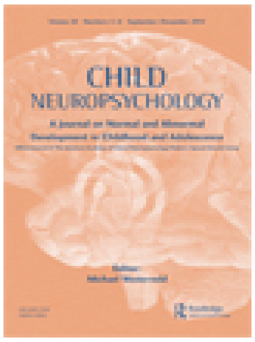

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A structural equation modeling of executive functions, IQ and mathematical skills in primary students: Differential effects on number production, mental calculus and arithmetical problems

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ABSTRACT

Though the relationship between executive functions (EFs) and mathematical skills has been well documented, little is known about how both EFs and IQ differentially support diverse math domains in primary students. Inconsistency of results may be due to the statistical techniques employed, specifically, if the analysis is conducted with observed variables, i.e., regression analysis, or at the latent level, i.e., structural equation modeling (SEM). The current study explores the contribution of both EFs and IQ in mathematics through an SEM approach. A total of 118 8- to 12-year-olds were administered measures of EFs, crystallized (Gc) and fluid (Gf) intelligence, and math abilities (i.e., number production, mental calculus and arithmetical problem-solving). Confirmatory factor analysis (CFA) offered support for the three-factor solution of EFs: (1) working memory (WM), (2) shifting, and (3) inhibition. Regarding the relationship among EFs, IQ and math abilities, the results of the SEM analysis showed that (i) WM and age predict number production and mental calculus, and (ii) shifting and sex predict arithmetical problem-solving. In all of the SEM models, EFs partially or totally mediated the relationship between IQ, age and math achievement. These results suggest that EFs differentially supports math abilities in primary-school children and is a more significant predictor of math achievement than IQ level.

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Executive functions; Intelligence; Mathematics; Structural equation modeling; Child neuropsychology

Mathematics is a primary science of understanding and knowledge in daily life for both adults and children (Taylor, 2013) that provides individuals with a series of tools, including problem-solving abilities, logical reasoning, and abstract-thinking skills that are essential for understanding and changing the world (DfES, 2004).

Recently, several studies have attempted to shed light on the cognitive processes underlying mathematics. Researchers have found evidence that intelligence (Floyd, Evans, & McGrew, 2003; Primi, Ferrão, & Almeida, 2010), language skills (Donlan, Cowan, Newton, & Lloyd, 2007), spatial attention (LeFevre et al., 2010), processing speed and phonological

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decoding (Fuchs et al., 2006) play a significant role in mathematical skills, among others. However, recent findings suggest that executive functions (EFs) are key predictors of math achievement. EFs are a set of cognitive processes necessary for goal-directed behavior (Luria, 1966; Stuss & Benson, 1986) that is considered a multidimensional construct which encompasses three separate but related components: working memory (WM), shifting and inhibition (Miyake et al., 2000). These higher-order cognitive processes predict both the development of pre-academic abilities (Espy et al., 2004; Shaul & Schwartz, 2014) and learning and academic achievement during school education (Jacobson, Williford, & Pianta, 2011; St Clair-Thompson & Gathercole, 2006; Thorell, Veleiro, Siu, & Mohammadi, 2013).

In the field of mathematics, several studies have found evidence demonstrating the contribution of all the three EF components to performance on different mathematical domains: WM (Agostino, Johnson, & Pascual-Leone, 2010; Alloway & Passolunghi, 2011; Andersson, 2008; Bull, Espy, & Wiebe, 2008; Holmes & Adams, 2006), shifting (Andersson, 2008; Bull & Scerif, 2001; Rosselli, Ardila, Matute, & Inozemtseva, 2009; van der Sluis, de Jong, & van der Leij, 2004; Yeniad, Malda, Mesman, van Ijzendoorn, & Pieper, 2013), and inhibition (Bull & Scerif, 2001; St Clair-Thompson & Gathercole, 2006). However, WM is the executive domain that consistently features in studies as the main predictor of math skills, with the findings related to shifting and inhibition being less conclusive (Bull & Lee, 2014).

Among the factors that might explain the heterogeneity of study results, the list includes the sample characteristics, the statistical techniques employed, and the tasks used in order to assess each construct (i.e., EFs and mathematics skills). Hence, for instance, in preschoolers, Espy et al. (2004) found that of the three EF components identified by means of exploratory factor analysis (EFA), only inhibition proved to be a significant predictor of math skills when controlling for the other EFs. Nevertheless, in a subsequent study, Bull, Espy, Wiebe, Sheffield, and Nelson (2011) found that executive control predicts math achievement as a single factor when using confirmatory factor analysis (CFA) techniques. In primary schooling, a number of studies analyzing the relationship between the three EFs and mathematics have found from the two EF factors distinguished (i.e., updating and a combined inhibition/switch factor) in 6-year-olds (Lee et al., 2012) and 7- to 8-year-olds (van der Ven, Kroesbergen, Boom, & Leseman, 2012) that only the updating component predicted mathematical skills. Some authors who examined three executive components in 5- to 6-year-olds (i.e., WM, flexibility and inhibition) also discovered that WM uniquely contributes to the variance in mathematical skills (Monette, Bigras, & Guay, 2011). However, through regression analysis, Bull and Scerif (2001) found that each component of the construct (i.e., WM, switching and inhibition) accounts for unique variance in math achievement in 7- to 8-year-olds. Finally, a number of studies carried out with older children that have used EFA and CFA techniques have found two relevant EF components. For example, St Clair-Thompson and Gathercole (2006) found that both WM and inhibition are related to math achievement in 11- to 12-year-olds, while van der Sluis, de Jong, and van der Leij (2007) found from the two components identified by means of CFA in 9- to 12-year-olds that only 'updating' predicted arithmetical performance. Other authors who have analyzed the flexibility component (i.e., verbal fluency) in children and adolescents aged 7 to 16 years as a single measure have also discovered that the former EF is a significant predictor of mathematics (Rosselli et al., 2009).

As regards the tasks used to assess mathematical skills, many studies use a unique composite measure. However, analyzing the influence of EFs using a unique measure does not offer understanding of those neurocognitive processes underlying different math skills. Indeed, previous studies using multiple measures have consistently demonstrated that EFs are differentially related to mathematical domains. For instance, Lan, Legare, Ponitz, Li, and Morrison (2011) found that inhibition only predicts counting skills, whereas WM uniquely predicts calculation in preschool children. Also with preschoolers, Röthlisberger, Neuenschwander, Cimeli, and Roebers (2013) presented results which suggest that EFs are more related to certain aspects of mathematics (i.e., sequence of numbers) than others (i.e., magnitude of comparison). It has even been demonstrated that the different components of WM (according to the model of Baddeley & Hitch, 1974) are also selectively related to different mathematical skills (Alloway & Passolunghi, 2011; Pina, Fuentes, Castillo, & Diamantopoulou, 2014; Simmons, Willis, & Adams, 2012). Thus, when studying the relationship between EF and mathematics, it seems essential to consider different skills, taking into account that existing evidence indicates that the contribution of EF to mathematical skills would depend on the domains assessed.

