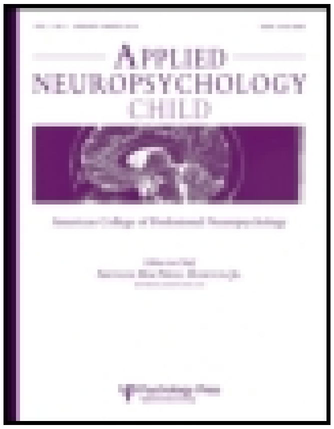

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Neuropsychological Assessment of Children With Reading Disabilities From 8 to 10 Years Old: An Exploratory Portuguese Study

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Reading disabilities are one of the most significant causes of school failure and may result from different causes and cognitive processes. A comprehensive battery of neuropsychological tests was applied to a control group of 102 children (46 girls, 56 boys) with no history of learning disabilities and 32 children (13 girls, 19 boys) with poor reading achievement (PRA) to characterize their cognitive profile. A principal component analysis of the cognitive measures was undertaken to identify cognitive domains. Age-adjusted normative data were computed from controls for verbal and visuospatial abilities, psychomotor skills, executive functions, and a total score. Significant differences were found between the 2 groups. Although single tests could not identify children with PRA, measures of oral and written language, immediate and working memory, calculation, and verbal learning discriminated the 2 groups. A logistic regression model using these factors allowed us to identify 91.2% of healthy children and 96.9% of children with PRA. PRA may result from different patterns of cognitive difficulties, and it is more common in children with oral language and working-memory deficits. Wide-range cognitive testing is necessary to identify strong and weak areas to plan personalized intervention programs.

Key words: *neuropsychological assessment, reading achievement, reading disabilities, specific reading disorder*

INTRODUCTION

Reading disabilities are common and may have a lasting effect on children's academic life, self-esteem, and professional achievement. In Portugal, a recent study in a community sample of children aged 6 to 10 years old, revealed a prevalence of reading disabilities of 5.4% (Vale, Sucena, & Viana, 2011). However, there are variations in prevalence between countries due to different diagnostic tests and criteria (Fletcher, 2009). In the United States, for instance, the Individuals with Disabilities Education Act considers a broader concept of specific learning disability that includes inadequate achievement in one or more of the following areas: oral

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expression, listening comprehension, written expression, basic reading skills, reading fluency skills, reading comprehension, mathematics calculation, and mathematics problem solving (National Joint Committee on Learning Disabilities, 1990). On the other hand, the recent *Diagnostic and Statistical Manual of Mental Disorders*-Fifth Edition (DSM-5; American Psychiatric Association, 2013) includes reading disabilities in the category of ''specific learning disorder'' but recognizes that it encompasses a variety of symptoms within several academic domains that can be further specified, namely concerning reading accuracy, fluency, and comprehension.

Learning to read is a complex linguistic achievement that requires a variety of cognitive processes. At the outset, these range from lower-level perceptual analysis for the identification and discrimination of written symbols, to the ability to match symbols to sounds (reading decoding). Yet, as larger chunks of information are processed, language and executive skills (working memory, monitoring, and inhibition) are necessary to identify the topic, suppress irrelevant information, make inferences, and monitor semantic and syntactic coherence across a sentence or text (reading comprehension).

As reading proficiency increases, its neural basis evolves (Johnson, Halit, Grice, & Karmiloff-Smith, 2002), and some processes become automatic and compulsory. One brain region called the ''visual word form area'' in the left-hemisphere mid-fusiform gyrus, develops a specific perceptual expertise that allows a fast and automatic processing of letter patterns at the prelexical or lexical level (Cohen et al., 2000; Maurer et al., 2006; Sandak, Mencl, Frost, & Pugh, 2004; Shaywitz et al., 2004), and it is possible that other networks will be recruited and developed to support integration of meaning across texts.

This concerted action of different cognitive processes and brain networks explains the occurrence of different types of reading disabilities. The most frequently studied has been the ''decoding subtype'' (or dyslexia) that is characterized by weak phonological skills, leading to poor mapping between symbols and sounds (Shankweiler et al., 1999). In addition, there are children whose main difficulty is at the level of reading comprehension, either because of subtle language difficulties (grammatical processing or diversity of vocabulary) or because of impairments in attention or other executive functions (''comprehension subtype''; Hulme & Snowling, 2009).

Although these subtypes can be considered distinct categories, some authors (Snowling & Hulme, 2012) view them as part of a spectrum, affecting different dimensions of language in continuity.

In addition, it has been demonstrated that many children with reading difficulties also present associated impairments of attention (Loo et al., 2004), language, or coordination development (Snowling & Hulme, 2012). This makes their diagnosis and intervention challenging and also makes it difficult to differentiate between causes, effects, and comorbidities. To identify these conditions and to establish adequate intervention programs, a detailed cognitive and psychological assessment is necessary.

Although there are studies in the Portuguese population tackling the development of specific cognitive domains such as language, memory, executive functions, and fine motor development (Martins & Fernandes, 2003; Martins et al., 2012; Martins, Vieira, Loureiro, & Santos, 2007; Townes et al., 2008), there are scarce normative data and validation studies directed to reading disabilities. The latter are not just clinically relevant but are of scientific interest because the Portuguese language has a rather transparent orthography, which has some impact on reading acquisition, compared with Spanish (Defiore, Cary, & Martos, 2002) and possibly English, where most studies on reading difficulties have been performed.

The aim of this study was to obtain normative data in a new neuropsychological assessment battery in native European Portuguese-speaking children aged 8 to 10 old—an age band in which transient reading difficulties should have been solved—and to validate it in a clinical group with reading disabilities to identify the most useful tests and specific neurocognitive profiles of those children.

METHODS

Participants

The study was performed in children aged 8 to 10 years old who fulfilled the following criteria: (a) being native Portuguese monolingual speakers; and (b) attending public and private regular schools within the district of Lisbon.

