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Neuropsychological and environmental predictors of reading performance in Brazilian children

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ABSTRACT

Word-level reading is strongly associated with phonological processing. The aim of this study was to investigate the effects of cognitive and environmental variables on word reading performance. Our sample consisted of 185 fourth-grade students. Linear regression analyses were used to investigate the role of the following variables as potential predictors of word reading accuracy and fluency: phonological processing (phonological awareness, rapid automatized naming, and phonological memory); verbal fluency; working memory; socioeconomic status and an indicator of school quality (IDEB) in Brazil. Phonological awareness and rapid automatic naming were the best predictors of reading, supporting the role of phonological processing as a key contributor to the lexical aspects of reading, beyond the early years of literacy acquisition. Environmental variables were significant predictors of irregular word reading (socioeconomic status) and fluency (IDEB), corroborating multicomponent models of reading performance. The present findings demonstrate the complex interplay of factors underlying reading performance and highlight the importance of a multidimensional approach to the study of reading.

KEYWORDS

Fluency; phonemic awareness; phonological awareness; reading; socioeconomic status

Introduction

Word recognition and the use of phonological decoding to access lexical information play a key role in the early stages of reading acquisition (Mani & Huettig, 2014). However, this process has only been scarcely studied in older children with difficulties in reading fluency and accuracy; therefore, further investigation is needed in older children with normal development. It is expected that children improve their performance in reading as they grow older, using lexical knowledge and the improvement of reading strategies (Salles & Parente, 2002; Seabra & Dias, 2012). During childhood, word recognition becomes automated, as education and exposure to reading in different contexts increases (Seigneuric & Ehrlich, 2005). However, Brazilian children are in high risk for adverse reading development once most of them finish elementary school with poor reading skills and, consequently, difficulties in comprehend what they read (INEP, 2015).

The cognitive processes involved in word-level reading have been described by dual route models (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) in terms of two distinct mechanisms, comprising a phonological and a lexical route. The phonological route is responsible for grapheme-phoneme conversion, while the lexical route enters familiar words into a visual input lexicon, which stores a combination of contextual, visual, phonological, and orthographic information (see Coltheart et al., 2001; Coltheart, 2005, 2006; Nobre & Salles, 2014, for a review). Phonological decoding is essential for reading acquisition as it allows for the generation of target pronunciations for unfamiliar words with novel orthographic features (Share, 1995).

Robust evidence supports the role of phonological ability in reading. Phonological awareness is a significant predictor of word recognition, especially in the initial stages of reading acquisition when the phonological route is predominant (Vellutino, Fletcher, Snowling, & Scanlon, 2004). The development of the lexical route and reading accuracy is also associated with morphological consciousness, vocabulary, intelligence, and short-term memory (Binamé & Poncelet, 2016; Deacon, Benere, & Pasquarella, 2012; Fricke, Szczerbinski, Foxboyer, & Stackhouse, 2016; Hulme, Nash, Gooch,

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Lervag, & Snowling, 2015; Kim & Pallante, 2012; Moll et al., 2014; Nobre & Salles, 2014). The cognitive predictors of reading fluency include oral language skills, orthographic speed, lexical access, pseudoword reading, and especially rapid automatized naming (RAN) (Hulme et al., 2015; Justi & Roazzi, 2012; Wolf & Katzir-Cohen, 2001). Phonological working memory tasks (digit, letter, and pseudoword spans) explain the individual variability of reading trajectories in children (Mayes, Calhoun, Bixler, & Zimmerman, 2009; Piccolo & Salles, 2013), and are often associated with reading fluency (Pham & Hasson, 2014). The Visuospatial working memory is also relevant since the visual component can contribute to the support of written information and eye movement during reading (Baddeley, 2003; Capovilla, Capovilla, & Suiter, 2004; Piccolo & Salles, 2013).

Studies of oral language, vocabulary, phonological awareness and word reading suggest that these cognitive-linguistic processes may have a greater effect on word reading than the working memory (Gentaz, Sprenger-Charolles, & Theurel, 2015; Landerl et al., 2013; Mayes et al., 2009). Phonological awareness has been found to be the most significant predictor of reading ability in younger children, while RAN appears to be more closely associated with reading in older children (Landerl et al., 2013). Since most research on the subject has been carried out in English, whose writing system is highly irregular (Kim & Pallante, 2012), additional studies are required to identify predictors of word-level reading performance (accuracy and fluency) in more regular languages, such as Brazilian Portuguese, especially in older children.

