DEVELOPMENT OF NUMERICAL COGNITION AMONG BRAZILIAN SCHOOL-AGED CHILDREN

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ABSTRACT

The Numerical Cognition is influenced by biological, cognitive, educational, and cultural factors and entails the following systems: *Number Sense (NS)* represents the innate ability to recognize, compare, add, and subtract small quantities, without the need of counting; *Number Production (NP)* which includes reading, writing and counting numbers or objects; *Number Comprehension (NC)*, i.e., the understanding the nature of the numerical symbols and their number, and the *calculation (CA)*. The aims of the present study were to: i) assess theoretical constructs (NS, NC, NP and CA) in children from public schools from 1st-to 6th-grades; and ii) investigate their relationship with schooling and working memory. The sample included 162 children, both genders, of 7-to 12-years-old that studied in public school from 1st-to 6th-grades, which participated in the normative study of Zareki-R (Battery of neuropsychological tests for number processing and calculation in children, Revised; von Aster & Dellatolas, 2006). Children of 1st and 2nd grades

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demonstrated an inferior global score in NC, NP and CA. There were no gender-related differences. The results indicated that the contribution of NS domain in Zareki-R performance is low in comparison to the other three domains, which are dependent on school-related arithmetic skills.

Keywords: Zareki-R, mathematical skills, neuropsychology, arithmetic, working memory

INTRODUCTION

Cohen Kadosh & Walsh (2009) stated that *Numerical Cognition (NCog)* relates to the patterns of activation that are modulated by the numerical magnitude conveyed by the number. For instance, the amount of two can be represented in many ways, such as: i) a word ("two"), a digit (2), in Roman numerals (II), non-symbolically (••), with fingers, in a temporal series (e.g. a drum beat) or with other words (pair, duo, brace) that carry semantic as well as numerical meaning.

McCloskey, Caramazza and Basili (1995) studied the cognitive mechanisms of the NCog based on the arithmetic performance of individuals with brain injury, and developed a framework for examining the abstract representation of quantity, activated in any numerical task. In their model, named later as Abstract Modular Model, the NCog is twofold in *Number processing* and *Calculation* **(CA)**. The number processing comprises the *Number Comprehension* (**NC)** system that is the understanding of the nature of the numerical symbols and their quantity, whereas the *Number Production* **(NP)** system includes reading, writing and counting numbers or objects. On the other hand, the CA system refers to the processing of operational symbols (-, +, x or ÷) and words (e.g., plus, minus, times), the retrieval of basic arithmetic facts from the long-term memory, and the procedures to implement arithmetic calculations (McCloskey et al., 1985; McCloskey, 1992). The model assumes that the abilities to understand and to produce numbers are independent of calculation skills (Grewel, 1969) and the mechanisms for NC are different from those for NP, besides, the *CA* relies on number processing.

In terms of NCog development, human infants, such as other species (Dehaene, 1997; Gallistel, 1990; Gallistel & Gelman, 2000) are sensitive to the numerosity since the beginning of the neurocognitive development. These evidences support a concept spread by Dehaene and Cohen (1997) as *Number Sense (NS),* an innate ability to represent quantities used to learn and perform mathematics effectively. Therefore, it develops independently of instruction (Dehaene, 1997) and begins with accurate representations of a small amount whereas large amounts are understood by means of approximate representations (Feigenson & Carey, 2003).

According to Shalev (2004) preschool children use the NS to understand simple mathematical relationships in order to calculate addition and subtraction of numbers up to three; by 3-to 4-years-old, the ability of NC and NP begin to develop effectively, so they can count up to four items and years later count up to 15 and understand the concept that these number represents. By eight years old, the NC and NP abilities are practically developed, thus children can write numbers of three digits, write arithmetic symbols, recognize and commit the skill related to CA, and do basic exercises of addition and subtraction. In addition, proficiency in multiplication and division are acquired between 9 and 12 years old. In this way, at elementary school, children learn the base-10 system, how to transpose numeric information from one code of representation to another (for example from verbal to Arabic forms) and basic arithmetic, so they can understand the nature of the operation, transcode, and integrate different sources into NCog to solve problems. In high school, these processes increases in complexity, acquiring multi-step procedures (Dehaene, 1997; Geary, Frensch & Wiley, 1993; O'Hare, 1999; Shalev, Manor, Amir & Gross-Tsur, 1993).

