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The Importance of Memory in Reading Processes

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Article Info

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Abstract

Introduction: Most authors argue that the main cause of reading difficulties is the phonological dimension. Nevertheless, there are alternative explanations, since the phonological processing includes three distinct processes. Regarding the role of memory, literature focuses mainly on visual and auditory memory, dismissing other types and memory function (e.g., procedural memory), whose impact may be important in reading.

Aim: To study the relationship between the visual, auditory and procedural memory on sublexical, lexical, syntactic and semantic reading processes.

Method: 110 children aged 7-11 years from several Portuguese schools completed a sociodemographic questionnaire, CPM, PROLEC-R, PADD, PMI4, Rey Complex Figure, TOMAL, MAI, Yuste Memory, Tower of Hanoi and TOMAL.

Results: Visual memory contributes to explain the statistical variance of the identification of letters, as well as sublexical, lexical, syntactic and semantic processes. The same applies to auditory memory, except regarding lexical processes. The procedural memory only contributes to the explanation of sublexical, lexical and syntactical processes.

Conclusions: Several modalities of memory (visual, auditory and procedural) play an important role in the explanation of reading processes.

Keywords: Importance of Memory; Auditory memory; Visual memory; Procedural memory.

Introduction

Reading Processes (RP) are among the most studied competences. Most authors seem to agree that Reading Disabilities (RD) may take many forms [49] and, although phonological fragilities appear to be their main explanatory factor [17, 77], there are alternative explanations.

Phonological processing refers to the perception, storage, retrieval and manipulation of language sounds during acquisition, comprehension and production of the verbal and written code [18] and includes three distinct processes: (a) phonological awareness, (b) lexical retrieval of phonological codes and (c) short-term verbal memory [76, 78].

Different authors suggest different conceptions of memory [4]. Many authors [9, 52, 60, 72, 74] argue that the changes in working memory (WM) are one of the main characteristics of the RD. Several scientific evidences suggest an association between reading skills, phonological awareness and short-term verbal memory [53] in such a way that, according to Smith-Spark, Fisk, Fawcett and Nicolson (2003) [71], it remains unclear whether RD are due to changes in WM or phonological processing.

However, the causal relation often found between RD and WM may not be so linear as some studies suggest [5]. According to Landerl and colleagues (2014) [47], although phonological awareness, automatic naming tasks and short-term verbal memory, are reliable predictors for developmental dyslexia, their contribution varies according to spelling's characteristics [47, 57]. Furthermore, for Melby-Lervag (2012) [53], phonetic awareness is the only major factor in explaining RD, since longitudinal and cross-sectional studies do not allow for a causal relationship between RD and short term verbal memory.

The concept of WM arises as a substitute for the concept of short-term memory (STM) and can be described as a system that requires conscious attention which consists of four different components (phonological loop, visuospatial sketchpad, central executive and phonological buffer), capable of retain and manipulate information, especially in cognitive tasks such as learning, comprehension and reasoning [4].

Although several studies reported that children with developmental dyslexia present difficulties in the phonological loop [28, 43, 58], many authors recognize the existence of a controversy regarding the role of the phonological loop and WM upon phonological awareness and RD [73, 61].

Dyslexic children show clear difficulties in WM with poor activation in the prefrontal, parietal and cerebella cortex [7]. Furthermore, according to Mortimore (2003), subjects with RD may show difficulties in episodic auditory memory, which includes the orthographic form of words and in procedural memory (responsible for the coding, storage and retrieval of procedures underlying motor, verbal and cognitive abilities [55,56].

According to Garcia, Mammarella, Tripodi and Cornoldi (2013) [33], while children with dyslexia have difficulties in visuospatial WM, children with nonverbal disabilities show difficulties in memorizing locations. By studying adult dyslexics, Hachamann and colleagues (2014) conclude that dyslexia is related to a specific short-term memory difficulty for sequential ordering but not for item information. Also, by studying children with both mathematical and reading disabilities Klesczewski and colleagues (2015) found that [45], while children without RD show difficulties in WM, children with RD show difficulties in the central executive functioning.

According to Bacon and Handley (2014), while most people use abstract verbal strategies for problem solving [1,2], dyslexics privilege reasoning strategies based on visual mental representations, which authors associate with limitations upon verbal and executive components of WM.

