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Number Processing and Calculation in Brazilian Children Aged 7-12 Years

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Numerical cognition is based on two components - number processing and calculation. Its development is influenced by biological, cognitive, educational, and cultural factors. The objectives of the present study were to: i) assess number processing and calculation in Brazilian children aged 7-12 years from public schools using the Zareki-R (Battery of neuropsychological tests for number processing and calculation in children, Revised; von Aster & Dellatolas, 2006) in order to obtain normative data for Portuguese speakers; ii) identify how environment, age, and gender influences the development of these mathematical skills; iii) investigate the construct validity of the Zareki-R by the contrast with the Arithmetic subtest of WISC-III. The sample included 172 children, both genders, divided in two groups: urban (*N* = 119) and rural (*N* = 53) assessed by the Zareki-R. Rural children presented lower scores in one aspect of number processing; children aged 7-8 years demonstrated an inferior global score than older; boys presented a superior performance in both number processing and calculation. Construct validity of Zareki-R was demonstrated by high to moderate correlations with Arithmetic subtest of WISC-III. The Zareki-R therefore is a suitable instrument to assess the development of mathematical skills, which is influenced by factors such as environment, age, and gender.

Keywords: Zareki-R, mathematical skills, children, neuropsychological assessment, arithmetic.

La cognición numérica se basa en dos componentes: el procesamiento numérico y el cálculo. Su desarrollo está influenciado por factores biológicos, cognitivos, educativos, y culturales. Los objetivos del presente trabajo fueron: a) evaluar el procesamiento numérico y el cálculo en niños brasileños de entre 7-12 años de escuelas públicas utilizando el Zareki-R (batería de pruebas neuropsicológicas para el procesamiento numérico y el cálculo en niños, revisada por von Aster y Dellatolas, 2006) con el fin de obtener datos normativos para los hablantes de portugués, b) determinar cómo el medio ambiente, la edad y el género influyen en el desarrollo de estas habilidades matemáticas, y c) investigar la validez de constructo del Zareki-R en contraste con el subtest de Aritmética WISC-III. La muestra incluyó a 172 niños evaluados por el Zareki-R, niños de ambos sexos, divididos en dos grupos: urbano (*N* = 119) y rural (*N* = 53). Los niños de origen rural presentaron puntuaciones más bajas en un aspecto de procesamiento numérico, los niños de 7-8 años demostraron una puntuación inferior global que los mayores; los varones presentaron un rendimiento superior tanto en el procesamiento numérico como en el cálculo. La validez del constructo del Zareki-R fue demostrada por las correlaciones de alta a moderada con el subtest de Aritmética WISC-III. El Zareki-R por lo tanto, es un instrumento adecuado para evaluar el desarrollo de habilidades matemáticas, que está influenciado por factores como el medio ambiente, la edad y el género.

Palabras clave: Zareki-R, habilidades matemáticas, niños, evaluación neuropsicológica, aritmética.

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Quantitative skills such as numerosity comprehension, ordinality, counting, and simple arithmetic develop during childhood (Cantlon, Platt, & Brannon, 2009; Geary, 1995, 2000). In the primary school, children learn the base-10 system, different numerical representations; for example, transcoding from verbal code (twenty three) into Arabic code (23), and basic arithmetic (Geary, 2000). In the high school, the complexity of these processes increases and includes procedures of multiple steps, such as multiplication and division (Dehaene, 1997; Geary, Frensch, & Wiley, 1993; O'Hare, 1999; Shalev, Manor, Amir, & Gross-Tsur, 1993).

Gelman and Galistel (1978) assumed five counting principles listed below, three of them related to procedures rules, one related to the concept of countable items, and the last one is a combination of the four principles. *The one-to-one-correspondance* emphasizes the discrimination of a specific counting code for each object (Word, or Arabic or other form); the child must coordinate two processes: first each item to be counted must be transferred from the original category to the counting category (division), once counted the item must be annulated in order to not be counted twice (tagging). A typical strategy is pointing the items (visual code) while counting loudly (verbal code). *The stable-order.* Counting involves more than the ability to assign random tags to the items in an array. The counting marks must be organized in a stable manner, repeated in certain order. *The cardinal principle.* The last word in a sequence of numbers in general represents the total amount and the numerosity of the set. The comprehension of this concept depends on the principle of one-to-one, in other words, the principle of the stable order of correspondence develops after the child learn to tag items already counted and to name a set of items. *The abstraction.* The child must understand that the counting is independent of the object characteristics (toys, actions, sounds etc). *The order-irrelevance.* The child must learn that direction of counting is irrelevant (from left to the right and vice versa). The regular use of this principle emerges around 4-5 years old.

The *calculation* refers to the mathematical operations such as addition, subtraction, multiplication, and division; which require operational words (more, less, times, divide) and symbols (+, –, × or ÷), the retrieval of them and other arithmetic facts, and the arithmetic calculation procedure. On the other hand, *number processing* refers to comprehension of the numeric symbols associated with quantities, and number production in reading, writing and counting of numbers (McCloskey, Caramazza, & Basili, 1985). The processing of the mathematical operations in practice depends on: a) the availability of cognitive number representations – visual Arabic, verbal, and analogue magnitude – (triple-code-model; Dehaene, 1997), that interact dynamically without the need of association between the numbers, and the quantities themselves (Dehaene & Cohen, 2000); b) numerical skills that are based on a variety of modality-specific representations (e.g., visuospatial and verbal-auditory codes) in diverse number-processing tasks supporting the specific-integrated (encoding-complex) view of number processing (Campbell & Clark, 1992).

