The Spanish Journal of Psychology
2011, Vol. 14, No. 2, On Line First
http://dx.doi.org/10.5209/rev_SJOP.2011.v14.n2.6

ISSN 1138-7416

Inhibitory Processes, Working Memory, Phonological Awareness, Naming Speed, and Early Arithmetic Achievement

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This study identified the cognitive processes that underlie the individual differences in early mathematical performance in elementary school children. Taking into account the Baddeley framework multicomponent model, the inhibitory processes, working memory, phonological awareness, and naming speed are considered to be related to early math learning. To examine this relationship, we compared the performance of a total of 424 typically developing middle-class children, aged between 4 and 7 years in a battery of cognitive and early numeric tests: The Utrecht Early Numeracy Test, the Rapid Automatized Naming Test, Spanish version of the Stroop task, the Numeracy Interference Test, Digit Span test, and Phonological Knowledge Test. The mean age of the participants was 72.21 months (*sd* = 14.8), and 48.6% were male and 51.4% were female. The results demonstrated that children performing worst on central executive, phonological processing, and inhibitory processes showed lower results in early mathematical tasks measured by The Utrecht Early Numeracy Test. Results supported the notion that the executive system is an important predictor of children's mathematical performance.
Keywords: inhibitory processes, working memory, phonological awareness, naming speed, arithmetic achievement, mathematics.

En este trabajo se identificaron las variables que están en la base de las diferencias de rendimiento en matemáticas en los primeros años de escolarización. Teniendo en cuenta el modelo multicomponente de Baddeley, se ha considerado que los procesos inhibitorios, la memoria de trabajo, la conciencia fonológica y la velocidad de denominación están a la base del aprendizaje matemático temprano. Con el fin de examinar esta relación se ha evaluado a un total de 424 escolares de 4 a 7 años (48,6 % eran niños y 51,4 % niñas) con una batería de pruebas cognitivas y de rendimiento matemático: el test de Utrech de matemática temprana, el test de velocidad de nominación, la versión española de la tarea de Stroop, un test de memoria de dígitos y un test de conciencia fonológica. Los resultados mostraron que aquellos alumnos que obtenían peores resultados en memoria de trabajo, conciencia fonológica y procesos inhibitorios, mostraban también peores resultados en tareas matemáticas evaluadas por el test de Utrech. Estos resultados apoyan la noción de que el funcionamiento de los procesos ejecutivos puede predecir los resultados en actividades de matemáticas tempranas.
Palabras clave: procesos inhibitorios, memoria de trabajo, conciencia fonológica, velocidad de denominación, aritmética, matemáticas.

The study was funded by the Spanish MEC grants SEJ2007-62420/EDUC and PAI, P09-HUM7918.

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Research has identified significant differences among children's math performance (Anderson, 2008). However, some studies do not provide a satisfactory rationalization for this variability (Geary, 2004). Although the differences are attributed to intelligence, this can only explain 9–25% of the variance in children's math achievement (Resing, Ruijssenaars, & Bosma, 2002). Recent studies indicate that other domain-general cognitive abilities, more specifically working memory (DeStefano, & LeFevre, 2004; Kyttala, & Lehto, 2008), may provide better explanations for variability in early math learning (Bull, Espy, & Wiebe, 2008; Kroesbergen, Van de Rijt, & Van Luit, 2007; Van der Sluis, de Jong, & Van der Leij, 2007). Although there are several models of cognition, Baddeley's multicomponent model has often been used to explore the role of cognitive processing in mathematical problem-solving (Swanson, Jerman, & Zheng, 2008). To comprehend and solve early math tasks, one must be able to keep track of incoming information (Swanson & Beebe-Frankenberger, 2004). This is necessary to understand words, phrases, and sentences that, in turn, are necessary to construct a coherent and meaningful interpretation of the tasks.

