participants' scores in the logical-relational mathematical skills.

Likewise, the results suggest that a two-predictor model composed of the VWM and the course significantly predicts the participants' numerical mathematical skills, $R2 = .512$, $F (2, 103) =54.0$, $p < .001$. In other words, this model can explain 51.2% of the variability of the children's NMS scores.

It should be noted that only the model proposed for the NMSs showed statistically significant differences in the course variable (see Table 3) and, therefore, the regression equation introduces this dichotomized variable (i.e., dummy variable) that takes the value 0 if the child attends prekindergarten and 1 if he/she attends kindergarten. In addition, it is worth mentioning that in both models the establishment variable (i.e., public, private and subsidized) and the gender variable (i.e., male, female) were considered as factors, neither of these being significant for the models.

Finally, the regression equation for the logical-relational EMSs would be: [y= α + (β1 *VWM) + ε], whose values are: [yi = 9.786 + (0.693 *score VWMi) + ε]. The subscript i indicates the person of interest.

Likewise, the regression equation for the numerical EMSs would be: [y= α + (β1 *VWM) + (β2 * dichotomized course) + ε] and whose values are: [yi = 5.427 + (1.051 *score VWMi) + (1.594*dichotomized coursei) + ε].

Table 3.
Regression models of executive functions predicting participants' mathematical skills

Dependent Variable	Model Coefficients				Model adjustment			Collinearity
	Predictor	Unstandardized regression coefficients	Standardized regression coefficients (β)	t	*Value p*	R^2	ΔR^2	VIF[a]
Logical-Relational Mathematical Skills	Intercept	9.786	–	9.42	<.001 ***	–	–	–
	VWM	0.693	0.559	5.84	.001 **	0.351	–	1.46
	INHCog	0.042	0.097	1.03	.302 *n.s.*	0.364	0.013	1.40
	VSWM	0.007	0.007	0.08	.932 *n.s.*	0.382	0.018	1.15
Numerical Mathematical Skills	Intercept	5.427	–	9.53	<.001 ***	–	–	–
	VWM	1.051	0.640	8.62	<.001 ***	0.490	–	1.16
	Course	1.594	0.318	2.14	.034 *	0.512	0.022	1.16

Note. VWM= Verbal Working Memory; INHCog= Cognitive Inhibition; VSWM= Visuospatial Working Memory.
*p <.05, ** p < .01, ***p <.001. n.s= not significant.
a. Variance inflation factor.
Source. Elaborated by the author.

In both regression equations, y corresponds to the criterion value, α to the estimated value for the intercept, β1 and β2 to the estimate of the unstandardized regression coefficients of the predictors (i.e., VWM and Course) and ε to the standard error of the prediction (see Table 3).

DISCUSSION

This study aimed to determine the predictive capacity of executive functions, specifically the VWM, VSWM, INHcon and INHcog, with respect to EMS, both logical-relational and numerical, in pre-school students. In this sense, we hypothesized that these four executive domains would emerge as predictors of both types of early mathematical skills.

The results were conclusive with respect to VWM as a strong predictor of both LRMS and NMS. This was not the case for VSWM since it did not prove to be a significant predictor of any of the EMSs.

Thus, these findings partially confirm our hypothesis regarding the predictive ability of both types of WM in LRMS and NMS. They also confirm that the results of different investigations regarding the contribution of VWM and VSWM on mathematical performance are inconclusive. For example, in their research, Presentación et al. (2015) conclude that it is the VWM that is most closely related to mathematical skills at an early age. The same conclusion is reached by Aragón et al. (2015) and González-Hernández et al. (2022), the latter showing that training and stimulation of VWM results in favorable outcomes with respect to mathematical performance. Allen et al. (2020) concluded that VWM is the EF that most contributes to the acquisition of mathematical skills during the early stages of schooling. However, these same authors, in a later study (Allen et al., 2021) update their results, pointing to VSWM as the executive function makes the greatest contribution to early mathematics learning. Ruiz et al. (2019), in line with the results of our research, found no influence of VSWM on mathematical proficiency. This is despite the current evidence regarding the relevance of VSWM as a predictor of mathematical performance (Michel et al., 2020), associated mainly with its role in facilitating the mental representation that students perform in problem solving (Flórez-Durango et al., 2022).

Considering this information, it is important to continue investigating the specific contribution of verbal and visuospatial WM in the development of the mathematical skills necessary for learning in this discipline area.