Studying the WM in Portuguese children, Moura, Simões and Pereira (2014) found that, compared to others [58], dyslexic children show greater difficulties in the phonological loop and the central executive, but not in the visuospatial sketch, which led the authors to conclude that the first two components would be significant predictors of reading and spelling abilities. However, the complexity of these disabilities seems to be such that, according to Brandenburg et al. (2015), the memory profiles of children with RD are different from those of children with difficulties in spelling [8].

In a recent study with Portuguese children, Carreteiro and Figueira (2015) found differences between the performance of children with and without RD in immediate memory tasks nevertheless, the authors recognize the need for additional, deeper studies [11].

Aim and Hypothesis

Based on the literature review, it can be said that: (1) comparatively to other domains, few studies analyse the role of memory processes in reading; (2) available studies do not clarify the importance of memory in RP; and (3) besides the fact that they do not distinguish between lexical (orthographic) and sublexical (phonological) reading processes, (4) they mainly focuses on visual or auditory memory, forgetting other memory modalities or functions, such as procedural memory, where the existence of concrete studies in the field of reading are unknown. Furthermore, (5) like in many other contexts, there are very few studies among this field regarding the Portuguese population.

Therefore, the present work research aims to study the relationship between the memory function and RP.

By memory function, we mean visual (verbal and non-verbal), auditory and procedural memory, with immediate recall. Among RP we highlight the identification of the letters, lexical processes (reading of words and irregular words), sublexical processes (reading of pseudo words and phonological awareness), syntactic processes (grammatical structures and punctuation marks) and semantics (sentences, text and oral comprehension).

Through this study we intend to contribute for the clarification of the importance of the several memory modalities in the RP specified above and, consequently, to contribute with new strategies for the assessment and intervention in RD.

Given the nature of the present investigation, it was decided to formulate only general hypotheses, which are basically an extension of the objective itself:

Hypothesis 1: Visual memory contributes to the explanation of RP.

Hypothesis 2: Auditory memory contributes to the explanation of RP.

Hypothesis 3: Procedural memory contributes to the explanation of RP.

Several authors have advocated an active role of visual memory [33, 56, 61] and especially auditory memory (42) in reading tasks, from which came up Hypothesis 1 and 2, respectively. Hypothesis 3 is based on authors such as Beaunieux and colleagues (2009) who [6], although with less expression, argue that the procedural memory has an important role in these tasks.

Method

Participants

In this study participants were 110 children (67 boys and 43 girls), aged from 7-11 years (M=9.22 and SD=1.14), from several Portuguese learning institutions (North, Central, South, Madeira and Azores). Written informed consents were obtained from both parents and learning institutions [36-41].

All participants met the following general inclusion criteria: a) age between 7-11 years; b) intellectual level greater or equal than the expected for their age, according to CPM standards for Portuguese population; c) absence of neurological disorders based on clinical history and d) absence of visual or hearing problems that could interfere with the ability of hearing or reading.

The choice of the age range took into account cognitive and developmental personality issues: it was decided not to include children with less than 6 years old, as this age coincides with the beginning of schooling, avoiding misunderstandings between the lack of knowledge and the lack of skills for reading. The range from 7-11 years is also the most sensitive and critical stage for RD's screening.

The participating children successfully completed an average of three years of schooling (SD =1.22, Min=1 and Max=6) and showed a low scholar failure (M =.24, SD=.70, Min=0 and Max=4).

In this study, in addition to children, also participated the majority of their respective parents: 83 fathers, aged from 23-59 years (M=41.62 and SD=6.90) and 86 mothers, aged from 25-49 years (38.49 and SD=4.84). At least one of the parents of each child participated in this study.

Instruments

In an attempt to operationalize the variables under study, several instruments were used:

General information: SDQ

A specific socio-demographic questionnaire (SDQ) was developed in order to collect general information about parents (age, education, occupational status, marital status and socioeconomic status - SES) and about each participating child (gender, age, education, number of academic failures, number of siblings, general health problems, neurological problems and visual or hearing difficulties).

Intellectual Level: CPM

Intellectual level was controlled by Raven Colored Progressive Matrices (CPM, developed by Raven, Raven and Court in 1947 and adapted to Portuguese population by Mário Simões, 1995). Internal consistency analyses conducted in this research confirmed very good values (α = .940, M = 29.53, SD = 5.75) [62].