Executive Functions (EFs), IQ and math achievement

In the science literature there also exist mixed results regarding the relationships between EFs, IQ and mathematical skills. On the one hand, there are studies that have demonstrated that both intelligence and EFs jointly contribute to the performance of different mathematical skills, using not only regression analysis (Andersson, 2008; Bull & Scerif, 2001) but also path analysis (Kyttälä & Lehto, 2008). On the other hand, structural equation modeling (SEM) and path analysis studies have demonstrated that WM indirectly influence the performance of different mathematical skills through intellectual skills (Lee, Lee, Ang, & Stankov, 2009; Lee, Ng, Ng, & Lim, 2004), concluding that WM is a component of fluid intelligence (Lee et al., 2009). Finally, some studies have demonstrated that when including WM as a mediator of the relationship between intellectual skills and math performance (Passolunghi, Vercelloni, & Schadee, 2007), IQ levels do not directly influence mathematical skills. Studies along these lines have also shown that EFs are more important predictors than IQ for math performance (Kroesbergen, van Luit, van Lieshout, van Loosbroek, & van de Rijt, 2009) and future academic achievement (Alloway & Alloway, 2010) at the beginning of formal schooling. Hence, in terms of how intellectual abilities and EFs influence math performance when being considered together, the current body of evidence is not conclusive. It has been argued that the inconsistency of results may be due to the statistical techniques used (Lee et al., 2009), that is, whether the analysis is carried out with observed variables (i.e., regression analysis) or at the latent level (i.e., SEM analysis).

The Present Study

The present study aims to analyze the relationships between EF, IQ and distinct math domains in 8- to 12-year-olds. Given that there is little research which examines the structure of EF in terms of CFA (Bull & Lee, 2014), the EF structure in the present sample is examined. Another aspect worth noting is how mathematical performance is assessed, whether by means of a single composite measure or by analyzing different domains. As suggested in previous studies (Cragg & Gilmore, 2014; Viterbori, Usai, Traverso, & De Franchis, 2015), it becomes important to examine different mathematical skills, considering that EFs differentially contribute to specific mathematical domains. Thus, the present study evaluates the contribution of EFs to three mathematical domains: number production, mental calculus and arithmetical problem-solving. It has also been noted that when examining possible predictors of academic achievement, it becomes crucial to factor in IQ (Dickerson Mayes, Calhoun, Bixler, & Zimmerman, 2009). Lastly, most studies analyzing the role of EFs in mathematics have used correlation and regression techniques (Cragg & Gilmore, 2014; Lee et al., 2009), with few investigations using latent variable models. Overall, correlational studies are limited to the variables included in the research, relating them without attributing causality. Conversely, SEM covers models or complex structures by establishing multivariate causal hypotheses (MacCallum & Austin, 2000). For these reasons, this work aims at studying the contribution of both EFs and IQ to mathematics using an SEM approach.

Based on previous empirical evidence (Miyake et al., 2000; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003), it was firstly hypothesized that the EF structure is diverse and consists of three components. However, since there is also evidence in favor of both a unitary structure (Fuhs & Day, 2011; Wiebe, Espy, & Charak, 2008; Wiebe et al., 2011) and a bi-dimensional one (Huizinga, Dolan, & van der Molen, 2006; St Clair-Thompson & Gathercole, 2006), different theoretical models will be tested in order to analyze whether the EF structure is unitary or diverse. In the case that it is diverse, the number of factors integrating the construct will be verified. Secondly, it was hypothesized that EFs are selectively associated to distinct math domains. Lastly, it was hypothesized that EFs have a direct effect on math performance, even when considering the combined effects of age and IQ levels.

Method

Participants

The sample was composed of a total of 118 children (54 girls and 64 boys) of the following ages: 8 years (n = 23; 12 girls), 9 years (n = 25; 14 girls), 10 years (n = 17; 8 girls), 11 years (n = 31; 14 girls), and 12 years (n = 22; 6 girls). Based on information collected from the educational establishment, the children met the following inclusion criteria: (i) no diagnosis of developmental disorders such as dyslexia or attention deficit hyperactivity disorder (ADHD), (ii) no known history of neurological, psychiatric or pedagogical treatment, (iii) regular school attendance, and (iv) no grade repetition. The Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1990) was used before administering cognitive tasks in order to establish that the children demonstrated a performance within the range expected for their age group. The children showed an intellectual functioning within the range expected (M = 91.58, SD = 10.36).

Instruments

Intelligence

Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1990). The K-BIT offers a measure of crystallized (Gc) and fluid (Gf) intelligence and is made up of two subtests: (a) vocabulary (verbal/crystallized/knowledge), which includes part A to test expressive vocabulary and part B to test value definitions, and (b) matrices (manipulative/fluid/mental processing). The internal consistency analyzed using the two-half method is .98 for the Vocabulary subtest and .97 for the Matrices subtest. The test–retest reliability coefficient is .94 for the Vocabulary subtest and .86 for the Matrices subtest (Kaufman & Kaufman, 1990).

Working Memory

Digit Span and Letter–Number Sequencing Subtests of the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV; Wechsler, 2005). The WISC-IV provides a composite index of WM. It consists of two main subtest: Digits, which provides a measure of immediate oral retention when evaluated with Digits Forward, and maintenance and manipulation of information when using Digits Backward. In Letters and Numbers, the examiner reads a series of numbers and letters. Participants are instructed to recall the series, ordering the numbers from lowest to highest and the letters in alphabetical order. The WISC-IV has been standardized in Argentina. The average internal consistency using the two-half method is .85 for Letters and Numbers, .82 for Digits Forward and .74 for Digit Backwards. The test–retest reliability coefficient is .77 for Letters and Numbers, .76 for Digits Forward and .68 for Digits Backward (Wechsler, 2010).

Inhibition

Stroop Color–Word Test (Golden, 1978). The Stroop Color–Word Test provides a measure of interference control and the ability to inhibit an automatic verbal response. It consists of three sheets: the word condition, the color condition, and the color–word condition. On the word condition sheet, the words “blue”, “red” and “green” are written in black capital letters and arbitrarily arranged. The color condition sheet is made up of elements (e.g., xxxx) equally arranged but printed randomly in blue, green or red. The color–word condition sheet includes the same group of words from the first sheet but printed in the colors of the second sheet, so that the colors do not correspond to the printed words. Thus, the participant has to inhibit the reading of the word in order to say the name of the color. The test–retest reliability is .86 for the word condition, .82 for the color condition and .73 for the color–word condition (Golden, 1978).