This study focuses on children's knowledge of preparatory math skills that usually receive little attention in schools. Inhibitory processes, central executive, phonological awareness, and naming speed were evaluated. *Inhibitory processes* are considered to be an important component of central executive (Carlson & Moses, 2001; Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003). As currently used in the cognitive literature, inhibition refers to the central, active suppression of information that is irrelevant to a task. *Working Memory* has been described as an active information processor responsible for storing and processing information for a short time (Baddeley, 1997). It includes three components: a central executive controlling system, which is considered primarily responsible for coordinating the activities of the phonological component and the visual–spatial component that also describes the resources from long-term memory. The central executive task requires children to hold increasingly complex information in the memory while responding to questions about a task. *Naming Speed* refers to rapidly responding to a variety of the most familiar visual symbols and stimuli in the language: letters, numbers, colors, and simple objects. *Phonological awareness* is the knowledge that words are made up of individual sounds. Phonological awareness is the precursor to phonics, which is a frequent method used to teach children to read. If a child cannot "sound out a word" or does not have good "word attack skills," it is possible that he/she may not have the underlying phonological awareness necessary to understand and use phonics. Phonological awareness includes syllabification and rhyming, isolating the beginning or ending sounds in a word, segmenting words into sounds, and deleting the beginning or ending sound and saying that word.

This study had the general goal to identify cognitive processes that underlie the individual differences in early mathematical performance in elementary school children. Inhibitory processes, central executive, phonological awareness, and naming speed are considered to be related to early math learning. We considered the working memory components: central executive, inhibitory processes, and the phonological loop (naming and phonological awareness). Some research has connected the working memory components to calculation and problem solving (Swanson et al., 2008). In arithmetic, the cognitive processes involved in performing calculations are embedded within the working memory system in that they require a combination of transitory information storage while performing other mental operations. For instance, to solve the problem 13 + 9, one must at the same time retain two or more portions of information (phonological codes representing the numbers 13 and 9) and then use one or more actions (e.g., retrieval) to combine the numbers to generate an answer. Alternatively, employing carrying or regrouping involves maintaining recently processed information while performing a related operation. To solve 13 + 29, one must keep the 2 from adding 9 + 3 while adding the 1 from the tens column of the 13 to the 1 from the tens column of the 1-2 produced from adding the 9 + 3 (Berg, 2008). Finally, phonological loop components were precursors for arithmetic and logic in first and second grade (Alsina, & Saiz, 2003; Passolunghi, Mammarella, & Altoè, 2008).

Method

Participants

A total of 424 typically developing middle-class children, aged between 4 and 7 years from schools in Cadiz (Spain) district participated in this study. Parental permission to gather data from the children was obtained prior to the study. The mean age of the participants was 72.21 months (sd = 14.8), 48.6% were male and 51.4% were female. Table 1 shows the descriptive data for all the groups.

Materials

Assessment material description

The Utrecht Early Numeracy Test (UENT) Spanish version (Navarro et al., 2011; Van de Rijt, Van Luit, & Pennings, 1999). The test takes a developmental perspective on children's number sense. The UENT assesses eight aspects of mathematical competence: concepts of comparison of quantitative and qualitative characteristics of objects; classification of objects in class or subclass; correspondence of one to one relation; seriation of objects in class or subclass based on criteria; using counting words, forwards and

Table 1
Summary of participants' schooling, age, and gender descriptive data

Groups	*N*	Age (*months*)			Gender			
		mean	*sd*	*range*	Male		Female	
					n	*%*	*n*	*%*
4 years	118	53.6	3.32	46–60	46	39.0	72	61.0
5 years	87	66.0	3.5	60–72	49	56.3	38	43.7
6 years	92	77.5	3.5	71–86	51	55.4	41	44.6
7 years	127	90.0	4.2	83–106	60	47.2	67	52.8
Total	424				206	48.6	218	51.4

backwards; structures counting, synchronous counting, shortened counting from the dice structure; resultative counting, structured and unstructured quantities as well as counting hidden quantities; and general knowledge of numbers, being able to use knowledge of the number system in simple problem condition. Each subtest has five questions. The UENT (version A) was individually administered in a 20-min session. After the administration, the given answers were judged on their correctness with the help of the UENT scoring key. The UENT reliability was (α = .835).

