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1 RUNNING HEAD: COGNITIVE PROFILES IN POOR READERS

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Varieties of Cognitive Profiles in Poor Readers:

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Evidence for a Visual Attention Span-Impaired Subtype.

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8

1 **Abstract**

2 A wide share of secondary school children does not reach the expected competence level in
3 reading. These children could benefit from more efficient intervention responses, providing a
4 better understanding of their cognitive weaknesses/deficits. Our aim was to explore the cognitive
5 heterogeneity of a population of poor readers identified from a large sample of 948 6th grade
6 children. We first assessed the contribution of phoneme awareness (PA), rapid automatized
7 naming (RAN) and visual attention span (VAS) to reading performance in a subset of 281 children
8 including poor and average readers/spellers. We show that all three skills are unique and
9 significant predictors of reading fluency. We then restricted the analysis to participants with
10 normal IQ and oral language skills to focus on 110 children with more specific reading difficulties.
11 A unique VAS deficit was found in 18% of these poor readers while 20% and 15.5% showed a
12 unique PA or RAN deficit. Children with multiple or no deficit were further identified. The overall
13 findings provide evidence for a variety of cognitive profiles in poor readers. They suggest that, in
14 addition to PA interventions, training programs targeting VAS might be useful for the non-trivial
15 share of poor readers who exhibit a VAS deficit.

16
17 *Keywords:* poor readers, phoneme awareness, visual attention span, rapid automatized naming,
18 reading acquisition

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1 Introduction

2 Reading is a complex task that relies on visual and visual attention skills for the processing
3 of letters within printed words (Besner et al., 2016; Laberge & Samuels, 1974; Vidyasagar &
4 Pammer, 2010) and, on phonological skills to translate relevant orthographic units into their
5 phonological counterparts. The role of phonological skills in reading has been extensively studied
6 during the last decades, which showed that learning grapheme-phoneme mappings for letter-string
7 decoding relies on phoneme awareness (PA), i.e. the basic ability to identify phonemes within
8 spoken words. The role of PA in reading acquisition is strongly established and no longer debated.
9 Lower PA predicts lower reading performance in children and a PA deficit results in impaired
10 reading skills in developmental dyslexia (Caravolas et al., 2012; Carroll et al., 2016; Melby-
11 Lervåg et al., 2012).

12 Although reading acquisition is sometimes viewed as being mainly a linguistic process
13 (Goswami, 2015), exploration of visual and visual attention skills showed evidence for a link
14 between visual processing skills, visual attention abilities and reading acquisition, in both the
15 dyslexic population (Bogon et al., 2014; Stein, 2014) and typically developing readers
16 (Franceschini et al., 2012; Tulloch & Pammer, 2019; Valdois et al., 2019). Different types of visual
17 attention deficits have been reported in developmental dyslexia. Deficits in visual attention
18 orienting and visual attention shifting are well documented but they extend to the auditory
19 modality and were found to more specifically relate with the phonological deficit (Facoetti et al.,
20 2010; Hari & Renvall, 2001; Lallier et al., 2013). They thus appear as potential underpinnings of
21 the phonological deficit rather than independent sources of poor reading outcome. In contrast,
22 another type of visual attention mechanism, the VA span -- that dissociates from visual attention
23 orientation and visual attention shifting (Lallier et al., 2010; Valdois et al., 2019) and is reported
24 in dyslexic individuals who have good phoneme awareness (Bosse et al., 2007) -- affects reading
25 performance independently of phonological skills in both developmental dyslexia (Bosse et al.,
26 2007; Saksida et al., 2016; Zhao et al., 2018) and typical reading (Bosse & Valdois, 2009; van den

1 Boer et al., 2013; Van den Boer et al., 2015). In support of two PA and VAS reading-related
2 independent skills, a neural dissociation was found to mirror the cognitive dissociation between
3 PA and VAS deficits in developmental dyslexia (Peyrin et al., 2012). VAS-impaired individuals
4 were found to show a dysfunction of the superior parietal lobules bilaterally but preserved
5 functioning of the left-hemisphere perisylvian regions while a selective dysfunction of the
6 perisylvian brain regions was reported in individuals with an isolated PA deficit. Further evidence
7 for the superior parietal lobules being the neuronal underpinnings of VAS was provided in expert
8 readers and dyslexic individuals (Reilhac et al., 2013; Lobier et al., 2012; Lobier et al., 2014;
9 Valdois et al., 2014; see also Valdois et al. 2019), showing that VAS relates to the dorsal brain
10 attention network.

11 These findings suggest that two cognitive skills would independently contribute to reading
12 acquisition, namely PA — which favors the identification of phonemes within spoken words and
13 their mapping to corresponding graphemes— and VAS — which allows simultaneous processing
14 of the letters that correspond to sublexical orthographic units and whole words (Valdois et al.,
15 2004). However, many studies explored the unique contribution of VAS and PA to normal or
16 impaired reading performance without controlling for rapid automatized naming (RAN) skills in
17 the populations under concern.

18 RAN is a powerful predictor of reading performance (Swanson et al., 2003; Lervåg &
19 Hulme, 2009; Shapiro et al., 2013; Landerl et al., 2019) and there is strong evidence for a RAN
20 deficit in poor and dyslexic readers (Decker et al., 2013; Powell et al., 2007; Wolf, et al., 2002).
21 Many studies have shown that RAN and PA exert an independent influence on reading (Powell et
22 al., 2007), and that a selective deficit of either RAN or PA defines distinct subsets of reading-
23 disabled children (Araujo et al., 2010; Wolf et al., 2002). Further, there is evidence that VAS
24 contributes to reading performance independently of RAN in developmental dyslexia (van den
25 Boer et al., 2015; Chen, Zheng & Suk, 2019).