NEPSY Knock-Tap (Korkman, Kirk, & Kemp, 1998). The NEPSY Knock-Tap test assesses self-regulation and inhibition. The participant must suppress a motor action in order to produce a motor response in conflict. Particularly, in the first section (i.e., items 1 to 15), when the examiner taps on the table, the child has to knock, and when the examiner knocks on the table the child has to tap. In the second part (i.e., items 16 to 30), the child has to tap with the side of his or her fist when the examiner knocks with his or her knuckles and knock with his or her knuckles when the examiner taps with the side of his or her fist. The child does not have to respond when the examiner taps on the table. The NEPSY battery has been standardized for Spanish-speaking children (Aguilar-Alonso, Torres Viñals, & Aguilar-Mediavilla, 2014). Several recent studies have employed this task to evaluate the inhibition component of EFs in English-speaking (Pratt, Leonard, Adeyinka, & Hill, 2014), French-speaking (Mainville, Brisson, Nougarou, Stipanicic, & Sirois, 2015) and Spanish-speaking (Aguilar-Alonso & Moreno-González, 2012) children.

d2 Test of Attention (Brickenkamp, 1962, Spanish adaptation by Seisdedos; Seisdedos Cubero, 2004). The d2 provides a measure of speed processing, selective attention, inhibitory control and mental concentration ability through selectively searching for relevant stimuli. The d2 is composed of a total of 658 items, organized in 14 lines each containing 47 letters. The stimulus is composed of the letters "d" and "p" with one or two dashes, placed either individually or in pairs above or below each letter. The participant has to search across the lines in order to recognize and cross all instances of "d" with two dashes (they can be positioned either above or below the letter) with a time limit of 20 seconds per line. It has been found that the d2 and the Stroop Color-Word Test load on a same factor in a factor analysis (Brickenkamp & Zillmer, 1998) and it provides a measure of the level of impulsivity (Wassenberg et al., 2008). The test has a high degree of internal consistency ($r > .90$), regardless of the statistic (two-half method and odd-even) and sample used (Brickenkamp, 1962). The present study uses the Total Efficiency of the Task variable, which provides a measure of attentional and inhibitory control and corresponds to the *number of processed elements* minus the *total number of errors made* (where the number of errors includes both errors of omission and errors of commission).

Shifting (Reactive and Spontaneous Flexibility)

Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993). The WCST provides a measure of EF, particularly of reactive cognitive flexibility and categorization ability. First, the examiner places four reference cards (containing one red triangle, two green stars, three yellow crosses, and four blue circles) in front of the participant. Then the participant is given 128 additional cards and is instructed to match each card to one of the four stimulus cards. Every time the participant places a card, he or she is told whether the placement was correct or incorrect; however, categories are not given to participants while they are classifying. Stability coefficients range between .39 and .72 (Heaton et al., 1993). A recent CFA study has found that this task strongly reflects the EF construct (Greve, Stickle, Love, Bianchini, & Stanford, 2005). The test has been standardized for Spanish-speaking children (Rosselli & Ardila, 1993).

Trail Making Test (TMT; Reitan & Wolfson, 1992). The TMT obtains a measure of sequencing, attention, motor performance, visual search and cognitive flexibility (Spreen & Strauss, 1998). Consisting of two forms, for TMT-A the participant has to draw lines in a sequence connecting 15 encircled numbers that are randomly dispersed on a sheet of paper. For TMT-B, the participant is required to alternate between numbers and letters (e.g., 1 with A, 2 with B, and so on). For both forms, the time and number of errors are recorded. The test–retest reliability coefficient ranges from .60 to .90 (Spreen & Strauss, 1998). It has been demonstrated by means of EFA and CFA that the task loads on the shifting factor of EFs (Lehto et al., 2003).

Semantic Verbal Fluency (SVF) (Fruits and Animals) and Phonologic Verbal Fluency (PVF) (FAS Fluency Test; Benton & Hamsher, 1989). The task gives the participant 60 seconds to say as many words as possible belonging to a particular category (SVF) or that begin with a specific letter (PVF). Verbal fluency tasks have standards for Spanish-speaking children (Arán Filippetti & Allegri, 2011; Ardila & Rosselli, 1994) and are widely used to measure EFs in children and adolescents from different countries (Arán Filippetti, 2013; Friesen, Luo, Luk, & Bialystok, 2015; John & Rajashekhar, 2014; Moura, Simões, & Pereira, 2013).

Five-Point Test (Regard, Strauss, & Knapp, 1982). This test obtains a measure of non-verbal fluency and spontaneous cognitive flexibility, defined as the participant's ability to generate novel tasks. The task includes a page that contains 35 identical squares arranged in five columns and seven rows. Each square includes five dots symmetrically set. The participants have to draw as many different figures as possible in a 3-minute period by connecting two or more dots with straight lines. The test–retest reliability coefficient for the number of unique designs is .77 (Tucha, Aschenbrenner, Koerts, & Lange, 2012).

Mathematical Skills

Mathematical Subtests from the Evaluación neuropsicológica infantil (ENI, [Children's Neuropsychological Assessment]; Matute, Rosselli, Ardila, & Ostrosky-Solis, 2007). ***Three domains were evaluated: Number Production, Mental Calculus, and Arithmetical Problems. Number Production is*** *organized* ***as follows***:

1. Reading Arabic Numbers: The participant has to read eight Arabic numbers written on a card: 2, 6, 18, 263, 5.003, 70.049, 930.116, 402.005.
2. Writing Arabic Numbers: The participant is requested to write the following sequences of dictated numbers: 1, 7, 61, 235, 8037, 42.001, 100.013, 6.050.010.
3. Magnitude Comparisons (Number Comparisons): Two sheets, each containing eight numbers (e.g., 1090 or 9010), are presented to participants one at a time; for each card, they are asked to say the larger number first and the smaller number second.

Mental Calculus is organized as follows:

1. Direct Series: Participants are requested to mentally count up from the number 7 in intervals of three (e.g., 7, 10, 13, etc.).
2. Inverse Series: Participants are requested to mentally count down from the number 94 in intervals of three (e.g., 94, 91, 88, etc.).
3. Mental Math: In this subtest, the participants must perform the calculations without using pen and paper. A total of 12 individual arithmetical operations

are verbally presented to participants: addition (2 + 3, 3 + 7, 23 + 14), subtraction (5 − 2, 11 − 7, 25 − 12), multiplication (5 × 3, 7 × 9), division (20 ÷ 2, 42 ÷ 7), and fraction problems (3/4 + 2/4, 1 − 2/3).

The Arithmetical Problems subtest involves eight worded arithmetical problems (deductive mathematical reasoning that considers two numerical propositions and requests that the participant provide a particular logic conclusion that follows from the two propositions). The participant is given a written version of each problem to her work out. Problems appear in a story format ranging from very easy (e.g., "If you have 3 apples and give 2 away, how many apples do you have left?") to more difficult (e.g., "A second-hand motorcycle was sold for $8,700, which is ¾ of its original price. What was its original price?"). One point is given for each correct answer.

Ethics Procedures

School principals were interviewed and received information concerning details of the research. Afterwards, a note was sent to children's parents or legal guardians requesting permission for their child to be included in the study. It was stated that participation was voluntary and anonymous. The parents or legal guardians provided their written consent before the assessment was undertaken.

Statistical Procedures

The mean (*M*) and standard deviation (*SD*) were calculated for each of the cognitive tasks. To test various EF models (i.e., three-factor, two-factor, one-factor and non-correlated factor models), CFA was used by means of AMOS Graphics v16.0 (Arbuckle, 2007). SEM was conducted to test different theoretical models that analyze predictors of different math abilities. The goodness-of-fit level of the models was evaluated using the χ^2 statistic, the Incremental Fit Index (IFI), the Akaike's Information Criterion (AIC), the Non-Normed Fit Index (NNFI), the Comparative Fit Index (CFI) and the Goodness-of-Fit Index (GFI). The NNFI, CFI and GFI have values that range between 0 and 1, with those greater than .90 indicating an acceptable fit (Hu & Bentler, 1995, 1999). IFI values can be greater than 1.0. Eventually, the root mean square error of approximation (RMSEA) was calculated for each model in order to test the degree of error. The RMSEA is considered acceptable when values are lower than .08.