The Rapid Automatized Naming Test (RAN) (Wolf & Denckla, 2003). The RAN is an individually administered reaction-time test. The goal of the task is to name the 200 stimuli as fast as possible. The stimuli are typically displayed on an 8.5×11 inch sheet of paper containing 5 rows of 10 stimuli. The typical naming task has a serial format, although a discrete task format could also be used. However, the highest correlation between the serial format tasks and reading components suggests that serial tasks are a better indicator of speed processing involved in reading. The task consists of two letter and number sets and two other color and picture sets. The task score is the time it takes for the individual to say all the names of the stimuli, starting from the top left stimulus, and proceeding row by row in a left-to-right fashion, until the bottom right stimulus is labeled and all stimuli are named. The RAN provides the record of the cognitive processes involved in reading letters, and the RAN reliability was (α = .809).

Stroop task. A Spanish version of the Stroop task (Golden, 2005) yields the measures of speed, effortful inhibition, and susceptibility to interference. Individuals were presented with a series of color words (black, blue, green, red, orange, and yellow) printed on a page and were required to quickly name aloud the color of the ink in which the words were written. For example, the individual had to say "blue" in response to the word "yellow" written in blue ink. The task consisted of three conditions: (a) neutral (rows of three to six Xs were presented in different colors), (b) Stroop (color words were written in incongruent ink colors, and there was no relationship between adjacent items), and (c) Inhibition Response (throughout the list, each word was printed in the color of the word that preceded it, e.g., the word "blue" printed in yellow would be followed by the word "orange" printed in blue, followed by the word "black" printed in orange, etc.). As the reading response is activated automatically, the color/word scheme competes with the ink/color scheme at the response level, resulting in a delay in response. This is the Stroop effect. This response competition may be resolved by inhibiting the color/word response. This inhibition is effortful, because the word and ink color are integrated in a single stimulus, and their corresponding perceptual and cognitive schemes are both initially activated. Instructions emphasized on both speed and accuracy. The tester used a digital stopwatch to time the latency in completing the naming of the stimuli on each card, and recorded the errors in color naming. Latency (in seconds) and error score for each condition (neutral, Stroop, and IR) were registered. The Stroop effect is evidenced by a longer latency in the Stroop condition than in the neutral condition, which provides a measure of susceptibility to interference. The Stroop task was individually administered in a 15-min session, and the Stroop task reliability was (α = .863).

Susceptibility to number interference was evaluated by the Spanish version of *The Numeracy Interference Test* (NIT) (Butterworth, 1999). The test consists of presenting three groups of number pairs, 15 pairs in each group. The first group (T1) comprises pairs of standard numbers always ≤ 9 (4 - 2; 8 - 3; 7 - 4). The second group (T2) comprises pairs of standard numbers ≤ 9, but in each pair one number is printed twice the size of the other number. This is the key to the test, given that there is a discrepancy between the size of the number and the quantity it represents. For example, if the pair 4–7 is presented, 4 is printed twice the size of 7, although it represents a smaller quantity. The third group (T3) has the same characteristics as T2, but there is no discrepancy with respect to the larger number of the pair printed twice the size. For example, in the pair 3-1, 3 is printed twice the size of 1, and is also the larger number among the two. The examiner asks the child in each case to say the numerically larger number of the pair, and not the number larger in physical size. Both the number of errors in each group of pairs and the latency in completing the tasks were noted, and the Spanish version of *RAN* reliability was (α = .812). The interference effect was calculated using an efficiency algorithm: correct responses for T2 (interference task A2) divided by time used for task (T2), multiplied by 100.

