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Attention, inhibitory control and early mathematical skills in preschool students

Marisol Cueli[1], Débora Areces[1], Trinidad García[1], Rui Alexandre Alves[2], and Paloma González-Castro[1]

[1] University of Oviedo and [2] University of Porto

Abstract

Background: Early mathematical skills may be important indicators of school success. Executive Functions (EFs) such as attention and inhibitory control may be related to the development of early mathematical skills. **Method:** This study is aimed at understanding the relationship between two EFs (attention and inhibitory control) and low and high relational and numerical mathematical skills in preschool students (143 children between 4 and 6 years old). Participants completed the Early Numeracy Test Revised and a continuous performance test which assessed attention (omissions and response time [RT]) and inhibitory control (commissions and variability). **Results:** Logistic Binomial Regression Analysis was carried out showing that in 4 to 6-year olds there are differences in omissions, RT and variability between the groups (low and high relational and numerical mathematical skills). However, once the effect of the age was controlled for, only RT predicted numerical mathematical skills. **Conclusions:** The results highlight the importance of attention in the numerical skills of preschool students, with a greater weight of response time which is better in students with higher numerical mathematics skills.

Keywords: Inhibition, attention, executive functions, mathematics, preschool.

Resumen

Atención, control inhibitorio y habilidades matemáticas tempranas en estudiantes de Educación Infantil. **Antecedentes:** las habilidades matemáticas tempranas pueden ser importantes indicadores del éxito escolar. Por otro lado, las Funciones Ejecutivas (FE) como la atención y el control inhibitorio se han relacionado con el desarrollo de habilidades matemáticas tempranas. **Método:** este estudio está dirigido a analizar la relación entre dos FEs (atención y control inhibitorio) y la baja y alta habilidad matemática relacional y numérica de 143 estudiantes de entre 4 y 6 años. Los participantes realizaron el Test de Competencia Matemática Temprana Revisado y un test de ejecución continua dirigido a evaluar la atención (omisiones y tiempo de respuesta [TR]) y el control inhibitorio (comisiones y variabilidad). **Resultados:** el análisis de regresión logística binomial mostró que en estudiantes de entre 4 y 6 años hay diferencias en las variables omisiones, TR y variabilidad entre los grupos de baja y alta habilidad matemática relacional y numérica. Sin embargo, una vez controlada la edad, solo el TR predijo la habilidad matemática numérica. **Conclusiones:** los resultados mostraron la importancia de la atención en las habilidades numéricas de estudiantes de Educación Infantil, con un mayor peso del TR que fue mejor en estudiantes con mejor habilidad matemática numérica.

Palabras clave: inhibición, atención, funciones ejecutivas, matemáticas, educación infantil.

Children's underachievement in mathematics is a consistent problem in different countries (Dowker, 2009). Cragg and Gilmore (2014) found a percentage of 21% of 11-year-old children (wo) finished primary school without reaching the expected level in mathematics. Clayton and Gilmore (2015) showed that approximately 6-14 % of school-age children have persistent difficulties with mathematics despite their adequate achievement in other domains. These findings highlights the importance of analyzing the variables related to mathematical skills development from the very first years. In this sense, Claessens, Duncan and Engel (2009) suggested that several pre-kindergarten mathematics skills may be important indicators of school success. Not coincidentally, mathematical learning starts at a very early age with the development of early numeracy and the general understanding of numbers (Passolunghi & Lanfranchi, 2012).

There are two approaches that can be taken to study the determinants of mathematical skills: a specific-domain approach (i.e., representation of numerical magnitudes, comparison skills) and a general-domain approach (i.e. working memory, processing speed, attention, inhibition, or general executive functions; Fias, Menon, & Szucs, 2013; Namkung & Fuchs, 2016). Previous studies have demonstrated a direct association between Executive Functions (EFs) and developing mathematical skills across a wide age range (Bull, Espy, & Weibe, 2008; Clements, Sarama, & Germeroth, 2015; Harvey & Miller, 2017). However, this link has not been substantially examined in multiple critical early mathematical domains (Harvey & Miller, 2017), and most studies have only used a single math domain (usually arithmetic) to correlate with specific EFs (Bull et al., 2008). Furthermore, it has

Received: July 30, 2019 • Accepted: January 28, 2020
Corresponding author: Trinidad García
Faculty of Psychology
University of Oviedo
33003 Oviedo
e-mail: garciatrinidad@uniovi.es

been suggested that the strength of these relationships varies with age (Brocki & Bohlin, 2004). Taking these aspects into account, the aim of this study is to analyze the relationship between two EFs (attention and inhibitory control) and early numerical skills in preschool students.

EFs refer to the self-regulatory processes involved in organizing and controlling behavior, emotions, attention, and thinking (Isquith, Crawford, Espy, & Gioia, 2005). Despite of the current debate about what domains constitute EFs in young children (Verdine, Irwina, Golinkoff, & Hirsh-Pasek, 2014), there is consistent agreement on at least three specific components: inhibitory control (IC), cognitive flexibility or shifting (CS), and working memory (WM) (Marcovitch & Zelazo, 2009; Wiebe et al., 2011). Inhibition refers to the ability to suppress distracting information and unwanted responses. Shifting is related to flexibly switching between different tasks and updating (Cragg & Gilmore, 2014). Working memory involves monitoring and manipulating information in mind (Cragg & Gilmore, 2014; Wiebe et al., 2011). When solving an arithmetic problem, these three functions are reflected in the need to inhibit impulsive answers, to carefully read and understand the problem, and to bear key data in mind, while changing strategies if one cannot find the solution (Clements, Sarama, & Germeroth, 2015). Other authors have indicated that the term EFs refers to a wide range of processes and skills that are in charge of goal-oriented behavior (Flores-Lázaro, Castillo-Preciado, & Jiménez-Miramonte, 2014; Meltzer, 2013), and involve more components such as organization and planning, response inhibition, cognitive flexibility, attentional capacity, and control of one's own emotional state (Diamond, 2013; García, Rodríguez, González-Castro, Álvarez-García, & González-Pienda, 2016).