In addition to cognitive variables, reading performance in children may also be influenced by environmental factors, such as socioeconomic status (SES)—generally measured by a combination of education, income, and occupation (McLoyd, 1998)—as well as home literacy (Aaron, Joshi, Gooden, & Bentum, 2008; Aaron & Joshi, 2009; Fletcher, 2009; Joshi & Aaron, 2012; Melvin et al., 2016). Discrepancies in the SES are strongly associated with differences in academic performance, language, executive functioning, and memory (Brito, Piccolo, & Noble, 2017; Noble et al., 2015; Noble, McCandliss, & Farah, 2007; Piccolo, Arteche, Fonseca, Grassi-Oliveira, & Salles, 2016). Delays in the acquisition of language skills (Hart & Risley, 2003; Hoff, 2013; Weisleder & Fernald, 2013) such as phonological awareness (Noble, Wolmetz, Ochs, Farah, & McCandliss, 2006) have been demonstrated in children from low SES backgrounds in relation to those with a higher SES even before entering school. Socioeconomic disparities are likely to be associated with variations in parenting and cognitive stimulation (Smith & Strick, 2001), as well as the language environment at home (Duursma, Pan, & Raikes, 2008; Haney & Hill, 2004; Melvin et al., 2016; Weisleder & Fernald, 2013).

In Brazil, school quality is another complex variable with significant associations with several factors, including the SES, resource availability, family involvement in education, teaching methods, and the quantity and quality of cognitive stimulation (Gardinal & Marturano, 2007). The performance of Brazilian public school students is far below expected for a developing country (INEP, 2015). Considering this evidence, the present study used the Basic Education Development Index (*Índice de Desenvolvimento da Educação Básica*; IDEB) to verify the influence of school quality on student performance in reading. This index is calculated based on a combination of school approval rates and performance on government mandatory standardized tests, such as the Brazil Exam and the National System for the Evaluation of Basic Education (*Sistema Nacional de Avaliação da Educação Básica*; SAEB) (INEP, 2007). When results were last published, in 2013, the national IDEB for Brazil was calculated at 5.2, which falls well short of the value of 6.0 recommended by the Organization for Economic Cooperation and Development (INEP, 2015).

The objective of the present study was to perform an integrated assessment of phonological processing abilities (phonological awareness, RAN, phonological working memory), visuospatial working memory, verbal fluency, nonverbal intelligence, and environmental variables (SES and IDEB) in order to identify predictors of word-level reading performance (accuracy and fluency) in fourth grade public school Brazilian students. Phonological processing skills (span tasks, RAN, and phoneme elision) were expected to be the strongest predictors of word reading ability (accuracy and fluency) (Landerl et al., 2013; Vellutino et al., 2004). SES, as measured by family income and parental education, was expected to influence word-level reading fluency (Alloway, Alloway, & Wootan, 2014), as it is known to contribute to both phonological processing and language development (Noble & Mccandliss, 2005).

Method

Participants

The sample consisted of 185 children 9 to 11 years old ($M = 9.30$; $SD = 0.55$), 107 (57.8%) girls. All participants were attending 4th grade in public schools in the cities of Porto Alegre (Rio Grande do Sul) and Belo Horizonte (Minas Gerais), from two federal and

Table 1. Sample demographics ($N = 185$).

	POA ($n = 56$)	BH ($n = 129$)	Mean comparison statistics	p
Gender M/F *(n/%)*	24 (42.9%)/32 (57.1%)	54 (41.9%)/75 (58.1%)	0.016[a]	0.900
Age (years) $M \pm SD$	9.48 ± 0.63	9.22 ± 0.49	16.475[b]	0.003
Raven $M \pm SD$	28.67 ± 3.78	29.10 ± 3.73	0.169[b]	0.487
MTA-SNAP-IV $M \pm SD$	4.69 ± 5.63	2.65 ± 4.13	0.670[b]	0.118
IDEB $M \pm SD$	5.41 ± 0.98	7.00 ± 0.97	365.818[b]	0.001
SES $M \pm SD$	33.03 ± 9.65	30.11 ± 7.1	4.422[b]	0.047

Note. POA = Porto Alegre city; BH = Belo Horizonte city; M = mean; SD = standard deviation; F = female; M = male; MTA-SANP-IV = questionnaire of symptomps of attention-deficit/hyperactivity disorder and oppositial-defiant disorder; IDEB = Basic Education Devolopment Index; SES = Socioeconomic Status (Brazilian Economic Classification Criteria).
[a]Between-group differences analyzed using chi-square tests.
[b]Mean values compared between groups using Student's T-test.