According to Dehaene (1997), the *number sense* represents the innate ability to recognize, compare, add, and subtract small quantities, without the need of counting, in a *mental number line*, which is a spatially oriented representation of the quantities, that increases with age and experience, and account to large numerosities. The number sense capacity plays a fundamental role in mathematical competence (Dehaene, 2001; Iuculano, Tang, Hall, & Butterworth, 2008). von Aster and Shalev (2007) described a four-step Developmental Model of Numerical Cognition, which considers that transitions from the pre-verbal period to adulthood, in both number skills and number sense, would culminate in the mental number line development. However, these changes demands more than an intact number system, they require experience, plasticity, and development of other skills such as visual imagery, language, and working memory.

On the other hand, socio-cultural, pedagogical, and linguistic factors may affect both number processing and calculation (Dellatolas, von Aster, Willardino-Braga, Meier, & Deloche, 2000; Gross-Tsur, Manor, & Shalev, 1996; Hein, Bzufka, & Neumärker, 2000; Koumoula et al., 2004). In contrast, studies showed that working memory is culture free of socioeconomic status and environmental aspects (Engel, Santos, & Gathercole, 2008; Koumoula et al., 2004; Santos & Bueno, 2003; Santos, Mello, Bueno, & Dellatolas, 2005).

Considering the complexity of the number processing and calculation cognitive systems, it is necessary to assess different aspects of the numerical domains separately, as for differential diagnosis and planning appropriate intervention strategies (von Aster, 2000). For this purpose, the ZAREKI (in German: *Neuropsychologische Testbatterie für* ***ZA****hlenarbeitung und* ***RE****tchnen bei* ***KI****ndern*; von Aster, 2001), or NUCALC for the acronym in English (*Neuropsychological Test Battery for* ***Nu****mber Processing and* ***Cal****culation in* ***C****hildren*), was developed. The preliminary version of this instrument was 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).

The ZAREKI was adapted for use in different countries and languages, for instance, German, French, and Greek (Dellatolas et al., 2000; Koumoula et al., 2004; von Aster, 2001; von Aster & Dellatolas, 2006). Since secondary quantitative abilities are influenced by educational systems, which change across countries and generations (Dellatolas et al., 2000; Geary, 2000), it is important to assess mathematical skills using an equivalent instrument in different languages, which benefit cross-cultural studies. Many studies were accomplished with the ZAREKI:

assessment of German and French children (von Aster, Deloche, Dellatolas, & Meier, 1997), illiterates (Deloche, Souza, Willadino-Braga, & Dellatolas, 1999), and patients with unilateral brain injury (Deloche, Dellatolas, Vendrell, & Bergego, 1996; Deloche & Willmes, 2000), etc.

Functional analysis indicated that the theoretical construct of the ZAREKI 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). The Figure 1 illustrates the relationship between the subtests of the ZAREKI with the three modules of representation (Verbal, Analog and Arabic codes) in contrast to the different combinations of the processing procedures overlapping them (input, internal transcoding, and output). The three modules are autonomous, interconnected and activated according to the particular needs of a given task and constitute a system for number processing and calculation. In this sense, according to the triple-code model, abilities such as approximation and number comparison depends on the analogue module, whereas abilities such as counting (in operations such as addition and subtraction, including the arithmetical fact retrieval) depends on the verbal module. Multi-digit operations and parity judgments rely on the visual Arabic module number form, in that numbers are represented by their Arabic code (von Aster, 2000). Moreover, the literature indicated that ZAREKI clearly differentiates and specifies the profile of mathematical skills in children being suitable for the diagnosis of Developmental Dyscalculia (DD) (von Aster, 2000; Shalev et al., 1993).

DD, also named as Specific Disorder of Arithmetical Skills (International Classification of Diseases, 10th Edition [ICD-10], OMS, 1993) or Mathematics Disorder (Diagnostic and Statistical Manual of Mental Disorders, 4th Edition, Text Revision [DSM-IV-TR], (APA, 2002), constitutes a specific difficulty in quantitative processing, which is expressed by difficulties to accomplish elementary operations such as addition, subtraction, multiplication, and division, not due to inefficient teaching or global intellectual disability (F81. 2, World Health Organization, 2005); and its diagnosis requires that these operations are assessed objectively by standardized tests (315.1, APA, 2002). The aetiology of DD is multi-factorial and includes genetic predisposition, neurological disturbances, environmental, and psychological factors (Shalev, 2004).

Hein et al. (2000) investigated the prevalence of arithmetic impairment in urban and rural children using the ZAREKI; they found a similar prevalence (around 6%) between simple arithmetic and reading and spelling disorders. In their study children with DD showed lower scores than their counterparts; besides, the discrepancy between the mean scores and standard deviation suggested that boys performed better than girls. Koumoula et al. (2004) assessed Greek children with the same instrument, and identified 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 estimation of quantities and problem solving. In Koumoula et al. (2004) the prevalence of children performing significantly worse in arithmetical skill was higher in rural than in urban students.

von Aster (2000) found differences associated with age and schooling on performance of German children. Moreover, boys performed better than girls in tasks of subtraction, oral comparison, and arithmetic problems; the gender difference was also observed by Rosselli, Ardila, Matute, and Inozemtseva (2009) in mental calculation and solving arithmetic problem tasks, these authors argued that boys presented a more efficient retrieval of arithmetic facts. von Aster (1994) hypothesised that girls seems to be more susceptible to anxiety and depression, which may affect their performance in maths exam. This assumption was supported by the study of Krinzinger and Kaufmann (2006) in that girls reported higher levels of math anxiety and/or more negative attitudes towards math than boys.