Although, for most children, EFs start developing early during childhood years (i.e., from birth to third grade) (Clements & Sarama, 2019), only recently, researchers have begun to study the structure, organization, and development of EFs in children under 5 years of age (Harvey & Miller, 2017; Marcovitch & Zelazo, 2009) in part because of the substantial evidence that EFs are related to later achievement in school-age children and the difficulty of assessment in 4 and 5 year-old children (Bull, Espy, & Wiebe, 2008; Duncan et al., 2007). Authors such as Espy et al. (2004) found that inhibitory control and working memory accounted for unique variance in preschool children's arithmetic mathematical performance. A relation between preschool inhibitory control and working memory and kindergarten reading and mathematics performance was also reported by Welsh et al. (2010). Overall, different studies have reported that inhibitory control and working memory may show a particularly close relationship with mathematics learning and achievement (Bull et al., 2008; Geary, 2013; Harvey & Miller, 2017; Miller, Rittle-Johnson, Loehr, & Fyfe, 2016; van der Ven, Kroesbergen, Boom, & Leseman, 2012).

Furthermore, other variables such as attention have been shown to be related to performance in mathematics due to influencing concentration on relevant, subtle, or masked stimuli (González-Castro, Rodríguez, Cueli, Cabeza, & Álvarez, 2014). Clements and Sarama's (2019) review showed that children with higher executive functioning skills, such as attention, working memory, and inhibitory control, also achieve higher levels in literacy, language, and mathematics.

Children who can better maintain effortful attentional control learn more quickly than their less attentive peers (Clark, Pritchard, & Woodward, 2010; Geary, 2013). Also, during preschool years, the ability to focus one's attention and ignore distractions makes it easier to learn how to count and map number symbols onto specific quantities (Geary, 2013). Attentional control manifests as the ability to maintain goal relevant information in mind while processing other information, and as the ability to stay focused and organized in classroom settings. Furthermore, attentional control has been associated with measures of math achievement independent of general intelligence (Clark et al., 2010; Duncan et al., 2007).

In order to analyze the relation between EFs and mathematical skills, researchers have mostly used Continuous Performance Test (CPTs) (Brueggemann & Gable, 2018; Ribner, Willoughby, & Blair, 2017). Brueggemann and Gable carried out a study with 31 first-year preschoolers, showing that attention was positively correlated with numeracy skills and knowledge in that sample.

Other studies have shown that individual differences in inhibitory control are associated with general mathematical performance in typically developing children (Allan, Hume, Allan, Farrington, & Lonigan, 2014; Gilmore et al., 2013). On the contrary, it has been suggested that poor inhibition skills explain part of the low mathematical performance in children with developmental dyscalculia (Szucs, Devine, Soltesz, Nobes, & Gabriel, 2013), and in children with Attention Deficit Hyperactivity Disorder (ADHD). However, other studies failed to find an association between inhibition and math performance (Bellon, Flas, & De Smedt, 2016; Keller & Libertus, 2015).

Therefore, the association between inhibition and mathematical performance remains unclear. As Cragg and Gilmore (2014) suggested, this association is likely to vary depending on the math skills under investigation. For example, early numeracy or basic mathematical skills, include different components such as (verbal) counting, knowing the number symbols, recognizing or discerning quantity patterns, comparing numerical magnitudes, and estimating quantities (Bunck, Terlien, van Groenestijn, Toll, & Van Luit, 2014; Desoete, Ceulemans, De Weerdt, & Pieters, 2012). In short, early numeracy includes both relational skills (associated with Piagetian tasks; e.g., comparisons, classifications, correspondence and seriations) and numerical skills (e.g., verbal counting, structured counting, resulting counting, general knowledge of numbers and number estimation on a number line) (Aragón-Mendizábal, Aguilar-Villagrán, Navarro-Guzmán, & Howell, 2017; Van Luit et al., 2015).

It has been suggested that the strength of the relationship between EFs and mathematical skills varies with age from preschool through elementary school-age years (Brocki & Bohlin, 2004). In this sense, Schmitt, Geldhof, Purpura, Duncan and McClelland (2017) examined the longitudinal relations between EFs and academic skills during the transition from preschool to kindergarten. They observed significant reciprocal relations between EFs and math during preschool, although these relations demonstrated to change over time.

The general aim of our study, along these lines, is to understand the relation between two EFs (attention and inhibitory control) and relational and numerical mathematical skills in preschool students. Our two specific aims were: (1) To analyze differences in EFs between students with low and high levels of relational mathematical skills, numerical mathematical skills, and mathematics competence level (MCL); (2) To analyze the predictive power of the EFs regarding the probability to show low specific mathematical skills (relational and numerical) and MCL. Our research questions were: Are there differences in attention and inhibition with respect to the level (low or high) of relational and numerical mathematical skills and

MCL? How do EFs predict a low level in relational and numerical mathematical skills and in MCL? To give answer to this question, a sample second- and third-year preschool students completed a CPT (which provided information about attention and IC) and the early numeracy test (which included assessment of relational and numerical mathematical skills). Our initial hypothesis is that students with low mathematical skills (relational and numerical skills, and MCL) will have lower scores in the EFs (attention and IC) and that these EFs will demonstrate a statistically significant predictive capacity for mathematical skills.