two state schools in each city. All participants had learned to read in Brazilian Portuguese, had no history of neurological or psychiatric illnesses as reported for their families and/or school and tested by MTA-SNAP-IV, and performed at or above the 25th percentile on Raven's Colored Progressive Matrices Test (Angelini, Alves, Custódio, Duarte, & Duarte, 1999; Raven, 1995). The characteristics of children recruited from each city are shown in Table 1. The percentage of boys and girls was similar in both cities. The mean age of children from the city of Porto Alegre (POA) was higher than that of participants from Belo Horizonte (BH). However, the groups did not differ as to their nonverbal intelligence scores (Raven) or a Brazilian version of the MTA-SNAP-IV for evaluation of symptoms of attention-deficit/hyperactivity disorder and oppositional-defiant disorder (Mattos, Serra-Pinheiro, Rohde, & Pinto, 2006; Swanson, Nolan, & Pelham, 1992) results. The mean IDEB of schools in BH was higher than that of institutions in POA. Children from POA had a higher SES than those recruited in BH.

According to the criteria established by a survey of the Brazilian Association of Research Companies - ABEP (2015), the SES distribution of the sample (number/percentage of children per strata) was as follows: A1 ($n = 7$; 3.8% of the sample); B1 ($n = 24$; 13%); B2 ($n = 57$; 30%); ($n = 45$; 24.3%); C2 ($n = 19$; 10.3%); and D-E ($n = 3$; 1.6%). Socioeconomic classification "A" corresponds to the highest SES (families with the highest education and income) and "E" the lowest (families with the lowest education and income), considering the Brazilian population statistics from ABEP. This information was not provided by 19.45% of the participants.

Study design and procedures

The present study had a mixed design and was descriptive, correlational and explanatory. Participants were selected by nonrandom convenience sampling. This study was approved by the Research Ethics Committees of the University Federal de Minas Gerais (protocol number 939.562), and the Department of Psychology of the University Federal do Rio Grande do Sul (protocol number 1.023.371). After each school agreed to participate, group and individual assessment sessions were scheduled with children whose guardian had provided written consent for participation in the study. Assent forms were also signed by all participating children. Parents were asked to fill out a Health and Sociodemographic Questionnaire, as well as the MTA-SNAP-IV (Mattos et al., 2006; Swanson et al., 1992). Children participated in two assessment sessions. First, the Colored Progressive Matrices Test - Special Scale (Angelini et al., 1999) was administered in group sessions involving a maximum of eight students and lasted about 20 minutes. The remaining neuropsychological and reading tests were administered in a second, individual session that lasted approximately 90 minutes. All instruments were administered by trained students and health professionals. After the assessment, a report of the performance of each child was given to the school and their respective guardians.

Instruments and procedures

a. *Raven's Colored Progressive Matrices* (Angelini et al., 1999). This instrument provides a measurement of nonverbal intelligence. In this study, the test total score was used. This task presents internal consistency index with Cronbach's alpha coefficient of 0.91
b. *MTA-SNAP-IV Questionnaire* (Mattos et al., 2006; Swanson et al., 1992). The Brazilian version of this instrument was used to evaluate symptoms of inattention, hyperactivity, and opposition associated with attention deficit/hyperactivity disorder (ADHD).

Predictors

c. *Adapted socioeconomic and health questionnaire.* This questionnaire collects sociocultural data, and

investigates the health, development and educational history of each child. The SES was determined using the Brazilian Economic Classification Criteria (ABEP, 2015), an index combining parental education and family income that characterizes the family socioeconomic condition. For the analysis of the SES, the total score in the survey was used.

d. *Basic Education Development Index (*IDEB; INEP, 2007). The IDEB evaluates educational quality as a function of grade progression and standardized test performance. Ratings are calculated every two years and measured on a scale ranging from zero to ten. For the analysis in this study, the score based on that scale (0–10) was used.

e. *Phoneme Suppression Task* (Lopes-Silva, Moura, Júlio-Costa, Haase, & Wood, 2014). This instrument provides a measure of phonological awareness. A series of words are read to the child, who is asked to answer how each word would sound without a particular phoneme. In eight of the 28 items, the child is asked to remove a vowel; whereas, in the remaining 20 items, they must repeat the word without a consonant. Performance is scored based on the number of correct answers. This task presents Cronbach's alpha of 0.68.