In a cross-cultural study of Brazilian, French and Swiss children, aged 7 to 10 years Brazilian children were from central and suburbs of Brasília city, recruited in public and private schools (Dellatolas et al., 2000). The authors obtained an age effect on the Score A, which is formed by the core tasks of the battery: two involving number transcription, the two tasks of number comparison, and the two tasks of calculation. French children from 7 to 8 years old obtained better scores than children from other nationalities; however, the groups showed equivalent performance at age 10. In regards to the Brazilian sample, children from the suburbs presented lower scores than children from central areas in specific tasks: at ages 7-8 in written comparison, dictation and reading of numbers; at ages 8-9 in mental calculation and arithmetic problem; at ages 9-10 in mental calculation and contextual estimation. Boys presented better performance than girls in both oral and written comparison of numbers. However, this study had an irregular distribution of children by age range in different schooling grades, for instance a child at age 9 to10 could study at 2nd or 3rd grade, and this can be a confounding factor in terms of schooling achievement. Besides, the socioeconomic status was estimated according to the city regions (central versus suburb) instead of being objectively measured, which makes the discrimination of environment and socioeconomic aspects difficult.

Other Brazilian neuropsychological studies in mathematical skills remain rare (Dias et al., 2009). Correa and Meireles (2000) observed a progressive development in the capacity to establish relationship of inverse order between divisor and quotient in children aged 5-7 years. Haydu, Costa, and Pullin (2006) demonstrated that the presentation in different forms of arithmetic problems

Representation Modules

		VERBAL											ARABIC											ANALOGIC										
	Subtests Involved	CD	CB	DN	RN	PN	OC	PE	CE	WC	MC	PS	CD	CB	DN	RN	PN	OC	PE	CE	WC	MC	PS	CD	CB	DN	RN	PN	OC	PE	CE	WC	MC	PS
		X	X	X	X		X	X	X		X	X	X		X	X	X				X			X				X	X	X	X	X		
Input	auditory verbal		▨	▨			▨		▨		▨	▨			▨														▨		▨			
	visual Arabic				▨											▨	▨				▨							▨				▨		
	visual quantity	▨											▨											▨						▨				
Internal Translation	verbal-Arabic	▨		▨									▨		▨																			
	Arabic-verbal				▨											▨																		
	Arabic analog																▨				▨							▨				▨		
	verbal analog						▨		▨																				▨		▨			
	analog verbal							▨																▨						▨				
	analog arabic												▨											▨										
Output	spoken verbal	▨	▨		▨			▨			▨	▨				▨																		
	written arabic			▨									▨		▨																			
	motor response						▨		▨								▨				▨							▨	▨		▨	▨		

Legend. CD = Counting dots; CB = Counting backwards; DN = Dictation of numbers; RN = Reading numbers; PN = Positioning numbers on an analogue scale; OC = Oral comparison; PE = Perceptive estimation; CE = Contextual estimation; WC = Written comparison; MC = Mental calculation; PS = Problem solving.

Figure 1. Functional analysis of the Zareki-R subtests according to the Triple Code System (Dehaene & Cohen, 2000). Adapted of Von Aster (2000).

facilitates the addition operation. Raad, Pimentel, and Almeida (2008) did not find differences on arithmetic performance of boys and girls from the 2nd grade in two public schools of Aracaju city in Sergipe State. Oliveira and Tourinho (2001) showed better performance for problems solving by the end of the 1st grade in comparison with the beginning of it. These studies are useful contributions, however, they assessed particular aspects of mathematical skills in restrict age bands, using different instruments, and, therefore, it is difficult to generalize the results in terms of mathematical development, and the factors that interfere in its functioning.

More recently a revised version of the Neuropsychological test battery for Number Processing and Calculation in Children, recognized as *Zareki-R* was released (von Aster & Dellatolas, 2006). However, studies with the revised version still sparce (von Aster & Dellatolas, 2006; Rotzer et al., 2009), and the present work is the first normative study of the Zareki-R into Portuguese language. Silva and Santos (2011) assessed Brazilian children with learning disabilities and remarkable difficulties in arithmetic using the Zareki-R. These children presented a global score one and a half standard-deviation below children with learning difficulties in reading and writing, and were impaired in both number processing (dictation of numbers) and calculation (mental calculation and arithmetic problem solving). Their impairment was even worse - two standard deviation below - when compared with typically developing children, which is compatible with the first criterion of ICD-10 for Developmental Dyscalculia (Silva & Santos, 2009). Rotzer et al. (2009) also used Zareki-R and found similar results. Moreover, Silva and Santos (2011) observed significantly positive correlations between mental calculation and problem solving subtests and visuospatial and phonological working memory tasks. Santos and Silva (2008) obtained a high positive correlation between the Zareki-R total score ($r = .73$, $p < .05$) and the subtest "arithmetic" of the SAT, School Achievement Test (TDE, *Teste de Desempenho Escolar*; Stein, 1994), which indicates the construct validity of the Zareki-R.

The objectives of the present study were to: a) assess number processing and mental calculation in Brazilian children aged 7-12 years from public schools using the Zareki-R in order to obtain normative data for Portuguese speakers; b) identify how environment, age and gender factors influence the development of these mathematical skills; c) investigate the validity of the construct of the Zareki-R by the contrast with the Arithmetic subtest of WISC-III. The authors hypothesize that rural children might present a slight inferior performance than urban in both number processing and mental calculation, therefore, a global difference in mathematical skills. Besides, we suppose that older children will perform better than younger, and boys will perform better than girls in mental calculation.