Results

Descriptive Statistics

Table 1 shows the descriptive statistics for intellectual skills, EF measures and the different mathematical tasks for the total sample, while Table 2 presents task inter-correlations among measures.

Table 1. Descriptive Statistics for Cognitive Measures.

Variable	Task	Indicators	M	SD
Crystallized intelligence (Gc)	K-BIT	Expressive vocabulary	97.83	10.53
Fluid Intelligence (Gf)		Matrices	91.74	11.34
Working Memory	WISC-IV	Digits Forward and Digits Backward	15.90	3.48
		Letters and Numbers	15.51	3.33
Inhibition	Stroop	Color–Word	25.11	6.41
	Knock-Tap	Knock-Tap	27.86	1.93
	d2	Attentional Control and Inhibitory Control	256.92	90.78
Shifting	Trail Making Test	Part B	52.38	18.72
	WCST	All categories	5.36	1.19
	Five-Point Test	Unique designs	23.59	7.89
	Verbal Fluency Task	Total semantic and phonological fluency	39.45	11.29
Number production	ENI	Reading numbers	6.44	1.72
		Writing numbers	6.43	1.64
		Magnitude comparison	6.81	1.61
Mental calculus		Direct series	6.81	1.28
		Inverse series	5.25	2.41
		Mental math	7.50	2.88
Arithmetical problems		Arithmetical problem-solving	4.20	1.51

Note. ENI = Evaluación neuropsicológica infantil [Children's Neuropsychological Assessment]; K-BIT = Kaufman Brief Intelligence Test; TMT-B = Trail Making Test, Part B; WCST = Wisconsin Card Sorting Test; WISC-IV = Wechsler Intelligence Scale for Children – Fourth Edition.

Confirmatory Factor Analysis (CFA)

The following EF models were compared: a three-factor model, diverse two-factor models, a one-factor model and a model of uncorrelated factors. To determine the model that best fits the data, the NNFI, CFI, IFI, AIC, RMSEA and differences in χ^2 were considered. As shown in Table 3, the three-factor model demonstrates an excellent fit as the χ^2 adjustment is not significant, the NNFI, CFI and IFI values are above .90 and the RMSEA is below .08. Subsequently, different two-factor models were tested to prove if the EF structure is best explained by a two-factor model. The results indicate that the fit of all the two-factor models is significantly worse than that of the three-factor model. For the one-factor model, all the correlations between the latent variables were fixed to 1. Table 3 shows there is no significant improvement of fit for the unidimensional model over the three-factor model. Finally, a model of uncorrelated factors was tested in which all the correlations between the latent variables were fixed to zero. This model could not be identified. The final three-factor model is shown in Figure 1.

Structural Equation Model

Firstly, in order to analyze the contribution of age, sex and IQ (Gc and Gf) to different math domains, different models were tested (Table 4, Models 1–3). In Model 1, which analyzes the contribution of age, sex and IQ to *number production*, the significant predictors are age (β = .86) and Gf (β = .14). In Model 2, which examines the contribution of age, sex and IQ to *mental calculus*, the significant predictors are consistently age (β = .84) and Gf (β = .20). Finally, in Model 3, which analyzes the contribution of age, sex and IQ to *arithmetical problem-solving*, the significant predictors are age (β = .59), sex (β = .12), Gf (β = .31) and Gc (β = .23). As shown in Table 4, the NNFI, CFI and GFI for all these models obtain values over .90, and the RMSEA is ≤ .08; thus, all three models are considered to have a good adjustment.

Table 2. Correlations among Measures.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Gc	–																		
2. Gf	.38**	–																	
3. DF	.25**	.10	–																
4. DB	.11	.18	.45**	–															
5. LNS	.14	.27**	.46**	.58**	–														
6. Stroop	.09	.14	.31**	.39**	.29**	–													
7. KT	.10	.21*	.25**	.34**	.45**	.09	–												
8. IC	.01	.11	.26**	.40**	.49**	.54**	.26**	–											
9. TMT-B	−.12	−.23*	−.20**	−.43**	−.41**	−.41**	−.26**	.38**	–										
10. WCST	.20*	.21*	.20*	.22*	.30**	.21*	.29**	.09	−.19*	–									
11. FPT	−.06	.32**	.22**	.39**	.47**	.36**	.27**	.34**	−.47**	.16	–								
12.VF	.24**	.23*	.28**	.42**	.47**	.46**	.28**	.38**	−.43**	.28**	.49**	–							
13. RN	−.09	.11	.84**	.50**	.62**	.40**	.32**	.52**	−.36**	.26**	.49**	.48**	–						
14. WN	−.04	.13	.41**	.58**	.67**	.50**	.34**	.62**	−.46**	.27**	.52**	.51**	.84**	–					
15. MC	.20*	.16	.54**	.34**	.55**	.32**	.15	.35**	−.34**	.17	.35**	.48**	.45**	.54**	–				
16. DS	.09	.20*	.46**	.24**	.26**	.26**	.29**	.31**	−.22*	.26**	.27**	.39**	.34**	.46**	.36**	–			
17. IS	.20*	.23*	.64**	.47**	.59**	.47**	.28**	.35**	−.56**	.22*	.44**	.56**	.55**	.64**	.55**	.45**	–		
18. MM	.03	.21*	.80**	.62**	.72**	.50**	.30**	.52**	−.52**	.26**	.53**	.53**	.70**	80**	.49**	.39**	.67**	–	
19. AP	.25**	.40**	.59**	.45**	.60**	.46**	.28**	.42**	−.40**	.37**	.48**	.61**	.55**	59**	.50**	.39**	.65**	.71**	–

Note. *p < .05; **p < .01. AP = Arithmetical problems; DB = Digits Backward; DF = Digits Forward; DS = Direct series; FPT = Five-Point Test; Gc = Crystallized intelligence; Gf = Fluid intelligence; IC = d2 Test of Attention Inhibitory Control; IS = Inverse series; KT = Knock-Tap; LNS = Letters and Numbers sequencing; MC = Magnitude comparison; MM = Mental math; RN = Reading numbers; TMT-B = Trail Making Test, Part B; VF = Verbal fluency; WCST = Wisconsin Card Sorting Test; WN = Writing numbers.

Table 3. Fit Indices for the Three-Factor Model and Reduced Models.