Geary (1995) organizes these mathematical skills in two categories, biologically primary or secondary. He states a biologically primary cognitive system, which processes the core quantitative competencies, such as implicit understanding of numerosity, ordinality, counting and simple arithmetic that develops gradually over the years, as well as language (Cantlon, Platt & Brannon, 2008; Geary, 1995, 2000). These basic quantitative competencies related to NS and NC, such as oral and contextual comparison and estimation of numbers, turn into more complex and biologically secondary abilities of quantitative competencies acquired by the children in formal education. New systems of NCog are developed, i.e., NP (verbal counting, reading and dictation of numbers, and number transcoding) and CA *(*mental calculation and problem solving) in basic arithmetic (Geary, 2000), which are culturally dependent, and, consequently, different across nations and generations (Dellatolas et al, 2000).

The ability to calculate depends on multifactorial and complex cognitive processes such as working memory and executive functions (Luccia & Ortiz, 2009). Working memory can be defined as a complex system that has the ability to retain and manipulate information for short periods of time in ongoing tasks, besides being responsible for trade information with long-term memory (Baddeley, 2000; Baddeley & Hitch, 1974). There are extensive evidences that working memory skills contribute to the acquisition of a range of important complex abilities in childhood, which are likely to have direct impact upon a child's success within school, including mathematics (Mc Closkey, Caramazza, Basili, 1985; Santos et al, 2012). Scores on measures of working memory are closely associated with arithmetic skills (Bull, Johnson, & Roy, 1999; Siegel & Linder, 1984; Siegel & Ryan, 1989, Silva & Santos, 2011), because it represents flexible and effective cognitive functioning in academic and professional achievement, and in daily activities (Gathercole, 1999).

Dehaene and Cohen (1997) proposed a neurocognitive model for NCog. The model known as "triple-code" postulates three main systems to represent numbers: visual Arabic, verbal, and analogue magnitude systems. According, to this model, it is possible to transcode from verbal to a visual Arabic code (writing numbers under dictation) and vice-versa (reading Arabic numbers), without activating necessarily the "analogical representation of number" (without the numbers associated with the quantity they represent). The analogue magnitude system corresponds to the semantic representation of numbers of previous models. The ability to quickly understand, approximate, and manipulate numerical quantities, the NS, is also related to the representation and manipulation of nonverbal magnitudes in a "mental number line", that is spatially oriented in that numbers are organized by their proximity (Dehaene*,* 2001; 2003; von Aster & Shalev, 2007). NS is the basis to the development of secondary, symbolic or verbal, number competencies (Feigenson, Dehaene, & Spelke, 2004; Iuculano, Tang, Hall, & Butterworth, 2008). Symbolic NS is extremely dependent on the input a child receives (Clements & Sarama, 2007) it intermediates the acquisition of the conventional mathematics that is taught in school.

von Aster and Shalev (2007) structured a four-step Developmental Model of Numerical Cognition, whose capacity increases gradually over the years, as well as working memory. The Step 1 (infancy) the inherited core-system representation of cardinal magnitude and related functions (such as, approximation and subtizing, i.e., an automatic process to determine the magnitude of a small set of items) provide the basic meaning of numbers. It is precondition for the Step 2 (preschool) to associate an amount of objects or events to spoken quantitative words, and for the Step 3 (school) written or Arabic number forms. On the Step 4, the linguistic and Arabic symbolism turns into a precondition for the development of a mental number line (Step 4) emerges as a the ordinal core system of NCog.

The four-step's model considers that the transition from NS to symbolic systems occurs through formal education and develops the mental number line over years and adulthood. However, these transitions depend on intact NCog systems, in order words, number processing and CA relies on plasticity, experience, development of other cognitive abilities, socioeconomic and educational factors (Geary, 2000; Dellatolas, von Aster, Willardino-Braga, Meier & Deloche, 2000, Gross-Tsur, Manor & Shalev, 1996; Hein, Bzufka & Neumark, 2000; Koumoula et al, 2004; Santos et al, 2012). However, socioeconomic, environmental, and cultural aspects do not influence the working memory development (Engel, Santos, & Gathercole, 2008; Koumoula et al., 2004, Santos & Bueno, 2003; Santos, Mello, Bueno, & Dellatolas, 2005), and might be a marker of mathematical skills.