Digit Span Sub-test from Wechsler Intelligence Scale for Children (WISC-IV) (Wechsler, 2005). This test requires the examiner to verbally present the digits at a rate of one digit per second. The forwards test requires the participant to repeat the digits verbatim, while the backwards test requires the participant to repeat the digits in the reverse order. Digits backwards were used as a central executive measurement (Pickering, Baques, & Gathercole, 1999). The number of digits increases by one until the participant consecutively fails two trials of the same digit span length. The digit span was individually administered in a 5-min session, and the digit span reliability was (α = .897).

Phonological Awareness was assessed by *The Phonological Knowledge Test* (PECO) (Ramos & Cuadrado, 2006). The PECO has 30 items in total with 3 different types of activities (identification, addition, and omission), such as syllable knowledge (15 items) and phoneme knowledge (15 items). The PECO *Syllable Knowledge* has three types of tasks: (a) to identify one syllable in the word: the examiner says several words and the student must identify in which word he heard some specific sound; (b) to add a syllable to make a new word: a piece of word or pseudo-word is presented, such as obtaining a new word or pseudo-word when we add another sound at the beginning, in the middle, or at the end. For example, if we add /*so*/ at the end of /*pato*/, the word that we get is /*patoso*/ (e.g., in English, if we add /*less*/ at the end of /*home*/, we get the word /*homeless*/); and (c) to omit a syllable in a word: the examiner introduces a word or a picture, and the student must say which syllable is missing. For example, “This is a /*silla*/ [chair]”. If I just say /*lla*/, “which sound is missing?” The *PECO* also has three types of phoneme knowledge tasks: (a) to identify one phoneme in the word: for example, children have to point out the words that have the sound /*f*/ (faro [lighthouse], zumo [juice], gafas [glasses], sapo [toad]); (b) to add a phoneme to make a new word, a piece of a word is presented orally, such as when we add another sound at the beginning, in the middle, or at the end, we get a new word. For example, “If we add /*a*/ at the beginning of /*leta*/, then how does it sound?” (/aleta/; [*fin*]); and (c) to omit a phoneme in a word; for example, “if in /perro/ [dog], we omit the sound /p/, what do we get?” (/erro/). The PECO was individually administered in a 20-min session, and the PECO reliability was (*α* = .801).

Procedure

After a pilot study with 15 participants, different from the sample, the children were tested with mobile research equipment during their first or second kindergarten, or first grade year. They were assessed individually in a quiet place in their schools during a normal school day. Tasks were administered over three to four sessions within a 2-week interval by four qualified researchers in child assessment. Each testing session lasted for approximately 25 min. We counterbalanced the test administration to control the order effects. The task order was random among the participants with each test administrator. Children of 4 only completed the UENT. Children of 5 did not complete the Stroop’s task and NIT.

Results

The means and standard deviations for the measures of the UENT, RAN, Stroop task, NIT, WISC-IV, and PECO are shown in table 2. In addition to a descriptive analysis of data, the Pearson’s correlation (WM, inhibitory processes, naming speed, and phonological awareness) for the UENT performer was analyzed. As expected, the UENT scores increased with the students’ age. Furthermore, 4-year-old children got a mean of 9.8 in the total test; 7.9 in Relational (which includes Concepts of Comparison, Classification, Correspondence, and Seriation); and 1.9 in the Numbers section, which included counting words, forwards and backwards, structures counting, synchronous counting, shortened counting, resultative counting, and general knowledge of numbers.

When the processing speed and other process integration were analyzed by RAN, we observed that the children took less time in identifying numbers, letters, colors, and drawings according to their ages (table 2). Furthermore, they also made fewer errors in naming the same. Similar data were also obtained for letters, colors, and drawings, with regard to the effortful inhibition assessed by the Stroop task, in 6- and 7-year-old children. These data suggested a higher inhibitory effort when participants were older. The progression data for susceptibility to interference according to age, evaluated by NIT (correct T2 and T3; and time T2 and T3) suggested a higher interference effect according to participants’ age. The central executive, assessed by the digits backwards test, also increased digits span with age. Finally, the phonological awareness was evaluated for students of age 5-, 6- and 7-years old. Data collected after PECO demonstrated an increase in phonological awareness with age. Equivalent results were found in phonemic identification, addition, and omission (see table 2).