Models	χ^2	*df*	*p*	NNFI	CFI	IFI	AIC	RMSEA	Δχ2a	Δdf	p
1. Three-factor model	38.86	**31**	**.157**	**0.97**	**0.98**	**0.98**	**86.86**	.047			
Two-factor models											
2. WM = Shifting	86.76	32	<.001	0.76	0.83	0.84	132.76	.121	47.89	1	<.001
3. Shifting = Inhibition	54.75	32	.007	0.90	0.93	0.93	100.75	.078	15.88	1	<.001
4. WM = Inhibition	43.26	32	.088	0.95	0.97	0.97	89.26	.055	4.39	1	.036
5. One-factor model	98.68	34	<.001	0.74	0.80	0.74	140.68	.128	59.81	3	<.001

Note. [a]Comparisons are with the three-factor model, i.e., Model 2 with Model 1, Model 3 with Model 1, etc. AIC = Akaike's Information Criterion; CFI = Comparative Fit Index; IFI = Incremental Fit Index; NNFI = Non-Normed Fit Index; RMSEA = root mean square error of approximation; WM = Working memory. NNFI, CFI and IFI values greater than .90, low AIC values and RMSEA values below .08 are indicators of good adjustment. The χ^2 difference tests show that all the reduced models (i.e., Models 2–5) provide a significantly worse fit than the three-factor model. The best-fit model values are presented in bold type.

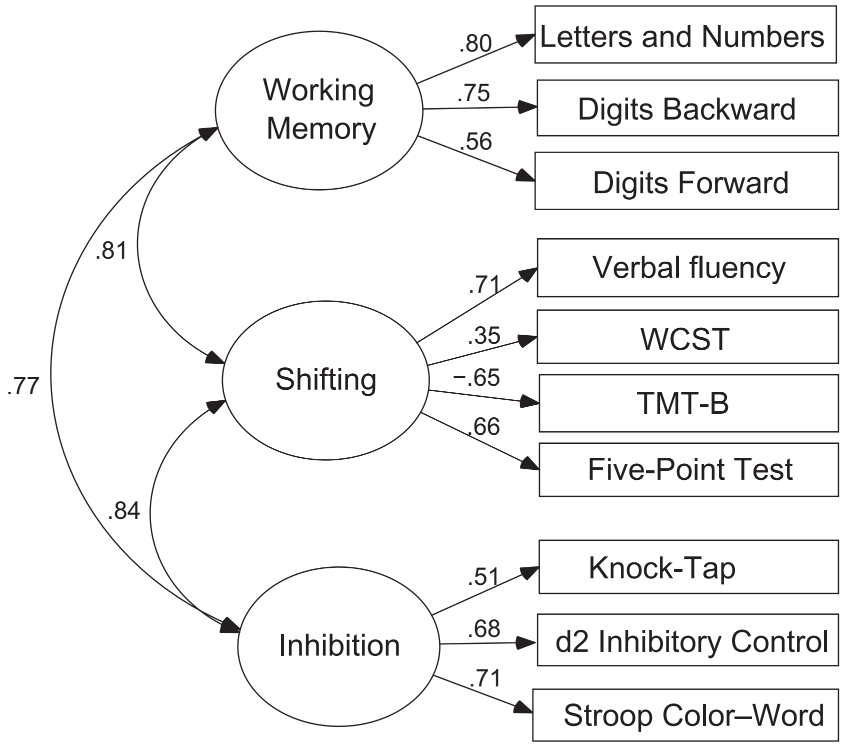

Figure 1. Estimated EF model.

Note. Solid lines indicate significant effects. TMT-B = Trail Making Test, Part B; WCST = Wisconsin Card Sorting Test.

Subsequently, different models were tested in order to analyze which specific EF relates to the different mathematical domains (Table 4, Models 4–6). In each of these models, the three EF components were included as predictors of performance on number production, mental calculus and arithmetical problem-solving. As seen in Table 4, every model has a good fit as the NNFI, CFI and GFI are greater than .90 and the RMSEA is lower than .08. In Model 4, which analyzes the contribution of the three EFs to *number production*, the only significant predictor is WM (β = .50). Likewise, in Model 5, which examines the

Table 4. Goodness-of-Fit Index (GFI) for All Models.

Models	χ^2	gl	p	χ^2/gl	AIC	NNFI	CFI	GFI	RMSEA
M1	22.25	13	.052	1.71	52.25	0.96	0.97	0.95	.078
M2	23.81	13	.033	1.83	53.81	0.93	0.96	0.94	.084
M3	7.43	5	.191	1.49	27.43	0.96	0.98	0.97	.064
M4	76.71	58	.051	1.32	142.71	0.96	0.97	0.92	.053
M5	99.97	59	.001	1.69	163.97	0.91	0.93	0.90	.077
M6	64.30	39	.007	1.65	118.30	0.91	0.94	0.91	.074
M7	28.09	17	.044	1.65	66.09	0.96	0.98	0.95	.075
M8	16.66	17	.478	.980	54.66	1.00	1.00	0.97	.000
M9	22.96	16	.115	1.44	62.96	0.97	0.98	0.96	.061
M10	11.54	16	.775	.721	51.54	1.01	1.00	0.98	.000
M11	60.87	23	.000	2.65	104.87	0.79	0.87	0.90	.119
M12	43.36	23	.006	1.89	87.36	0.89	0.93	0.92	.087

Note. AIC = Akaike's Information Criterion; CFI = Comparative Fit Index; GFI = Goodness-of-Fit Index; IFI = Incremental Fit Index; M1 = contribution of age, sex and IQ (Gc and Gf) to number production; M2 = contribution of age, sex and IQ to mental calculus; M3 = contribution of age, sex and IQ to arithmetical problem-solving; M4 = contribution of EFs to number production; M5 = contribution of EFs to mental calculus; M6 = contribution of EFs to arithmetical problem-solving; M7 = direct effects of WM and Gf on number production with Gf mediating WM effects; M8 = direct effects of WM and Gf on number production with WM mediating Gf effects; M9 = direct effects of WM and Gf on mental calculus with Gf mediating WM effects; M10 = direct effects of WM and Gf on mental calculus with WM mediating Gf effects; M11 = direct effects of shifting and IQ on arithmetical problem-solving with IQ mediating shifting effects; M12 = direct effects of shifting and IQ on arithmetical problem-solving with shifting mediating IQ effects; NNFI = Non-Normed Fit Index; RMSEA = root mean square error of approximation. In Models 7–12, the direct effects of age on math abilities and the indirect ones through EFs were also tested.

contribution of EFs to *mental calculus*, WM is again the only significant predictor (β = .56). Finally, in Model 6, analyzing the contribution of EF to *arithmetical problem-solving*, the unique significant predictor is shifting (β = .68).

Lastly, different models were tested in order to analyze the joint contribution of demographic (i.e., age and sex) and of those cognitive variables (i.e., IQ and EF) that have been shown to be significant predictors for each mathematical domain, and to investigate whether the relationship between EFs and mathematical skills is mediated by Gc and Gf or whether EFs mediate Gc or Gf in the prediction of mathematical performance. For this purpose, two models were used for each mathematical domain—a model which tests the direct effects of EFs and IQ on mathematical skills with IQ mediating the effects of EFs, and a model which tests the direct effects of EFs and IQ on mathematical skills with EFs mediating the effects of IQ.

Models 7 and 8 analyze the effects of the predictor variables on *number production*. The model that best fits the data (Model 8) suggests that age and WM have direct effects on number production, that WM partially mediates the relationship between age and number production, and that WM totally mediates the relationship between Gf and number production (Table 4 and Figure 2).