1 The overall findings thus support independent contribution of RAN and PA to reading
2 performance on one hand and of VAS and PA on the other hand but the number of studies that
3 explored all three different subskills in the same population is still limited. Rather consistent results
4 emerge from van den Boer et al. (2013, 2014, 2018)'s studies on typical readers. They consistently
5 showed that VAS contributes to different facets of reading performance, independently of PA and
6 RAN. In contrast, the examination of all three skills in dyslexic children (Saksida et al., 2016)
7 failed to show any unique contribution of VAS to reading after control for PA and RAN. In
8 disagreement with many previous findings, this latter research further failed to identify any subset
9 of dyslexic individuals with a unique VAS deficit. Such discrepancy might follow from
10 methodological differences between studies, including the choice of tasks indexing VAS abilities
11 and potential recruitment bias. In some previous studies, the proportion of VAS-impaired dyslexic
12 individuals might have been exacerbated (authors' reference), probably due to higher probability
13 for dyslexic children with visual impairments to be addressed to research teams known for their
14 interest in visual skills. In the same way, Saksida et al. (2016) acknowledged that their population
15 gathered children with very severe dyslexia, which might have exacerbated the proportion of
16 multi-deficit children.

17
18 The purpose of the current study was to estimate the variety of cognitive profiles and the
19 prevalence of VAS, PA, and/or RAN deficits in a sample of poor/dyslexic readers while avoiding
20 potential recruitment bias. For this purpose, we started from a large sample of 948 6th grade
21 children to identify a subset of poor readers whose performance was compared to that of average
22 readers. Sixth grade in France is compulsory for all children, so that focusing on poor readers
23 within this population was viewed as the best possible way to overcome any recruitment bias. We
24 first focused on the larger population of poor and average readers to estimate the contribution of
25 VAS, PA and RAN to the participants' reading outcome. In line with previous findings on typically
26 developing children (van den Boer et al., 2013, 2014, 2018), we expected VAS to be an

1 independent predictor of literacy skills, after control of PA and RAN. Second, we assessed the
2 existence of distinct cognitive profiles within the population of poor/dyslexic readers. Assuming
3 that all three factors independently contribute to reading, different cognitive profiles characterized
4 by a unique VAS, PA or RAN deficit would be identified. In particular, we anticipated the
5 existence of a VAS-impaired profile and expected this profile to characterize a non-trivial
6 proportion of poor/dyslexic readers. The assumption for independence of the three VAS, PA and
7 RAN deficits does not exclude that some children might show a double, or even a triple deficit,
8 but a higher proportion of children was expected to show a single deficit. Overall, the current study
9 aims at better understanding the cognitive underpinnings of literacy acquisition and the
10 heterogeneity of cognitive profiles in poor reading. This issue is critical to inform education policy
11 on the special needs of poor readers and promote the development of new intervention programs
12 targeting relevant cognitive skills.

13

14

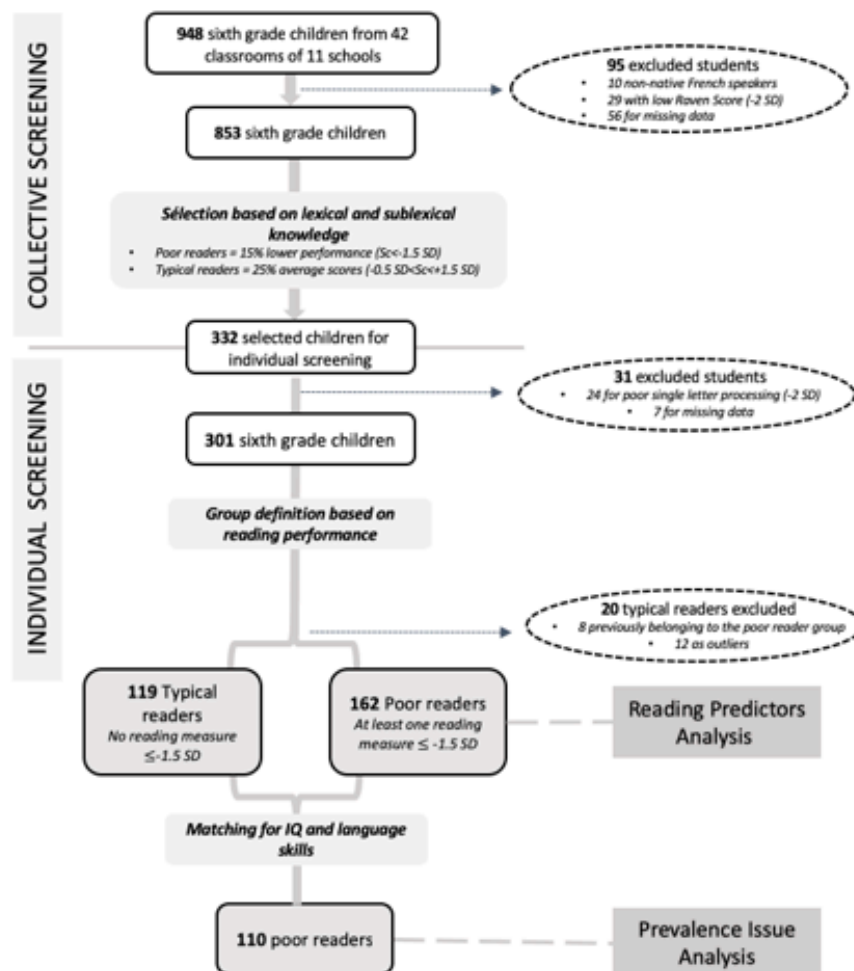
Method

15 Participants

16 The participants' selection procedure is illustrated on Figure 1. Nine hundred and forty-
17 eight 6th grade French children participated to the initial screening. Participants were recruited in
18 42 classrooms from 11 schools of the Academy of Grenoble, that were located in rural, urban and
19 suburban areas. All participants completed the tasks of lexical and sublexical orthographic
20 knowledge, vocabulary, oral comprehension and intellectual efficiency (see the next section
21 "Collective Screening Tasks"). From these data, two scores were calculated as indexes of each
22 child's lexical and sublexical knowledge. The composite score indexing lexical knowledge was
23 computed as mean performance (based on percentages of accurate responses) on the two tasks of
24 irregular word spelling and orthographic forced-choice (Pearson's $r=.75^{***}$). The composite score
25 indexing sublexical knowledge was computed from scores on pseudo-word spelling and pseudo-
26 homophonic judgment (correlation at $.48^{***}$). Non-native French speakers (N=10), students with

1 Raven's score inferior to 23 (i.e., score ≤ -2 SD; N=29) and children with missing data (N=56)
 2 were excluded from the selection. Then, 332 children were selected for subsequent individual
 3 assessment: a group of children having the poorest lexical and/or sublexical skills (scores $\leq -1,5$
 4 SD) and a group of children with average performance ($-0.5 \leq$ scores $\leq 1,5$ SD) on these two skills.