Regarding INH, our results report that neither INHCon nor INHCog were significant predictors of any of the EMSs (i.e., LRMS and NMS), a finding that differs from the results of recent research such as that of Coulanges et al. (2021) and Cueli et al. (2020), who found that INH has a predictive power, even greater than WM, in the development of EMS. Despite this evidence, there are also studies, such as ours, that have concluded that inhibition EF is not a predictive variable of mathematical performance (Azar et al., 2019; Cheung & Chang, 2022). For example, in Cheung & Chan's (2022) research, which sought to relate several EFs, including INH, to mental calculation and mathematical problem solving in 225 children in pre-school education, INH was not found to be related to either mental calculation or problem solving in the participants, which is evidence that young children are still developing their executive functioning skills.

We believe that a possible explanation for this finding suggests that age could be related to the influence of the maturational component in the development of INH. Several studies have concluded that the ability to inhibit a response in a task increases considerably as children get older (Fonseca et al., 2016) and that important developments in inhibitory control take place in the first 6 years of life, with a marked improvement between the ages of 5 and 6 (Aydmune et al., 2019). Another possible explanation is that mathematical tasks require higher-order inhibitory processing (Cheung & Chang, 2022). In this regard, semantic extraction is necessary to identify irrelevant information in mathematical problem solving, and children need adequate mathematical knowledge to identify information as irrelevant. Therefore, it is possible that inhibitory tasks and mathematical tasks actually impose different levels of inhibitory processing (Lee & Lee, 2019).

Additionally, the lack of relationship and explanatory power of inhibition, both behavioral and cognitive, in the mathematical skills of the children in our sample could be attributed to the type of tests used to assess inhibition that we used in this study, while some previous research has found that mathematical performance is more strongly related to inhibition of numerical than non-numerical information (Gilmore et al.,, 2015; Navarro et al., 2011; Szucs et al., 2013) and in this study, inhibition was assessed by tasks that required inhibition of non-numerical information.

Another interesting finding of our research alludes to the course variable as a predictive factor of NMS, a finding that could be associated with the development of cognitive abilities as a function of the structural and functional changes of the brain, produced by biological development itself (Arán-Filippetti, 2011). Meanwhile executive functions continue a gradual development with age, i.e., the older the age, the better the response of the brain's own capacities. (Muchiut et al., 2019) and therefore, also better mathematical performance.

The gender variable did not prove to be a relevant predictor for EMS, coinciding with other research works where, in relation to mathematical learning, no major differences in relation to gender have been evidenced in early stages of schooling (Alsina & Berciano, 2018; Arteaga et al., 2021), but they have been found in later stages, in which significant differences have been found between boys and girls, in favor of boys, which could be explained by both explicit and implicit gender stereotypes that associate mathematical knowledge with the male gender (Del Río et al., 2016; Limas et al., 2020; Pezzo, 2017).

Although the results of the present research show that the type of educational establishment does not have a direct relationship with respect to the development of EF sand EMS, at the same time, several studies affirm that the socioeconomic status of the students has a direct relationship with their academic performance, indicating that there is lower EF performance in children from lower socioeconomic strata compared to their middle socioeconomic status peers (Azar et al., 2019; Moscuen et al., 2018). Based on the above, the results of this study could be explained by the type of sample chosen, in addition to the low access to public schools in comparison to subsidized schools, so it would be relevant for future research to take this background into consideration.

Among the limitations of our research we can mention, on the one hand, the type of sample used, since, being of the purposive type, it restricts the generalization of the results. The limited sample size of the study and the location of the population studied are also considered a limitation, so it would be advisable to expand the sample and its respective demographic sectors for future research.

In conclusion, it would be relevant to continue researching this topic, since there is still no conclusive empirical evidence about the predictive capacity of WM (verbal and visuospatial) and INH (behavioral and cognitive) in EMS, especially in preschool population.

Finally, we believe that this study has important practical implications, in that, given the important role that executive skills play in early mathematics learning, it can serve and/or be used as input for pre-school educators to adjust their teaching strategies to children who are still developing their executive functioning skills. In addition, we believe that the results of this research can be useful for the design of early cognitive stimulation programs of mathematical abilities in the classroom, with the purpose of enhancing children's VWM and thus their future mathematical performance in school.

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Conflicts of interests: The authors declare that they have no conflicts of interest among the parties involved in the performance of the study.

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