Participants were divided in two groups: a control group (CO) consisting of a sample of 102 children (46 girls, 56 boys; $M_{\text{age}} = 111$ months) attending the third and fourth grades of primary schools and identified by teachers as having a normal reading achievement and not suffering from developmental disorders or noncompensated sensory deficits; and a clinical group (CL) composed of 32 children (13 girls, 19 boys; $M_{\text{age}} = 112$ months) with poor reading achievement (PRA) recruited either from a public university research center (Language Research Laboratory), a private center for special education, or two regular schools. In all those referral centers, low achievement in reading was independently diagnosed by a special education specialist or by neuropsychologists, according to the DSM-Fourth Edition criteria, based on a clinic interview, neuropsychological assessment, and school information. The subtype of reading difficulty was not specified, but the neuropsychological or educational reports were based on a low reading proficiency for age/education and poor spelling or poor phonological awareness supporting, in the majority of cases, the diagnosis of a decoding subtype. In two cases, the word reading rate was within normal range but children presented a comprehension disorder. However, because those centers did not use the same diagnostic tools, it was decided to assemble all cases in a single group with PRA. Age at diagnosis, type and duration of intervention received, and associated comorbidities were also recorded.

Materials and Procedures

The Neuropsychological Assessment Battery for ages 8 through 10 years old (*NPAB 8–10*) is a composite of subtests directed to the following cognitive domains: nonverbal general cognitive development, spoken language, verbal learning and memory, reading, writing, calculation, visual-spatial processing, executive functions, and movement skills (see Table 1 for subtest description). The range of raw scores per specific domain and total raw scores are presented in Table 2. To compare the results of each child independently of their age, raw scores were transformed into age-adjusted standard scores (*T* scores).

Children were individually tested by one of the authors (C. S.) or by a qualified neuropsychologist, and time of application varied from 50 min to 1 hr and 15 min. Each child was characterized in terms of birth date, academic achievement, family composition, parent's occupation (for the classification of socioeconomic status), and general health or other learning problems. Parents of children in the CL group were interviewed to obtain information on: the age of onset of developmental and/or learning problems, if there was a formal diagnosis by a developmental pediatrician or psychologist, if there had been any kind of intervention, and if there was a family history of a similar problem.

The study was approved by the Ethics Committee and the Ministry of Education. For all the participants, a written informed consent was obtained from the parents or the child's caregiver.

Data were analyzed using the Statistical package for the Social Sciences Version 11.5 software. Univariate, bivariate, and multivariate analysis were carried out to determine means, standard deviations, variance, maximum and minimum percentiles for each age, school level, and sex groups. Chi-square, *t* test or Mann-Whitney U test, and the Kolmogorov-Smirnov test, as well as the Pearson correlation coefficient (if normal distribution) or

TABLE 1
NPAB 8–10 Domains, Subdomains, and Tasks

Domains and Subdomains	*Tasks*
General Cognition	
Nonverbal cognition	Raven's Progressive Colored Matrices (Raven, 1965)
Movement Skills	
Balance/stability	Romberg Test/Immobility (Fonseca, 1992)
	Sharpened Romberg/two feet in a line (Fonseca, 1992)
	Balance/standing on one leg (Fonseca, 1992)
Coordination	Eye–hand coordination (Fonseca, 1992)
	Eye–foot coordination (Fonseca, 1992)
	General Coordination: jumping task (Bruininks, 1978)
	General Coordination: dissociation task (Bruininks, 1978)
Fine manual skills	Writing dots (Bruininks, 1978)
	Legibility (Language Research Laboratory)
Visual-Spatial Processing	JLOT (Benton, Varney, & Hamsher, 1978)
Oral, written, and quantitative language	
Auditory perception	Nonwords Repetition (Language Research Laboratory)
PVF	Words starting with a "p"
SVF	Animal names
Reading	Words List Reading (Rebelo, 1993)
	Nonwords Reading (Language Research Laboratory)
	Reading velocity (adapted from Rebelo, 1993)
Dictation	Dictation A—14 words (Language Research Laboratory)
	Dictation B—17 words (Language Research Laboratory)
Calculation	EWCT (Language Research Laboratory)
Memory and Learning	
Verbal Memory	Rey Auditory Verbal Learning Test (Lezak, 1995)
Working memory	Digit Span subtest, Wechsler Intelligence Scale for Children-Third Edition (Wechsler, 1991)
Executive Functions	
Sustained Attention	Symbol Search subtest, Wechsler Intelligence Scale for Children-Third Edition (Wechsler, 1991)
Divided Attention	Trail-Making Test (Reitan, 1958, as cited in Lezak, 1995)

PVF = phonemic verbal fluency; SVF = semantic verbal fluency; JLOT = Judgment of Line Orientation Test; EWCT = Elementary Written Calculation Test.

TABLE 2
Range of Raw Scores Per Specific Domain and Total Score

Domains	*Raw Scores Calculation*	*Range*
General Cognition	RPCM score	0–36
Movement Skills	Immobility score + two feet in a line score + one-leg balance score + eye–foot coordination score + eye–hand coordination score + jumping task score + dissociation task score + writing dots score + legibility score	0–41
Visual-Spatial Processing	JLOT score	0–30
Spoken, written, and quantitative language	Semantic verbal fluency score + phonemic verbal fluency score – nonwords repetition errors – word reading errors – nonwords reading errors + reading velocity + Dictation A score + Dictation B score + Elementary Written Calculation Test score	−80–69
Memory and Learning	RAVLT Learning Index + RAVLT Memory Index + Digit Span total score	0–180
Executive functions	Symbol Search correct score – errors in TMT-A – errors in TMT-B	−28–45
Total Score	The sum of domain scores	−108–401

RPCM = Raven's Progressive Colored Matrices; JLOT = Judgment of Line Orientation Test; RAVLT = Rey Auditory Verbal Learning Test; TMT = Trail-Making Test.

the Spearman (if not normal) were also conducted. They were considered significant for p values less than .01.

