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# Predicting Future Poor Readers from Pre-reading Visual Skills: A Longitudinal Study

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# **Predicting Future Poor Readers from Pre-reading Visual Skills:**

## **A longitudinal study**

### **ABSTRACT**

Reading is essential for learning, from literature to physics, from paper to screens on e-readers and smart phones. Even if it is well known that learning to read implies good language skills, children also need to develop good oculomotor and visual-perception skills. Thereby, any deficits in visual processing may affect learning. The possible impact of visual deficits is rarely considered, especially with regard to eye movements and visual perception. Hence, these deficits are usually discovered much later or remain undiagnosed. The present study aimed at assessing the usefulness of visual processing related measures in the early detection of reading difficulties. Visual skill differences that are apparent early in kindergarten might provide predictive insights into risk for learning difficulties at school entry. We used a prospective, longitudinal approach where visual processes (assessed with the Developmental Eye Movement (DEM) test) were measured in 51 preschoolers, and the impact of these processes on future reading development was explored one year later, in Grade 1. Results showed that (1) 31% of our sample of preschoolers showed visual processing impairments (without any clinical complaints) and (2) reading accuracy and speed in first graders were significantly correlated with visual skills assessed in kindergarten, thus confirming the significant role of oculomotor and visual-perception processes in the acquisition of reading skills. These suggests the potential for these measures to be used clinically for identifying children at risk for low academic achievement, enabling appropriate targeting of early interventions.

Keywords: Longitudinal study; Reading acquisition; Kindergarten; Visual information processing; Eye movements; DEM-test; Preliteracy skills

## 25           **INTRODUCTION**

26           Although reading is rapid and automatic in skilled readers, in beginning readers it  
27 emerges only as a result of the complex and effortful interaction between perceptual/oculomotor  
28 processes and language processing (Schatschneider et al., 2004). These processes rely on  
29 children's grasp of fundamental skills, such as visual perceptual skills, spoken language skills,  
30 short-term memory and accurate eye control skills, that develop during the preschool years  
31 before the beginning of formal reading instruction (Nicolson & Fawcett, 2010; Pollatsek &  
32 Rayner, 2005; Rayner & Liversedge, 2011; Ziegler et al., 2008).

33           While a good deal of recent research has focused on the role of phonological skills in  
34 learning to perceive written language, little attention has been paid to the development of visual  
35 skills<sup>1</sup> in prereaders or about the role that these visual skills play in early reading development.  
36 However, reading is a visual task, highly constrained by the anatomical and functional limits of  
37 our visual system (for reviews, see Leibnitz et al., 2015, 2017). Whereas it is likely that both  
38 phonology and visual processes contribute to skilled reading acquisition and its dysfunction,  
39 few studies have been conducted to examine oculomotor and visuo-perceptual processes related  
40 to word recognition skills in children as they learn to read. This paper is therefore focused upon  
41 those processes and on their potential as explanation of reading behaviour and reading problems  
42 in the context of general emergent literacy skills.

### 43           **The importance of visual processing in reading**

44           Previous researchers have found high overlaps between visual skills and domain-general  
45 cognitive skills (e.g., sustained attention, nonverbal reasoning, and inhibitory control) (Buckley  
46 et al., 2018; Yang et al., 2019), as well as rapid automatic naming (RAN; Yang et al., 2020).

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<sup>1</sup> By visual skills or visual processing, we do not mean visual acuity but rather a complex visual and/or visuo-attentional mechanism specific to the reading activity

47 For sighted people, written language is perceived visually. The high visual acuity that is needed  
48 to rapidly identify words is spatially limited (Lee et al., 2003; Rayner & Bertera, 1979; Rayner  
49 & Morrison, 1981) and most studies today agree about the link between visual attention and  
50 oculomotor control during reading: visual attention affects saccadic programming, that is, the  
51 position where the eyes land in a word and acts as a filter that enhances letter identification  
52 under the attentional focus, thus limiting the detrimental effects of acuity and crowding  
53 (Carrasco, 2011; Strasburger, 2005; Tydgate & Grainger, 2009; Yeshurun & Rashal, 2010). One  
54 of the first tasks of the beginning reader is therefore to develop good oculomotor skills to  
55 overcome anatomic-functional constraints of the eye and be able to land in the best position  
56 within the words to be read, to extract the information being fixated, to program a saccade, to  
57 position the eyes on the next word, and so on (Ducrot et al., 2013; O'Regan & Lévy-Schoen,  
58 1987; Rayner, 1986).

59 Furthermore, visual processing shapes the way visual information is extracted from print  
60 (Aghababian & Nazir, 2000; Ducrot et al., 2013). In order to process letters within foveal strings  
61 and to apply grapheme-to-phoneme conversion rules, beginning readers must be able, at first,  
62 to segment the fixated information by shifting from distributed attention to more focused  
63 attention. Secondly, the child has to detect and take into account letter orientation (e.g. p  
64 becomes q with an orientation change), letter sharpness (e.g. c and e only differ from each other  
65 by a visual feature) and letter-in-word order (the same set of letters can make different words,  
66 e.g. pat, tap, apt in English). Finally, the child has to develop to inhibit all surrounding letters  
67 and words to reduce visual crowding—that is the interference generated by stimuli in close  
68 proximity—and optimize letter identification under the attentional focus (Tydgate & Grainger,  
69 2009). It follows that basic aspects of oculomotor control (which provide optimal visual input),  
70 the ability to orient the focus of attention as well as the ability to control its size are assumed to  
71 play a crucial role in the development of reading skills (Ducrot et al., 2013; Grainger, 2018;

72 Leibnitz et al., 2017; Morris & Rayner, 1991) and that their inadequate development might be  
73 one cause of reading disabilities (e.g., Biscaldi et al., 2000; Fischer & Weber, 1990).