5
 6 Figure 1: Illustration of the group selection procedure.
 7



8
 9 In the second phase of screening (see the next section “Individual Screening Tasks”) all
 10 332 participants performed the tasks of irregular word and pseudo-word reading, text reading and
 11 the standard Alouette reading test. The tasks of PA, RAN and VAS were further administered.
 12 Children’s single letter identification skills were further assessed, as a control task for VAS
 13 assessment. Indeed, poor performance in global and partial letter report tasks can be interpreted as

1 reflecting poor VAS if and only if single letter identification skills are preserved (Bosse et al.,
2 2007; Valdois et al., 2019). Participants with a single letter identification deficit (accuracy inferior
3 to -1.5 standard deviation on the total mean weighted score) were automatically excluded from
4 groups (N=24). Seven more children were excluded because of missing data on the reading tasks.
5 Performance from individual screening was used to check that all children previously classified as
6 poor spellers but none of the good spellers further showed poor reading performance. This led to
7 exclude eight participants who showed poor performance in collective screening but scored within
8 the normal range in individual screening. Twelve participants who were initially classified as
9 normal readers were further excluded because of scores out of the normal range (more than 2SD
10 below the mean) on at least one of the individually administered reading tasks. Thus, a population
11 of 162 poor readers and 119 average readers was selected at the end of the selection procedure.
12 Each poor reader showed poor performance on at least one of the reading measures (minimum of
13 1.5 SD below the mean). Normal readers had no reading measure inferior to -1.5 SD. By design,
14 the poor achievers showed both poor reading and poor spelling skills, which is by far the most
15 frequent association in French poor readers (Fayol et al., 2009).

16 We first focused on this population of 281 participants to explore the contribution of PA,
17 RAN and VAS to literacy skills. To address the prevalence issue, we restricted the poor reader
18 population to a sample of 110 children whose IQ and oral language skills matched those of the
19 normal readers to focus on children with more “specific” reading difficulties.

20

21 **Material**

22 *Collective Screening Tasks*

23 **Lexical Knowledge.** An irregular-word spelling task and an orthographic forced-choice
24 task were administered to assess word-specific orthographic knowledge in our participants. In the
25 former, children were asked to spell 37 irregular words in gapped sentences. All words included
26 at least one phoneme associated to a relatively infrequent grapheme (e.g., **h**iver-/ivÈr/, glaçon-

1 /glasø/) or a rare grapheme (e.g., **clown**-/klun/, **monsieur**-/møsjø/) which could not be inferred
2 from the phonemic analysis of the oral input. Words were first pronounced alone, then in a
3 sentence and finally repeated alone for the child writing them down. The score corresponded to
4 the number of words spelled accurately (max score = 37; Chronbach's alpha = .91). In the latter,
5 participants had to select the correct spelling of a word among three homophonic spellings (e.g.,
6 lycé, lycer, lycée -/lise/). For each of the 42 triplets, the two homophonic spellings were built up
7 by application of phoneme-grapheme correspondences that were attested in French for the target
8 position (beginning, internal or ending). One point was allocated for each target correctly identified
9 (max=42; Chronbach's alpha = .81).

10 **Sublexical Knowledge.** A pseudo-word spelling task and a homophonic judgment task
11 were administered to assess knowledge of letter-sound mapping. Twenty isolated pseudo-words
12 were dictated to the participants one at a time, then written down by the child. Half pseudo-words
13 included phonemes that translated into different graphemes depending on the context (e.g.,
14 **ambrusson**-/ãbrysø/, **guivette**-/givet/). None of the pseudo-words were neighbors of real words.
15 All were phonotactically legal. Each pseudo-word was pronounced twice, then written down by
16 the child. One point was allocated for any spelling that sounded like the dictated pseudo-word
17 (e.g., each of "flossaque, flossac, floçaque, flaussaque, flossak" are plausible spellings for /flosak/
18 score max=20; Chronbach's alpha = .77). In the oddity homophonic judgment task, participants
19 had to identify the pseudo-word among three that did not sound as the other two in 21 triplets of
20 orthographically dissimilar items (e.g., "zau" /zo/- "sau" /so/- "ceau" /so/). The children were asked
21 to silently read the three pseudo-words, then to identify and tick off the pseudo-word that
22 differently sounded ("zau" in the example). All items were orthographically legal. One point was
23 assigned to each accurate target identification (score max=21; Chronbach's alpha = .79).

24 **Vocabulary, Oral Comprehension and Intellectual Efficiency Assessment.** Vocabulary
25 was assessed using a forced-choice paradigm in a hand-made semantic judgment task on 30 target
26 words. For each oral target word (e.g., "beast"), the child had to select a synonym among 5 orally

1 named pictures (e.g., “animal”, “wolf”, “egg”, “cannibal”, “dictation”). For each target, the four
2 distractors were a close and a distant semantic neighbor (e.g., "wolf" and "egg"), a phonological
3 distractor of the synonymous target (e.g., "cannibal") and an unrelated word (e.g., "dictation").
4 The target word and the alternatives were read aloud by the experimenter and the child was asked
5 to make a cross in front of the synonym. The score was the total number of synonyms accurately
6 identified (score max=30; Chronbach’s alpha = .81).

7 Oral comprehension was assessed using a subset of the ECOSSE test (Lecocq, 1996) in
8 which the child was asked to select the image among four that best matched an oral sentence.
9 Twenty sentences were successively uttered by the experimenter. At each trial, the child responded
10 by ticking off the picture that best matched the oral sentence (score max=20). Finally, the Raven
11 Matrices test (PM38) assessed reasoning abilities taken as a measure of intellectual efficiency.