Reading Processes

To assess RP we used the PROLEC-R, Bateria de Avaliação dos Processor Leitores – Revista (Reading Processes' Assessment Battery – Revised), developed by Cuetos, Rodríguez, Ruano and Arribas (2007) [24], whose adaptation to Portuguese population is in course by Figueira, Lopes and Almeida (in press) complemented by PADD [29], Prova de Análise e Despiste da Dislexia (Dyslexia Assessment Test).

PROLEC- R

PROLEC-R is an individual test, based in the cognitive model of reading comprehension processes, for children aged 6-12 years. It involves nine tasks whose application time varies from 20-40 minutes: a) Identification of Letters, b) Same-Different, c) Words Reading, d) Pseudo words Reading, e) Grammatical Structures, f) Punctuation, g) Sentences Comprehension, h) Text Comprehension and i) Listening. The main aim of PROLEC-R is to assess the reading components which are affected in children unable to learn how to read [30]. According to his Spanish editor, PROLEC-R is one of the most important references in reading assessment in Spain [24]. Regarding internal consistency, Cuetos and colleagues (2007) obtained satisfactory values (.48 ≤α≤.79), that were overcome in the present study (.62 ≤α≤.97) [24].

PADD

PADD [11-15] is a Portuguese individual test, composed by 6 subtests (Letter Identification, Memory, Semantic Access, Phonological Awareness, Articulatory Awareness and Reading) for children aged 7-11 years. In this study only 2 subtests were used: Phonological Awareness subtest (composed by the indexes of Phonemes Subtraction, Fusion and Inversion) and part of the Reading subtest (Irregular Words, Pseudowords and Semantic Reading). In terms of internal consistency, this study confirmed the good values previously obtained by the author [11], with Cronbach alpha values ranging from .690 to .979 [62-65].

Memory tasks

Visual memory was assessed through the Immediate Memory Test [68], Rey's Complex Figure [64] and some of the TOMAL's subtests [65]. The auditory memory was assessed through the MAI (Cordero, 2002) and Memoria de Yuste (Hernanz, 2005) tests [81]. To assess procedural memory, the Tower of Hanoi [48] and a sub-test of TOMAL [65] were used.

PMI4

The Immediate Memory Test (PMI4), developed by Silva-e-Sá (2005), is a computerized immediate visual memory test [68], composed of 4 subtests: Discriminatory memory, text memory, digit memory and space location memory.

The discriminative memory subtest consists of successive presentations of 6 stimulus rectangles, involving 3 criteria (color name, color of the letter and color of the background) in order to assess the ability to memorize and discriminate several visual aspects of the same stimulus [68]. The text memory subtest assesses the ability to retain texts' visual information [68]. The digit memory assesses the immediate visual memory for numbers [68]. The subtest of space location memory assesses the ability to memorize visual stimuli's shape, color and space location [67-69].

Rey's Complex Figure

The Rey's Complex Figure (RCF) test, developed by André Rey (1941), is composed of a complex geometric figure that the subject should [63], at first, copy and then reproduce from memory. In the present study, the memory reproduction of the CRF was used to assess the non-verbal visual memory. Its reliability, assessed through Cronbach's alpha (α = .940), revealed a good internal consistency.

TOMAL

The TOMAL - Test of Memory and Learning [65, 35] is a standardized and extensive memory battery for people aged from 5 - 19 years. TOMAL is composed of 10 subtests (5 verbal and 5 nonverbal). In the present study we used the subtests of Face's Memory, Visual Selective Memory, Abstract Visual Memory, Visual Sequential Memory, Location Memory and Manual Imitation.

The Face's Memory (FM) subtest assesses non-verbal visual memory, asking the recognition and identification of black-and-white photos with faces of individuals of both genders, different ages and different ethnicities, within a set of distracters [35]. The reliability analysis assessed by Cronbach's alpha (α = .791) showed an acceptable internal consistency.

The Visual Selective Memory (VSM) subtest assesses non-verbal visual memory: after a demonstration, participants are asked to mark specific points on a page [35]. The reliability analysis, assessed by Cronbach's alpha (α = .892) showed good internal consistency.

Abstract Visual Memory (AVM) is a non-verbal memory task in which participants are asked to recognize certain neutral stimulus among a group of six distracting alternatives [35]. The reliability analysis, assessed by Cronbach's alpha (α = .874) showed good internal consistency.

Nonverbal Sequential Memory (NSM) is a non-verbal task that involves memorizing a sequence of unmeaningful geometric series. The reliability analysis, assessed by Cronbach's alpha (α = .745) showed an acceptable internal consistency.