The battery construct validity was explored using a principal component analysis (PCA). A multivariate logistic regression model was used for the prediction of PRA using the test results as dependent variables. Its results were analyzed in terms of the quality of the model adjustment (Nagelkerke R^2 determination coefficient, likelihood function and classification table) and the estimated coefficients (obtained values and significance test). Sensitivity, specificity, and positive and negative predictive values were also determined.

TABLE 3
Sample Distribution by Age, School Grade, Gender, Socioeconomic Levels, and Type of School

	Control Group (M_{age} = 112 months)	*Clinical Group (M_{age} = 113 months)*	*N*	χ^2
8 years old	38	10	48	$\chi^2(2) = 2.487$,
9 years old	48	13	61	$p = .288$
10 years old	16	9	25	
	102	32	134	
Boys	56	19	75	$\chi^2(1) = 0.198$,
Girls	46	13	59	$p = .657$
	102	32	134	
Public School	52	11	63	$\chi^2(1) = 2.629$,
Private School	50	4	54	$p = .105$
	102	15	117*	
SES				
Level 1	8	10	18	$\chi^2(3)$
Level 2	24	10	34	$= 15.034$,
Level 3	21	1	22	$p = .002$
Level 4	44	11	55	
	97	32	129*	

SES = socioeconomic status (Level 1 = lower; Level 4 = higher).
*It was not possible to accurately obtain these data for the total number of children.

RESULTS

Family and Demographic Variables

There were no significant differences between the CO and CL groups in mean age, age groups distribution, gender, or the ratio of public to private schools (Table 3). However, CL children attended lower school grades compared with children in the CO group ($t = 2.792$, $p = .006$) and came from families with a significantly lower socioeconomic level compared with the CO group.

Comorbidity diagnosis in children comprising the CL group ($N = 32$) was as follows: 7 had associated speech and language impairment, 8 had associated attention-deficit hyperactivity disorder, 1 had language and attention impairment, and 2 had developmental coordination disorders. Therefore 18 children qualified for more than one diagnosis, while 14 had isolated

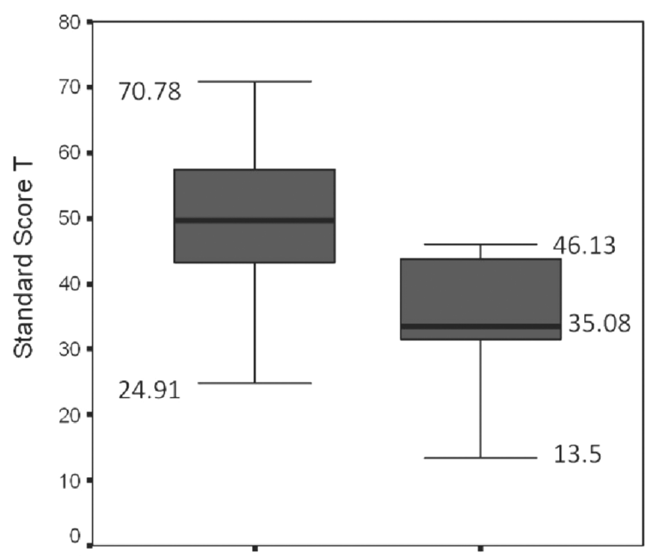

FIGURE 1 Standard scores from the control and clinical groups.

PRA. Most children (62.5%) were receiving specialized intervention programs: special education ($N = 18$), speech therapy ($N = 7$), psychotherapy ($N = 2$), pharmacological intervention ($N = 4$), and/or additional support from their regular teacher ($N = 6$). The intervention duration varied from 2 months to 4 years. Five children were not receiving any specialized support, and in 7 cases, this information was missing.

Differences in the Total Battery Scores

Mean total battery raw score was 14.25 ± 1.69 for the CL group (range = 10.02–17.76) and 11.79 ± 1.82 for the CL group (range = 7.52–13.99). The score followed a normal distribution in both groups.

Standard scores are presented in Figure 1. Controls had significantly higher scores than the CL group ($t = 5.215$, $p < .001$), and there was a positive correlation between score, age, and school grade that was significant only in controls. Socioeconomic status and the type of school (public vs. private) had no effect upon the battery total standard scores in both groups.

Tests Results by Domain

The CO and CL groups showed significantly different results in the majority of measures and in most domains of the battery. Cognitive tests were more consistently different between groups compared with movement skills tasks. As the age distribution of the two groups

TABLE 4
Task Score by Each Domain on the NPAB 8–10, Mean (or Median) and Standard Deviation (*SD*) Obtained by the Control Group (CO) and the Clinical Group (CL), and Significance Level