f. *Digit Span* - Brazilian version of the Wechsler Intelligence Scale for Children (Figueiredo, 2002). Digits Forward primarily measure short-term auditory memory while Digits Backward measures the child's ability to manipulate verbal information while in temporary storage. In Digits Forward, the child listens to and repeats a sequence of numbers. In Digits Backward, the child listens to a sequence of numbers and repeats them in reverse order. In both parts, the length of each sequence of numbers increases as the child responds correctly (span varies from 2 to 9 digits). Each item (8 for forward and 7 for backward task) contains two sets of digits, both being applied. Each correct response is worth one point; with a maximum of 16 points for forward and 14 for backward recall. Total scores on each of these measures (accuracy x trials) were used in the present study

g. *Letter span.* This instrument is analogous to the digit span task, and was developed for the present study in order to evaluate phonological working memory and short term memory. The task contains both a forward (range 3–6) and a backward (range 2–4) letter span condition, each of which is scored on a scale from 2 to 9. This task presents Cronbach's alpha coefficient of 0.66.

h. *Corsi Blocks* (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000). This task evaluates the working memory visuospatial component. The instrument measures the forward and backward recall of spatial sequences, span varies from 2 to 9 blocks. Two trials were given per block sequence of the same length. If at least one of these was repeated correctly, the next two trials of a sequence of an increased length were administered. Total scores were calculated by summing up the number of sequences reproduced correctly for forward and backward trials.

i. *Rapid Automatized Naming - Contingency Naming Test* (van der Sluis, de Jong, & van der Leij, 2004). This task evaluates processing speed and RAN - rapid automatized naming (speed of retrieval of phonological codes from long-term memory). In this study, serial naming was tested using three stimulus categories: letters, numbers, and shapes. Performance is evaluated based on the time taken to name the stimuli (in milliseconds) in each part of the task with Cronbach's alpha coefficient of 0.76.

j. *Orthographic and semantic verbal fluency tasks* (Salles et al., 2016). In the orthographic fluency section, the child is given 60 seconds to elicit as many words as possible starting with the letter M. In the semantic fluency task, they must name as many animals as possible in a 60-second period. Each section is scored based on the number of correct words elicited in the time provided. This task presents Cronbach's alpha coefficient of 0.63.*k)*

k. *School Achievement Test (*TDE; Oliveira-Ferreira et al., 2012; Stein, 1994). In the present study, only the word spelling (70 words) and arithmetic subtests (25 task) were administered and the tasks total scores were analyzed. This task presents internal consistency index with Cronbach's alpha coefficient of 0.98.

Reading outcomes

l. *Word and Pseudoword Reading Test (LPI;* Salles, Piccolo, & Miná, 2017). The task uses a set of 60 stimuli selected according to regularity, length, frequency, and lexicality. Stimuli are equally divided into three categories (regular, irregular, and pseudowords) and matched for frequency and length. The number of correctly read items was used for the analyses. This task presents Cronbach's alpha coefficient of 0.81.

m. *Word Reading Fluency Test* (Justi & Roazzi, 2012). The participant had 30 seconds to read 60 regular words. The number of correctly read items in the allotted time is used to calculate a fluency score. This task presents Cronbach's alpha of 0.70.

Data analysis

Descriptive analyses were used to examine the profile of the population sample (place of birth, SES, gender, age, intelligence, symptoms of inattention, and hyperactivity according to the MTA– SNAP –IV, school IDEB). We then analyzed the correlation between all variables. From the correlation matrix, we analyzed collinearity by observing coefficients (if correlations are <.50 we consider no collinearity). Multicollinearity was also verified by VIF (<1 means no multicollinearity). This procedure was followed by multiple linear regression analysis. Raw scores on neuropsychological instruments were converted into Z-scores due to the variability in scoring methods between tasks. The dependent variables considered were reading fluency and reading accuracy (words/pseudowords). Cognitive (neuropsychological) processes were used as independent variables, and entered into the model in the following order: phonological awareness, RAN, verbal fluency, phonological and visuospatial working memory (digit, letter and visuospatial span - Corsi blocks), nonverbal intelligence, and environmental variables (IDEB and SES). A stepwise procedure was used to reduce redundancy and increase parsimony.

Results

Bivariate correlations are reported in Table 2. The correlation results show that there was no collinearity between the predictors investigated in this study (correlations are not considered strong: all <0.5; VIF <1).