According to Goikoetxea (2001), the subtest of Location Memory (LM) assesses spatial memory [35]. The subject is faced with a set of large points distributed on a page, whose location should remember. The reliability analysis assessed by Cronbach's alpha (α = .904) showed good internal consistency.

Manual Imitation (MI) is a sequential psychomotor memory task in which the participants are asked to reproduce a set of hand movements in the same order in which they were previously presented. The reliability assessment trough Cronbach's alpha (α = .809) showed good internal consistency.

MAI

The Immediate Auditory Memory test (Teste de MemóriaImediata - MAI), developed by Cordero (2002), is designed for children from 4^{th} to 8^{th} grade and consists of three parts: in the first part (Logical Memory) [39], a logical history, with two paragraphs, is red to assess the child's ability to recall the details. The second part (Numerical Memory), like the Memory of Digits of the Wechsler intelligence scales, shows series of digits which the participants should repeat, either in the direct or in the reverse order. Finally, the Associative Memory test consists of ten words that are presented to the child in three different moments, varying the order of presentation. The internal consistency of the MAI, assessed through the Cronbach's alpha (α = .847), showed a good reliability.

MY

The Yuste Memory (Memória de Yuste– MY) tests, developed by Carlos Yuste (1985) are designed in four levels according the years of schooling: Elementary (1^{st} - 2^{nd} years), Level I (2^{nd} - 4^{th} years), Level II (4^{th} - 7^{th} years) and Level III (8^{th} - 10^{th} years). In this study, Level II, composed by two tasks, was used: Word recall, in which a list of 30 words is red to a further identification between a total of 120 words, and History recall, in which is red an adventure that the Children should remember later. The internal consistency of the MAI was assessed using the Cronbach's alpha (α = .740) revealing an acceptable reliability.

Tower of Hanoi

Tower of Hanoi, first presented by Lucas (1883), consists of three rods, and several disks of different sizes which can slide onto any rod [48]. The puzzle starts with the disks in a neat stack in ascending order of size on one rod, the smallest at the top, thus making a conical shape.

The Tower of Hanoi has been widely used to assess procedural memory [1, 6, 10, 66, 80], making even an integral part of some neuropsychological assessment batteries for children [70].

In the present study, the child was initially given the correct resolution of the Tower of Hanoi and then asked to perform the task alone. It was decided to finish the task when the child had completed the task successfully or after 10 minutes. The result was calculated by the quotient between the number of movements produced correctly within the time limit and the time (in seconds) the child took to complete the task [27,29,30,32,34].

Procedures

After obtained written consent and once controlled all general inclusion criteria, children and parents were assessed trough previously described instruments.

A preliminary analysis by Kolmogorov-Smirnov test (p>.05), Shapiro-Wilk test (p>.05) and Normal QQ Plots (deviations between -2 and+2) has shown that the variables does not significantly deviate from normal distribution.

Hypotheses were tested using a multiple hierarchical linear regression model. Model application requests were checked regarding statistical Tolerance (T>.1) and VIF (VIF <10) in order to avoid multicol linearity effects. According Durbin-Watson's statistic (d≈2), errors are random and independent. Significant effects were considered when p<.05.

Results

Visual Memory

The contribution of visual memory for the explanation of the statistical variance of RP was tested through regression analysis, with the following models: model 1 (individual factors) contemplates the sociodemographic variables of the child (gender, age, education and Intellectual level); Model 2 (family factors), adds the sociodemographic variables of the family (parental subsystem, number of siblings, parents' age, parental education, existence of previous learning disabilities among parents, parents' occupational status and parents' SES) and, finally, model 3 (visual memory performance) is complete with the combination of the results obtained in the RCF, PMI-4 and subtests FM, VSM, AVM, NSM and LM of TOMAL.

Rey's Complex Figure

As can be seen in Table 1, multiple hierarchical linear regression applied to the PROLEC-R's indexes regarding non-verbal visual memory, assessed by RCF (model 3), was only statistically significant for Sentence Comprehension (R^2change = .033, F change = 4.410, p = .041). The same analysis applied to PADD subtests was not significant for any of the subtests.