12

13 *Individual Screening Tasks*

14 **Reading Assessment.** Reading skills were assessed using tasks of isolated word and
15 pseudo-word reading, taken from the ODEDYS neuropsychological battery (Jacquier-Roux et al.,
16 2002). Participants were administered lists of 20 low-frequency irregular words and 20 pseudo-
17 words. The participants were instructed to read aloud each list as quickly and as accurately as
18 possible. The Alouette reading test was administered to estimate the children’s reading level
19 (Lefavrais, 1965). Finally, a more conventional text-reading task was administered to assess
20 reading fluency. Children were asked to read aloud a 100-word text as quickly and accurately as
21 possible within the 1-minute time limit. For all the reading tasks, the score was the number of
22 words correctly read per minute.

23 **Phoneme Awareness.** Tasks of phoneme deletion and spoonerisms were administered. In
24 the former, participants had to delete a specific phoneme from either a word or a pseudo-word
25 (e.g., Say the word “piste” /pist/ without the /s/ or, say the invented word “clire” /klir/ without the
26 /l/). The fourteen experimental words and the 14 pseudo-words were presented in two blocks (score

1 max=28; Chronbach's alpha = .79). The spoonerism task required switching the first phonemes of
2 two words and pronouncing the resulting pseudo-words (e.g., /fanan-bisɛl/ from the word pair
3 /banan-fisɛl/ "banana-string" (score max=10; Chronbach's alpha = .89). Accuracy was recorded
4 for each task.

5 **Visual Attention Span.** The conventional tasks of global and partial letter report were used
6 to assess VA span abilities (Bosse et al., 2007). In global report, participants were asked to report
7 as many letters as possible from 5-consonant strings (e.g., RHSDM; angular size = 5,4°) that were
8 presented at the center of the screen for 200ms. In partial report, each briefly presented 5-letter
9 string was immediately followed by a retro-cue -- a vertical bar displayed for 50ms 1.1° below the
10 target letter—that indicated which letter should be reported. The dependent measure was the
11 percentage of target letters accurately reported (identity not location) across the 20 trials (max raw
12 score=100; Chronbach's alpha = .89) in global report and across the 50 trials in partial report (max
13 raw score=50; Chronbach's alpha = .84).

14 **Letter Identification Control Task.** To control for single letter processing skills, each of
15 the letters used in the report tasks were randomly presented at 5 different presentation durations
16 (33, 50, 67, 84 and 101ms), immediately followed by a mask. Ten letters were displayed at each
17 time duration. Participants were asked to name each letter immediately after its presentation. The
18 total score was computed as the sum of the weighted scores at each display duration (score at 33ms
19 * 5 + score at 50ms *4 + score at 67ms *3 + score at 84ms *2 + score at 101ms).

20 **Rapid Automated Naming (RAN).** The RAN task required the rapid naming of a visual
21 array of 50 digits build up from 10 digits that were repeated 5 times each. The participants were
22 asked to name the digits as accurately and as fast as possible. The dependent variable was the total
23 time taken to name the items.

24

25 **Procedure**

1 All 948 participants were first engaged in a two-hour collective screening that assessed
2 their lexical and sublexical orthographic knowledge to select two groups of poor readers/spellers
3 and normally achieving pupils. A short break was proposed every 30 minutes and on request if
4 necessary. The screening was conducted in classrooms with the participation of previously trained
5 teachers.

6 After the selection (see previous sections), the selected children of the two groups were
7 individually assessed for their reading skills to properly define two groups of poor and average
8 readers. The individual assessment took place in a quiet room of the school with a research
9 assistant.

10 The investigation was carried out in close collaboration with the “Rectorat de Grenoble”
11 (the local Education Authority). Parents were informed of the screening procedure and study
12 purpose. Their written informed consent was obtained, authorizing their child’s participation. The
13 pupils were orally informed by their teachers. The protocol was agreed by the local ethic comity
14 for non-interventional studies (CERNI) of the Grenoble-Alpes University. A CNIL (Commission
15 Nationale de l’Informatique et des Libertés) approval (approval number: N0820589) was obtained
16 that guarantees the rights of the participants in terms of privacy, data protection and anonymity.

17

18

Results

19

20 Overview of the Participants’ Performance

21 *Descriptive Results*

22 Table 1 shows an overview of the performance of the two groups of 162 poor and 119 normal 6th
23 grade readers for the collective and individual tasks.