Domain	*Subdomain*	*Test/Task*	*Mean CO (SD)*	*Mean CL (SD)*	*p*
1. Global Cognition	Nonverbal cognition	– Raven's Progressive Colored Matrices			
		Time (seconds)	**255** (51.64)	**271** (42.37)	*ns*
		Score	**25.91** (4.23)	**23.93** (4.49)	*
2. Movement Skills	Balance/stability	– Immobility (Romberg Test)	**58** (9.56)	**45.19** (21.05)	***
		– Two feet in a line (Sharpened Romberg Test)	**12** (6.77)	**11.35** (7.33)	*ns*
		– Single-leg balance	**11.40** (7)	**5.72** (4.83)	*ns*
	Coordination	– Eye–hand coordination	**1.5** (1.09)	**1.4** (0.91)	*ns*
		– Eye–foot coordination	**1.9** (1.14)	**1.33** (0.72)	*ns*
		– General coordination:			
		– Jumping task (number of successes)	**2.83** (1.2)	**2.73** (0.96)	*ns*
		– Movement's dissociation task (seconds)	**19.2** (1.05)	**19.06** (1.94)	*ns*
	Graphic motor skills	– Writing dots with a pen (Bruininks-Oseretsky task)	**30.54** (4.85)	**28.86** (5.22)	*ns*
		– Legibility	**2.28** (0.66)	**1.34** (0.55)	***
3. Visual-Spatial Processing		– "Judgment of Line Orientation Test", correct answers	**19.43** (4.71)	**15.77** (5.26)	**
4. Spoken, Written, and Quantitative Language	AP	– Nonwords repetition (errors)	**0.98** (1.24)	**3.65** (2.77)	***
	PVF	– Words starting with "p"	**7.06** (2.69)	**6.2** (2.02)	*ns*
	SVF	– Names of animals	**14.49** (4.13)	**13.22** (7.78)	*ns*
	Reading	– Words list reading (errors)	**2.98** (2.31)	**7.26** (5.11)	*
		– Words' reading velocity (seconds)	**52** (23.46)	**82.97** (50.98)	**
		– Nonwords' reading (errors)	**2.54** (2.03)	**7.6** (4.89)	***
		– Nonwords' reading velocity (seconds)	**33.35** (13.08)	**56.61** (37.93)	**
	Dictation	– Dictation A—14 words	**13.25** (1.02)	**10** (2.9)	***
		– Dictation B—17 words	**9.62** (3.06)	**5.35** (2.99)	***
	Calculation	– Elementary Written Calculation Test (score)	**12.26** (2.27)	**9.32** (3.42)	***
5. Learning and Memory	RAVLT	– RAVLT Memory Index	**42.20** (7.92)	**34.81** (7.80)	***
		– RAVLT Learning Index	**45.27** (7.47)	**38** (8.19)	***
	Working Memory	– Digit Span Subtest	**11.35** (1.95)	**9.25** (2.05)	***
6. Executive Functions	Sustained Attention	– Symbol Search	**20.78** (3.89)	**17.71** (4.38)	***
	Divided Attention	– TMT-A (errors)	**0.19** (0.48)	**0.16** (0.45)	*ns*
		– TMT-B (errors)	**1.09** (2.07)	**1.51** (2.18)	*ns*
		– TMT-A (time, seconds)	**26.92** (10.25)	**33.10** (17.84)	*
		– TMT-B (time, seconds)	**58.7** (27.26)	**77.56** (28.99)	***

AP = auditory perception; PVF = phonemic verbal fluency; SVF = semantic verbal fluency; RAVLT = Rey Auditory Verbal Learning Test; TMT = Trail-Making Test; *ns* = not significant.

*$p < .05$ = moderately significant. **$p < .005$ = very significant. ***$p < .001$ = highly significant.

TABLE 5
Nomination of the Components Considering the Original Variables

	Nomination of the Components	Includes
First Component	*Memory and Learning*	The learning index and Indexes 5, 7, and 8 from RAVLT
Second Component	*Oral and Written Language*	Errors in nonwords repetition, errors in "nonwords" reading, correct words in Dictations A and B
Third Component	*Visual Analysis Abilities*	Errors in Symbol Search, JLOT scores, and the RPCM score
Fourth Component	*Digit Span: immediate auditory memory*	Number of digits forward and the maximum digits forward
Fifth Component	*Digit Span: working memory*	Number of digits backward and the maximum digits backward in *Digit Span*
Sixth Component	*Executive functions: initiative and sustained attention*	Semantic verbal fluency, phonemic verbal fluency, correct items in SS
Seventh Component	*Memory to new verbal information*	Indexes 1 and 6 from RAVLT
Eighth Component	*Executive Functions TMT-A*	Time and errors in TMT-A
Ninth Component	*Executive Functions TMT-B*	Time and errors in TMT-B

RPCM = Raven's Progressive Colored Matrices; JLOT = Judgment of Line Orientation Test; SS = Symbol Search; RAVLT = Rey Auditory Verbal Learning Test; TMT = Trail-Making Test.

was similar, we present the raw domain scores for each group using means and medians (Table 4).

Principal Component Analysis and Logistic Regression

PCA including 24 cognitive measures produced a solution with nine factors that explained 75.47% of the observed variance (Tables 5 and 6). The variable "*elementary written calculation score*" was excluded from the PCA, because it showed low loadings in two factors. "*Reading velocity*" and "*handwriting legibility*" did not load in any factor and were also excluded.

The initial logistic regression model to predict the presence of PRA included the following independent variables: nine factor scores; the three quantitative variables excluded from PCA, as mentioned; and gender, socioeconomic status, and parent's education level. The model explained 84.9% of the variance (Nagelkerke R^2) and showed a good adjustment quality. This model

TABLE 6
Total Variance Explained by the Nine Extracted Factors in the Principal Component Analysis

	Initial Eigenvalues			*Extraction Sums of Squared Loadings*			*Rotation Sums of Squared Loadings*		
Component	*Total*	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumulative %*
1	6.663	27.761	27.761	6.663	27.761	27.761	3.637	15.153	15.153
2	1.995	8.314	36.076	1.995	8.314	36.076	2.884	12.015	27.168
3	1.808	7.532	43.607	1.808	7.532	43.607	1.977	8.237	35.405
4	1.591	6.629	50.237	1.591	6.629	50.237	1.951	8.130	43.535
5	1.388	5.783	56.020	1.388	5.783	56.020	1.877	7.820	51.355
6	1.263	5.262	61.281	1.263	5.262	61.281	1.584	6.598	57.953
7	1.217	5.070	66.351	1.217	5.070	66.351	1.490	6.209	64.163
8	1.170	4.874	71.225	1.170	4.874	71.225	1.396	5.817	69.980
9	1.019	4.247	75.472	1.019	4.247	75.472	1.318	5.492	75.472
10	0.874	3.643	79.115						
11	0.752	3.132	82.247						
12	0.648	2.699	84.946						
13	0.609	2.538	87.484						
14	0.515	2.145	89.630						
15	0.460	1.915	91.545						
16	0.407	1.697	93.242						
17	0.333	1.386	94.628						
18	0.309	1.286	95.914						
19	0.268	1.117	97.031						
20	0.205	0.852	97.883						
21	0.183	0.762	98.645						
22	0.146	0.608	99.253						
23	0.111	0.464	99.717						
24	6.801E-02	0.283	100.00						

Note. Extraction method: principal component analysis.