Table 1. Multiple hierarchical regression analysis applied to RP regarding visual memory

Model 3	R	R^2	Adjusted R^2	SE estimate	Change Statistics				
					R^2 change	F change	df1	df2	Sig. F Change
Name of the Letter (PROLEC-R)									
PMI4	.799	.639	.474	27.92797	.138	2.791	6	44	.022
TOMAL	.763	.582	.454	28.46444	.081	9.480	1	49	.003
Same-Different (PROLEC-R)									
PMI4	.788	.621	.448	12.46572	.170	3.281	6	44	.009
Words Reading (PROLEC-R)									
PMI4	.746	.557	.355	26.85677	.146	2.423	6	44	.041
TOMAL	.775	.601	.479	24.15429	.190	23.368	1	49	.000
Pseudowords Reading (PROLEC-R)									
PMI4	.829	.688	.546	17.96938	.177	4.144	6	44	.002
TOMAL	.768	.591	.465	19.49460	.079	9.509	1	49	.003
Irregular Words Reading (PROLEC-R)									
TOMAL	.870	.757	.682	3.175	.015	3.031	1	49	.088
Grammatical Structures (PROLEC-R)									
TOMAL	.864	.746	.668	1.414	.055	10.615	1	49	.002
Punctuation (PROLEC-R)									
TOMAL	.765	.586	.459	5.47376	.195	23.103	1	49	.000
Sentences Comprehension (PROLEC-R)									
FCR	.796	.633	.521	1.251	.033	4.410	1	49	.041
TOMAL	.800	.640	.529	1.240	.039	5.338	1	49	.025
Texts Comprehension (PROLEC-R)									
PMI4	.820	.672	.524	2.357	.109	2.445	6	44	.040
Listening (PROLEC-R)									
TOMAL	.839	.704	.613	.982	.125	20.651	1	49	.000
Phonological Awareness (PADD)									
PMI4	.910	.828	.770	5.10472	.025	7.089	1	48	.011
TOMAL	.922	.850	.781	4.97831	.048	2.784	5	44	.029
Pseudowords Reading (PADD)									
PMI4	.829	.688	.546	17.96938	.177	4.144	6	44	.002
TOMAL	.905	.819	.736	5.868	.068	3.321	5	44	.012
Irregular Words Reading (PADD)									
TOMAL	.919	.845	.775	2.671	.055	3.106	5	44	.017
Semantic Reading (PADD)									
TOMAL	.891	.795	.701	1.292	.057	2.456	5	44	.048

PMI4

Multiple hierarchical linear regression applied to PROLEC-R's indexes regarding verbal visual memory assessed trough PMI4 (model 3), was statistically significant for the indexes Name of the Letters (R^2change = .138, *F* change = 2.791, *p* = .022), Same-Different (R^2change = .170, *F* change = 3.281, *p* = .009), Word Reading (R^2change = .146, *F* change = 2.423, *p* = .041), Pseudoword Reading(R^2change= .177, *F* change = 4.144, *p* = .002) and Text Comprehension (R^2change= .109, *F* change = 2.445, *p* = .040) – Table 1. The same analysis applied to PADD subtests was significant for Phonological Awareness (R^2change= .025, *F* change = 7.089, *p* = .011) and Pseudoword Reading (R^2change = .177, *F* change = 4.144, *p* = .002) – Table 1.

TOMAL

Multiple hierarchical linear regression applied to the PROLEC-R indexes regarding visual non-verbal memory assessed by TOMAL subtests (model 3), was statistically significant for Name of the Letters (R^2change= .081, *F* change = 9.480, *p* = .003), Word Reading (R^2change = .190, *F* change = 23.368, $p<$ .001), Pseudoword Reading (R^2change= .079, *F* change, *p* = .003), Grammatical Structures (R^2change= .055, *F* change = 10.615, *p* = .002), Punctuation (R^2change= .195, *F* change = 23.103, $p<$ .001), Sentences Comprehension (R^2change= .039, *F* change = 5.338, *p* = .025)and Oral Comprehension (R^2change= .125, *F* change = 20.651, $p<$ .001) – Table 1. The same analysis applied to PADD was significant for all considered subtests: Phonological Awareness (R^2change= .048, *F* change = 2.784, *p* = .029), Pseudoword Reading (R^2change= .068, *F* change = 3.321, *p* = .012), Irregular Word Reading (R^2change= .055, *F* change = 3.106, *p* = .017) e Semantic Reading (R^2change= .057, *F* change = 2.456, *p* = .048) – Table 1.