Models 9 and 10 analyze the effects of the predictor variables on *mental calculus*. The best-fit model (Model 10) suggests that only age and WM have direct effects on mental calculus. Further, the model indicates that WM partially mediates the relationship between age and mental calculus and totally mediates the relationship between Gf and mental calculus (Table 4 and Figure 3).

Finally, Models 11 and 12 analyze the effect of the predictor variables on *arithmetical problem-solving*. The model that best fits the data (Model 12) indicates that sex and shifting have direct effects on arithmetical problem-solving and that shifting totally mediates the relationship between age, Gc and Gf and arithmetical problem-solving (Table 4 and Figure 4).

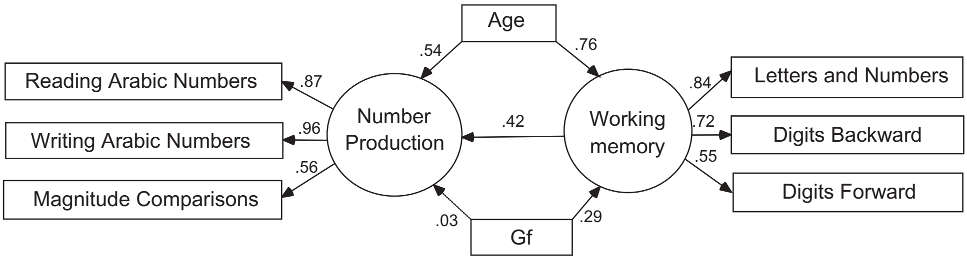

Figure 2. Final SEM of number production predictors.

Note. Solid lines indicate significant effects and dashed lines indicate non-significant estimates.

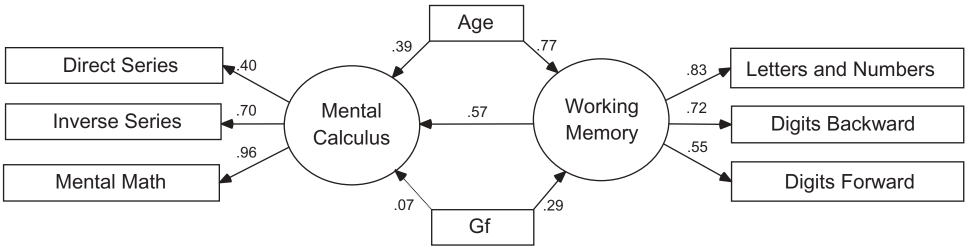

Figure 3. Final SEM of mental calculus predictors.

Note. Solid lines indicate significant effects and dashed lines indicate non-significant estimates.

Discussion

The present study aimed at analyzing the relationship among EF, IQ levels (i.e., Gc and Gf) and different math domains in primary-school children. Although some studies have demonstrated that both Gc (Bull et al., 2011) and Gf (Kyttälä & Lehto, 2008) are related to math skills in children, less is known about the role of IQ in mathematical performance when EF and age are considered together as possible predictors. Thus, an SEM approach was used in order to acknowledge whether the relationship between EF and mathematical skills is mediated by intelligence (Lee et al., 2004, 2009) or if EF mediates IQ in predicting mathematical performance (Passolunghi et al., 2007; Passolunghi, Mammarella, & Altoè, 2008).

Structure of EFs in Primary-School Children

On the basis of Miyake et al.'s (2000) three-factor model identified in college students and further replicated in 8- to 13-year-olds by Lehto et al. (2003), it was hypothesized that the EF structure in primary-school children consists of three separate but correlated factors. EFA studies have also found a factor solution of three executive factors; Levin et al. (1991) and Welsh, Pennington, and Groisser (1991) found three components in 7- to 15-year-olds and 8- to 12-year-olds, respectively. However, some studies have found that in preschoolers (Fuhs & Day, 2011; Wiebe et al., 2008, 2011) and adults (de Frias, Dixon, & Strauss, 2006), EFs are better explained by a single factor. Since the relationship among EF components changes as children develop (Best, Miller, & Jones, 2009), it is important to test the EF structure in different age groups. Therefore, prior to the analysis of the relationship between EFs and

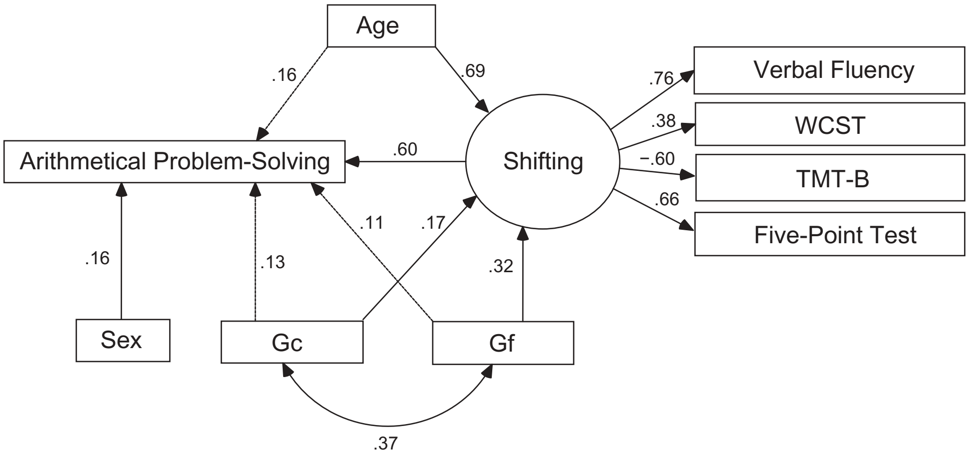

Figure 4. Final SEM of arithmetical problem-solving predictors.

Note. Solid lines indicate significant effects and dashed lines indicate non-significant estimates. TMT-B = Trail Making Test, Part B; WCST = Wisconsin Card Sorting Test.

different academic skills, it is important to identify the model that best describes the nature of EFs within the sample of children under study. Unfortunately, only a few studies have tested the EF structure in children before studying its relationship with mathematical skills, existing research that assumes the EF diversity, but that rarely tested it (Bull & Lee, 2014).

The results confirm our hypothesis; CFA offers support for a three-factor solution with WM, shifting, and inhibition. The WM factor, which is made up of the Digits Forward, Digits Backward, and Letter and Number subtasks of the WISC-IV, reflect the brain system that enables the maintenance and manipulation of the information necessary to carry out complex cognitive tasks (Baddeley, 1992). Many authors have proposed WM as a core component of EFs (Diamond, 2006; Miyake et al., 2000; Roberts & Pennington, 1996). The Inhibition factor which consists of the Stroop Color–Word Task, the Knock-Tap and the d2, captures the ability to inhibit irrelevant information in a manner which grants enough time to provide an answer and self-regulate behavior during the performance of complex goal-directed tasks. The tasks included in the shifting factor (i.e., the WCST, the TMT, the verbal fluency tasks and the Five-Point Test) assess both types of cognitive flexibility proposed by Eslinger and Grattan (1993): reactive flexibility and spontaneous flexibility. Thus, shifting reveals information about the capacity for cognitive change and the production of novel responses to problem-solving. Taken together, these data suggest that the EF construct in school-aged children can be explained by three strongly-correlated factors that rely on a common underlying mechanism.