Method

Prior to testing, informed written consent for both experiments was obtained from the children's parents. It was explained to each child that the experiment could be discontinued at any time. The Ethics Committee of UNESP, São Paulo State University approved the study, case nº 0095/2005.

Participants

Participants were 172 children (86 boys) aged 7-12 years. In regards to gender the children were distributed across age bands: twelve boys at age 7, ten boys at age 8, eighteen boys at age 9, twenty-five boys at age 10, eleven boys at age 11 and ten boys at age 12. The children were raised in urban area of Assis and Ourinhos cities in São Paulo State ($N = 119$) or in rural area from the same region ($N = 53$). The children were recruited in government schools from 1st to 6th grades. The schools were selected according to three aspects: a) being public schools, b) attending children at the target age bands, and c) attending also children raised in rural areas. It is important to mention that the rural children of this sample lived in the rural environment but studied in the same urban schools than their counterparts.

All of the children were Brazilian nationals, native Portuguese speakers, and non-bilingual. The age bands and schooling grades were equivalent in all cases. The inclusion criterion was normal intellectual level: 50 children of the sample were assessed by the Raven's Coloured Progressive Matrices (percentile > 24 and < 75; Angelini, Alves, Custódio, Duarte, & Duarte, 1999) and 122 children were assessed by the Wechsler Intelligence Scale for Children - WISC III (IQ >80 and <120; Wechsler, 2002). The intellectual level was assessed in order identify potential outliers; participants were recruited for two different projects, which explain the use of Raven's matrices for some of them.

None of the children was identified as presenting learning disabilities, emotional disturbances, motor difficulties, speech or hearing impairments, or neurological or psychiatric diagnosis, based on parent and teacher reports. The socioeconomic status (SES) was assessed by the Brazilian Association of Marketing Research Institutes Scale, which stratifies in five classes from A/richest to E/poorest (ABIPEME; Almeida & Wickerhauser, 1991). Difference in SES between the two groups was found, in that urban children $M = 54.89$, ($SD = 18.44$) obtained higher scores ($t = 5.61$; $p < .001$) than rural children $M = 38.45$, ($SD = 15.16$), these mean scores represent the opposite extremes boundaries of middle class (38-58 points). Sociodemographic information is presented on Table 1.

Material

The Zareki-R (von Aster & Dellatolas, 2006) assesses the number representation in children considering cognitive abilities that are prerequisites for the acquisition of

Table 1
Sample description by groups

	Total		Urban		Rural	
	N	%	*N*	%	*N*	%
Age (years)						
Age 7	30	17.44	23	19.33	7	13.21
Age 8	20	11.63	11	9.24	9	16.98
Age 9	38	22.09	29	24.37	9	16.98
Age 10	44	25.58	33	27.73	11	20.75
Age 11	21	12.21	13	10.92	8	15.09
Age 12	19	11.05	10	8.40	9	16.98
Gender						
Boys	86	50	60	50.42	26	49.06
Girls	86	50	59	49.58	27	50.94
Total	172	100	119	100	53	100

Legend. *N* = number of participants; % = percentage of cases

arithmetic skills. Zareki-R has been originally published in German and French language versions (von Aster, Weinhold Zulauf, & Horn, 2006; von Aster & Dellatolas, 2006; respectively) with its respective standardization. As for the French version, von Aster and Dellatolas (2006) found significant and high correlations between Zareki-R scores and the mathematic part of the Test of Scholar Achievement in different grades (TAS, Test d'Acquisitions Scolaires Francais et Mathematiques; Lepez & Riquier, 1997) reported by children's teachers.

The Zareki-R has 11 subtests specialized in mathematical skills, nine of them assess number processing (i-ix) and two assess calculation (x-xi): i) *Counting dots (CD):* Children have to enumerate different set of dots. The scoring system considers the number of results. Qualitatively, it is considered: production of the usual sequence of spoken numbers, oral and manual synchronization while pointing and counting dots, visual control for discrimination of the dots already counted and remaining items, transcoding the information from spoken verbal number to Arabic digit form (the number of items, i.e., the k-value is 6) ; ii) *Counting backwards (CB):* the children must count the dots in backward the sequences: from 23 to 1 and from 67 to 54 (Items k = 2); iii) *Dictation of numbers (DN):* the child is asked to write, in Arabic numerals, eight numbers presented orally (e.g. 14), (Items k = 8); iv) *Reading numbers (RN):* the child is asked to read loudly eight numbers written in Arabic numerals, such as 15 and 6485, (Items k = 8); v) *Positioning numbers on an analogue scale (PN):* the scales are vertical lines represented with a "0" at the bottom and a "100" at the top, which are transacted by 4 small horizontal lines at different locations. The child is asked to point to the horizontal which corresponds to an Arabic numeral, aurally or visually presented by the examiner (Items k = 12); vi) *Oral comparison (OC):* Eight pairs of numbers are presented aurally (e.g., 34601 and 9678) and the child must judge which one is larger (Items k = 8); vii) *Perceptive estimation (PE):* The child has to give orally an estimative, without counting, in of the quantities of items shown in a picture, visually presented by 5 seconds, for example the number of balls in the picture (the precise answer is 57 balls), (Items k = 8); viii) *Contextual estimation (CE):* The child must judge sentences in terms of coherence between quantities and context, for instance: "ten leaves on a tree" is 'little', 'median' or a 'lot'?, (Items k = 10); ix) *Written comparison (WC):* Pairs of numbers in Arabic numeral form are presented visually, for instance, 1007 and 1070, and the child must judge which one is larger, (Items k = 10); x) *Mental calculation (MC):* Eight additions, eight subtractions, and six multiplications are presented aurally (e.g.: 5 + 8; 14 - 6, and 3 x 2), (Items k = 22); xi) *Problem solving (PS):* The child has to solve six numerical problems of increasing complexity. The first story problem is: 'Peter has 12 marbles; He gave 5 to his friend Anne; how many marbles Peter has now?', (Items k = 6). The battery also includes a subtest to measure phonological working memory, however, it is not included in the total score: xii) *Memory of Digits (MD):* This requires the forward (FDS) and backward (BDS) repetition of digit sequences of increasing length, three sequences of each length were performed. In the FDS the child repeats the digits in the same order as the experimenter spoke them, (Items k = 24). In the BDS, the subject repeats the digits in reverse order. Additionally, as presented by Dellatolas et al. (2000), the Score A is