Method

Participants

Participants in this study were 143 students enrolled in six classes of the second and third years of preschool in the Principality of Asturias (North of Spain). Schools were in the center of a city and all the families reported a medium-high socio-economic level.

The students were aged between 4 and 6 years old (in months M = 60.04, SD = 8.53). Of these students, 51.7% were female (n = 74) and 48.3 were male (n = 69). Participants were in the second (n = 73) and third (n = 70) years of preschool. Sample selection was made through convenience and accessibility procedures. All students presented informed consent from their parents.

Students were divided into two groups according to their level in the two specific mathematical skills (relational and numerical mathematical skills) and according the MCL: low and high relational mathematical skills, low and high numerical mathematical skills, and low and high MCL. The low relational skills group was composed of 82 students (34 boys and 48 girls) with a mean of age of 55.71 months; while the high relational skills group was composed of 61 students (35 boys and 26 girls, mean age 65.87 months). The low numerical skills group was composed of 76 students (45 boys and 31 girls, mean age 54.95 months); and the high numerical skills group included 67 students (38 boys and 29 girls, mean age 65.82 months). Last, the low MCL group was composed of 74 students (29 boys and 45 girls) with a mean age of 54.34 months and the high MCL group was made up of 69 students (40 boys and 29 girls; mean age 66.16 months).

There were no statistical differences in the gender-distribution of males and females in the current sample $\chi^2(1) = 0.175$, p = .676.

Instruments

Raven's Coloured Progressive Matrices (CPM; Raven, Court, & Raven, 1996). Raven's Progressive Matrices provide a reliable, nonverbal assessment of intelligence. The test offers three progressively more difficult forms intended for different populations. Participants are asked to identify the missing component in a series of patterns of figures. In this study we used the Coloured Progressed Matrices (CPM). It is aimed at assessing children from 4 years old and up. It consists of 36 items in 3 sets of 12. It takes between 15 and 30 minutes to administer and provides a standardized score (M = 100, SD = 15) for each child. In terms of internal consistency, following the test manual, the Split Half Reliability was between .83 and .87.

Early Numeracy Test Revised (ENT-R; Aragón-Mendizábal et al., 2017; Navarro et al., 2012). The original tool was developed by Van Luit and Van de Rijt (2009) and was standardized for the Spanish population (Van Luit et al., 2015). It evaluates early numerical skills, and detects students at risk of mathematics learning difficulties. This tool is especially useful in the transition from pre-school to elementary education to confirm which students need support to cope with new mathematical learning, encouraging early intervention to remedy these shortfalls. The test includes two subtests for the assessment of relational mathematical skills and numerical mathematical skills. Specifically, it includes four types of relational skills: comparisons, classifications, correspondence and seriations, each evaluated through 5 items. It also includes four types of numerical mathematical skills: verbal counting, structured counting, resulting counting (the child has to count sets of objects without pointing), and general knowledge of numbers. Each numerical skill is also evaluated by 5 items. In addition, it provides an ENT-R total score or an overall value for the Mathematics Competence Level (MCL) from a set of 8 variables. It is designed to be used with students between 4 and 7 years old, and has three parallel versions with 40 items each. For this study we used the A version. It takes on average around 30 minutes to complete and is individually administered. The original Cronbach's alpha reliability index was .92 (Aragón-Mendizábal et al., 2017), in the current sample it was .83.

Continuous Performance Test. For the assessment of attention and inhibitory control (IC), and given the ages of the sample, it was necessary to develop a specific task using the E-prime software (Version 2.0). It was desinged following a previously used methodology (i.e., Slot, van Viersen, Bree, & Kroesbergen, 2016). This task was called Early Task of Attention. The design was based on the Test of Variables of Attention (TOVA; Greenberg, 1996). It is very similar to the TOVA but considering the subjects' ages the task lasted 13 minutes and used two very basic stimuli, a cross and a circle (TOVA requires 21.6 minutes for children older than 5 years old and 10.9 minutes for children between 4 and 5 years old). During the first 3 minutes the student does some training in order to make sure that they have understood the task. The procedure consists of the presentation on a computer screen of the two stimuli: when the first stimulus, the cross, appears, the child must press the spacebar (target stimuli); when the second stimulus, the circle, appears, the child should not do anything (see Figure 1). In TOVA, the stimuli are two simple geometric figures: the target stimulus is a square with a second but smaller square inside of it near the upper border, and the non-target stimulus is a square with the smaller square near the lower border. The interval of presentation was 2500 milliseconds and each stimulus was shown for 200 milliseconds (in TOVA, stimuli are presented for 100 milliseconds at a between-stimuli interval of 2,000 milliseconds). Following the principles of TOVA, the task includes two halves associated with two conditions: In the first (infrequent condition), the ratio of stimuli was 1 target stimulus for every 3 non-target stimuli, while in the second half (frequent condition) the ratio of stimuli presented was 3 target for every 1 non-target. In total, in the first half 30 target stimuli were presented and 90 non-target stimuli; in the second half, 30 non-target stimuli and 90 target stimuli. The task measures omissions (the subject does not detect a correct stimulus, a measure related to attentional capacity), commissions (the subject responds to a incorrect stimulus, related to inhibitory control), response time (RT; milliseconds that the subject takes to respond, associated with attentional capacity), and variability (difference between RTs or deviation of the RT, which is related to inhibitory control).