Table 3 show the results of the regression models for the outcomes investigated in this study: The first regression model showed that the strongest predictors of performance on the word–pseudoword reading task (total score) were forward digit span scores ($\beta = 0.19$; $p = 0.03$), phoneme suppression ($\beta = 0.37$; $p < 0.001$), and RAN objects ($\beta = -0.23$; $p = 0.008$). This model explained 27% of the variance in word–pseudoword reading task scores. The second regression model for regular word reading included phoneme suppression ($\beta = 0.34$; $p < 0.001$) as the only predictor variable, and explained 11% of the variance. On the other hand, the third model describing the regression model

Table 2. Bivariate correlations between the variables (Person r).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	1.000																					
2	.028	1.000																				
3	.126	.053	1.000																			
4	.020	.265**	.269**	1.000																		
5	.074	.131	.274**	.551**	1.000																	
6	−.081	.101	.128	.369**	.246**	1.000																
7	−.120	.046	.180*	.317**	.143	.276**	1.000															
8	.069	−.027	.256**	.347**	.117	.271**	.088	1.000														
9	.258**	.174	.253**	.165	.236**	.110	−.018	.174*	1.000													
10	.079	.114	.284**	.291**	.099	.111	.126	.295**	.363**	1.000												
11	.050	.099	.127	.285**	.291**	.228**	.105	.156	.169	.264**	1.000											
12	.089	.052	.110	.235**	.188**	.110	.010	.097	.241**	.191*	.366**	1.000										
13	−.080	.256**	.264**	.469**	.237**	.243**	.203*	.371**	.034	.241**	.304**	.151*	1.000									
14	.054	.178*	.185**	.453**	.232**	.136	.126	.138	.121	.161	.166*	.070	.346**	1.000								
15	−.049	.231**	.220**	.612**	.388**	.269**	.278**	.186*	.006	.171	.205**	.130	.482**	.393**	1.000							
16	.066	.088	.076	.472**	.328**	.246**	.289**	.287**	.100	.193*	.186**	.153*	.283**	.349**	.423**	1.000						
17	.091	.208*	.198**	.627**	.398**	.280**	.282**	.221*	.128	.196*	.223**	.186*	.430**	.619**	.790**	.831**	1.000					
18	−.239**	.057	−.119	−.356**	−.219**	−.142*	−.014	−.304**	−.194*	−.038	−.093	−.188**	−.213**	−.142	−.213**	−.282**	−.314**	1.000				
19	−.234**	.029	−.134	−.328**	−.201**	−.214**	−.016	−.273**	−.277**	−.198*	−.144*	−.192**	−.215**	−.154*	−.226**	−.279**	−.304**	.719**	1.000			
20	−.199**	.109	−.147*	−.227**	−.230**	−.259**	−.116	−.186*	−.139	−.140	−.070	−.084	−.142	−.157*	−.260**	−.233**	−.305**	.343**	.457**	1.000		
21	.310**	.154	.191**	.578**	.439**	.323**	.140	.302**	.285**	.256**	.267**	.242**	.451**	.451**	.476**	.411**	.528**	−.455**	−.507**	−.366**	1.000	
22	.060	−.026	.181*	.227**	.210**	.225**	.219*	.122	.014	.089	.143*	.057	.214**	.128	.355**	.234**	.305**	−.057	−.065	−.114	.194**	1.000

Note. 1: IDEB; 2: SES (ABEP) - Total score; 3: Raven; 4: TDE Spelling - Total score; 5: TDE Arithmetics - Total score; 6: Letter span forward span; 7: Digit span forward total score; 8: Digit span backward total score; 9: Corsi Blocks forward total score; 10: Corsi Blocks backward total score; 11: Verbal Fluency - M – Total; 12: Verbal Fluency - Animals – Total; 13: Phoneme supression total; 14: –Regular word reading –LPI; 15: –Irregular word reading – LPI; 16: Pseudowords reading – LPI; 17: Reading task – LPI; 18: RAN - Letters - Reaction Time; 19: RAN - Numbers - Reaction Time; 20: RAN- Figures - Reaction Time; 21: Word reading fluency; 22: Letter span backward span.
*$p < 0.01$. **$p < 0.001$.

Table 3. Linear regression models.