Table 2
Sociodemographic aspects by groups

	Total			Urban			Rural		
	N	*M (SD)*		*N*	*M (SD)*		*N*	*M (SD)*	
SES	160	49.45	(19.03)	107	54.89	(18.44)	53	38.45	(15.16) *
WISC-III– IQV	122	106.56	(11.75)	69	109.65	(10.89)	53	102.46	(11.68) *
CPM#	50	66.50	(20.01)	50			—		

(*) $p < .05$; (#) urban children from Ourinhos city aged 9 to 10 years. *Legend. N* = number of participants; *M* = mean; *SD* = standard deviation; SES = socioeconomic status; WISC-III = Wechsler Intelligence Scale for Children; IQV = Verbal Intelligence Quotient; CPM = Raven's Coloured Progressive Matrices.

calculated by the sum of the six following subtests of ZAREKI-R: dictation of number, reading numbers, mental calculation, problem solving, oral comparison and written comparison.

Procedures

The children were assessed with a larger battery of neuropsychological tests, involving short and long term-memory for visuospatial and verbal stimuli, which will not be reported in this article. The neuropsychological assessment was carried out individually at child's school in a quiet room. The Zareki-R was administered in a single session and engaged 30-minute in average; the subtests order was not fixed, but verbal tasks (MD, DN, CB, MC, OC, CE, and PS) were alternated with visuomotor e perceptive ones (CD, RN, WR, PE, and PN).

Statistical analyses

The analyses were carried out with STATISTICA, version 5.0 (Statsoft, 1995). Three sets of analyses were performed. In the first, multivariate analysis of variance (MANOVA) were carried out for Zareki-R subtests. In this case, the between-subject factors were 2 groups (urban and rural), while the within-subjects factors were the scores in each subtest of Zareki-R, except the subtest Memory of Digits. The t-test was carried out for the Total score, Score A, and Memory of Digits of Zareki-R, with the same between-subject factors. Due to differences between groups on Zareki-R subtests, the subsequent analyses were conducted with group as covariant.

In the second set of analyses, multivariate analysis of covariance (MANCOVA) - group as a covariant - were carried out, between-subject factors were 6 ages (from 7 to 12 years) and 2 genders (male and female) and the same within-subject factors were used to investigate the factors that determine the main effects obtained. Analyses of covariance (ANCOVA) – group as a covariant – were performed for the Total score, Score A, and Memory of Digits of Zareki-R, with the same within- and between-subject factors. In the first and second sets of analyses the Scheffé *post hoc* test was used with a significant alpha level of $p \leq .05$.

In the third set, Pearson's product moment correlations between scores in Zareki-R and Arithmetic of WISC-III, and Memory of Digits of Zareki-R were carried out. For the discussion, we adopted moderate to high correlations ($r > .40$) as minimum score. To assess the effect size of group and gender effect was used Cohen's d calculated

Table 3
ZAREKI-R performance in Brazilian children by groups and gender

	Urban (*N*=119)		Rural (*N*=53)		*p*	Cohen *d*	Boys (N=86)		Girls (N=86)		*p*	Cohen *d*
	M	*(SD)*	*M*	*(SD)*			*M*	*(SD)*	*M*	*(SD)*		
CD	3.49	(.82)	3.58	(.72)	.45	–.11	3.53	(.79)	3.50	(.79)	.77	.03
CB	3.26	(1.09)	2.96	(1.18)	.10	.26	3.31	(.99)	3.02	(1.24)	.08	.25
DN	13.26	(4.11)	12.42	(4.27)	.21	.20	13.42	(3.85)	12.58	(4.44)	.18	.20
RN	14.16	(3.79)	13.83	(3.93)	.60	.08	14.48	(3.57)	13.64	(4.03)	.15	.22
PN	16.46	(5.07)	14.99	(5.31)	.08	.28	16.68	(5.13)	15.33	(5.17)	.08	.26
OC	14.08	(2.57)	13.25	(3.32)	.07	.27	14.48	(2.17)	13.16	(3.26)	< .01*	.47
PE	6.08	(2.22)	6.40	(2.37)	.40	–.13	6.38	(2.26)	5.98	(2.26)	.24	.17
CE	12.72	(4.67)	14.04	(4.89)	.09	–.27	12.84	(5.01)	13.42	(4.52)	.42	–.12
WC	18.97	(2.06)	18.23	(2.62)	.04*	.31	19	(1.98)	18.49	(2.51)	.13	.22
MC	29.88	(11.28)	26.51	(11.54)	.07	.29	30.48	(11.37)	27.21	(11.33)	.05*	.28
PS	7.33	(3.64)	6.58	(3.62)	.21	.20	7.99	(3.59)	6.21	(3.48)	< .01*	.50
Total	139.56	(31.85)	132.76	(33.56)	.20	.20	142.58	(30.97)	132.35	(33.25)	.03*	.31
Score A	97.68	(24.02)	90.79	(25.01)	.08	.28	99.82	(23.36)	91.29	(24.94)	< .01*	.35
MD	25.05	(6.83)	20.22	(5.19)	< .01	.79	23.53	(6.93)	23.60	(6.59)	.89	–.01