Auditory Memory

The contribution of auditory memory for the explanation of the statistical variance of RP was tested through regression analysis, with the following models: model 1 (individual factors) contemplates the sociodemographic variables of the child (gender, age, education and Intellectual level); Model 2 (family factors), adds the sociodemographic variables of the family (parental subsystem, number of siblings, parents' age, parental education, existence of previous learning disabilities among parents, parents' occupational status and parents' SES) and, finally, model 3 (auditory memory performance) becomes complete with the combination of the results obtained in MAI and MY tests [44,51,59,75,79].

According to Table 2, multiple hierarchical linear regression applied to the PROLEC-R indexes regarding auditory (verbal) memory assessed by MAI and MY (model 3), was statistically significant for most of the indexes of PROLEC-R: Name of the Letters (R^2change= .088, *F* change = 5.132, *p* = .010), Same-Different (R^2change= .153, *F* change = 9.291, $p<$ .001), Word Reading (R^2change= .162, *F* change = 9.116, $p<$ .001), Pseudoword Reading (R^2change= .200, *F* change = 16.621, $p<$ .001), Punctuation (R^2change= .128, *F* change = 6.386, *p* = .003), Text Comprehension (R^2change= .126, *F* change = 9.711, $p<$ .001) and Oral Comprehension (R^2change= .071, *F* change = 4.887, *p* = .012). The same analysis applied to PADD was significant for Phonological Awareness (R^2change= .022, *F* change = 3.105, *p* = .031), and Pseudoword Reading (R^2change= .038, *F* change = 4.255, *p* = .020).

Table 2. Multiple hierarchical regression analysis applied to RP regarding auditory memory

Model 3	R	R^2	Adjusted R^2	SE estimate	Change Statistics				
					R^2 change	F change	df1	df2	Sig. F Change
Identification of Letters (PROLEC-R)									
MAI/MY	.767	.589	.452	28.51689	.088	5.132	2	48	.010
Equal-Different (PROLEC-R)									
MAI/MY	.777	.604	.472	12.19178	.153	9.291	2	48	.000
Words Reading (PROLEC-R)									
MAI/MY	.757	.573	.430	25.24832	.162	9.116	2	48	.000
Pseudowords Reading (PROLEC-R)									
MAI/MY	.843	.711	.615	16.54378	.200	16.621	2	48	.000
Punctuation (PROLEC-R)									
MAI/MY	.720	.518	.358	5.96226	.128	6.386	2	48	.003
Text Comprehension (PROLEC-R)									
MAI/MY	.830	.689	.585	2.199	.126	9.711	2	48	.000
Listening (PROLEC-R)									
MAI/MY	.807	.651	.534	1.078	.071	4.887	2	48	.012
Phonological Awareness (PADD)									
MAI/MY	.908	.824	.745	5.38086	.022	3.105	5	44	.031
Pseudowords Reading (PADD)									
MAI/MY	.888	.788	.712	6.131	.038	4.255	2	47	.020

Procedural memory

The contribution of procedural memory for the explanation of the statistical variance of RP was tested through regression analysis, with the following models: model 1 (individual factors) contemplates the sociodemographic variables of the child (gender, age, education and Intellectual level); Model 2 (family factors), adds the sociodemographic variables of the family (parental subsystem, number of siblings, parents' age, parental education, existence of previous learning disabilities among parents, parents' occupational status and parents' SES) and, finally, model 3 (procedural memory performance)becomes complete with the performance on Towers of Hanoi and Manual Imitation subtest of TOMAL.

Towers of Hanoi

As can be seen in Table 3, multiple hierarchical linear regression applied to the PROLEC-R indexes regarding procedural memory assessed by the Towers of Hanoi was only statistically significant for Word Reading (R^2change = .071, F change = 5.387, p= .026) and Irregular Word Reading (R^2change = .046, F change = 4.254, p = .040). The same analysis applied to PADD was not significant for any subtest.

Table 3. Multiple hierarchical regression analysis applied to RP regarding procedural memory

Model 3	R	R^2	Adjusted R^2	SE estimate	Change Statistics				
					R^2 change	F change	df1	df2	Sig. F Change
Pseudowords Reading (PROLEC-R)									
HANOI	.741	.549	.363	16.98847	.071	5.387	1	34	.026
Irregular Words Reading (PROLEC-R)									
HANOI	.797	.636	.485	2.177	.046	4.254	1	34	.047
Punctuation (PROLEC-R)									
TOMAL	.663	.439	.268	6.36631	.049	4.303	1	49	.043

MI-TOMAL

Multiple hierarchical linear regression applied to the PROLEC-R indexes regarding procedural memory assessed by the Manual Imitation subtest of TOMAL was only statistically significant for Punctuation (R^2change = .049, F change = 4.303, p = .043).The same analysis applied to PADD was not significant for any subtest.