The Pearson’s correlation (central executive, inhibitory processes, naming speed, and phonological awareness) for UENT performance data are displayed in tables 3–7. Processing speed analyzed by RAN revealed significant results ($p < .01$) with the total and relations subtests UENT scores for 7-year-old children in speed letters, error letters, speed colors, and error colors. For 6-year-old children, significant results were obtained in total UENT scores for speed digits, error digits, error letters, and speed drawings.

Table 2

Means and standard deviations for measures of The Utrecht Early Numeracy Test (UENT), The Rapid Automatized Naming Test (RAN), Spanish version of the Stroop task, The Numeracy Interference Test (NIT), Digit Span sub-test from Wechsler Intelligence Scale for Children (WISC-IV), and The Phonological awareness Test (PECO)

UENT	4 y	5 y	6 y	7 y
Relational	7.9 *(3.0)*	13.1 *(2.7)*	16.3 *(2.1)*	18.0 *(1.8)*
Numbers	1.9 *(2.2)*	8.6 *(4.1)*	13.9 *(3.8)*	17.1 *(2.4)*
Total	9.8 *(4.4)*	21.7 *(5.8)*	30.2 *(5.5)*	35.2 *(3.7)*
Speed digits (RAN)	81.1 *(30.2)*	71.9 *(28.4)*	46.8 *(15.2)*	32.7 *(7.8)*
Errors digits (RAN)	1.6 *(3.4)*	2.1 *(4.0)*	0.29 *(1.0)*	0.2 *(0.9)*
Speed letters (RAN)	83.8 *(18.9)*	80.3 *(28.3)*	50.3 *(16.2)*	34.4 *(8.7)*
Errors letters (RAN)	0.5 *(0.7)*	1.9 *(3.2)*	1.4 *(3.5)*	0.4 *(1.2)*
Speed colors (RAN)	96.2 *(31.1)*	81.4 *(33.7)*	65.9 *(18.8)*	53.3 *(15.1)*
Errors colors (RAN)	0.9 *(2.7)*	0.7 *(1.7)*	0.4 *(1.0)*	0.20 *(0.4)*
Speed draws (RAN)	95.3 *(27.4)*	81.7 *(28.3)*	64.9 *(14.1)*	53.4 *(13.7)*
Errors draws (RAN)	0.9 *(2.2)*	0.4 *(1.0)*	0.2 *(0.5)*	0.07 *(0.2)*
Identification ph (PECO)		7.0 *(2.0)*	9.1 *(1.1)*	9.6 *(0.9)*
Addition ph (PECO)		3.8 *(2.7)*	6.3 *(2.5)*	8.4 *(1.8)*
Missing ph (PECO)		2.7 *(1.9)*	7.2 *(2.5)*	8.6 *(2.0)*
Total Ph (PECO)		13.6 *(5.2)*	22.9 *(5.3)*	26.5 *(4.6)*
Digits forward (WISC-IV)		5.5 *(1.1)*	6.2 *(1.2)*	6.7 *(1.2)*
Digits backward (WISC-IV)		3.5 *(1.7)*	4.7 *(1.1)*	5.6 *(1.2)*
Total digits (WISC-IV)		9.1 *(2.2)*	11 *(1.7)*	12.2 *(1.8)*
Correct colors (STROOP)			22.3 *(18.6)*	31.0 *(17.2)*
Error colors (STROOP)			9.1 *(8.0)*	5.09 *(5.6)*
Correct T1 (NIT)			14.4 *(1.5)*	14.6 *(5.9)*
Correct T2 (NIT)			14.2 *(1.3)*	14.3 *(0.8)*
Correct T3 (NIT)			14.3 *(2.8)*	14.7 *(9.2)*
Time T1 (NIT)			13.9 *(2.1)*	18.2 *(1.1)*
Time T2 (NIT)			30.9 *(10.5)*	21.8 *(4.5)*
Time T3 (NIT)			23.6 *(8.6)*	18.0 *(1.6)*

Furthermore, for 5-year-old children, significant correlations were obtained in total UENT scores for speed colors and speed drawings, while 4-year-old children got significant correlations in speed colors ($r = -.323$, $p < .01$) and speed drawings ($r = -.336$, $p < .01$) (table 3).