24 The poor readers were 4 months older on average than normal readers due to higher occurrence
25 of grade repetition.

26

27

1 Table 1
 2 Comparison of the two groups of poor (N=162) and normally achieving (N=119) 6th grade
 3 readers

		Poor readers Mean (SD)	Average readers Mean (SD)	t (279)
<i>Collective screening</i>				
Chronological Age (CA)	months	144.9 (6.6) ***	140.9 (5.9)	5.3
Raven matrices (Raven)	max=60	34.9 (5.8) ***	38.6 (5.4)	-5.3
<i>Lexical Composite Score</i>	%	53.0 (14.5) ***	74.9 (9.9)	-14.2
Word spelling	max=37	13.3 (6.4) ***	23.2 (5.4)	-13.5
Orthographic forced-choice	max=42	29.4 (6.0) ***	36.6 (3.3)	-11.8
<i>Sublexical Composite Score</i>	%	51.9 (15.1) ***	70.7 (11.6)	-11.3
Pseudo-word spelling	max=20	10.5 (4.0) ***	14.0 (2.9)	- 8.1
Pseudo-homophone judgment	max=20	10.8 (3.3) ***	14.9 (3.3)	-10.4
<i>Vocabulary</i>	max=30	16.0 (4.9) ***	18.5 (4.5)	- 4.3
<i>Oral Comprehension</i>	max=20	16.9 (1.8) ***	17.8 (1.4)	- 4.1
<i>Individual Screening</i>				
<i>Reading</i>				
Reading Age (RA)	months	107.1 (12.4) ***	137.9 (17.0)	-17.6
Irregular Word				
Score (IW _{sc})	max=20	14.0 (3.4) ***	18.1 (1.7)	-11.9
Time (IW _t)	sec	31.7 (15.0) ***	18.9 (5.3)	8.9
Fluency (IWf)	w/min	32.4 (17.5) *	63.0 (20.7)	-13.4
Pseudo-Word				
Score (IW _{sc})	max=20	15.7 (2.4) ***	18.1 (1.1)	-10.1
Time (IW _t)	sec	34.2 (10.9) ***	23.2 (5.7)	10.0
Fluency (IWf)	w/min	30.0 (9.2) ***	50.0 (14.8)	-14.0
Text Passage	w/min	111.2 (29.0) ***	166.2 (31.2)	-15.2
<i>Phonemic Awareness (PA)</i>				
Phoneme deletion				
Words (WDEL)	max=14	10.2 (2.6) ***	12.3 (1.4)	-8.1
Pseudo-Words (PWDEL)	max=14	9.6 (3.1) ***	12.1 (1.8)	-7.8
Spoonerisms (SPO)	max=10	6.3 (2.4) ***	8.4 (1.6)	-8.1
<i>Rapid Naming (RAN)</i>				
Digit Naming	sec	26.6 (5.3) ***	23.2 (3.9)	6.0
<i>Visual Attention Span (VAS)</i>				
Global Report (GLOR)	max=144	92.2 (15.8) ***	105.2 (15.2)	-5.4
Partial Report (PAR)	max=72	45.9 (9.8) ***	52.0 (7.9)	-4.3
<i>Control task</i>				
Letter identification (LET)	%	93.3 (5.5) ^{ns}	94.5 (5.4)	-1.8

4

5 Note: * $p < .05$; *** $p < .0001$

6

1 They performed significantly lower on vocabulary, oral comprehension and Raven tasks. As a
2 consequence of our selection criteria, they showed both lower lexical (i.e., word spelling and
3 orthographic forced-choice) and lower sublexical (i.e., pseudo-word spelling and pseudo-
4 homophone judgment) knowledge. Individual screening showed that they further exhibited lower
5 performance on all the reading measures and lower performance in PA and RAN tasks. Their VAS
6 was lower than for the average readers despite normal single letter processing skills.

7

8 *Correlation Analyses*

9 Simple and partial correlation analyses were conducted on all the measures for the full
10 sample of 281 participants. Because of our initial selection of two distinct groups of poor and
11 average spellers, analyses were first performed to test whether the data on the different variables
12 were normally distributed. When required, time and score data were log- and Arcsine-
13 transformed respectively to meet normality assumption. After transformation, all the reading
14 measures based on the number of items accurately read by minute were found to be normally
15 distributed. On account of significant correlations of chronological age (CA) and Raven score
16 (IQ) with the reading measures, partial correlations were carried out controlling for these two
17 variables. A Holm-Bonferroni correction was applied (Holm, 1979). Results of the simple and
18 partial correlation analyses are provided on Table 2.

19

20 Partial correlation analyses show reliable and significant correlations between the reading
21 measures and phoneme awareness, visual attention span and rapid automatized naming. Rapid
22 automatized naming does not correlate with any of the measures of phoneme awareness, but
23 slight and significant correlations are found between VAS and some of the PA measures.

1 **Table 2:** Simple and partial correlations (bellow the diagonal, controlling for chronological age (CA) and Raven score (IQ)) among reading
 2 fluency, phoneme awareness, visual attention skills and rapid naming for all participants (N=281). Simple correlations with the factor coefficients
 3 from the PCA analysis are further provided

	RA	LET	Lex	Suble x	Text	IW _f	PW _f	WDE L	PWD EL	SPO	GLOR	PAR	RAN	PA _f	VAS _f	RAN _f
QI	.25*	.18	.25*	.29*	.24*	.25*	.19*	.20*	.21*	.21*	.21*	.17	-.03	0.21*	0.18*	0.01
CA	-.23*	-.09	-.28*	-.27*	-.22*	-.21*	-.17	-.14	-.16	-.12	-.20*	-.05	0.11	-0.15	-0.11	0.11
LET	0,13	--	0,16	0,16	0,12	.17	.17	.02	.11	.07	.19*	.26*	-.12	0.02	0.25*	-0.05
Lex score	0,70*	0,12	--	.60*	.74*	.75*	.63*	.44*	.38*	.45*	.40*	.31*	-.30*	0.42*	0.30*	-0.23*
Sublex score	0,51*	0,11	0,52*	--	.57*	.55*	.50*	.40*	.39*	.45*	.24*	.19*	-.24*	0.44*	0.14	-0.18*
Reading																
Text	0,85*	0,06	0,67*	0,49*	--	.75*	.71*	.47*	.39*	.42*	.41*	.28*	-.48*	0.43*	0.27*	-0.41*
IW _{wpm}	0,73*	0,13	0,71*	0,49*	0,74*	--	.68*	.43*	.36*	.42*	.39*	.33*	-.36*	0.39*	0.30*	-0.28*
PW _{wpm}	0,78*	0,13	0,59*	0,47*	0,72*	0,69*	--	.35*	.32*	.38*	.43*	.33*	-.50*	0.31*	0.32*	0.43*
Phonology																
WDEL	0,38*	-0,03	0,34*	0,31*	0,39*	0,36*	0,31*	--	.71*	.51*	.24*	.23*	-.13	0.87*	0.11	-0.01
PWDEL	0,33*	0,09	0,30*	0,33*	0,31*	0,29*	0,28*	0,68*	--	.55*	.26*	.29*	-.13	0.88*	0.16	-0.01
SPO	0,36*	-0,01	0,35*	0,40*	0,33*	0,32*	0,33*	0,48*	0,52*	--	.29*	.26*	-.19*	0.75*	0.16	-0.16
VA span																
GLOR	0,37*	0,17	0,32*	0,16	0,37*	0,34*	0,42*	0,17	0,19	0,23*	--	.56*	-.29*		0.83*	0.24*
PAR	0,27*	0,25*	0,27*	0,16	0,25*	0,29*	0,27*	0,23*	0,27*	0,19*	0,51*	--	-.15		0.89*	0.06
Rapid Naming																
RAN (digits)	-0,51*	-0,14	-0,29*	-0,22*	-0,52*	-0,39*	-0,54*	-0,10	-0,13	-0,17	-0,30*	-0,17	---		0.14	0.96