Synthesis

Table 4 synthetizes our main results. Visual Memory does contribute to the explanation of all PADD subtests and PROLEC-R indexes (except for Irregular Words). The same applies to Auditory Memory, which just does not contribute for the explanation of Irregular Words, Grammatical Structures and Sentence Comprehension (all from PROLEC-R) and the PADD Irregular Word Reading and Spelling subtests. Finally, Procedural Memory seems only to contribute for the explanation of the PROLEC-R indexes of Pseudoword Reading, Irregular Word Reading and Punctuation.

Table 4. Explanation of RP trough memory functions

Tests	Factors	Visual Identification		Lexical Processes			Syntactic Processes		Semantic Processes			PADD			
		NL	ID	LP	PP	IRR	EG	SP	CF	CT	CO	CF	PP	IRR	LO
Visual Memory															
RCF	Individual Factors	.004	.000	.000	.000	.000	.000	.001	.000	.000	.000	.000	.000	.000	.000
	Family Factors	.009	-	-	-	.036	.009	-	.005	.065	.078	.018	.008	.000	.028
	Memory Factors	-	-	-	-	-	-	-	**.041**	-	-	-	-	-	-
PMI4	Individual Factors	.004	.000	.000	.000	.000	.000	.001	.000	.000	.000	.000	.000	.000	.000
	Family Factors	.009	-	-	-	.036	.009	-	.005	-	-	.018	.008	.000	.028
	Memory Factors	**.022**	**.009**	**.041**	**.002**	-	-	-	-	**.040**	-	**.011**	**.028**	-	-
TOMAL	Individual Factors	.004	.000	.000	.000	.000	.000	.001	.000	.000	.000	.000	.000	.000	.000
	Family Factors	.009	-	-	-	.036	.009	-	.005	-	-	.018	.008	.000	.028
	Memory Factors	**.003**	-	**.000**	**.003**	-	**.002**	**.000**	**.025**	-	**.000**	**.029**	**.012**	**.017**	**.048**
Auditory Memory															
MAI/MY	Individual Factors	.004	.000	.000	.000	.000	.000	.001	.000	.000	.000	.000	.000	.000	.000
	Family Factors	.009	-	-	-	-	.009	-	.005	-	-	.018	.008	.000	.028
	Memory Factors	**.010**	**.000**	**.000**	**.000**	-	-	**.003**	-	**.000**	**.012**	**.031**	**.020**	-	-
Procedural Memory															
HANOI	Individual Factors	.000	-	-	-	.002	.001	-	.018	.015	-	.000	.000	.000	.000
	Family Factors	-	-	-	.036	.017	.002	-	.000	.007	.011	-	-	-	-
	Memory Factors	-	-	-	**.026**	**.047**	-	-	-	-	-	-	-	-	-
TOMAL	Individual Factors	.004	.000	.000	.000	.000	.000	.001	.000	.000	.000	.000	.000	.000	.000
	Family Factors	.009	-	-	-	.046	.009	-	.005	-	-	.018	.025	.008	.000
	Memory Factors	-	-	-	-	-	-	**.043**	-	-	-	-	-	-	-

Correlations

Considering the differences between the explanatory capacity of the RCF and the other visual memory selected tests, it was decided to study the correlation between the scoring of each of these tests and the CPM's scoring. According to Table 5, when compared to the score of the remain visual memory tests, RCF's scoring presents a higher, statistically significant correlation, with the CPM score (r_p = .583, p<.001, n = 88).

Table 5. Correlation between memory tests' scores and CPM's scores

		FCR	PMI4-T	PMI4-SN	PMI4-LE	TOMAL-MF	TOMAL-MSV	TOMAL-MVA	TOMAL-ML
CPM	r_p	.583	-.170	-.071	-.295	.522	-.014	.571	.328
	p	.000	.123	.521	.006	.000	.897	.000	.002
	n	88	84	84	84	89	88	88	88

Discussion

According to the results, not only the auditory memory (widely described in the literature) but also the visual memory and even the procedural memory seem to play an active role in the explanation of at least some memory processes, which is congruent with our hypotheses.