	Reading task (LPI)		Regular word reading (LPI)		Irregular word reading (LPI)		Pseudoword reading (LPI)		Word reading fluency	
	0.27		0.11		0.30		0.17		0.45	
R^2_{adj}	B	t	B	t	B	t	B	t	B	t
Phoneme Suppression	0.37***	4.37	0.34***	3.59	0.42*	2.55	0.14	1.33	0.35***	4.62
RAN - Objects	−0.23*	−2.71	−0.13	−1.13	−0.15	−1.73	−0.11	−1.07	−0.08	−0.98
RAN - Letters	−0.13	−1.49	−0.02	−0.72	−0.38*	−2.44	−0.21*	−2.31	−0.10	−1.02
RAN - Numbers	−0.10	−1.05	−0.03	−0.84	−0.04	−0.33	−0.10	−1.01	−0.32***	−4.10
Digit Span Forward	0.19*	2.19	0.10	0.58	0.40*	2.66	0.26**	2.97	0.04	0.62
Digit Span Backward	0.08	0.89	−0.08	0.10	−0.07	−0.78	0.19*	2.07	0.01	0.15
Letter Span Forward	0.10	1.16	0.10	0.05	0.07	0.88	0.13	1.04	0.01*	0.52
Letter Span Backward	0.13	1.15	0.08	0.57	0.33*	2.22	0.14	1.59	0.04	2.44
Corsi Blocks Forward	0.02	0.33	0.10	1.14	−0.08	−0.92	−0.04	0.31	0.10	1.32
Corsi Blocks Backward	0.08	0.93	0.15	0.82	0.06	0.79	0.06	1.08	0.06	0.89
Verbal Fluency Letter M	0.08	0.94	0.10	0.65	0.04	0.54	0.13	1.20	0.06	0.80
Verbal Fluency Animals	0.08	1.03	0.06	0.18	0.02	0.31	0.05	1.02	0.85	1.12
Raven	0.00	0.00	0.10	1.00	0.04	0.46	−0.04	−0.56	−0.00	−0.08
SES	0.14	1.67	0.50	0.73	0.04*	2.27	0.08	1.04	0.04	0.63
IDEB	0.06	0.69	0.04	0.85	0.80	−0.80	0.01	0.37	0.27***	3.62

Note. LPI = Word and Pseudoword reading test; RAN = Rapid Automatized Naming; SES = Socioeconomic Status; IDEB = Basic Education Development Index. *$p < 0.05$; **$p < 0.005$; ***$p < 0.001$.

for irregular word reading as an outcome (involves lexical route of reading), was predicted by cognitive factors such as phoneme suppression ($\beta = 0.42$; $p = 0.012$), RAN letters ($\beta = -0.38$; $p = 0.017$), digit span forward ($\beta = 0.40$; $p = 0.009$), letter span backward ($\beta = 0.33$; $p = 0.028$), and SES, which accounted for 30% of the variance in this score. Finally, the pseudoword reading outcome (involves phonological route of reading) was most strongly predicted by the forward digit span task ($\beta = 0.26$; $p = 0.004$), followed by backward digit span scores ($\beta = 0.21$; $p = 0.023$) and letter naming (RAN) ($\beta = 0.19$; $p = 0.04$). Together, these variables accounted for 17.2% of the variance in this measure.

The model for word reading fluency as a dependent variable was significantly predicted by phoneme suppression ($\beta = 0.35$; $p < 0.001$), number naming (RAN) ($\beta = -0.43$; $p < 0.001$), letter span forward ($\beta = 0.35$; $p = 0.016$), and the environmental variable IDEB ($\beta = 0.27$; $p < 0.001$). These factors explained 45% of the variance in this measure. The phonological processing is the most important contributor to word reading accuracy and fluency performance in this sample. Also, the order of the variables allowed us to investigate the specific contribution of cognitive variables to different reading process performance after environmental variables were taken into account.

Discussion

Although several neuropsychological and cognitive variables were examined as potential predictors of word-level reading, only those related to phonological processing (letter span, RAN, and phoneme suppression) were found to be significant; however, the sample was no longer (or should no longer be) in the early stages of reading acquisition (Bigozzi, Tarchi, Caudek, & Pinto, 2016; Landerl et al., 2013; Skebo et al., 2013; Vellutino et al., 2004). Even though previous studies have only discussed the importance of phonological processing in the initial stages of literacy acquisition (Skebo et al., 2013), the present findings show that its influence on reading accuracy continues to be significant in older children attending public schools in Brazil. The phonological awareness task (phoneme suppression) was found to be a significant predictor of all aspects of reading in this sample of children, who were currently halfway through primary education.