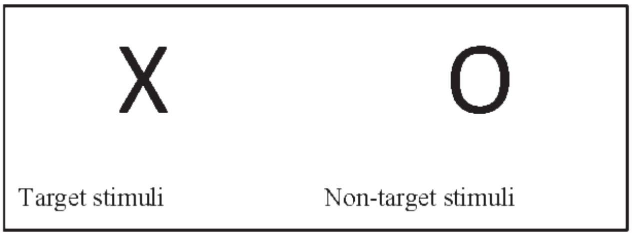

Figure 1. Stimuli included in the continuous performance test

Procedure

First, we tested the Raven CPM which allowed us to identify the students who had difficulties or exceptional abilities (scoring less than 80 or over than 130), as a result 4 students were excluded. Following that, students individually completed the ENT-R and a continuous performance test (the Early Task of Attention). The evaluation was performed during two sessions for each child individually. All the assessment tasks were coordinated and guided by the same educational psychologist who was a member of the research group.

The sample was divided according to score in the two subtests (relational and numerical mathematical skills) and the MCL. Thus, we obtained two groups for each variable (low and high relational mathematical skills; low and high numerical mathematical skills; low and high MCL). Following the procedure used in a recent study by Cueli et al. (2018), the two groups were discernable (e.g. low and high) by examination of the 50th percentile in each variable. The low achievement group was made up of students with scores below the 50h percentile. The high achievement group included students with scores above the 50th percentile. It is important to note that these levels specify a student's classification within this particular study-sample, so a high level is not indicative of high proficiency in mathematics, but rather, a higher level in comparison with the other students in this sample.

The study was conducted in accordance with The Helsinki Declaration of the World Medical Association.

Data analysis

First, descriptive analysis of the sample set and potential predictors were analyzed in terms of means and standard deviations, skewness and kurtosis. Pearson's correlations between pair of variables were also calculated (Table 1).

In order to analyze the differences between the low and high achievement groups in the four dependent variables (omissions, commissions, response time and variability) t test was used. After that, the predictive power of the EFs with respect to the presence of low specific mathematical skills was analyzed through binomial logistic regression analysis, taking low mathematical skills as reference groups (low relational skills, low numerical skills and low MCL). Adjusted odds ratios were calculated, which can indicate if the variable results in a risk factor (odds ratios greater than 1) or a protective factor (odds ratios less than 1). Finally, to analyze the validity of the models and therefore the explanatory contribution of the variables, Nagelkerke's R^2 and the percentage of correct classifications were included. Nagelkerke's R^2 was used as an estimation of predictive power of the regression model. This statistic has a minimum value of 0 and a maximum value is 1 and indicates the variation in the outcome variable that is explained by the logistic regression model. The closer the coefficient to 1, the better the predictive power of the tested model.

All the analyses were performed with the statistical program SPSS 19.0 for Windows.

Results

First, the sample characteristics were analyzed. All variables met normality conditions with values of skewness and kurtosis between ±3 and ±10 (Kline, 2011).

Pearson correlation coefficients were calculated to examine the associations between the different variables being studied (Table 1). The results show that the relational and numerical skills and the MCL were significantly related. A high relational component was related with a high numerical component and better MCL. In addition, as the relational component increased, the number of omissions

Table 1
Correlation matrix of mathematics skills and executive functions including means, standard deviations, skewness and kurtosis

	1. Relational component	2. Numerical component	3. MCL	4. Omissions	5. Comissions	6. RT	7. VAR
1							
2	.719***						
3	.886***	.953***					
4	-.416***	-.432***	-.453***				
5	-.048	-.033	-.041	.110			
6	-.444***	-.542***	-.535***	.496***	-.260**		
7	-.498***	-.552	-.571***	.682***	.170*	.724***	
M	13.31	7.56	40.09	13.34	10.69	761.19	284.62
SD	3.91	5.50	25.11	11.69	9.00	157.96	89.08
Skewness	-0.22	0.30	0.37	1.35	1.73	0.54	0.13
Kurtosis	-1.03	-0.94	-0.91	1.95	3.09	-0.02	-0.52
Minimun	4	0	1	0	1	446.97	109.11
Maximum	20	20	98	61	45	1192.98	510.77

Note: RT = Response Time, VAR = Variability, *M* = Mean, *SD* = Standard Deviation
* $p \le .05$, ** $p \le .01$, *** $p \le .001$

decreased and the RT and variability produced better scores. The same happened when the numerical component increase, which is linked to lower omission, RT and variability scores.

We performed a *t* test for independent samples to analyze the differences between the groups which demonstrated differences in omissions, RT and variability between the low and high relational, numerical and MCL groups (see Table 2).

We carried out a binomial regression analysis to achieve our second aim. Initially, relational skills were taken as dependent variable and age and gender linked to the variables provided by the CPT (omissions, commissions, RT and variability) as co-variables. Only age exhibited predictive value for the relational component, although RT was close to significance. In the case of age, the odds ratio was less than 1, showing that as children get older, there are better results in relational skills. The model was statistically significant, showing a moderate, but not great, predictive value of 48.5% (Nagelkerke's R^2 = .485). This model classified 79.6% of the sample correctly.

For numerical skills, the model was statistically significant once again, although with a slightly higher predictive value (Nagelkerke's R^2 = .579) than in the previous analysis. The model classified 83.8% of the cases correctly. Specifically, age and RT exhibited a predictive value for this component. As Table 3 shows, RT would constitute a risk factor given that the odds ratio is greater than 1 (see Table 3), indicating that lower responses time is are related to lower numerical mathematical skills.