Considering the complexity of the NCog systems, it is necessary to assess various numerical fields, such as NS, NP, CA, and NC, to provide a trustful differential diagnosis and to establish appropriate strategies of interventions for children with Developmental Dyscalculia (von Aster, 2000). The ZAREKI (in German: Neuropsychologische Testbatterie fûr ZAhlenarbeitung und REtchnen bei KIndern; von Aster, 2001), also known as NUCALC by the acronym in English (Neuropsychological Test Battery for Number Processing and Calculation in Children) was developed to account NCog assessment in children. It was based on a previous instrument, the EC301 battery (batterie standardisée d'evaluation du calcul et du traitement des nombres) developed to assess numerical skills in adults (Dellatolas, Deloche, Basso & Claros-Salinas, 2001; Deloche, 1995; Deloche et al., 1995).

Studies in different languages have been carried out with ZAREKI with children living in Germany and France, which benefits the cross-cultural approach (von Aster, Deloche, Dellatolas, & Meier, 1997), in addition, ZAREKI was also used with illiterates (Deloche, Souza, Willadino-Braga & Dellatolas, 1999), children and patients with unilateral brain injury (Deloche, Dellatolas, Vendrell, & Bergego, 1996; Deloche & Willmes, 2000). Functional analysis indicated that the theoretical construct of the subtests are oriented by Dehaene's Triple Code Model (Dehaene & Cohen, 2000; von aster, 2000) and is consistent with the four-step Developmental Model of Numerical Cognition (von Aster & Shalev, 2007). Furthermore, the literature indicated that ZAREKI evidently differentiates and specifies the profile of mathematical skills in children being suitable for the Developmental Dyscalculia diagnosis (von Aster, 2000).

Koumoula et al. (2004) assessed Greek children with ZAREKI and observed that children from rural areas and low socioeconomic level presented inferior performance than the urban children in mental calculation, reading and writing of numbers, oral comparison of numbers, contextual estimative of quantities and problem solving. von Aster (2000) found differences associated with age and schooling on performance of children from Zurich. A cross-cultural research assessed children from Zurich, France and Brazil, of 7-to 10-years-old (Dellatolas et al., 2000). An age effect was found in some tasks of the ZAREKI: two involving number transcription, two tasks of number comparison, and two tasks of CA. French children from 7-to 8-years-old got better scores than children from other nationalities of the same age; on the other hand, all the groups exhibited equivalent performance by 10-years-old. Brazilian children from the suburbs presented lower scores in specific tasks than children from central areas.

von Aster and Dellatolas (2006) released **Zareki-R** (Neuropsychological test battery for Number Processing and Calculation in Children, Revised). Conversely, studies with the revised version are increasing (Ribeiro & Santos, in 2012; Rotzer et al., 2009; Santos et al., 2012; Silva & Santos, 2011). For instance, Silva e Santos (2011) investigated which aspects of number processing, calculation and working memory were related to deficits in arithmetic among Brazilian children diagnosed with learning disorders, using Zareki-R. The participants were children of 9-to 10-years-old with learning disorders, divided in two groups based on their calculation score: impaired in arithmetic (IA; N=19) and non-impaired in arithmetic (NIA; N=11). The IA group exhibited slightly lower scores than NIA children on intellectual level and Block Span, and deficits in dictation of numbers (NP), mental calculation and problem solving (CA) tasks of the Zareki-R. The results indicate that the IA group had specific deficits in visuospatial working memory and performed poorly in NCog tasks. Moreover, it was observed moderate association between mental calculation and measures of working memory (phonological and visuospatial). In general, the performance of IA children in Zareki-R was one and a half standard deviation below normative data, which fulfill criteria for Developmental Dyscalculia. These results were similar to Rotzer et al. (2009). As for the construct validity, Santos and Silva (2008) found moderate to high significant correlations between the six subtests of the ZAREKI-R and the gold standard Test of Arithmetic of the Schooling Achievement Test (in Portuguese TDE - Teste de Desempenho Escolar; Stein, 1994) [counting dots (r = 0.43); counting backwards (r = 0.44), dictation of numbers (r = 0.69), mental calculation (r = 0.76), reading numbers (r = 0.64); problem solving (r = 0.55)], and also between the total score of both Zareki-R and the Arithmetic Test of TDE (r = 0.73).