TABLE 7
CO and CL Groups Mean (or Median), Cutoff Values, Sensibility (Sen), Specificity (Spe), Positive Predictive Value (PPV) and Negative Predictive Value (NPV)

Test/Task	*Mean/Median Control Group*	*Mean/Median Clinical Group*	*Cutoff Values*	*Sen*	*Spe*	*PPV*	*NPV*
RPCM (score)	25.9	23.9	21	.20	.91	.40	.78
Romberg Test (score)	3.5	3.1	3	.20	.95	.38	.89
Legibility (score)	2.27	1.3	2	.69	.89	.65	.90
JLOT (score)	19.4	15.8	17	.55	.70	.37	.83
Nonwords repetition (errors)	1	3.7	2	.65	.88	.52	.93
Word list reading (errors)	3	7.3	4	.67	.80	.35	.94
Words' reading velocity (level)	2.9	1.9	2	.44	.84	.44	.84
Nonwords' reading (errors)	2.5	5	4	.65	.80	.40	.92
Dictation A (correct words)	14	10	13	.90	.84	.55	.98
Dictation B (correct words)	9.6	5.4	8	.75	.75	.40	.93
EWCT (score)	14	9.3	10	.55	.82	.50	.84
RAVLT Learning Index	44	38	42	.63	.65	.36	.85
RAVLT Memory Index	42.2	34.8	39	.63	.68	.38	.85
Digit Span Subtest (score)	11.4	9.3	9	.56	.80	.47	.85
TMT-A (errors)	0	0	1	.03	.96	.20	.77
TMT-B (errors)	0	1	2	.27	.87	.35	.79
TMT-A (seconds)	26.9	29.3	32	.39	.75	.32	.80
TMT-B (seconds)	52.3	77.6	66.1	.68	.71	.41	.88
Symbol Search (score)	20.8	17.7	18	.58	.81	.49	.87

RPCM = Raven's Progressive Colored Matrices; JLOT = Judgment of Line Orientation Test; EWCT = Elementary Written Calculation Test; RAVLT = Rey Auditory Verbal Learning Test; TMT = Trail-Making Test.

allowed us to identify 91.2% of healthy children and 96.9% of children with PRA.

The regression equation allowed us to determine the probability of having PRA for each child:

Prob (of having PRA) = $\frac{1}{1+e^{-z}}$, where Z is calculated by the following expression: Z = −23,704–1,247 F1 − 4.07 F2 − 1.562 F4 − 1.465 F5 − 1.279 EWCT Score + 0.176 Age, and *e* is the exponent function (constant = 2.72).

Because the probability, a priori, of finding a child with reading difficulties is .238, we consider that the event will occur if the estimated probability takes values greater than .238. Otherwise, the event will not occur. The *verbal learning and memory* component (F1), the *written and spoken language* component (F2), the *immediate auditory memory* component (F4), the *working-memory* component (F5), the *Elementary Written Calculation Test* (EWCT) score, and *age* are the variables that best discriminate groups.

A higher score in the components and in the *EWCT* corresponded to a lower probability of having reading difficulties. The child's *age* showed an opposite effect: the older the child is, the higher the probability of detecting reading difficulties.

NPAB 8–10 Sensitivity and Specificity

Sensitivity (Sen) and specificity (Spe) to discriminate children with reading impairment from controls were calculated for the full battery and for different test combinations. The best combination yielded a sensitivity of .71 and specificity of .80.

The best sensitivity and specificity were reached by the Dictation A (*correct words*, sen = .9, spe = .84), Dictation B (*correct words*, sen = .75, spe = 0.75), and maximum Digit Span Forward (sen = .72, spe = .73). Globally, tests tended to reach higher levels of specificity and, therefore, better negative predictive values (Table 7). The resulting *receiver-operating characteristics*

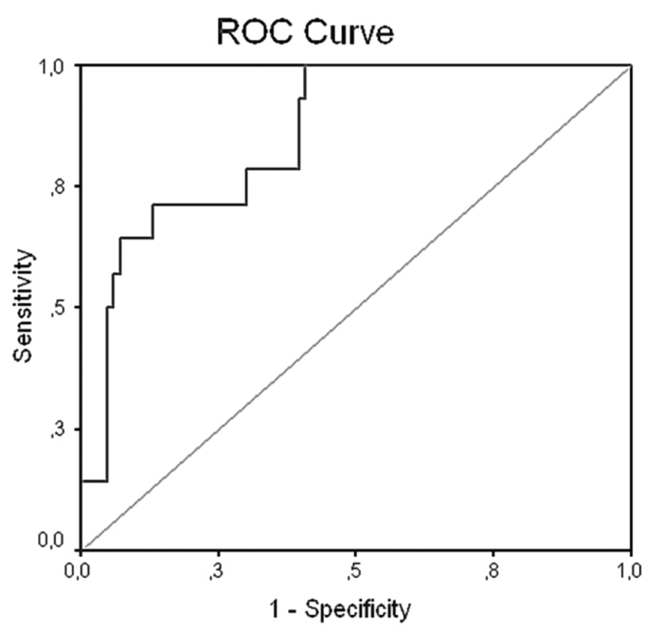

FIGURE 2 Receiver-operating characteristics curve: NPAB 8–10 total score.