These results are in line with several authors who argue the importance of memory skills upon reading tasks [3, 16, 31, 46, 54, 71, 72], namely Menghiniand colleagues (2013) and Mortimore (2003) [54, 56], who emphasize the importance not only of auditory memory, but also of visual memory [71, 72]. However, these findings are contrary to the view that only visual memory or auditory memory would be relevant for RP [8, 43].

Visual Memory's contribute

The global analysis and the cross-checking of the several instruments used both to assess memory and RP, points out that visual memory contributes to explain the generality of RP (visual identification, sublexical processes, lexical processes, Syntactic processes and semantic processes). The same conclusion was reached in other studies, Garcia (2013), Mortimore (2003) or Ram-Tsur and collaborators (2008) who advocate the importance of visual memory in RP [33, 56, 61].

The fact that, unlike PMI-4 and the selected TOMAL subtests, the RCF only explains a sub-test of PROLEC-R (Sentence Comprehension) is associated with the nature of the test itself, which proves to be more demanding from the intellectual level point of view. The high significant correlation found between the RCF's scores and CPM's scores, seems to confirm this theory.

Auditory Memory's contribute

Concerning the auditory memory, the same analysis points to a contribution in the explanation of all the reading processes, except for the lexical processes (irregular word reading and word completion), which arises in line with the investigations of authors like Kibby (2009) [42], Mortimore (2003) and Moura and colleagues (2014) [56].

Procedural Memory's contribute

Also procedural memory seems to have a significant contribution to explain some RP (Irregular Words Reading, Pseudowords Reading and Punctuation, assessed PEOLEC-R).

Although the role of procedural memory in RP has already been described in the literature [6,81], the fact that this memory function does contribute for the explanation of these tasks assessed by PROLEC-R but not by PADD may, eventually indicate some lack of robustness, which lead us to alert to the need for future replications.

Global Analysis

From the comparison between the contributions of the several modalities of memory for the explanation of RP, evidenced in the present study, it can be concluded that contrary to the current tendency, the widest explanation seems to come from visual memory and not from auditory memory.

If we consider the theory of Neural Recycling, proposed by Dehaene (2007), according to which reading appeals to the neuronal mechanisms of vision [25], defending the existence of a neuronal hierarchy that supports the visual recognition of words, these results appear to be plausible.

If we try to integrate these results into the classical reading theories [50, 22], according to which the individual essentially has two ways of reading (one lexical and other sublexical) it's possible to conclude that, while auditory memory is particularly important in sublexical processes (whose affectation leads to the onset of the condition described by phonological dyslexia – [17,19,20,21], visual memory is important on both lexical (whose affectation leads to the onset of the condition described by orthographic dyslexia - Castles, Bates and Coltheart, 2006)[17] and sublexical processes – and subsequently in the explanation of the mix dyslexia also known as hyperlexia [26] which appears when both pathways are affected.

Conclusions

According to the results of the present study, visual memory, auditory memory and procedural memory contribute significantly for the explanation of RP.

Among several memory functions, the greatest contribution seems to come from visual memory, which seems to explain overall RP, and the less robust contribution comes from procedural memory that only revealed explanatory capacity for PROLEC-R pseudowords and irregular words reading's subtests.

Despite the current focus found in literature explaining RP through auditory memory, if we consider the theory of neuronal recycling, advanced by Dehaene (2007), these results seem to make perfect sense [25].

In an attempt to fit these results into dual-route reading models [22,23,24,50], it seems also possible to concluded that while auditory memory is important for the explanation of the phonological (sublexical) route, visual memory presents explanatory capacity for both (orthographic - lexical and phonological) routes.

We consider that the present study does contribute, not only for a better understanding of RP but also for the diagnosis and intervention in RD. Nevertheless, we recognize the need for additional studies that allow a deeper understanding of this issue and possibly replicate these conclusions, particularly regarding the role of procedural memory whose robustness, as we have seen, seems to raise some gaps.

Compliance with Ethical Standards

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Conflict of Interest

The authors of this manuscript declare no potential conflict of interest. The authors declare no relationships with any companies, whose products or services may be related to the subject matter of the article and that this work has not received any funding.

Research involving Human Participants and/or Animals

This article does not contain any studies with animals performed by any of the authors. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Written informed consent was obtained from parents. Written informed consent was also obtained from schools' directive boards assuming deontological responsibilities.

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