A recent Brazilian study (Santos et al., 2012) that used the Zareki-R to assess number processing and calculation in Brazilian children from 7-to 12-years-old from public schools aimed to identify how environment, age and gender factors influence the development of these mathematical skills. The sample included 172 children divided in two groups: urban (N=119) and rural (N=53). Rural children presented lower scores in only one aspect of number processing (written comparison), a measure of NC, therefore, low influence of environmental aspects; children from 7-to 8-years-old demonstrated an inferior global score when compared to older ones, confirming that the achievement of most of the mathematical skills are age-related; boys presented a superior performance in both number processing and calculation when compared to girls. Zareki-R's validity of construct was also demonstrated by the moderate significant correlation with Arithmetic subtest of WISC-III (Wechsler, 2002), (r_p = 0.64). The authors concluded that Zareki-R is a suitable instrument to identify the development of mathematical skills, which is influenced by factors such as environment, age, and gender. It is important to mention that this work was the first normative study of the Zareki-R in Portuguese language; however, this study did not perform an analysis of the NCog systems.

As for the present study, the Zareki-R subtests were divided in four constructs: NS, NC, NP and CA, in order to investigate whether the development of mathematical skills is associated with schooling and so develop the specific skills, thus the objectives of the present study were to: i) investigate the development of specific systems of NCog (NS, NC, NP and CA) in Brazilian children in public school from 1st-to 6th-grades using the Zareki-R; and ii) their relationship with education and phonological working memory.

The authors hypothesize, first, that there will be no school grade effects to the NS system, because it is presented as an innate characteristic; second, children with less education might present a slight inferior performance, than children with higher education in NC, NP and CA, because these systems depend on formal education; third, we suppose that mathematical skills increase linearly with the process of formal education and also, we expected that the working memory will have influence on number processing and CA.

METHOD

Participants

A total of 162 Brazilian children (83 boys), aged 7-to 12-year, participated in the study, after the written consent of their parents. They were recruited in two studies (Ribeiro & Santos, in 2012; Santos et al., 2012), lived in Assis or Ourinhos, in São Paulo State, and studied in public schools from 1st-to 6th-grades (See Table 1). As inclusion criteria, children had normal intellectual level: 122 children of the sample were assessed by the Wechsler Intelligence Scale for Children - WISC III (IQ range from 81-to 119; Wechsler, 2002) and 40 other children, from Ourinhos, were assessed by the Raven's Coloured Progressive Matrices (percentile range from 25-to 74; Angelini et al, 1999). Exclusion criteria was presence of learning disabilities, emotional disturbances, motor difficulties, speech or hearing impairments, or neurological or psychiatric diagnosis, based on parent and teacher reports. Socioeconomic status (SES) was assessed by the Brazilian Association of Marketing Research Institutes Scale that stratifies in five classes, from A/richest to E/poorest

(ABIPEME; Almeida & Wickerhauser, 1991). Although significant differences among ages were obtained in SES by ANOVA [F (5, 154) = 2.62; p = 0.02], the post hoc analysis (Tukey) did not identified such differences; all age groups were in C class (middle class, 38-58; corresponds to 4 to 10 times the reference value of Brazilian minimum wage). See Table 1.

Table 1. Sociodemographic aspects by age bands.

Age in years	**7**	**8**	**9**	**10**	**11**	**12**	**Total**
N (%)	20 (12.3)	20 (12.3)	38 (23.4)	44 (27.1)	21 (12.9)	19 (11.7)	**162(100)**
Sex % boys	41.2	52.2	47.1	57.2	61.1	42.9	**51.3**
SES [M(SD)]	43.25 (18.03)	48.00 (16.85)	51.97 (19.56)	56.27 (20.56)	44.14 (14.29)	42.79 (18.04)	**49.45 (19.03)**
N (%) by age according to the school grade distribution							
1st	14 (82.3)	3 (17.6)	-	-	-	-	**17 (10.4)**
2nd	6 (26.0)	17 (73.9)	-	-	-	-	**23 (14.1)**
3rd	-	-	33 (97.0)	1 (2.9)	-	-	**34 (20.9)**
4th	-	-	5 (10.2)	43 (87.7)	1 (2.0)	-	**49 (30.2)**
5th	-	-	-	-	17 (94.4)	1 (5.5)	**18 (11.1)**
6th	-	-	-	-	3 (14.2)	18 (85.7)	**21 (12.9)**