4 Note: *p<.0028 (Holm-Bonferroni Correction); RA= Reading Age; RAN= Rapid digit Naming; IW_f= irregular word fluency (number of words
 5 accurately read per minute) ; PW_f= pseudo-word fluency; WDEL= phonemic deletion on words; PWDEL= phonemic deletion on pseudo-words;
 6 SPO=spoonerism; LET= single letter Identification threshold; GLOR= Global report; PAR= partial report; PA_f=PA factor from the ACP; VAS_f=
 7 visual attention span factor; RAN_f= rapid naming factor.

1 **Predictors of Literacy Skills**

2 *Factor Analysis*

3 A principal components analysis was conducted to reduce the data set before exploring the
4 incidence of PA, VAS and RAN disorders on the whole population of 281 children. We used a
5 Varimax rotation (mini. eigenvalue = .85) on the data from the three PA tasks, the two VAS scores
6 and rapid digit naming. All factor loadings greater than 0.70 were used for interpretation. The
7 analysis revealed a three-factors solution. The first factor (called PA factor hereafter) accounted
8 for 46 % of total variance (eigenvalue = 2.64) and received high loadings from phoneme deletion
9 (on both words and pseudo-words) and spoonerisms. The second factor (called VAS factor; 32 %
10 of total variance; eigenvalue = 1.22) received high loadings from global and partial report. The
11 third RAN factor accounted for 22% of the total variance (eigenvalue = 0.84). The three factors
12 accounted cumulatively for 78.8% of total variance.

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14 *Hierarchical Regression Analyses*

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16 Individual factorial coefficients derived from the factorial weights of the Principal
17 Components Analysis were used to explore the concurrent predictors of literacy skills in the whole
18 population. Hierarchical regression analyses were used. For each outcome reading variable
19 (irregular word, pseudo-word and text reading), controlled measures of chronological age, Raven
20 score, oral comprehension and single letter identification were first entered in the equation, then
21 the three factors of interest (i.e., PA, VAS and RAN). A Shapiro-Wilk test showed normality of
22 the residuals for all the regression models. The unique contribution of each factor to each reading
23 variable – estimated by the incremental R^2 for each significant factor when entered last in the
24 analysis – is shown on Table 3.

25

Table 3: Results of hierarchical linear regression analyses computed on the whole sample (N=281), with the Irregular Word (IW), Pseudo-Word (PW) and Text Reading fluency as dependent variables; the ΔR^2 columns present the incremental R^2 for each significant factor when entered after all the other factors in the analysis, representing the unique contribution of that factor to the dependent variable.

Dependent variable:	IW reading			PW reading			Text reading		
Equation synthesis:	R = 0.60; Adj.R ² = .35; (F(7,273) = 22.23***)			R = .68; Adj.R ² = .43; F(7,273)=31.51***			R = .68; Adj.R ² = .45; F(7,273) = 32.79***		
Factors :	β	t (273)	ΔR^2	β	t (273)	ΔR^2	β	t (273)	ΔR^2
CA	-.005	-0.33		.001	0.07		.00	0.28	
Raven	.025	1.52		.011	1.12		.02	1.99*	.01
LET	.497	1.05		.140	-0.48		-.21	-0.74	
COMP	.020	2.19*	.01	.045	0.78		.11	2.04*	.01
PA factor	.605	6.60***	.10	-.364	6.35***	.08	.40	7.34***	.11
RAN factor	-.569	-6.44***	.10	-.596	-10.76***	.23	-.54	-10.04***	.20
VAS factor	.475	5.15***	.06	.359	-6.21***	.08	.31	5.34***	.06

Note: CA= chronological age; LET=isolated letter identification threshold; COMP= comprehension; PA= phoneme awareness; RAN= rapid automatized naming; VAS= visual attention span. * = $p < .05$; ** = $p < .01$; *** = $p < .001$

The total model R^2 values ranged from 0.35 for irregular word reading to 0.43 for pseudo-word reading and 0.45 for text reading (all $ps < .001$). Beyond chronological age, IQ, single letter identification skills and oral comprehension, all three cognitive processes (PA, VAS and RAN) accounted for a significant and unique part of variance in the three reading subskills. The children who named digits faster showed higher reading skills, whatever their PA and VAS abilities. The unique contribution of RAN accounted for 23% of variance in pseudo-word reading, 20% in text reading and 10% in irregular word reading. Having higher PA skills independently favored higher reading performance, as shown by the significant 10%, 8%, and 11% of variance in irregular word, pseudo-word and text reading that was uniquely explained by the PA factor. Beyond PA and RAN, the VAS factor was an additional independent predictor of reading performance, accounting for 6% of unique variance in irregular word and text reading and 8% in pseudo-word reading. The overall results show that PA, VAS and RAN are independent concurrent predictors of reading performance.