EFs and Math Abilities

Considering previous empirical research, it was hypothesized that EF components are differentially related to distinct mathematical domains. The results show that when taking into account all three EFs in SEM analysis, WM is the unique predictor of *number production* and *mental calculus* achievement. Conversely, shifting is the only predictor of *arithmetical problem-solving*. In line with the results of Viterbori et al. (2015) who studied the performance of third graders, the present study shows that in the presence of WM and flexibility, inhibition is not a significant predictor of mathematical skills.

Several studies have demonstrated the predictive role of WM in mathematics both in preschoolers (Kolkman, Hoijtink, Kroesbergen, & Leseman, 2013; Kroesbergen et al., 2009; Monette et al., 2011) and school-age children (Andersson, 2008; Passolunghi et al., 2008; van der Ven et al., 2012). Also consistent with our results, previous studies have proved the effects of WM in number knowledge and counting (Holmes & Adams, 2006), numerical magnitude skills (Kolkman et al., 2013), multiplication performance (Agostino et al., 2010) and written (Andersson, 2008) and mental (Holmes & Adams, 2006) arithmetical skills. Moreover, it has been suggested that the different components of WM, according to the Baddeley and Hitch (1974) model (i.e., central executive, phonological loop and visuospatial sketchpad) do not equally influence mathematical skills, and that the central executive component is the main predictor (Andersson, 2008; Campos, Almeida, Ferreira, Martinez, & Ramalho, 2013; De Smedt et al., 2009). However, the predictive role of the phonological loop (Alloway & Passolunghi, 2011; Andersson, 2008) and the visuospatial sketchpad (Alloway & Passolunghi, 2011; Szucs, Devine, Soltesz, Nobes, & Gabriel, 2013) has also been demonstrated, with dissociable effects on different math skills according to the WM component analyzed (Caviola, Mammarella, Cornoldi, & Lucangeli, 2012; Simmons et al., 2012), as well as on school grades (De Smedt et al., 2009; van de Weijer-Bergsma, Kroesbergen, & van Luit, 2015). Given the tasks used in the current study, the results offer additional evidence to support the role of the central executive and phonological loop in number production and mental calculus, emphasizing the role of WM in these math skills beyond that of other EFs, age and IQ. Previous studies have also found that when analyzing the joint contribution of the three EFs, only WM proved to be a significant predictor of math achievement (Lee et al., 2012; van der Ven et al., 2012). It has been suggested that the supervision and coordination of multiple processes and access to arithmetical knowledge via long-term memory are functions of the central executive component of WM, which plays a significant role during arithmetic performance (Andersson, 2008). Another explanation is that the WM is necessary to both store and manipulate partial results and recall the information needed to solve mathematical operations (van der Ven, 2011; van der Ven et al., 2012). Besides, a higher WM capacity is associated with more efficient memory strategies (Barrouillet & Lépine, 2005).

The present results also indicate that shifting is a predictor of mathematical skills, particularly arithmetical problem-solving. Regarding the relationship between this EF and math skills, there remains inconsistency among studies. Though there may be a potential resolution for this disagreement in terms of the tasks used to evaluate each construct, along with whether or not the three EFs are considered as predictors of mathematics (Bull & Lee, 2014), a recent meta-analytic study concluded that shifting is a domain-free contributor of mathematical performance, regardless of the sample and statistical procedure used (Yeniad et al., 2013). In the present work, through the use of well-known tasks to evaluate reactive and spontaneous cognitive flexibility, it was found that this EF component is a significant predictor of arithmetical problem-solving, even more so than age and IQ. Previous studies have also demonstrated that spontaneous flexibility—as measured by VF tasks (Rosselli et al., 2009)—and reactive flexibility—as measured by the WCST (Andersson, 2008; Bull & Scerif, 2001)—are important predictors of mathematics. Besides, significant differences have been found among children with low and high arithmetic skills in the TMT—another well known task of reactive flexibility (McLean & Hitch, 1999). It was also found in van der Sluis et al. (2007) that performance on the TMT is related to children's arithmetic skills. Thus, the present results provide additional support for the role of shifting in arithmetic skills, as measured by the WCST, the TMT and VF tasks. It has been argued that shifting is necessary for inhibiting a learned strategy and switching to a new one (Bull & Scerif, 2001), as well as for progressing through the steps of multi-step problems (van der Sluis et al., 2007; van der Ven, 2011).

Overall, the present results confirm that there are differential effects on different math skills; distinct EFs underlie mathematical performance with regard to the analyzed domain. Specifically, WM is involved in number production and mental calculus, whereas shifting is selectively associated with arithmetical problem-solving. Dissociations between different mathematical skills have been explained on the basis of the triple-code model of Dehaene and Cohen (1995, 1997). This model postulates three types of numerical representations that rely on distinct brain structures: a visual Arabic code, subserved by the occipitotemporal areas of both hemispheres, a verbal code, subserved by perisylvian regions of the left hemisphere, and an analogical quantity code, localized in the inferior parietal regions of both hemispheres. This fact would explain how calculus could be affected by the relative preservation of number production (i.e., reading and number writing), as demonstrated in clinical patients (Dehaene & Cohen, 1997). Salguero-Alcañiz and Alameda-Bailén (2010) have also demonstrated that there is a double dissociation between numerical reasoning and the performance of arithmetic operations (i.e., calculus) in patients with cerebral acquired damage. This suggests that in healthy subjects, different cognitive processes are involved in distinct arithmetical operations (Salguero-Alcañiz & Alameda-Bailén, 2013), as consistently demonstrated in kindergarten (Lan et al., 2011; Röthlisberger et al., 2013) and school-aged children (Pina et al., 2014), as well as in the sample analyzed in the current study.

Age, Sex, and IQ Effects When Considering EFs in Predicting Math Abilities

When considering age, sex, IQ, and EFs as predictors of math achievement in SEM models, it was found that age is a significant predictor of number production and mental calculus. These results are consistent with previous findings that have demonstrated a better performance with age on different mathematical skills (Agostino et al., 2010; Rosselli et al., 2009). However, the results indicate that age plays a more important role than WM in number production, while WM and shifting play a more significant function than age in the prediction of mental calculus and arithmetical problem-solving, respectively. For number production and mental calculus, direct effects of age over each math domain, and indirect ones through WM, were found. Conversely, for arithmetical problem-solving, only indirect effects of age through shifting were found. Apparently, EFs partially or totally mediate the relationship between age and mathematical performance according to the mathematical domain analyzed. Previous studies have also demonstrated that WM partially (Agostino et al., 2010) or totally (Zheng, Swanson, & Marcoulides, 2011) mediates the relationship between chronological age and different math skills (i.e., multiplication performance and problem-solving) in children. This suggests that age-related changes in math abilities may be partly due to age-related changes in EFs.

Secondly, in line with Rosselli et al. (2009), it was found that sex does not influence those tasks that value number production, but does predict the task of arithmetical problem-solving. Consistently, the results show that boys obtained higher scores (*M* = 4.47, *SD* = 1.56) than girls (*M* = 3.89, *SD* = 1.38) in tasks of arithmetical problem-solving. According to Rosselli et al. (2009), it is not expected to find differences in terms of sex in number knowledge, since it is considered a primary numerical skill that is more independent from culture and experience than secondary numerical skills.