Material

Zareki-R (von Aster & Dellatolas, 2006) is an international specialized battery test that assesses the NCog of school-age children. Normative data for Brazilian children in each subtest and total score were presented by Santos et al. (2012). The Zareki-R has 11 subtests specialized in mathematical skills and one subtest of phonological working memory (*Memory of Digits* - *MD*). The Total Score is composed by the sum of these subtests, except MD. To assess the purpose of this article, the subtest were divided in four constructs*: Number Sense (NS),* composed by the sum of Counting dots and Perceptive estimation scores; *Number Comprehension (NC)*, composed by the sum of Oral comparison, Written comparison and Contextual estimation scores; *Number Production (NP)*, composed by the sum of Counting backwards, Dictation of numbers and Reading numbers scores; *Calculation (CA),* composed by the sum of Mental Calculation and Problem solving scores. The *Positioning numbers on an analogue scale* subtest was not included in any construct score because is a measure of mental number line, but alone could not be set as composite score. The description of each subtest is presented in Santos et al. (2012) and Silva and Santos (2011).

Procedures

The neuropsychological assessment protocol was described by Santos et al., (2012). Children were assessed in their own schools in a quiet room. Zareki-R was administered in a single 30-minutes (in average) session; the order of subtests was not fixed and verbal tasks were alternated with nonverbal ones. The Ethics Committee for Research with Human Beings from UNESP (São Paulo State University) approved the study, case nº 0095/2005.

STATISTICAL ANALYSES

The analyses were carried out with STATISTICA, version 7.0 (Statsoft, 2004). Two sets of analyses were performed. In the first, an analysis of variance (ANOVA) was carried out for Zareki-R subtests constructs. In this case, the between-subject factors were 6 school levels (from 1^{st}-to 6^{th} grades), while the within-subjects factors were four construct scores of Zareki-R (NS, NC, NP and CA). Tukey *post hoc* test was used with a significant alpha level of $p < 0.05$.

In the second set of analyses, Pearson's product moment correlations between scores in Zareki-R and education level, Memory of Digits, and Total Scores of Zareki-R were carried out. For the discussion, we adopted moderate to high correlations (r>0.4) as minimum score.

Finally, two exploratory analyses were done. The first was related to gender effects on development of NCog (the same within-subjects factors were adopted). The second one aimed to consider the relation between education level and the framework proposed by von Aster (2000), based on his functional analysis of Zareki substests, by which the Zareki-R subtests were clustered by representation modules present in triple-code model: verbal, visual Arabic and analogical (Dehaene & Cohen, 1997).

RESULTS

Table 2 shows the results obtained with the Zareki-R by theoretical constructs. In general, there were no differences between school grades in Number Sense; in Number Production, there was a progressive increase in performance in the first school grades; in Number Comprehension and Calculation, the first and second grade children had lower performance than the children of subsequent school grades.

School grade effect. A 6 (grades) x 4 (constructs) ANOVA was performed and revealed a school grade effect [F (20,508.39) = 8.47; p<0.0001]. The *post-hoc* test did not show differences for NS($^{\#}$). 1st-grade children performed worse than all other school levels for NP (^{b}), as well as 2nd-grade children performed worse than 3-to 6-grade children in the same construct. 1st-and 2nd-grade children performed worse than 3rd-to 6th-grade children in NC and CA (^{a}).

Table 2. Zareki-R theoretical constructs and Memory of Digit by school grade and gender.

School grades	N	NS$^{\#}$ M (SD)	NC^{a} M (SD)	NP^{b} M (SD)	CA^{a} M (SD)	MD$^{\#}$ M (SD)
1st	17	8.65 (2.37)	38.18 (7.20)	16.82 (9.70)	17.12 (12.83)	23.53 (7.80)
2nd	23	9.04 (2.51)	41.00 (9.45)	23.87 (10.05)	25.65 (16.00)	21.91 (7.87)
3rd	34	9.76 (2.50)	47.59 (4.84)	33.56 (2.34)	38.29 (9.55)	23.29 (6.32)
4th	49	10.27 (2.40)	47.57 (5.68)	34.22 (2.99)	43.18 (8.62)	24.33 (6.85)
5th	18	10.17 (1.98)	48.56 (5.20)	34.67 (1.57)	43.22 (8.20)	22.22 (7.29)
6th	21	10.19 (2.32)	51.10 (3.25)	34.38 (1.24)	43.62 (6.97)	26.10 (5.20)
Gender#						
Male	83	9.98 (2.52)	46.46 (6.88)	31.45 (7.61)	38.75 (14.28)	-
Female	79	9.61 (2.30)	45.97 (7.49)	30.24 (8.32)	35.15 (12.88)	-

Legend: NS: Number Sense; NC: Number Comprehension; NP: Number Production; CA: Calculation; MD: Memory of Digits; M: Mean; SD: Standard Deviation. (a) 1st-to 2nd < 3rd-to 6th, p<0.5; (b) 1st< 2nd < 3rd-to 6th, p<0.5; (#)Not significant.