(ROC) curve is presented (Figure 2) with an area under the curve of .856, which is considered *very satisfactory.*

DISCUSSION

Developmental reading disabilities are a heterogeneous group of disorders associated to different underlying processes. To identify the cognitive profile associated with PRA, a group of children with PRA were compared to age-matched controls on several neuropsychological tests and domains through the *NPAB 8–10*. It was found that children with PRA had overall lower scores and showed significant impairments in different domains: language/verbal learning and memory, visual-spatial processing, executive functions, and to a much lesser extent, nonverbal cognition and motor skills. This is in accordance with theories that posit that developmental disorders are associated with multiple defects and not to a single processing disorder (Pennington, 2006).

Considering all the analyzed domains, the most discriminative between the two groups were those involving language skills (spoken and written language, immediate auditory memory and working memory, calculation, and verbal learning and memory), showing that linguistic abilities play an important role in reading achievement, as referred by Snowling (2001) and other authors. In fact, the present results indicate and corroborate the finding that nonword repetition, nonword reading, and working-memory tasks are fundamental tools in the assessment and identification of children with reading difficulties. However, we do also recognize that it is not possible to ground ourselves exclusively in these kinds of tasks, because there are other characteristics that can be present and contribute to the child's specific profile, such as executive functions deficits (Sesma, Mahone, Levine, Eason, & Cutting, 2009) or visual perception difficulties (Williams et al., 2011).

Regarding the battery used, the PCA confirmed its construct validity because it aggregated all tests and measures by the domains they were expected to evaluate.

The first factor included the main verbal memory and learning indexes of the Rey Auditory Verbal Learning Test (RAVLT). The second factor associated nonword repetition, nonword reading, and dictation tasks, which probe phonological abilities. The third component includes Symbol Search Test (*number of errors*), as well as Raven's Progressive Colored Matrices (RPCM) and Judgment of Line Orientation, which are related to visuospatial abilities, spatial cognition, and nonverbal reasoning. While visual abilities were also significantly worse in the CL group, multiple regression analysis showed that spatial cognition was not discriminative of the two groups. The inclusion of the RPCM in the battery aimed, mainly, to guarantee that the reading difficulties were not due to general nonverbal cognitive deficits. It was not possible to establish cutoffs for this test with acceptable sensitivity and specificity. Likewise as Simões (2000) concluded, RPCM is not an adequate instrument to either detect or confirm *learning disabilities*. However, it is useful to exclude the presence of a global intellectual disability, a premise of the learning disability definition itself and a risk factor for reading disorders (Catts, Fey, Tomblin, & Zhang, 2002).

The two Digit Span tasks (Forward and Backward) did dissociate in PCA, loading in the fourth and fifth factors. This may be due to the fact that they do evaluate different abilities, namely *immediate auditory memory* and *auditory working memory*, respectively, as Lezak, Howieson, and Loring (2004) had already suggested. Likewise, in future research, it may be worthwhile to treat these measures separately. These tasks proved to be specific but not sensitive to discriminate between groups.

The verbal fluency task also loaded with Symbol Search, which can be interpreted as both being measures of *executive functions*: initiative and sustained attention (Lezak et al., 2004).

A seventh component, which we nominated as *verbal memory for new information*, resulted from Indexes 1 through 6 of the RAVLT, which were not in the first component. In fact, Spreen (1998) cites several studies that point to different measures of verbal learning and memory in this test.

Previous studies also cited by Spreen (1998) referring to a poor correlation between the Trail-Making Test (TMT) Parts A and B are supported by this study. This test appears to be separated into two parts, which denotes the different nature of the information it provides. As Bradford (1992) concluded, Part A is more related to spatial abilities, and Part B is more related to language abilities and alternation. Other interpretations relate each part of the TMT to sustained and divided attention (D'Agati, Cerminara, Casarelli, Pitzianti & Curatolo, 2012). These data point, once more, to the importance of considering subtest scores separately to avoid interpretation errors.

Overall, the factors resulting from this exploratory PCA point to a major contribution of the linguistic skills to PRA. In relation to the most discriminative components, the "*spoken and written language*" component was the most important, followed by the "*immediate auditory memory*" component and the "*working-memory*" and the "*verbal learning and memory*" components. The variables "*EWCT*" and *age* were also related to the probability of a reading disorder. These findings corroborate previous studies stressing the importance of decoding processes in the early stages of reading acquisition, which some refer to as the "bottleneck" for younger children (Gough, Hoover, & Peterson, 1996). It shows that the same is valid for languages with a shallow orthography such as Portuguese. Furthermore, these results also suggest that most included cases with PRA were of the decoding type, because that is known to be related to phonologic deficits.

In contrast, there were tests that did not significantly contribute to discriminating groups such as the movement skills tests: balance and stability, coordination, and graphic motor skills. The exceptions in this domain were only the Romberg Test (or *immobility task*) and *handwriting legibility*, which need further investigation.

Although this study has been conducted on children within a short age range, there were significant differences for most of the tests between age groups. These findings highlight the importance of previous experiences and learning in this period of life and reinforce the relevance of age- and grade-adjusted norms for each test. In fact, this age span also corresponds to the period in which one can find more gain in reading tasks (Catts, Bridges, Little, & Tomblin, 2008).

On the other hand, gender, socioeconomic status, attending a private or public school, and the number of siblings did not influence the total raw score in any of the two groups. Relative to gender and type of school (i.e., private vs. public), Nogueira et al. (2005) found similar results when assessing healthy children in first through seventh grade. Although socioeconomic status is often correlated with reading acquisition, this variable did not seem to contribute to cases with PRA, which suggests a more important role of genetic than environmental factors to reading disorders. This has been corroborated by many studies (Castles, Datta, Gayan, & Olson, 1999).