Last, in the case of the overall MCL score, the model was again statistically significant. This model showed the best predictive value of the tested relations (Nagelkerke's R^2 = .638). The percentage of cases that this model is able to correctly predict is 83.8%, the

Table 2
Means and standard deviations for the four dependent variables, omissions, commissions, RT and variability in the low and high groups for relational and numerical skills and the MCL

		Omissions		Commissions		RT		VAR	
		M(SD)	**t**	**M(SD)**	**t**	**M(SD)**	**t**	**M(SD)**	**t**
Relational	Low *n* = 82	17.21 (12.30)	-5.23 ***	10.79 (9.57)	-0.15	817.34 (152.68)	-5.39 ***	317.65 (80.67)	-5.61 ***
	High *n* = 61	8.13 (8.42)		10.56 (8.24)		685.72 (132.22)		240.76 (80.87)	
Numerical	Low *n* = 76	17.38 (11.61)	-4.77 ***	10.41 (8.21)	0.40	842.08 (141.02)	-7.76 ***	326.39 (69.57)	-6.92 ***
	High *n* = 67	8.75 (10.03)		11.01 (9.87)		669.45 (122.50)		236.52 (85.08)	
MCL	Low *n* = 74	18.39 (11.94)	-6.04 ***	10.57 (8.19)	0.17	839.73 (142.08)	-7.16 ***	330.03 (71.91)	-7.46 ***
	High *n* = 69	7.91 (8.63)		10.83 (9.86)		676.96 (128.53)		235.20 (79.42)	

Note: *M* = Mean, *SD* = Standard Deviation, MCL = Mathematics Competence Level. High scores in omissions and commissions indicate a worse performance
* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

Table 3
Results of the binomial logistic regression analysis regarding the probability of showing lower levels in relational skills, numerical skills and MCL

	Relational skills			Numerical skills			MCL		
	β	**OR_A**	**p**	**β**	**OR_A**	**p**	**β**	**OR_A**	**p**
Age	**-.157**	**0.0854 (0.795-0.918)**	**<.001**	**-.170**	**0.843 (0.783-0.909)**	**<.000**	**-.206**	**0.814 (0.751-0.883)**	**<.000**
Gender	.226	0.798 (0.326-1.949)	.620	.137	0.872 (0.337-2.259)	.778	.518	0.596 (0.216-1.641)	.317
RT	0.005	1.005 (1.000-1.011)	.056	**.007**	**1.007 (1.001-1.013)**	**.015**	.004	1.004 (0.998-1.010)	.160
Omissions	.053	1.054 (0.988-1.124)	.108	-.003	0.997 (0.940-1.056)	.908	.040	1.041 (0.972-1.115)	.250
Comissions	0.043	1.044 (0.982-1.109)	.165	.036	1.036 (0.971-1.106)	.285	.020	1.020 (0.952-1.093)	.576
Variability	0.000	0.993 (0.982-1.003)	.860	-.002	0.998 (0.998-1.009)	.766	-.001	0.999 (0.998-1.011)	.864

Note: OR_A = Adjusted Odds Ratio

same as for the model predicting numerical skills. Once again, as table 3 shows, age was the only variable that showed statistically significant predictive value over this component. As children get older, scores in MCL increase.

Discussion

The present study examines the relation between EFs and specific mathematical skills in preschool students. As we hypothesized, students with low mathematical skills (relational and numerical skills) have lower scores in the EFs (attention and inhibitory control). Pearson correlations showed that when numerical and relational mathematical skills are lower, students have more omissions and slower RTs.

Regarding the differences between the groups with different mathematical skills, the *t* test showed differences in omissions, RT and variability in the relational and numerical skills, and in the MCL. Omissions and RT are related to attention while variability is more associated with inhibition. These results are in the line of previous studies which support the connection between EFs, mainly attention, working memory, and inhibitory control, and mathematics performance (for a revision see Clements & Sarama, 2019). Other authors, such as Brueggemann and Gable (2018), also found significant relationships between attention and early numeracy skills. These relationships were demonstrated for both relational and numerical skills in the present study. On the other hand, the absence of differences in commissions (related to inhibition and impulsivity), is also in agreement with previous studies that failed to find an association between inhibition and math performance (Bellon et al., 2016; Keller & Libertus, 2015). In this sense, the lack of agreement between our results and those of some previous studies could be related to the specific mathematical skills assessed or even to the fact that some studies have focused on the achievement in the subject instead of the skills required for learning mathematics.

As for the binomial regression analysis, results showed that the EFs lost explanatory power in the prediction of the mathematics skills when age is considered in the model. In the three relational models tested (prediction of relational skills, numerical skills, and MCL), age was a significant predictive factor in all cases, showing that as children get older, both specific mathematical skills and mathematics general competence increases. Given that inter-group differences were significant without controlling for the effect of the age (as seen in the *t* test), the poor effect of EFs predicting numerical and relational mathematics skills could be related to the influence of the maturational component on the development of EFs at 4 and 5 years old. Jones, Rothbart and Posner (2003) observed that the ability to inhibit a response in a task increased from 22% to 90% between 36 and 48 months of age. According to Carlson and Moses (2001) important developments in inhibitory control take place in the first 6 years of life, with marked improvement between age 3 and 6. Also, Zelazo and Ulrich (2011) indicated that changes in the prefrontal cortex between ages two and five allow for dramatic increases in EF skills during early childhood.