As shown by regression analysis, phonological awareness and RAN predicted both aspects of word reading (accuracy and fluency) evaluated in the present study. This finding supports the role of phonological processing as the most important skill in reading development (Justi & Roazzi, 2012; Vellutino et al., 2004). Reading in languages with transparent orthographies has already been found to be predicted by skills such as serial naming (RAN) and phoneme segmentation (Kim & Pallante, 2012). As such, the present findings support the hypothesis of a similarity in predictors of reading ability across different orthographies (Moll et al., 2014). When compared with semitransparent languages, our results advance our understanding of predictors of reading regular and irregular words across languages. The effects appear to be attributable to syllabic complexity and orthographic depth. Syllabic complexity selectively affects decoding, whereas orthographic depth affects both word reading

and nonword reading. Transparent orthographies, with a clear relationship between graphic and sound representation, such as Spanish and Italian, can promote the early domain of the phonological stage, unlike nontransparent languages such as English and French (Dehaene, 2012; Seymour et al., 2003). It is expected that Brazilian children will master reading regular and irregular words faster, because the development of reading in English or French can be twice as slow as in transparent orthographies. Our results indicate that the children evaluated do not yet demonstrate high accuracy in the initial stage of decoding isolated words, such a finding could impair other more complex reading skills such as fluency and comprehension.

Phonological working memory was also included as a significant predictor of all dependent variables except for regular word reading (which can be read by any of the reading routes). As hypothesized, short-term verbal memory was found to be consistently associated with reading ability (Mayes et al., 2009; Piccolo & Salles, 2013). According to Baddeley's working memory model, the phonological loop plays a significant role in reading accuracy (Baddeley & Hitch, 1974; Baddeley, 2000; Aguilar-Vafaie, Safarpour, Khosrojavid, & Afruz, 2012), contributing to processes such as decoding, reading comprehension, and reading speed (Nevo & Breznitz, 2013).

In the present study, backward span tasks (which are especially associated with working memory) were also selected as predictors of reading ability and fluency. However, visuospatial working memory, as measured by the Corsi blocks, was not a significant predictor of reading ability in the sample. This finding corroborates those of previous studies, which suggest that, even when visuospatial working memory is found to contribute significantly to reading ability, its influence is much weaker than that of phonological processes (Kudo, Lussier, & Swanson, 2015). Additionally, it is possible that visuospatial skills are more closely related to reading comprehension than word-level reading (Pham & Hasson, 2014; Piccolo & Salles, 2013; Salles & Corso, 2015).

Like the phonological working memory, the speed of retrieval of phonological codes from long-term memory (as measured by RAN) was a significant predictor for all dependent variables, except for regular word reading (which was only predicted by phonological awareness). That result is in accordance with the literature in the field, as reported by a recent meta-analysis which found that the size of the relationship between RAN and reading skills has been estimated to be 0.48 (Araújo, Reis, Petersson, & Faísca, 2015). Previous research also reported the association between RAN and reading fluency in transparent languages (Papadopoulos, Spanoudis, & Georgiou, 2016) and a strong predictor of reading accuracy (Georgiou, Parrila, & Papadopoulos, 2008; Poulsen, Juul, & Elbro, 2015; Savage & Frederickson, 2005). The RAN is related to reading because both of them require efficient access to, and retrieval of, phonological representations from long-term memory and depend, in part, on the speed at which the underlying processes are executed (Kail, Hall, & Caskey, 1999; Torgesen, Wagner, & Rashotte, 1994; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Kail & Hall, 1994; Wagner & Torgesen, 1987). Finally, other researchers have suggested that attentional processes (e.g., response inhibition) may be responsible for the RAN-reading relationship (Bexkens, van den Wildenberg, & Tijms, 2015; Semrud-Clikeman, Guy, Griffin, & Hynd, 2000; Shao et al., 2013).

Several similarities were observed between the regression models for word reading accuracy and fluency (Kibby, Lee, & Dyer, 2014). All measures of reading in the present study were more strongly explained by phonological processing skills. The only difference between regression models for accuracy and fluency was the predictive significance of the environmental variable IDEB, which provides supporting evidence regarding the influence of school type on reading fluency. Additionally, the accuracy of irregular word reading (lexical route of reading) was influenced by the SES. In accordance with our findings, previous research reported that parental practices were positively correlated to the reading of infrequent words, which supports the relationship between SES and reading irregular words (Oliveira et al., 2016). The association between the IDEB and the SES with the fluency and accuracy of irregular word-reading may be explained by the importance of education, reading exposure, family income and parental education for the acquisition of these cognitive-linguistic skills (Alloway et al., 2014; Christensen, Schieve, Devine, & Drews-Botsch, 2014; Foster, Froyen, Skibbe, Bowles, & Decker, 2016; Larson, Russ, Nelson, Olson, & Halfon, 2015; Noble et al., 2007).