Effortful inhibition assessed by a Spanish version of the Stroop task for children of 6 and 7 years of age demonstrated significant Pearson's correlation with UENT total score in 7-year-old children. Non-significant Pearson's correlation was obtained with 6-year-old children (table 4).

Table 3

Pearson's correlation for The Utrecht Early Numeracy Test (UENT) and The Rapid Automatized Naming Test (RAN)

RAN	UENT Relational				UENT Numbers				Total UENT			
	4 y	5 y	6 y	7 y	4 y	5 y	6 y	7 y	4 y	5 y	6 y	7 y
Speed digits	−.03	.037	−.197	−.019	−.37	−.49*	−.237*	−.236**	−.27	−.329	−.242*	−.165
Errors digits	.137	−.062	−.216*	−.006	−.216	−.262*	−.357*	−.064	−.07	−.216	−.333*	−.045
Speed letters	−.55	−.227	−.216*	−.337**	−.572	−.244	−.135	−.346**	−.64	−.276	−.185	−.382**
Errors letters	.261	−.224	−.218*	−.353**	−.16	−.264	−.184	−.350**	−.02	−.276	−.219*	−.404**
Speed colors	−.244*	−.059	−.137	−.229**	−.307*	−.370*	−.101	−.424**	−.323*	−.288**	−.124	−.398**
Errors colors	−.083	.062	−.135	−.159	−.81*	−.177	−.105	−.218*	−.09	−.096	−.126	−.226*
Speed draws	−.221*	−.109	−.306*	−.141	−.365*	−.335*	−.287*	−.289*	−.336*	−.301*	−.321*	−.259**
Errors draws	−.136	−.154	−.262*	−.118	−.04	−.075	−.161	−.132	−.114	−.124	−.216	−.145

* $p < .05$; ** $p < .01$

Table 4
Pearson's correlation for The Utrecht Early Numeracy Test (UENT) and Stroop Task

STROOP	UENT Relational		UENT Numbers		Total UENT	
	6 y	7 y	6 y	7 y	6 y	7 y
Correct colors	−.046	.244**	.015	.398**	−.009	.385**
No. Error colors	−.042	−.143	−.060	−.261**	−.060	−.240**

** $p < .01$

The progression for susceptibility to interference according to age, evaluated by NIT showed significant Pearson's correlation with 6 and 7-year-old children in UENT numerical ($r = .486$; $p < .01$; $r = .470$; $p < .01$), relational ($r = .386$; $p < .01$; $r = .383$; $p < .01$), and total scores ($r = .469$; $p < .01$; $r = .501$; $p < .01$).

Central executive assessed by digits backwards test data showed significant Pearson's correlations in UENT numerical, relational and total scores for 6- and 7-year-old children (table 5). With regard to total digits, 6-year-old children demonstrated a score of $r = .563$, $p < .05$, and 7-year-old children revealed a score of $r = .239$, $p < .05$.

Finally, phonological awareness evaluated by PECO had some significant correlations with UENT total scores of 5- to 7-year-old participants. For total phonemes PECO scores, significant ($p < .01$) for children with 5, 6 and 7 years old (table 6).

We also calculated the Pearson's correlation for different cognitive variables for participants of 6 and 7 years old. Significant correlations between number naming speed, phonological awareness, working memory and interference effect were found (table 7).