When we look at the specific mathematics skills, the fact that none of the variables included (omissions, commissions, RT and variability) predicted low or high relational skills indicates that students can achieve relational skills independently of the level of EFs. Furthermore, the absence of differences in these (relational) skills, supports the idea of the importance of the Response To Intervention (RTI) model and the assessment of children's long term difficulties (American Psychiatric Association, 2013), given that low levels of EFs when 3-5 years old could not yet be related to low achievement in other domains like mathematics. In any case, authors as Schmitt et al. (2017) showed that EFs are significant predictors of mathematics in preschool and kindergarten, concluding that they may be foundational for the development of early mathematical skills. However, in their study, children's mathematical skills were measured by using applied problems which assess early mathematical operations (e.g., counting, addition, and subtraction) wich are, in consequence, closer to the numerical skills.

In the present study, and concerning numerical skills, once the effect of age was controlled, differences in attention were found, reflected in lower RTs, which may show that the difficulties in learning numerical skills could be related to low levels of attention or slowness in performing tasks. One implication is the role of RT in the components of mathematics. Research has shown that the most prominent cognitive feature among children with mathematics difficulties is a processing speed deficit (Cirino, Fuchs, Elias, Power, & Schumacher, 2015; Peng et al., 2016). Namkung and Fuchs (2016) studied a set of domain-general cognitive skills and domain-specific academic skills (working memory, processing speed, language, attention, nonverbal reasoning, and incoming calculations) at the beginning of fourth grade to predict calculation performance at the end of fourth grade. They found that processing speed, attentive behavior, and incoming calculations uniquely predicted whole-number calculation competence.

These results might have implications for the day-to-day work in the classroom, where lower levels of attention can be reflecting, at the same time, poor mathematical skills or slowness during the performance of an activity. Both possibilities can act as important risk factors for difficulties in the acquisition of numerical skills. On the other hand, the intervention over the EFs could benefit the development and acquisition of mathematical skills, specifically numerical skills, or, in contrast, the stimulation of mathematical skills could improve children's EFs (see Clements & Sarama, 2019, for a review of math activities that may help develop EFs).

Last, this study must be interpreted in the light of the following limitations. First, sample size and sample selection were done according to accessibility, although it was necessary due to the difficulty of going into the schools and working with preschool children. Second, the main limitation of the present study is that working memory was not considered as a possible predictor variable, despite being one of the variables with the strongest association with mathematical skills. It would also be of interest to include other EFs components such as shifting or planning in future studies. Likewise, it would be interesting to analyze students' progress and, consequently, mathematical skills development, in primary school in those students who had lower EFs during preschool. Last, it would be necessary to deep into the role of RT in mathematical skills development, given that higher RTs might be associated with lower levels of attention but also with other symptoms such as anxiety or emotional difficulties (p.e., Rodríguez, González-Castro, García, Núñez, & Álvarez, 2014).

In conclusion, the results of our study highlight the importance of attention predicting numerical skills in preschool years, with a greater weight of response time which is better in students with higher numerical mathematics skills. It is also worth noting that, considering the whole range of predictive variables tested (age, gender, and EFs), the predictive power of the purposed model was higher when MCL -or general mathematics competence- was the variable to predict (about 64%). However, the percentage of correct classification of children with high a low mathematical competence was the same as in the model predicting only numerical skills. These results suggest that the set of variables examined may play an important role in predicting general mathematics competence, but their influence seems to be different –except for age - when specific components of mathematics competence are considered, at least, at early developmental stages.

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References

Allan, N. P., Hume, L. E., Allan, D. M., Farrington, A. L., & Lonigan, C. J. (2014). Relations between inhibitory control and the development of academic skills in Preschool and kindergarten: A meta-analysis. *Developmental Psychology, 50*(10), 2368-2379. http://dx.doi.org/10.1037/a0037493

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders (fifth edition)*. Washington, DC: Author.

Aragón-Mendizábal, E., Aguilar-Villagrán, M., Navarro-Guzmán, J. I., & Howell, R. (2017). Improving number sense in kindergarten children with low achievement in mathematics. *Anales de Psicología, 33*(2), 311-318. http://dx.doi.org/10.6018/analesps.33.2.239391

Bellon, E., Flas, W., & De Smedt, B. (2016). Are individual differences in arithmetic fact retrieval in children related to inhibition? *Frontiers in Psychology, 7*, e825. http://dx.doi.org/10.3389/fpsyg.2016.00825

Brocki, K. C., & Bohlin, G. (2004). Executive functions in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology, 26*(2), 571-593. http://dx.doi.org/10.1207/s15326942dn2602_3

Brueggemann, A., & Gable, S. (2018). Preschoolers' selective sustained attention and numeracy skills and knowledge. *Journal of Experimental Child Psychology 171*, 138-147. https://doi.org/10.1016/j.jecp.2018.02.001

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology, 33*(3), 205-228. http://dx.doi.org/10.1080/87565640801982312

Bunck, M. J. A., Terlien, E., van Groenestijn, M., Toll, S. W. M., & Van Luit, J. E. H. (2017). Observing and analyzing children's mathematical development, based on action theory. *Educational Studies in Mathematics, 96*, 289-304. http://dx.doi.org/10.1007/s10649-017-9763-6

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development, 72*, 1032-1053. http://dx.doi.org/10.1111/1467-8624.00333