1

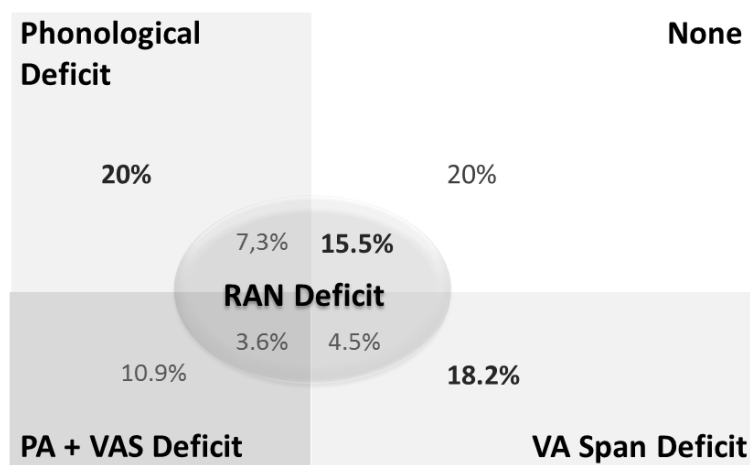
2 **Prevalence of the Cognitive Deficits**

3 The prevalence issue was examined on a subset of 110 out of the 162 poor readers, who
 4 were matched to the controls in cognitive efficiency and oral language skills. The new group of
 5 poor readers did not differ from the controls (all $ps \geq .05$) in either IQ (Raven scores; meanpr =
 6 37.4, SD = 5.1 vs. meannr = 38.6, SD = 5.4, for poor and normal readers respectively), vocabulary
 7 skills (meanpr = 16.8, SD = 4.5 vs. meannr = 18.5, SD = 4.5), oral comprehension (meanpr = 17.2,
 8 SD = 1.8 vs. meannr = 17.8, SD = 1.4) and single letter identification (meanpr = 93.3, SD = 5.5
 9 vs. meannr = 94.5, SD = 5.4).

10 Figure 2

11
 12 Repartition of the 6th grade poor readers according to their VA span, phonological and RAN
 13 factorial coefficients derived from the Principal Components Analysis. In bold, the proportion of
 14 children with a unique deficit.

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18 The new group performed similarly as the initial group of 162 poor readers on all the other
 19 variables, showing significantly lower performance than the controls. To establish the incidence
 20 of each type of disorders, we analyzed the distribution of the individual PA, VAS and RAN factor
 21 coefficients derived from the Principal Components Analysis. The poor readers whose scores fell
 22 below the 10th percentile of the normal reader group factorial coefficients were considered as

1 having a cognitive deficit, either a VAS (coef. $< -.82$), a PA (coef. $< -.65$) or a RAN (coef. $< -.65$)
2 deficit.

3 As illustrated on Figure 2, most poor readers (53.7%) were found to exhibit a unique
4 deficit, either a unique PA deficit (20%), a unique VAS deficit (18.2%) or a unique RAN deficit
5 (15.5%). Some children exhibited a double deficit, either a PA and VAS deficit (10.9%), or a PA
6 and RAN deficit (7.3%) or a RAN and VAS deficit (4.5%). Only 3.6% showed a triple disorder
7 while 20% of the participants exhibited none of them. A substantial proportion of poor readers
8 showed a VAS or a RAN deficit in the absence of PA deficit. Overall, 41.8% poor readers had a
9 PA disorder (isolated or not), 37.3% a VAS disorder and 31% a RAN disorder.

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Discussion

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The present study aimed at determining whether a VAS disorder was a unique predictor of reading performance, independently of PA and RAN abilities, and whether a variety of cognitive profiles could be identified in poor readers, including a subtype with a single VAS deficit. We started from a large sample of children to identify a subset of children who did not reach the expected competence level in literacy. This population of poor readers was likely to include both children with delayed reading skills and children with specific reading disorders (or developmental dyslexia). Results show that VAS independently contributed to the participants' poor reading outcome and that all three skills (PA, VAS and RAN) were concurrent and independent predictors of reading performance. To circumscribe the population to children with "pure" reading disorders, we then focused on a reduced sample of 110 poor readers who were matched in IQ and language skills (oral comprehension and vocabulary) with average readers. Most poor readers (53.7%) were found to exhibit a single deficit and a balanced picture emerged with 20.0% children exhibiting a unique PA deficit, 18.2% a unique VAS deficit and 15.5% a unique RAN deficit.

Independent Contribution of VAS to Reading

1 We first explored whether VAS remained as a concurrent predictor of reading after control
2 of both PA and RAN. The current findings are unequivocal. VAS was a significant explanatory
3 factor for all reading subskills (irregular word, pseudo-word and text reading), independent from
4 PA and RAN that were additional independent predictors. Very similar findings were previously
5 reported for the Dutch language (van den Boer et al., 2013, 2014, 2015), suggesting that the
6 contribution of VAS to reading extends to languages that differ in orthographic transparency. The
7 unique VAS contribution to both irregular word and pseudo-word reading fluency fits well with
8 previous interpretations on the role of VAS in reading acquisition (Bosse et al., 2007; Valdois et
9 al., 2004, 2019). On the one hand, children with higher VAS, thus higher multi-element parallel
10 processing skills, are expected to process longer orthographic units more efficiently, which would
11 result in more efficient processing of long graphemes and syllables, thus more accurate and faster
12 pseudo-word reading. On the other hand, higher VAS abilities would facilitate parallel processing
13 of the whole word letter-string, thus contributing to irregular word reading. VAS is known to
14 reflect the amount of visual attention allocated to processing and how visual attention distributes
15 over the letter string during reading (Lobier et al., 2013; Ginestet et al., 2019). Neuroimaging data
16 support this interpretation, showing that VAS abilities relate to brain regions that are part of the
17 dorsal attentional network (Lobier et al., 2012, 2014; Peyrin et al., 2011, 2012; Reilhac et al., 2013;
18 Valdois et al., 2019) but do not belong to the phonological brain network. Overall, assuming that
19 VAS contributes to letter identification within strings and visuo-orthographic processing in
20 reading while PA relates to phonemic processing and phonological decoding (Zoubrinetzky et al.,
21 2016) may well account for their independent contribution to reading.

22 The current findings further show that RAN performance accounts for a part of variance in
23 reading beyond that explained by VAS and PA. This finding is well in line with the huge amount
24 of data showing that RAN is a strong predictor of reading fluency (Landerl et al., 2019; Moll et
25 al., 2014). However, the underlying causal mechanisms that explain the relationship between RAN
26 and reading remain to be identified.