Table 5
Pearson's correlation for The Utrecht Early Numeracy Test (UENT) and central executive (Digit Span from WISC-IV). Digits backwards was used as a central executive measurement

WISC-IV	UENT Relational		UENT Numbers		Total UENT	
	6 y	7 y	6 y	7 y	6 y	7 y
Digits forwards	.244*	.154	.166	.176	.212*	.186*
Digits backwards	.533*	.278*	.596*	.191*	.625*	.264*
Total digits	.525*	.221*	.511*	.200*	.563*	.239*

* $p < .05$** $p < .01$

Table 6
Pearson's correlation for The Utrecht Early Numeracy Test (UENT) and Phonological Awareness (PECO)

PECO	UENT Relational			UENT Numbers			Total UENT		
	5 y	6 y	7 y	5 y	6 y	7 y	5 y	6 y	7 y
Identification Phonemes	.145	.240*	.096	.063	.141	.012	.113	.193	.056
Addition Phonemes	.256*	.420**	.124	.097	.392**	.027	.190	.439**	.085
Missing Phonemes	.291**	.456**	.316**	.291**	.287**	.236**	.343**	.380**	.316**
Total Phonemes	.383**	.468**	.236**	.345**	.340**	.183*	.424**	.422**	.247**

*$p < .05$; ** $p < .01$

Table 7
Pearson's correlation for central executive (digits backward), interference effect (NIT), number naming speed (RAN), and phonological awareness (PECO)

	Central Executive	Interference effect	Number naming speed	Phonological awareness
Central Executive	1			
Interference effect	.294**	1		
Number naming speed	–.430 **	–.449 **	1	
Phonological awareness	.560 **	.180*	–.480**	1

* $p < .01$; ** $p < .05$

A hierarchical regression was calculated to determine the statistical weight of different cognitive variables, predicting early mathematical achievement assessed by UENT. Comparison was carried out using UENT total, relational, and numbers sub-scales scores as dependent measures. Regression data suggested three significant factors: susceptibility to interference effect, assessed by NIT ($F(1,118) = 49.80$; $p < .0001$); central executive ($F(2,117) = .41.10$; $p < .0001$), and phonological awareness ($F(3,116) = 29.45$; $p < .0001$). The hierarchical regression model found allows us to predict that interference, central executive and phonological awareness explain 41.6 % of variance for the UENT total score. Hierarchical regression calculated for UENT relational sub-scale suggested three statistically significant factors ($p < .0001$): susceptibility to numerical interference effect assessed by NIT ($F(1,118) = 30.62$); central executive ($F(2,117) = 25.2$); and phonological awareness ($F(3, 116) = 19.08$). Furthermore, hierarchical regression calculated for UENT number sub-scale scores suggested the following statistically significant factors: susceptibility to word interference assessed by NIT ($F(1,118) = 45.27$); and central executive ($F(2,117) = 34.43$). Neither age nor naming had significant changes in the hierarchical regression.

Discussion

The purpose of this study was to identify the cognitive processes that underlie the individual differences in early mathematical performance in elementary school children. We determined whether those cognitive processes were a valid construct in the prediction of mathematical performance. As observed in the correlations between the UENT and NIT, time correlates with all the values of UENT. We observed that children with higher correct responses in the number interference tasks spent less time in naming digits. Students slower in naming speed also showed higher interference. Data demonstrated that the interference between automatic and controlled cognitive processes negatively interferes in the development of numeric performance. It appears that when cognitive processes are more automatic in 7-year-old children, the interference may be greater (Orrantia, 2005). Participants who had slowest reaction-time in naming speed spent more time discriminating the number interference. The data obtained suggest that more errors are produced when more time is used in a discrimination task, in the items evaluated by UENT. Naming speed training is suggested to achieve better early mathematical performance, because children with the slowest naming speeds were also the slowest at number discrimination (Diamond, Barnett, Thomas, & Munro, 2007). Both the processes can be automatic, although children who were still not capable of automatically controlling those functions, committed more errors and were slower. A possible explanation for this may be related to the central executive (Swanson, 2008; Fuchs et al., 2006).