Concerning the sensitivity and specificity of this battery to identify cases with PRA, it was necessary to undertake specific adjustments, test by test, because we found that for many of them, differences between the control children and the children with reading challenges were often subtle or nonexistent. Each cutoff point was adjusted to not detect too many false positives. Sensitivity, specificity, and predictive values of negatives and positives are usually considered *inadequate* if less than .6, *weak* if between .6 and .7, *moderately satisfactory* between .7 and .8, *satisfactory* between .8 and .9, and *good* if greater than .9.

Results show that immediate auditory memory and dictation tasks (requiring spelling) were the most sensitive and specific in detecting the existence of a reading problem. In general, tests were found to have better specificity than sensitivity levels, which means that when a child has a negative test, probably, she *does not have* the condition. However, sensitivity would allow us to confirm that when a child has a positive result, probably, she *has* the condition. This situation did not occur for any test. Because the ROC curve has an area of .86 and is thus situated above the diagonal line that goes from the points [0, 0] and [100, 100], it may be considered good and supports the coherence of the model.

Using the proposed cutoff points in this study, it is possible to detect the true positives in 71%, but it may acknowledge 29% of false positives, which does not allow us to state that a child *has* a disorder. Therefore, we reaffirm the need to analyze the full battery for each child, domain by domain, to identify her specific profile. It is worth noting that cases with PRA were not classified or separated by subtype and also that the battery does not include specific tests directed to reading comprehension. It is possible that sensitivity and specificity could be different if those data were available.

We acknowledge some limitations in this study. Firstly, the use of convenience samples does not guarantee the representativeness of the results. Secondly, the heterogeneity of the clinical group does not allow us to infer its application to reading disorder subtypes and may hide relevant subpopulation characteristics. However, this battery's primary purpose was to be able to identify those with reading difficulty independently of subtype and associated impairments. Yet, the heterogeneity of cases makes it difficult to control the effect of disorders such as attention-deficit hyperactivity disorder and specific language impairment, which are more frequent in children with reading disorders. Finally, the narrow age range selected might not include cases that are only diagnosed when reading comprehension becomes crucial for learning.

It is worth developing future confirmatory studies to evaluate the ability of this battery to differentiate among specific reading disorder subtypes, in other age groups, and to determine which tests are most useful to identify each subtype.

CONCLUSION

This study aimed to compare the performance of children with PRA to the performance of children in a control group in several neuropsychological tasks as part of a comprehensive assessment battery (NPAB 8–10). The assessment battery proved to have good construct validity, and it was possible to identify developmental effects and significant differences between groups in several domains, especially in language skills, corroborating the relevance of phonological abilities for reading acquisition in a language with a transparent orthography. In the remaining domains, there were differences but with a lower statistical significance (*nonverbal cognition* domain) or without statistic significance (*movement skills*).

These results suggest that the NPAB 8–10 is useful to characterize the neurocognitive profile of children with PRA, and recognition of the stronger and weaker functions will allow for a better, individualized intervention program development. The results of the PCA also emphasize the need for considering some tests' scores separately and not only the total score—namely the TMT-A and TMT-B scores, Digit Span Forward and Backward, and the different indexes of learning and verbal memory—because they provide different types of information.

REFERENCES

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: Author.

Benton, A. L., Varney, N., & Hamsher, K. (1978). Visuospatial judgment: A clinical test. *Archives of Neurology*, *35*, 364–367.

Bradford, D. (1992). *Interpretive reasoning and the Halstead-Reitan tests*. Brandon, VT: Clinical Psychology Publishing.

Bruininks, R. H. (1978). *Bruininks-Oseretsky test of motor proficiency examiner's manual*. Circle Pines, MN: American Guidance Service.

Castles, A., Datta, H., Gayan, J., & Olson, R. (1999). Varieties of developmental reading disorder: Genetic and environmental influences. *Journal of Experimental Child Psychology*, *72*, 73–94.

Catts, H. W., Bridges, M. S., Little, T. D., & Tomblin, J. B. (2008). Reading achievement growth in children with language impairments. *Journal of Speech, Language and Hearing Research*, *51*, 1569–1579.

Catts, H. W., Fey, M. E., Tomblin, J. B., & Zhang, X. (2002). A longitudinal investigation of reading outcomes in children with language impairments. *Journal of Speech, Language and Hearing Research*, *45*, 1142–1157.

Cohen, L., Dehaene, S., Naccache, L., Lehericy, S., Dehaene-Lambertz, G., Hénaff, M., & Michel, F. (2000). The visual word form area: Spatial and temporal characterization of an initial stage of reading in normal subjects and posterior split-brain patients. *Brain*, *123*, 291–307.

D'Agati, E., Cerminara, C., Casarelli, L., Pitzianti, M., & Curatolo, P. (2012). Attention and executive functions profile in childhood absence epilepsy. *Brain and Development*, *34*, 812–817. doi:10.1016/j.braindev.2012.03.001

Defior, S., Cary, L., & Martos, F. (2002). Differences in reading acquisition development in two shallow orthographies: Portuguese and Spanish. *Applied Psycholinguistics*, *23*, 135–148.

Fletcher, J. (2009). Dyslexia: The evolution of a scientific concept. *Journal of the International Neuropsychological Society*, *15*, 501–508.

Fonseca, V. (1992). *Manual de observação psicomotora, significação psiconeurológica dos factores psicomotores* [*Manual of psychomotor observation, psychoneurological meaning of psychomotor factors*]. Lisbon, Portugal: Editorial Notícias.

Gough, P. B., Hoover, W. A., & Peterson, C. L. (1996). Some observations on a simple view of reading. In C. Cornoldi & J. V. Oakhill (Eds.), *Reading comprehension difficulties: Processes and intervention* (pp. 1–13). Mahwah, NJ: Erlbaum.