Cirino, P. T., Fuchs, L. S., Elias, J. T., Powell, S. R., & Schumacher, R. F. (2015). Cognitive and mathematical profiles for different forms of learning difficulties. *Journal of Learning Disabilities, 48*(2), 156-175. http://dx.doi.org/10.1177/0022219413494239

Claessens, A., Duncan, G., & Engel, M. (2009). Kindergarten skills and fifth-grade achievement: Evidence from the ECLS-K. *Economics of Education Review, 28*(4), 415-427. http://dx.doi.org/10.1016/j.econedurev.2008.09.003

Clark, C. A. C., Pritchard, V. E., & Woodward, L. J. (2010). Preschool executive functioning abilities predict early mathematics achievement. *Developmental Psychology, 46*, 1176-1191. http://dx.doi.org/10.1037/a0019672

Clayton, S., & Gilmore, C. (2015). Inhibition in dot comparison tasks. *ZDM Mathematics Education, 47*(5), 759-770. http://dx.doi.org/10.1007/s11858-014-0655-2

Clements, D. H., & Sarama, J. (2019). Executive function and early mathematical learning fifficulties. In A. Fritz, V. G. Haase & P. Räsänen (Eds.), *International handbook of mathematical learning difficulties* (pp. 755-771). New York: Springer. https://doi.org/10.1007/978-3-319-97148-3_9

Clements, D. H., Sarama, J., & Germeroth, C. (2015). Learning executive function and early mathematics. Directions of causal relations. *Early Childhood Research Quarterly, 36*(3), 79-90. http://dx.doi.org/10.1016/j.ecresq.2015.12.009

Cragg, L., & Gilmore, C. (2014). Skills underlying mathematics: The role of executive function in the development of mathematics proficiency. *Trends in Neuroscience and Education, 3*(2), 63-68. http://dx.doi.org/10.1016/j.tine.2013.12.001

Cueli, M., Areces, D., García, T., Rodríguez, C., Vallejo, G., & González-Castro, P. (2018). Influence of initial mathematical competencies on the effectiveness of a classroom-based intervention. *British Journal of Educational Psychology.* http://dx.doi.org/10.1111/bjep.12239

Desoete, A., Ceulemans, A., De Weerdt, F., & Pieters, S. (2012). Can we predict mathematical learning disabilities from symbolic and nonsymbolic comparison tasks in kindergarten? Findings from a longitudinal study. *British Journal of Educational Psychology, 82*(1), 64-81. http://dx.doi.org/10.1348/20448279.002002

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135-168. http://dx.doi.org/10.1146/annurev-psych-113011-143750

Dowker, A. (2009). Use of derived fact strategies by children with mathematical difficulties. *Cognitive Development, 24*, 401-410. http://dx.doi.org/10.1016/j.cogdev.2009.09.005

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology, 43*, 1428-1446. http://dx.doi.org/10.1037/0012-1649.43.6.1428

Espy, K. A., McDiarmid M. M., Cwik, M. F., Stalets, M. M., Hamby, A., & Senn, T. E. (2004). The contribution of executive functions to emergent mathematic skills in pre-school children. *Developmental Neuropsychology, 26*(1), 465-486. http://dx.doi.org/10.1207/s15326942dn2601_6

Fias, W., Menon, V., & Szucs, D. (2013). Multiple components of development dyscalculia. *Trends in Neuroscience and Education, 2*(2), 43-47. http://dx.doi.org/10.1016/j.tine.2013.06.006

Flores-Lázaro, J. C., Castillo-Preciado, R. E., & Jiménez-Miramonte, N. A. (2014). Development of executive functions, from childhood to youth. *Anales de Psicología, 30*(2), 463-473. http://dx.doi.org/10.6018/analesps.30.2.155471

García, T., Rodríguez, C., González-Castro, P., Álvarez-García, D., & González-Pienda, J. A. (2016). Metacognition and executive functioning in Elementary School. *Anales de Psicología, 32*(2), 474-483. http://dx.doi.org/10.6018/analesps.32.2.202891

Geary, D. C. (2013). Early foundations for mathematics learning and their relations to learning disabilities. *Current Directions in Psychological Science 22*(1) 23-27. http://dx.doi.org/10.1177/0963721412469398

Gilmore, C., Attridge, N., Clayton, S., Cragg, L., Johnson, S., Marlow, … Inglis, M. (2013). Individual differences in inhibitory control, not non-verbal number acuity, correlate with mathematics achievement. *PLoS One, 8*(6), e67374. http://dx.doi.org/10.1371/journal.pone.0067374

González-Castro, P., Rodríguez, C., Cueli, M., Cabeza, L., & Álvarez, L. (2014). Math competence and executive control skills in students with attention deficit/hyperactivity disorder and mathematics learning disabilities. *Revista de Psicodidáctica, 19*(1), 125-143. http://dx.doi.org/10.1387/RevPsicodidact.7510

Greenberg, M. L. (1996). *Test of Variables of Attention (TOVA)*. Los Alamitos, CA: U.A.D.