Central executive positively correlated with the number interference. It seems that an efficient central executive makes number discrimination easier. It also correlated with number naming speed. Data obtained suggest that stimulus recovery is faster when the span of working memory is bigger. The working memory is also considered as a basic process for phonological awareness mentioned by Passolunghi, Vercelloni, and Schadee (2007), as well as Durand, Hulme, Larkin, and Snowling (2005). Students with the digits backwards highest scores also performed the highest in mathematical tasks. The significant correlations between central executive and number interference established the central executive connections with early math.

The hierarchical regression model fits a scheme where the highest variance for early math achievement was predicted by interference, central executive and phonological awareness. The phonological loop was assessed by naming and phonological awareness. The missing phonemes task had the highest correlation with UENT performance because it is the most difficult task in the PECO test, and it requires higher working memory skills. Furthermore, a strong relationship between central executive, phonological awareness, and interference was observed for every group of participants. Interference effect explained more variance than the other predicting variables for mathematical performance, especially with the UENT numerical scores. These results can be explained considering the different UENT tasks categories. Relational tasks were evaluated by perceptual stimuli that the students could always see, while many of the numerical tasks were evaluated using abstract problems. The hierarchical analysis also suggested that the central executive had a higher responsibility in mathematical performance than the articulatory loop. Neither naming nor phonological awareness were critical in explaining results for numerical math tasks. NIT was the highest predictor for math performance, especially for UENT numerical tasks. Inhibitory processes may be a component of the central executive because it is a kind of attention task. In contrast to other studies (Swanson & Beebe-Frankenberger, 2004), in this study neither naming speed nor age explained differences in mathematical performance. Berg (2008) did not find impact of naming speed in arithmetic tasks evaluated by standard performance tests either. However, Swanson, and Beebe-Frankenberger, (2004) did, but working with younger children. In conclusion, the type of tasks used for assessing mathematical performance seems essential.

The more the time used in digit recognition (RAN), the lower were the scores obtained in UENT. On RAN test each age group had the same performance sequence: participants had lower reaction times for naming digits and letters than pictures. But the lowest score was for naming colours (Guzmán et al*.,* 2004). The age-related differences suggest that once children are aware of well-learned concepts, the naming speed has less influence. The speed and the errors in letter recognition were always significant with UENT. This also suggests that the access to the written codes is related to the score in this test. The UENT items were presented to children without any written material. Therefore, further research is necessary to understand the relationship between early math tasks and naming letter access.

One of the core problems that children face in solving mathematical problems relates to an increase in the central executive related operations. Central executive system plays a critical role in integrating information during arithmetic problem-solving (Passolunghi et al., 2007; Lefevre, Destefano, Coleman, & Shanahan, 2005). Children who were 6- and 7-years old performed well in the Stroop tasks as well as the UENT. Furthermore, phonological awareness contributed to high scores in UENT, although some of the components had a smaller influence, for example, missing phonemes, probably because of their relationship with central executive. A gradual increase in the phonological awareness test scores for children 5–7 years of age is in agreement with the previous studies (Solsona, Navarro, & Aguilar, 2006; Wise et al., 2008).

In summary, our results from a large sample of normally developing children provided evidence of inhibitory processes, central executive, and phonological awareness as precursors to early arithmetic performance. Central executive is seen as a more general function, while inhibitory processes and phonological awareness have more specific influence on arithmetic performance. Those students with the lowest UENT scores also had the lowest central executive performance. Data suggested that a poor central executive leads to a higher level of difficulty in irrelevant information control. That means a lower UENT performance. The central executive deficit and low NIT scores found for participants with poor number sense suggests non appropriate functioning of working memory. Children with math learning difficulties keep irrelevant information in their central executive when solving the UENT tasks. However, research on the cognitive processes involved in mathematics is still at a basic stage, and the results should be considered preliminary to the development of a deeper understanding in this area. The concurrent correlation of these skills with measures of arithmetic performance found in this study is in line with some recent theories of number processing (e.g., Durand et al., 2005), but this raises many more detailed questions on how the numerical processing may be involved in the children's arithmetic performance.

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Received December 29, 2009
Revision received December 22, 2010
Accepted January 17, 2011