(*) $p \leq .05$. Gender effect by ANCOVA, group as covariant. *Legend*. Zareki-R = Neuropsychological Tests Battery of for Number Processing and Mental Calculation in children, Revised; *N*= number of participants; *M*= mean; *SD*= standard deviation; CD = Counting dots; CB = Counting backwards; DN = Dictation of numbers; RN = Reading numbers; PN = Positioning numbers on an analogue scale; OC = Oral comparison; PE = Perceptive estimation; CE = Contextual estimation; WC = Written comparison; MC = Mental calculation; PS = Problem solving. Score A= is calculated by the sum of the six following subtests of Zareki-R: dictation of number, reading numbers, mental calculation, problem solving, oral comparison and written comparison. MD= Memory of Digits.

Table 4
ZAREKI-R performance in Brazilian children by age

	Age 7 (N = 30)		Age 8 (N = 20)		Age 9 (N = 38)		Age 10 (N = 44)		Age 11 (N = 21)		Age 12 (N = 19)	
	M	*(SD)*	*M*	*(SD)*	*M*	*(SD)*	*M*	*(SD)*	*M*	*(SD)*	*M*	*(SD)*
CD	3.40	(.89)	3.50	(.83)	3.26	(.89)	3.68	(.64)	3.67	(.66)	3.68	(.75)
CB[a]	1.97	(1.43)	3.25	(1.21)	3.21	(.99)	3.55	(.76)	3.57	(.60)	3.58	(.51)
DN[b]	6.07	(3.81)	11.65	(3.76)	14.45	(2.42)	15.23	(1.18)	15.05	(1.36)	15.05	(1.03)
RN[b]	7.67	(4.61)	13.30	(3.33)	15.53	(1.25)	15.80	(.67)	16.00	(.00)	15.84	(.37)
PN[a]	10.38	(5.96)	15.53	(5.33)	15.61	(4.46)	18.41	(2.97)	17.86	(4.01)	18.58	(3.01)
OC[d]	10.67	(3.49)	12.15	(3.80)	15.00	(1.41)	14.52	(1.64)	15.00	(1.30)	15.26	(1.37)
PE	5.20	(2.20)	5.40	(2.44)	6.42	(2.42)	6.73	(2.12)	6.33	(1.98)	6.63	(2.03)
CE[a]	9.13	(3.81)	13.40	(4.45)	12.68	(4.73)	14.14	(4.89)	14.48	(4.29)	16.21	(2.49)
WC[a]	16.33	(3.07)	18.40	(2.87)	19.26	(1.08)	19.41	(1.70)	19.52	(0.87)	19.47	(1.47)
MC[c]	12.47	(9.37)	25.15	(11.82)	31.26	(8.00)	34.80	(6.72)	34.43	(6.93)	33.79	(6.09)
PS[c]	2.77	(3.33)	5.50	(3.86)	7.53	(3.13)	8.66	(2.51)	8.62	(2.01)	9.47	(1.81)
Total[c]	85.51	(27.46)	127.17	(31.70)	144.21	(18.38)	154.91	(14.25)	154.52	(12.85)	157.58	(11.81)
Score A[b]	55.96	(21.26)	86.10	(24.12)	103.02	(11.95)	108.40	(10.58)	108.61	(8.72)	108.89	(8.96)
MD	21.46	(6.14)	23.90	(8.39)	23.00	(6.25)	24.63	(6.96)	22.95	(7.00)	25.89	(5.39)

Legend. Age effect by MANCOVA, group as covariant; Scheffé post-hoc: (a) 7 < 8-12; (b) 7 < 8 < 9-12; (c) 7 < 8 and 8 < 10-12; (d) 7-8 < 9-12; $p \leq .05$ in all cases. Zareki-R = Neuropsychological Tests Battery of for Number Processing and Mental Calculation in children, Revised; *N*= number of participants; *M*= mean; *SD*= standard deviation; CD = Counting dots; CB = Counting backwards; DN = Dictation of numbers; RN = Reading numbers; PN = Positioning numbers on an analogue scale; OC = Oral comparison; PE = Perceptive estimation; CE = Contextual estimation; WC = Written comparison; MC = Mental calculation; PS = Problem solving; MD= Memory of Digits. Score A= is calculated by the sum of the six following subtests of Zareki-R: dictation of number, reading numbers, mental calculation, problem solving, oral comparison and written comparison.

through the free software (Devilly, 2005); small, median, and large effects are respectively correspondent to effect sizes of .20, .50, and .80 (Rice & Harris, 2005).

Finally, considering that working memory could be a possible factor explaining the results, using the same within- and between-factors of first and second sets we carried out exploratory analyses with Memory of Digits as covariant, and the results were similar to the analyses reported below in that group was the covariant.

Results

Tables 3 and 4 present the results obtained with the Zareki-R by groups, gender and age, respectively. In general, urban children had higher scores than rural in the subtest Written comparison and Memory of Digits, the performance increased with age, and boys had higher scores than girls in Mental calculation, Oral comparison, Problem solving, and Total score.