1

2 **Heterogeneity of Cognitive Profiles in Poor Readers**

3 A second main contribution of our work is to show the existence of multiple profiles of
4 poor readers and provide evidence that a non-trivial number of poor readers/spellers exhibit a
5 single VAS deficit. Our population of poor readers was selected from a large sample of children
6 that was representative of French pupils to increase confidence in current estimations and avoid
7 recruitment bias. Most poor readers/spellers were found to exhibit a single deficit of either VAS,
8 PA or RAN. Other subsets showed either a double or no deficit and a few children exhibited a
9 triple deficit. These findings agree with the relatively strong dissociation between PA and VAS
10 previously reported in dyslexic individuals (Bosse et al., 2007; Germano et al., 2014; Zoubrinetzky
11 et al., 2014, 2016), but they contrast with those of Saksida and collaborators (2016) who reported
12 a phonological deficit in most of their dyslexic participants and no evidence for a dissociation
13 between PA and VAS deficits. The impact of poor PA on poor reading outcome was also
14 emphasized by Carroll and collaborators (2016) in their follow-up of a large population of children
15 from school entry to third grade. However, in line with current findings, they reported a PA
16 problem in only a subset (less than a third) of poor readers. The overall data suggests that the
17 prevalence of PA disorders may have been overestimated in some previous studies (probably due
18 to recruitment bias or methodological issues). The contribution of PA to reading acquisition is
19 firmly established (Caravolas et al., 2012; Hulme et al., 2012) and there is consistent support for
20 the existence of a subset of poor/dyslexic children with a single PA deficit (Bosse et al., 2007;
21 Zoubrinetzky et al., 2014). However, our findings in line with many previous ones (Carroll et al.,
22 2016; O'Brien et al., 2012; Pennington et al., 2012) clearly support a multiple cognitive deficit
23 view of poor reading outcome and developmental dyslexia.

24 Nevertheless, a non-trivial proportion of poor readers were found to exhibit no deficit in
25 either PA, RAN or VAS. Future research is needed to determine whether some poor readers suffer
26 from another kind of deficit, not considered in the present study, or whether their poor performance

1 only reflects delay in reading acquisition due to environmental factors. Other factors than PA,
2 RAN or VAS can affect reading skills. Crowding is such a factor. Some poor/dyslexic readers
3 exhibit excessive visual crowding, which leads to impaired recognition of letters when surrounded
4 by other letters (Callens et al., 2013; Bertoni et al., 2019; Spinelli et al., 2002). Excessive crowding
5 has a detrimental effect in reading, leading to slower speed and reading errors (Spinelli et al., 2002;
6 Martelli et al., 2009). Part of our population of poor readers may have suffered from excessive
7 visual crowding. Another limit of the current study is that no information was collected on the
8 participants' family socio-economic status (SES). Children from lower SES are less likely to
9 engage in reading activity, which limits their reading experience and exposure to print
10 (Hemmerechts et al., 2017). Limited print exposure has detrimental effects on the growth in
11 reading skills (Cunningham & Stanovich, 1997), which might explain the existence of poor readers
12 who otherwise show no cognitive deficits per se.

13

14 **Implications in Education**

15 Evidence for multiple cognitive profiles of poor readers opens new perspectives for the
16 prevention and remediation of reading difficulties. In particular, the current findings lead to
17 question the limits of large-scale intervention programs that target phoneme awareness based on
18 the implicit assumption that these trainings are appropriate for all children. There is ample
19 evidence from meta-analyses of intervention studies that PA training reliably enhances reading
20 skills (Bus & van Ijzendoorn, 1999; Ehri et al., 2001; Melby-Lervåg et al., 2012; Torgesen, 2002).
21 There is no doubt that PA training is particularly useful at the preschool level and at the beginning
22 of literacy instruction, but there is also evidence that PA training is not sufficient to achieve
23 substantial improvements in all children, in particular in the older and disabled children (Ehri et
24 al., 2001). In showing that poor readers are a cognitively heterogeneous population, our findings
25 suggest that PA/phonics interventions should be more effective if provided to children with poor

1 PA skills. Our findings further suggest that children who exhibit good PA but poor VAS should
2 benefit more from VAS-targeted intervention programs.

3
4 Evidence that a subset of poor readers failed to develop normal VAS abilities highlights
5 the need for new intervention programs appropriately designed to target VAS. Advances in
6 research on developmental dyslexia provide some insights on how VAS might be improved.
7 Indeed, positive effects on VAS and reading have been reported following intensive training using
8 the COREVA© Visual Exercise Battery or the MAEVA© software in dyslexic children (Valdois
9 et al., 2014; Zoubrinetzky et al., 2019). These previous intervention studies suggest that
10 progressive increase in the number of items to be simultaneously processed and progressive
11 decrease of available processing time are two features that are critical to enhance VAS abilities.

12 These two features also apply to action video games. Playing action video games has
13 positive effects on several cognitive skills, in particular visual attention (Bediou et al., 2018, for a
14 review). Furthermore, there is some evidence that intensive (but short) action-video-game training
15 when provided to dyslexic children improves their reading skills (Franceschini et al., 2013, 2017).
16 The effect of action video games on reading might be at least in part mediated by positive effects
17 of action video games on VAS. Indeed, action video game players show both faster reading and
18 higher VAS than non-players (Antzaka, et al., 2017). Armed with knowledge on the features to
19 be targeted to improve VAS performance in dyslexic children and knowledge about the basic
20 principles that define action video games and enhance visual attention, future research would be
21 able to design effective educational games that tap VAS abilities. VAS-targeted interventions
22 should be all the more appropriate for the prevention or remediation of reading difficulties that
23 recent evidence from longitudinal and training studies suggests that VAS may causally relate to
24 reading (Valdois et al., 2014, 2019; Zoubrinetzky et al., 2019).

25

1 Targeting the cognitive deficit in poor/dyslexic readers does not preclude from providing
2 additional trainings that directly tap reading skills, as reading fluency or comprehension
3 interventions (Galushka et al., 2014; Suggate, 2016). The rationale is that improving the basic
4 cognitive skills on which reading relies is a necessary step to improve word processing while
5 reading. Such training must be supplemented by increased exposure to print and additional reading
6 activities that will benefit to all poor readers.

7

8

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