Pearson's product-moment Correlations between Zareki-R constructs and Arithmetic of WISC-III, Memory of Digits and Total Score

The results revealed significant and positive relationship between the four constructs of Zareki-R and education. Moderate correlations were observed to the following constructs: Number Comprehension ((r_p =0.54; p<0.0001), Number Production ((r_p =0.64; p<0.0001) and Calculation ((r_p =0.61; p<0.0001). There were significant and positive, but low, correlation between the Memory of Digits and NC, NP and CA of Zareki-R. Finally, there were significant and positive correlations between the Total Score of Zareki-R and the constructs. High correlations were observed to the following constructs: Number Comprehension ((r_p =0.84; p<0.0001), Number Production ((r_p =0.92; p<0.0001) and Calculation ((r_p =0.94; p<0.0001). See Table 3.

Table 3. Correlations between Memory of Digit, Zareki-R and theoretical constructs.

	Schooling	*MD*	*Zareki-R score Total*
NS	r=0.22	r=0.008	r=0.29
	p=0.014	p=0.930	p=0.001
NC	r=0.54*	r=0.31	r=0.84*
	p<0.001	p<0.001	p<0.001
NP	r=0.64*	r=0.33	r=0.92*
	p<0.001	p<0.001	p<0.001
CA	r=0.61*	r=0.36	r=0.94*
	p<0.001	p<0.001	p<0.001

(*) Moderate and high correlations ((r_p >0.4). *Legend:* Zareki-R = Neuropsychological test battery for Number Processing and Calculation in Children, Revised; WISC-III = Wechsler Intelligence Scale for Children; *NS: Number Sense; NC: Number Comprehension; NP: Number Production; CA: Calculation; MD: Memory of Digits.*

Exploratory analyses

An ANCOVA – school grades as covariant – between both genders and four constructs was performed and did not revealed any gender effect [*F* (4,156)=1,07; *p*=0.37]. An ANOVA considering the 6 grades and the 3 modules (verbal, visual-Arabic and analogue) revealed a school grade effect [F (15, 425.53) = 10.621;

p<0.0001], in that 1st-grade children had lower scores than all grades for verbal and visual-Arabic modules; 2nd-grade children had lower scores than 3rd-to 6th-grade children in same modules; and, 1st-and 2nd-grade children performed worse than 3rd-to 6th-grade children in analogue module.

DISCUSSION

The present study aimed to investigate the development of specific domains of NCog (NS, NC, NP and CA) in Brazilian children enrolled in public schools from 1st-to 6th-grades using the Zareki-R; and their relationship with education and phonological working memory.

In accordance with our hypothesis there were no differences in the NS system, because it corresponds to an innate ability, which develops independently of educational instruction, as a biological primary quantitative ability for children with typical development (Cantlon, Platt & Brannon, 2008; Dehaene, 1997; 2001; Dehaene & Cohen, 1997; Feigenson, Dehaene, & Spelke, 2004; Gallistel, 1990; Gallistel & Gelman, 2000; Geary ,1995; Geary, 1995, 2000; Feigenson & Carey, 2003; Feigenson, Dehaene, & Spelke, 2004; Shalev , 2004). Our results confirm that the NS is a key capability for numeracy (Dehaene, 2001; Iuculano, Tang, Hall, & Butterworth, 2008) and is pre-requirement to the development of a mental number line to perform more complex mathematical tasks.

In our study, children in 1st and 2nd grades succeed in NS tasks but had poorer performance in the ones which taps on NP, NC and CA systems. It is important to explain that when the study was conducted, the 1st grade and so the literacy process begun officially at age 7. For this reason this result was expected since these tasks are related to secondary quantitative abilities (Geary, 2000), such as verbal and Arabic number systems (von Aster & Shalev, 2007), that develops gradually with experience, culture, and education.