Finally, as regards the influence of IQ on different math skills, it was found that in the presence of EFs, IQ does not directly influence mathematical outcomes. Consistently, previous studies using an SEM approach have found that WM mediates the relationship between intellectual skills and math performance (Passolunghi et al., 2007, 2008). However, the inverse pattern has also been demonstrated, meaning that EFs contribute both directly to math performance and indirectly through Gf (Lee et al., 2004). In the present study, the best-fit models assumed that WM mediates the relationship between Gf and performance on both number production and mental calculus. Moreover, in those models where Gf is included as mediator of the relationship between WM and the aforementioned mathematical skills, Gf proved to be a significant predictor of mental calculus only (β = .12), while WM played a more important role in predicting this skill (β = .51). Thus, in line with previous studies, WM is not a proxy for IQ, but rather represents a dissociable factor in the prediction of mathematical skill (Alloway & Alloway, 2010; Alloway & Passolunghi, 2011). Consistently, Passolunghi et al. (2007) found that when considering this EF in the prediction of math skills, the level of intelligence does not directly influence math achievement. Conversely, in terms of arithmetical problem-solving, it was found that shifting mediates the relationship between IQ and this skill performance. Once again, when analyzing the inverse pattern (i.e., if IQ levels mediate the relationship between shifting and arithmetical problem-solving), it was found that although Gc (β = .19) and Gf (β = .10) predict this skill, the association between this mathematical domain and shifting is stronger (β = .48). Bull et al. (2011) also found that the relationship between executive control and mathematic achievement is not mediated by Gc in preschool children. Apparently, the influence of IQ on the mathematical domains analyzed in the current study might be explained by shared variance with WM for number production and mental calculus, and shifting for arithmetical problem-solving.

These results have major implications for clinical and educational practice. Firstly, understanding those cognitive processes underlying the performance of different math skills favors both the diagnosis of mathematical difficulties and the design of intervention strategies, considering those EF skills involved. Specifically, the results suggest that the EFs of WM and shifting are more important in the prediction of the mathematical domains analyzed in this study than age and IQ. These findings are consistent with cross-sectional studies which indicate that EFs contribute to the performance of different mathematical skills beyond the variance explained by age (Andersson, 2008; Rosselli et al., 2009) and IQ in both healthy children (Alloway & Passolunghi, 2011; Andersson, 2008; Bull & Scerif, 2001; Espy et al., 2004) and clinical samples (Alloway, 2007). Moreover, the present findings stress the importance of considering all three EF components when analyzing the implication of EFs in mathematics, since they contribute differently to performance in different mathematical domains. Hence, an early diagnosis of the weaknesses that children may demonstrate in each specific executive skill could contribute to the appropriate handling of mathematical difficulties. Finally, these findings show the need to develop and implement curricular changes that support and promote the development of the child's executive skills from the beginning of formal schooling, thus improving the development of mathematical skills throughout the educational cycle. Previous studies have demonstrated that it is feasible to improve EFs after training with transferable effects in learning (Alloway, 2009), and that good executive skills provide children with an initial advantage in mathematics that they keep during the first years of primary school (Bull et al., 2008).

Limitations and Future Directions

This study contributes to the understanding of the executive processes which underlie mathematics. However, some limitations need to be discussed. While the results of this study provide support for a three-factor structure of EF in agreement with previous work (Espy et al., 2004; Lehto et al., 2003; Miyake et al., 2000; Monette et al., 2011), it should be noted that a different set of tasks has been used compared to other research. Nevertheless, there is consistency between the present findings and previous research. First, the role of WM (Agostino et al., 2010; Alloway & Passolunghi, 2011; Andersson, 2008; Bull et al., 2008; Kolkman et al., 2013) and shifting (for a review, see Yeniad et al., 2013) in mathematics has been demonstrated in several previous studies. Moreover, the fact that inhibition failed to predict mathematical outcomes is not unexpected. Recent EFA and SEM studies that have analyzed the contribution of all three EFs to mathematics have found that inhibition is not a significant predictor in children (Lee et al., 2012; Monette et al., 2011; van der Ven et al., 2012; Viterbori et al., 2015) or that it only plays a minor role (van der Ven, 2011). However, some correlational studies have found that inhibition accounts for unique variance in math skills after controlling for both WM and shifting in preschoolers (Espy et al., 2004) and 6- to 8-year-olds (Bull & Scerif, 2001), though with considerable differences in the magnitude of the effect of inhibition (i.e., 12% vs. 2%). It may be that the statistical techniques used could partly explain these contradictory results. Another possibility is that the discrepancies between these findings may be caused by task measurement issues. For example, Bull and Scerif (2001) used two versions of the Stroop task, numerical and color–word, in order to assess inhibition, and found that only the numerical task related to math skills. Andersson (2008) also failed to find a significant contribution of inhibition—as measured by the Stroop task—to arithmetical performance in children. Some authors have argued that the nature—motor vs. cognitive or response inhibition vs. interference monitoring (Espy et al., 2004; Viterbori et al., 2015)—the complexity (Lan et al., 2011) and the higher vs. lower WM demands (Bull & Lee, 2014) of inhibitory tasks could selectively influence math achievement. Nevertheless, in the current study no significant association was found with math skills when distinct subtypes of inhibition were considered. Based on these results, an alternative explanation may be that the contribution of inhibition to mathematics, when the other EFs are included as predictors, is age-related. In this regard, it is important to note that most of the aforementioned studies were carried out at younger ages (i.e., in preschool children and 6- to 8-year-olds) compared to the children included in the current study and used a composite measure of mathematics. Future research would benefit from considering different EF measures in order to analyze the contribution of each component to mathematics at different ages. It is also important to use different EF assessment techniques, including, for instance, behavioral scales that have proved ecological validity, such as the Behavior Rating Inventory of Executive Function (BRIEF; Gioia & Isquith, 2004; Gioia, Isquith, Guy, & Kenworthy, 2000), or the relationship of EFs to academic achievement, e.g., the Childhood Executive Functioning Inventory (Thorell et al., 2013; Thorell & Nyberg, 2008).

Another limitation is that the WM measures used in the current study only involve the storage and handling of verbal material (i.e., phonological loop and central executive components). Based on previous literature, and considering the age range analyzed, there was no expectation to find a significant association between the visuospatial sketchpad and math performance; both cross-sectional (Holmes & Adams, 2006; Rasmussen & Bisanz, 2005) and longitudinal (De Smedt et al., 2009; van de Weijer-Bergsma et al., 2015) studies have shown that the importance of the visuospatial sketchpad for mathematics decreases with age (from 7 to 8 years), while the role of the phonological loop is likely to increase as children get older. However, considering that, to our knowledge, the role of the three components of WM in math skills together with measures of IQ and the other EFs has not yet been analyzed, the inclusion of a visuospatial WM task could provide a better understanding of the contribution of WM systems to mathematics when considering other possible cognitive predictors.

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