Harvey, H. A., & Miller, G. E. (2017). Executive function skills, early mathematics, and vocabulary in head start preschool children. *Early Education and Development, 28*(3), 290-307. http://dx.doi.org/10.1080/10409289.2016.1218728
Isquith, P., Crawford, J., Espy, K., & Gioia, G. (2005). Assessment of executive function in preschool-aged children. *Mental Retardation & Developmental Disabilities Research Reviews, 11*, 209-215. http://dx.doi.org/10.1002/mrdd.20075
Jones, L., Rothbart, M., & Posner, M. (2003). Development of executive attention in preschool children. *Developmental Science, 6*(5), 498-504. http://dx.doi.org/10.1111/1467-7687.00307
Keller, L., & Libertus, M. (2015). Inhibitory control may not explain the link between approximation and math abilities in kindergarteners from middle class families. *Frontiers in Psychology, 22*(6), 685. http://dx.doi.org/10.3389/fpsyg.2015.00685
Kline, R. B. (2011). *Principles and practice of structural equation modeling*. New York: Guilford Press
Marcovitch, S., & Zelazo, P. D. (2009). A hierarchical competing systems model of the emergence and early development of executive function. *Developmental Science, 12*, 1-18. http://dx.doi.org/10.1111/j.1467-7687.2008.00754.x
Meltzer, L. (2013). Executive function and metacognition in students with learning disabilities: New approaches to assessment and intervention. *International Journal for Research in Learning Disabilities, 1*(2), 31-63. http://dx.doi.org/10.4324/9780203893753
Miller, M. R., Rittle-Johnson, B., Loehr, A. M., & Fyfe, E. R. (2016). The influence of relational knowledge and executive function on preschoolers' repeating pattern knowledge. *Journal of Cognition and Development, 17*(1), 85-104. https://doi.org/10.1080/15248372.2015.1023307
Namkung, J. M., & Fuchs, L. S. (2016). Cognitive predictors of calculations and number line estimation with whole numbers and fractions among at-risk students. *Journal of Educational Psychology, 108*(2), 214-228. http://dx.doi.org/10.1037/edu0000055
Navarro, J. I., Aguilar, M., Marchena, E., Ruiz, G., Menacho, I., & Van Luit, J. E. H. (2012). Longitudinal study of low and high achievers in early mathematics. *British Journal of Educational Psychology, 82*(1), 28-41. http://dx.doi.org/10.1111/j.2044-8279.2011.02043.x
Passolunghi, M. C., & Lanfranchi, S. (2012). Domain-specific and domain-general precursors of mathematical achievement: A longitudinal study from kindergarten to first grade. *British Journal of Educational Psychology, 82,* 42-63. http://dx.doi.org/10.1111/j.2044-8279.2011.02039.x
Peng, P., Namkung, J. M., Fuchs, D., Fuchs, L. S., Patton, S., Yen, L., … Hamlett, C. (2016). A longitudinal study on predictors of early calculation development among young children at-risk for learning difficulties. *Journal of Experimental Child Psychology, 152,* 221-241. http://dx.doi.org/10.1016/j.jecp.2016.07.017
Raven, J. C., Court, J. H., & Raven, J. (1996). *Raven Matrices Progresivas* [Raven's Progressive Matrices]. Madrid: TEA.
Ribner, A. D., Willoughby, M. T., & Blair, C. B. (2017). Executive function buffers the association between early math and later academic skills. *Frontiers in Psychology, 8*, e869. http://dx.doi.org/10.3389/fpsyg.2017.00869
Rodríguez, C., González-Castro, P., García T., Núñez, J. C., & Álvarez, L. (2014). Attentional functions and trait anxiety in children with ADHD. *Learning and Individual Differences, 35*, 147-152. https://doi.org/10.1016/j.lindif.2014.07.010
Schmitt, S. A., Geldhof, G. J., Purpura, D. J., Duncan, R., & McClelland, M. M. (2017). Examining the relations between executive function, math, and literacy during the transition to kindergarten: A multi-analytic approach. *Journal of Educational Psychology, 109*(8)*,* 1120-1140. http://dx.doi.org/10.1037/edu0000193
Szucs, D., Devine, A., Soltesz, F., Nobes, A., & Gabriel, F. (2013). Developmental dyscalculia is related to visuo-spatial memory and inhibition impairment. *Cortex, 49*, 2674-2688. http://dx.doi.org/10.1016/j.cortex.2013/06.007
Van Luit, J. E. H., Van de Rijt, B. A. M., Navarro, J. I., Aguilar, M., Alcalde, C., Marchena, E., … García-Sedeño, M. (2015). *Test de evaluación de la competencia matemática temprana-informatizado (TEMT-i)* [Early Mathematical Competence Test-computerized]. Madrid: EOS.
Van Luit, J. E. H., & Van de Rijt, B. A. M. (2009). *The Early Numeracy Test Revised*. Graviant, Doetinchem: The Netherlands.
Verdine, B. N., Irwina, C. M., Golinkoff, R. M., & Hirsh-Pasek, K. (2014). Contributions of executive function and spatial skills to preschool mathematics achievement. *Journal of Experimental Child Psychology, 126*, 37-51. http://dx.doi.org/10.1016/j.jecp.2014.02.012
Welsh, J. A., Nix, R. L., Blair, C., Bierman, K. L., & Nelson, K. E. (2010). The development of cognitive skills and gains in academic school readiness for children from low-income families. *Journal of Educational Psychology, 102*(1), 43-53. http://dx.doi.org/10.1037/a0016738
Wiebe, S. A., Sheffield, T., Nelson, J. M., Clark, C. A. C., Chevalier, N., & Espy, K. (2011). The structure of executive function in 3-year-olds. *Journal of Experimental Child Psychology, 108,* 436-452. http://dx.doi.org/10.1016/j.jecp.2010.08.008
Zelazo, P. D., & Ulrich, M. (2011). Executive function in typical and atypical development. In U. Goswami (Ed.), *The Wiley-Blackwell handbook of childhood cognitive development* (2nd edition, pp. 574-603). Hoboken, NJ: Wiley-Blackwell.