Hulme, C., & Snowling, M. (2009). *Developmental disorders of language, learning and cognition*. Chichester, UK: Wiley-Blackwell.

Johnson, M., Halit, H., Grice, S., & Karmiloff-Smith, A. (2002). Neuroimaging of typical and atypical development: A perspective from multiple levels of analysis. *Development and Psychopathology*, *14*, 521–536.

Lezak, M. (1995). *Neuropsychological assessment* (3rd ed.). New York, NY: Oxford University Press.

Lezak, M., Howieson, D., & Loring, D. (2004). *Neuropsychological assessment* (4th ed.). New York, NY: Oxford University Press.

Loo, S., Fisher, S., Francks, C., Ogdie, M., MacPhie, I., Yang, M., … Smalley, S. (2004). Genome-wide scan of reading ability in affected sibling pairs with attention-deficit/hyperactivity disorder: Unique and shared genetic effects. *Molecular Psychiatry*, *9*, 485–493.

Martins, I., & Fernandes, T. (2003). Avaliação cognitiva e neurológica numa população recém-escolarizada [Cognitive and neurological evaluation in a recently schooled population]. *Psychologica*, *34*, 187–214.

Martins, I. P., Lauterbach, M., Luís, H., Amaral, H., Rosenbaum, G., Slade, P. D., & Townes, B. D. (2012). Neurological subtle signs and cognitive development: A study in late childhood and adolescence. *Child Neuropsychology*, *19*, 466–478.

Martins, I. P., Vieira, R., Loureiro, C., & Santos, M. E. (2007). Speech rate and fluency in children and adolescents. *Child Neuropsychology*, *13*, 319–332.

Maurer, U., Brem, S., Kranz, F., Bucher, K., Benz, R., Halder, P., … Brandeis, D. (2006). Coarse neural tuning for print peaks when children learn to read. *NeuroImage*, *33*, 749–758.

National Joint Committee on Learning Disabilities. (1990). *Definition of learning disabilities*. Retrieved from http://www.ldonline.org/pdfs/njcld/NJCLDDefinitionofLD.pdf

Nogueira, G., Castro, A., Naveira, L., Nogueira-Antunano, F., Natinzon, A., Gigli, S., … Marchesi, M. (2005). Evaluation of the higher brain functions in 1st and 7th grade school children belonging to two different socioeconomic groups. *Revista de Neurología*, *40*, 397–406.

Pennington, B. F. (2006). From single to multiple deficit models of developmental disorders. *Cognition*, *101*, 385–413.

Raven, J. C. (1965). *Coloured Progressive Matrices, sets A, Ab, B*. London: H.K. Lewis & Co.

Rebelo, J. (1993). *Dificuldades da Leitura e da Escrita em Alunos do Ensino Básico* [*Reading and writing difficulties in basic teaching level students*] (2nd ed., Colecção Horizontes da Didáctica). Oporto, Portugal: Edições ASA.

Sandak, R., Mencl, W., Frost, S., & Pugh, K. (2004). The neurobiological basis of skilled and impaired reading: Recent findings and new directions. *Scientific Studies of Reading*, *8*, 273–292.

Sesma, H., Mahone, E., Levine, T., Eason, S., & Cutting, L. (2009). The contribution of executive skills to reading comprehension. *Child Neuropsychology*, *15*, 232–246. doi:10.1080/09297040802220029

Shankweiler, D., Lundquist, E., Katz, L., Stuebing, K., & Fletcher, J., Brady, S., … Shaywitz, B. (1999). Comprehension and decoding: Patterns of association in children with reading difficulties. *Scientific Studies of Reading*, *3*, 69–94.

Shaywitz, B., Shaywitz, S., Blachman, B., Pugh, K., Fulbright, R., Skudlarsky, P., … Gore, J. (2004). Development of left occipitotemporal systems for skilled reading in children after a phonologically-based intervention. *Biological Psychiatry*, *55*, 926–933.

Simões, M. (2000). *Investigações no âmbito da aferição nacional do teste das matrizes progressivas de Raven (MPCR)* [*Investigations in the ambit of the national measurement studies with the Raven's Coloured Progressive Matrices Test* (*RCPM*)]. Lisbon, Portugal: Fundação Calouste Gulbenkian.

Snowling, M. (2001). From language to reading and dyslexia. *Dyslexia*, *7*, 37–46.

Snowling, M., & Hulme, C. (2012). The nature and classification of reading disorders—a commentary on proposals for DSM-5. *Journal of Child Psychology and Psychiatry*, *53*, 593–607. doi:10.1111/j.1469-7610.2011.02495.x

Spreen, O. (1998). *A compendium of neuropsychological tests* (2nd ed.). New York, NY: Oxford University Press.

Townes, B. D., Rosenbaum, G., Martin, M. D., Martins, I. P., Luis, H., & Bernardo, M. (2008). A longitudinal factor analytic study of children's neurocognitive abilities. *International Journal of Neuroscience*, *118*, 1009–1023.

Vale, A., Sucena, A., & Viana, F. (2011). Prevalência da Dislexia entre Crianças do 1°Ciclo do Ensino Básico falantes do Português Europeu [Dyslexia prevalence among European Portuguese speaking children attending basic school teaching levels]. *Revista Lusófona de Educação*, *18*, 45–56.

Wechsler, D. (1991). *The Wechsler Intelligence Scale for Children-Third Edition*. San Antonio, TX: Psychological Corporation.

Williams, C., Northstone, K., Sabates, R., Feinstein, L., Emond, A., & Dutton, G. (2011). Visual perceptual difficulties and underachievement at school in a large community-based sample of children. *PLoS One*, *6*, e14772. doi:10.1371/journal.pone.0014772