McCloskey et al. (1985) assumes that NC and NP have distinct mechanisms, but do not consider the existence of a hierarchy in difficulty between them. In this study, the performance of the three first grades indicates a major difficulty in tasks related to the NP system when compared with NC system, especially in first grade. A previous study using ZAREKI in Brazilian children did not identify such difference (Dellatolas et al. (2000), and other studies about development of number acquisition did not consider this aspect (Koumoula et al. 2004; Landerl & Kolle, 2009; von Aster & Shalev, 2007; Wilson & Dehaene, 2007).

The groups of 3rd-to 6th grades obtained linearly highest scores in NC, NP and CA domains, showing an school-related improvement by the acquisition of the symbolic NCog system (verbal and Arabic) and the ordinal magnitude system (mental number line), corroborating Dellatolas et al. (2000), Koumoula et al. (2004), and von Aster and Shalev (2007). Moreover, the stabilization in performance of Brazilian children by 3rd grade (mean age 9.02 ± 0.17) for NC and NP, as assessed by Zareki-R, were similar to the results presented in Shalev et al. (1993) and Koumoula et al. (2004), for German and Greek children, respectively; the same can be assumed for CA. Therefore, mathematic skills seem to be dependent on both brain maturation (von Aster, 2000) and schooling (von Aster & Shalev, 2007), besides, the correlations observed between these constructs and education level support this view. It is important to point that children from this study did not have learning disorders or substantial discrepancy between their age and their school level.

In other words, the general results showed that the NCog development is associated with age and education, and these specific skills are in compliance with the steps of the Developmental Model of Numerical Cognition, beginning with an early innate and gaining complexity at the formal education (Dehaene, 1997, Dehaene & Cohen, 2000; Geary, 2000; von Aster & Shalev, 2007). Moreover, the results observed in the second exploratory analysis that clustered Zareki-R subtest according to triple-code model support the dependence of formal education to the acquisition of verbal and visual-Arabic representation.

Some tasks of the battery were able to differentiate children achievement across grade levels (Dellatolas et al. 2000; Koumoula et al. 2004), while others, such as mental calculation and number comparison (Dellatolas et al. 2000; Rosselli et al. 2009; Santos et al. 2012) were previously sensitive to gender differences. In our study, children showed a progressive improvement on the basis of formal education in tasks related to NP (Counting backwards, dictation and reading numbers), but also NC (Oral and written comparison and contextual estimation) and CA tasks (mental calculation and problem solving). But the differences in the four constructs were not gender related; perhaps the use of composite scores diluted the statistical power.

In addition, the correlations analysis indicated that the NS domain in Zareki-R performance is less relevant than the other three domains, which clearly are dependent on school-related arithmetic skills. As we can see, these are tasks that include both the processing of numerical magnitudes as the calculation itself (Geary, 1993, 2000; Landerl & Kölle, 2009; McCloskey et al. 1986; von Aster & Shalev, 2007; Weinhold-Zulauf, Schweiter & von Aster, 2003). Besides, different of our hypothesis, the result suggest that working memory has a general influence in ongoing cognitive tasks in typical developing children, whereas the NS and formal education contributed more than working memory to the development of NCog (von Aster & Shalev, 2007).

One limitation of this study is that the number of participants by school grades was small and unbalanced. However, the participants' selection criteria prevented many confounder variables, therefore the interpretations are reliable in terms of children with typical development. Other limitation was that only a measure of phonological working memory was used to evaluate the influence of this function on arithmetic skills, while other components have been considered of relevance on literature (Rotzer et al. 2009; Silva & Santos, 2011). This might explain in part the low correlation of its ability and the theoretical constructs investigated, besides, the analysis were carried out using the composite score of the test (forward and backward orders in assembly) instead looking at the working memory span that could be a more sensitive measure of its development.

In conclusion, the performance of the Brazilian children from public schools at Zareki-R was slightly related to environmental, age and educational factors. In agreement with our previous hypothesis, the children didn't present grade effects to the NS system. On the other hand, as it was expected, children from 3^{rd}-to 6^{th} grades obtained higher scores in NC, NP and CA system, showing an school-related that the acquisition of the symbolic NCog system and the ordinal magnitude are influenced by schooling, besides, dissimilar of our hypothesis, the result propose that working memory has a general influence in ongoing cognitive tasks in typical developing children, whereas the NS and formal education contributed more than working memory in NCog.

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