The IDEB and the SES were especially associated with lexical reading (as assessed by the ability to read irregular words), an important contributor to reading fluency (Kibby et al., 2014; Kim & Pallante, 2012; Wolf & Katzir-Cohen, 2001; Wolff, 2014). The lexical route provides direct access to meaning. Lexical processing skills and automatized reading require practice and

exposure to reading, both of which may be strongly influenced by the child's environment (Alloway et al., 2014; Christensen et al., 2014; Foster, et al., 2016; Larson et al., 2015; Noble et al., 2007), as suggested by previous evidence of the contribution of the SES to the variability in language skills (Noble et al., 2007). Since the SES is determined by a combination of family income, parental occupation and education levels, several factors may contribute to its influence on reading ability. Resource availability and the incentive to read contribute to the reading performance of children of several ages. The home learning environment, where children acquire reading habits from a very early age, is a strong predictor of academic achievement (Foster et al., 2016). Studies suggest that supportive and high quality environment, in addition to reading encouragement, ensure a better reading performance of children. They are better prepared for school, already know the workings of books, writing, and some specificities of language (Cabrera, Scott, Fagan, Steward-Streng, & Chien, 2012; da Silva Baltar & da Mota, 2016). For this, the environment is sometimes considered an important predictor for reading. In this study the SES proved to be a predictor for the reading of irregular words because it alone explains that the greater offer of stimuli makes the fundamental experiences for the development of the language possible (Peeters, Verhoeven, de Moor, van Balkom, & van Leeuwe, 2009; Zhao, Zhao, Weng, & Li, 2014).

According to multicomponent models of reading (Aaron & Joshi, 2009; Joshi, Taos, Aaron, & Quiroz, 2012), both family- and school-related factors are an important source of environmental influence on reading performance (Brito, et al., 2017; Piccolo et al., 2016). These findings support the combined involvement of the phonological processing and the SES in reading ability (Alloway et al., 2014; Noble & Mccandliss, 2005), especially in the context of irregular words and reading fluency. The educational variable IDEB may also be associated with the SES and several other features of the school environment. In older children, factors such as school—such as opportunities to read in the classroom and the incentive to read during extracurricular periods, through activities such as homework—and the influence of other social environments may come into play, reducing the impact of the SES on neuropsychological skills. As such, reading fluency is thought to be influenced both by cognitive-linguistic skills (lexical route), and by practice and exposure to reading.

Future studies with larger samples may wish to analyze differences in reading performance by place of birth, and other features of the family environment, such as income, paternal and maternal education levels, all of which have been found to be associated with some aspects of reading. It would also be important for these studies to include a measure of reading comprehension, and consider additional factors such as children's emotional status and other variables associated with the SES such as stress levels and the linguistic environment. There is also a need for longitudinal studies on the efficacy of reading intervention programs, to help identify the causal variables associated with reading performance (Georgiou, Torppa, Manolitsis, Lyytinen, & Parrila, 2012; Hooper, Roberts, Sideris, Burchinal, & Zeisel, 2010; Kim & Pallante, 2012).

The present findings suggested that phonological processing continues to be an important predictor of reading ability in more advanced grade levels. As such, these skills should continue to be addressed and enhanced in primary education, even after the initial stages of reading instruction. The influence of environmental factors on reading fluency and accuracy also highlights the need for public policies and preventive strategies with a focus on these variables.

In terms of practical implications, the present study contributes to better understand what the predictors of regular and irregular word reading in older children. Our findings add evidences to the existing literature which reports that pseudowords evaluate the phonological route, while irregular words reading evaluates lexical route (Seymour et al., 2003). By identifying predictors of reading fluency and accuracy, the present study makes an important contribution to the development of preventive interventions for children at risk for learning disabilities.

While the importance of enhancing phonological processing skills in early primary education has already been established, the present findings suggest that these efforts must continue in later grade levels. This could prevent/reduce the incidence of difficulties in reading acquisition. Phonological processing skills contributed to the accuracy and fluency of word recognition (automatic reading), a necessary but not sufficient condition for reading comprehension. The present study contributes to the growing literature on reading acquisition in languages with more transparent orthographies such as Brazilian Portuguese (Joshi et al., 2012). Additionally, it suggests that fourth grade children with better phonemic awareness and letter-sound knowledge may demonstrate greater accuracy and fluency when decoding words and possibly even complex texts.

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