Group effect. A 2 (group) x 11 (subtest) MANOVA was performed. A group effect was observed [$R(11,160) = 2.11$; $p = .02$]. Urban children were better than rural in Written comparison ($p = .04$). No effect of group was observed by ANOVA in the Total Score ($t = 1.27$; $p = .63$) and Score A of Zareki-R ($t = 1.71$; $p = .70$). There was group effect in the subtest Memory of Digits of Zareki-R ($t = 4.58$; $p = .02$), in that urban children performed better than rural.

Gender effect. A 2 (gender) x 11 (subtest) MANCOVA was performed, group as a covariant, and revealed a gender effect [$R(11,159) = 2.43$; $p < .01$]. Boys performed better than girls in Mental calculation ($p = .05$), Oral comparison ($p < .01$), and Problem solving ($p = .11$). ANCOVAs – group as a covariant – indicated gender effect to the Total score [$F(1, 169) = 4.30$; $p = .03$] and Score A [$F(1, 169) = 5.32$; $p < .02$]; boys performed better than girls, but not to Memory of Digits [$F(1, 169) = .01$; $p = .89$].

Age effect. A 6 (age) x 11 (subtest) MANCOVA was performed, group as a covariant, and revealed an age effect [R (55,721) = 5.47; $p < .001$]. ANCOVA – group as a covariant – observed an age effect to the Total Score [$F(5, 165) = 58.57$; $p < .001$], and Score A [$F(5, 165) = 63.94$; $p < .001$]. ANCOVA – group as a covariant – also observed an age effect to Memory of Digits [$F(5, 165) = 2.33$; $p = .04$], but the *post-hoc* test did not discriminated the differences. Except for Counting dots and Perceptive estimation subtests, the age effect was observed in all tasks. 7-year-old children performed worse than all other ages for the other subtests and Score A, except for Oral comparison, in that 7- and 8-year-old children performed worse than 9- to 12-year-old children. 8-year-old children performed worse than 9- to 12-year-old children in Dictation of numbers, Reading numbers, and Score A, and worse than 10- to 12-year-old children in Mental calculation, Problem solving and Total score.

Exploratory analysis with gender and age as covariants altogether in MANCOVA and ANCOVAs for the total score, Memory of Digits, Zareki-R subtests, and for Score A indicated that there were no interactions between these factors.

Correlation between Zareki-R and Arithmetic of WISC-III or Memory of Digits

The correlation matrix was calculated considering the four-step developmental model of number acquisition (von Aster & Shalev, 2007) which states that number line development is associated with working memory (subtest memory of dots). Moreover, the subtest Arithmetic of WISC-III was used as a gold standard for the assessment of mathematical skills. The results revealed significant and positive relationship between all the subtests of Zareki-R and the subtest Arithmetic of WISC-III. Moderate correlations were observed to the following subtests: Counting backwards ($r = .49$), Dictation of numbers ($r = .49$), Mental calculation ($r = .49$), Reading numbers ($r = .49$), Oral comparison ($r = .41$), Problem solving ($r = .58$), Total score ($r = .65$), and Score A ($r = .62$). There were significant and positive correlation between the Memory of Digits and the others subtest of Zareki-R, except for Counting Dots ($p = .10$) and Perceptive estimation ($p = .87$), but none of them were over .4. See Table 5.

Discussion

The present study investigated the mathematical skills such as calculation and number processing of Brazilian children aged 7 to 12 years from public schools in two cities of São Paulo State and identified some factors that influenced the development of these abilities. The performance was mainly age and gender-related, and indicated minimal environmental influence.

As for the environmental factor, rural children achieved lower score than urban children only in two tasks (Written comparison and Memory of Digits), with preserved calculation; whereas in the study of Koumoula et al. (2004) rural children obtained lowers scores in seven subtests of ZAREKI (von Aster, 2001), including Written comparison, but not Memory of Digits. In previous studies it was suggested that a low socioeconomic level and educational environment could determine such differences (Dellatolas et al., 2000; Koumoula et al., 2004). In the present study, socioeconomic status was objectively assessed, rather than inferred by the environment factor, and the statistical analysis indicated that rural children in fact had low socioeconomic scores than urban children. In spite of it, the rural group showed a slight low score restricted to one aspect of number processing; and, even though, the effect size showed that this difference had small magnitude. It means that, despite of this socioeconomic discrepancy both groups performed Zareki-R almost similarly. Since all rural children studied in the same schools as the urban children, therefore obtain the same educational stimulation, we consider that the pedagogy method is a more specific

Table 5

Correlation between Zareki-R and Arithmetic of WISC-III

	Arithmetic of WISC-III (N = 1 22)	MD of Zareki-R (N = 172)
Counting dots	.18	.12
Counting backwards	.49*	.35
Dictation of numbers	.49*	.35
Reading numbers	.49*	.27
Positioning numbers on an analogue scale	.33	.33
Oral comparison	.41*	.21
Perceptive estimation	.22	–.01
Contextual estimation	.36	.25
Written comparison	.38	.32
Mental calculation	.62*	.36
Problem solving	.58*	.38
Total score	.64*	.39
Score A	.62*	.38

(*) Moderate and high correlations $r > .40$; $p < .05$. *Legend*. Zareki-R = Neuropsychological test battery for Number Processing and Calculation in Children, Revised; WISC-III = Wechsler Intelligence Scale for Children; MD= Memory of Digits; Zareki-R = Neuropsychological Tests Battery of for Number Processing and Mental Calculation in children, Revised.

determinant of the arithmetic performance than the socioeconomic status.

The performance was age-related, even controlling statistically the environmental factor, in that children aged 7 and 8 years obtained lower scores in Zareki-R in comparison to older children, except in two subtests: counting dots and perceptive estimation. This result was expected since counting dots is an ability related to the core verbal system of the four-step Developmental Model of Numerical Cognition, which develops at the preschool age (von Aster & Shalev, 2007), which is consistent with Gelman and Gallistel (1978) principles, that the counting competence allows children to compare quantities and solve arithmetic using counting strategies as reasoning tools. Besides, older children have more facility to perform the battery, at least for items influenced by schooling; for example, there was ceiling effect in Reading numbers subtest at age 11.

Dellatolas et al. (2000), Koumoula et al. (2004), and von Aster and Shalev (2007) showed that many domains of number processing and calculation are dependent on schooling achievement (Score A) and have an improvement age-related since the symbolic number representation system (verbal and Arabic) and the ordinal magnitude system (mental number line) are learnt during primary school. Therefore, mathematic skills seem to be dependent of both brain maturation (von Aster, 2000) and schooling (von Aster & Shalev, 2007).

Boys performed better than girls at Zareki-R total score, in calculation (Mental calculation and Problem solving), and in one subtest of number processing (Oral comparison), in all cases the effect was confirmed controlling the environmental factor by the ANCOVA. However, the effect size showed that the gender difference had small magnitude for Mental calculation and Oral comparison and median magnitude for the Problem solving subtest. We consider that the differences were number representation-related rather than associated with general cognitive ability because all children had average scores on intelligence measure, phonological short-term span or other neuropsychological tests. Previous studies have found lowers scores for girls in calculation (Hein et al., 2000; Rosselli et al., 2009; von Aster, 2000) and in number comparison (Dellatolas et al., 2000; von Aster, 2000). Rosselli et al. (2009) attributed the gender effect to more efficient arithmetical fact retrieval for the boys. In our study boys and girls performed similarly all memory tasks; so, it is unlikely that long-term memory (results not reported in the present study) could explain the gender contrast. Although, we did not assessed mood or stress in our sample, Krinzinger and Kaufmann (2006) considered that the low performance of girls in arithmetic could be explained by a higher level of math anxiety and to negative attitudes toward math, what is consistent with von Aster (1994) that associated these lower scores of girls with emotional aspects.

In the present study urban children performed the subtest Memory of Digits of Zareki-R better than rural children. Many studies showed that digit span task is free from culture aspects, such as environment and socioeconomic status (Engel et al., 2009; Koumoula et al., 2004; Santos & Bueno, 2003; Santos et al., 2005). A possible explanation for this incongruence is the scoring system of Zareki-R, in that higher score in Memory of Digits cannot be interpreted necessarily as higher span on phonological working memory, instead higher scores are associated with the consistence of correct response, because the child may have a span, for instance of four items, but failure to reproduce the three trials and consequently obtain less points than a child with the same span but that answered correctly all three trials. Moreover, the Memory of Digits presents a composite score with the sum of forward and backward trials. So, these particularities may be an artefact. In the other hand, the correlations between Memory of Digits and Zareki-R's subtests were low statistically significant (.1 to .3) and corroborate with previous studies associating arithmetic skills and working memory (Gathercole & Alloway, 2004; Gathercole, Alloway, Willis, & Adams, 2006; Geary, 2000; Koumoula et al., 2004; Siegel & Ryan, 1989; Silva & Santos, 2011; Swanson, 2006), which is also consistent with the four-step Developmental Model of Numerical Cognition (von Aster & Shalev, 2007).

In addition, it was found moderate to high positive correlations ($r > .40$) between Zareki-R and the subtest Arithmetic of the WISC-III, which demonstrated the Zareki-R construct validity; however, in the Arithmetic WISC-III subtest, different components of numerical cognition are in concert, thus, it is a good measure for screening but not accurate for diagnosis. Santos and Silva (2008) showed that children who presented inferior scores in the Arithmetic subtest of the School Achievement Test (SAT; Stein, 1994), which assess only calculation according to the schooling grade expectation, were impaired in both aspects of mathematical skills - calculation and number processing when assessed by the Zareki-R. Therefore, the Zareki-R seems to be more comprehensive to assess mathematical skills than SAT and WISC-III, and seems to be an important instrument for the diagnosis of Developmental Dyscalculia.

The limitation of the present study is that the sample included children from two cities of the Sao Paulo State (Assis and Ourinhos), which restrict in part the generalization of the results, however, the results were not completely discrepant of the previous normative studies with ZAREKI and Zareki-R in general aspects (Dellatolas et al., 2000; Hein et al., 2000; Koumoula et al., 2004; von Aster, 2000; Rotzer et al., 2009). A present goal from the authors is to investigate if the current profile is equivalent in different regions of the country and include children at age 6 because recently Brazilian law anticipated the beginning of the 1st grade of the primary school officially from age 7 to age 6; whereas for younger children, in preschool level, seems to be more suitable to assess mathematical skills by the Zareki-K (Weinhold-Zulauf, Schweiter, & von Aster, 2003), Kindergarten adapted version in Portuguese by Santos, Paschoalini, and Molina (2006).

In conclusion, the performance of the Brazilian children at Zareki-R was slightly related to environmental, and mainly influenced by age, and gender factors. In disagreement with our previous hypothesis, rural children presented lower performance only in one number processing aspect. It is important to hallmark that the socioeconomic factor did not seems to be main determinant of this difference, since the pedagogy method produced similar performance between rural and urban children. On the other hand, as it was expected, children from 7 to 8 years old showed a global inferior scores in comparison to older children; besides, boys performed better than girls in calculation and in one aspect of number processing. These results are important to the development of the cognitive rehabilitation strategies.

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