74         The idea of the implication of visual skills in learning to read is not a recent one  
75 (Morgan, 1896), but it remains an infrequently investigated issue. However, the findings from  
76 dyslexics and typically developing readers suggest a strong relationship between reading ability  
77 and visual processing skills (such as visual-perceptual, oculomotor and visual-attentional  
78 processes, for reviews, see (Bellocchi et al., 2013; Blythe & Joseph, 2011; Ducrot et al., 2013;  
79 Kulp & Schmidt, 1996a). For example, Yang and Meng (2020) longitudinally followed 108  
80 preschoolers and revealed a strong association between preschool visual processes and Grade  
81 1 reading outcomes, thus supporting the concept that visual performance is key to learning and  
82 more specifically to reading acquisition (see also González et al., 2014; Memiş & Sivri, 2016).

83         In the same vein, a body of research suggests that deficits in visual-perceptual or  
84 oculomotor processing may contribute to reading difficulties (Franceschini et al., 2012; Gori &  
85 Facoetti, 2015; Granet et al., 2006; Meng et al., 2011; Vidyasagar & Pammer, 2010; Zhou et  
86 al., 2014; see also Bellocchi et al., 2013, for a review). For example, children who have deficits  
87 in visual perception often cannot efficiently distinguish words printed in different sizes or colors  
88 (Fischer et al., 2000; Visser et al., 2004). In addition to poor performance on tasks requiring  
89 phonological awareness, children who had poor reading abilities may present visual perception  
90 deficits, e.g. (1) disturbances in contrast sensibility (Lovegrove et al., 1980), weak sensitivity  
91 in detecting coherent motion or forms (Cornelissen et al., 1995), letter identity confusions  
92 and/or location errors (Pelli et al., 2004; Whitney & Levi, 2011); distortion, blurring, merging  
93 or moving of letters or words (Kovács, 2000; Stein & Walsh, 1997), (2) oculomotor dysfunction  
94 (e.g., increased duration and number of fixations, reduced saccade amplitude, increased ocular  
95 regression leading to misread words, missing words and skipping lines (De Luca et al., 2002;  
96 Hutzler & Wimmer, 2004) and/or (3) visual attention impairments (e.g. problems focusing

97 attention, Kramer & Hinojosa, 1999; high sensitivity to the crowding effect, Martelli et al.,  
98 2009; Zorzi et al., 2012; symmetrical OVP curve, (Bellocchi & Ducrot, 2021; Ducrot et al.,  
99 2003) when they attempt to read (see also, Bosse & Valdois, 2009; Ducrot & Lété, 2008, 2020;  
100 Lallier et al., 2010; Lété & Ducrot, 2008). It also has been found that remediation based on  
101 training of oculomotor and visuo-attentional abilities improves reading abilities in dyslexic  
102 children (Caldani et al., 2020; Launay & Valdois, 2004; Lehtimäki & Reilly, 2005).

103

#### 104 **Predictors of reading development**

105 The findings from dyslexics and typically developing readers suggest that the problems  
106 children experience in learning to read during the elementary years and beyond are related to  
107 the preliteracy skills that they bring with them from preschool and kindergarten (e.g. Lonigan,  
108 2006; Wagner et al., 1994). It is generally accepted that phonological skills are important for  
109 the development of reading (for a review, see Kirby et al., 2008). Evidence that these skills are  
110 necessary precursors for learning to read, is that pre-reading children in kindergarten who score  
111 poorly on tests of phonemic awareness (i.e., the ability to recognize and manipulate individual  
112 speech sounds) and rapid automatic naming (RAN) are more likely to become poor readers over  
113 the next few years (Carroll et al., 2003; Lonigan et al., 2000; Parrila et al., 2004; Schatschneider  
114 et al., 2004)<sup>2</sup>.

115 As previously stated, the importance of phonological and orthographic skills in learning  
116 to read shouldn't overshadow the fact that a written or printed word is, above all, a visual  
117 stimulus, and visuo-attentional and oculomotor skills (which provide optimal visual input) may  
118 play a crucial role in successful reading development. If visual perception is not fully developed

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<sup>2</sup> It should be noted that other linguistic skills play important roles in successful reading acquisition, as knowledge of alphabetic letters (Lonigan et al., 2000; Parrila et al., 2004; Storch & Whitehurst, 2002) and word forms (Goodman, 1986; Lonigan et al., 2000).

119 by the time a child is in preschool, his or her ability to read (Flax et al., 1984; Kulp & Schmidt,  
120 1996a, 1996b), to spell, and to write (Borsting et al., 2005) may be affected. These visual  
121 disorders which often appear in the absence of complaints expressed by the subject or his/her  
122 family may lead to eye fatigue, increased tiredness of the child, blurriness, headaches, and/or  
123 burning eyes, and then, depending on their severity, to difficulty sustaining attention and focus.  
124 All of which may interfere with visual exploration, reading fluency and distract from reading  
125 comprehension.

126         Recent research suggests that in addition to skills with language sounds, visual-spatial  
127 attention may be an important predictor of reading development. Franceschini et al. (2012)  
128 showed that children who had poor reading abilities during the first or second year of reading  
129 education made significantly more errors on a visual-search task and a spatial-cueing task than  
130 normal readers had when they were in kindergarten. Moreover, poorly developed visual  
131 information processing skills, which refer to the cognitive abilities required to extract and  
132 organise visual input derived from the environment, have also been associated with poorer  
133 learning outcomes (Vinuela-Navarro et al., 2017; Wood et al., 2018). In an earlier study, Kavale  
134 (1982) performed a meta-analysis of 161 major studies relating visual perception and reading  
135 performance. His results indicated that visual perception is a significant correlate of reading  
136 achievement, and is predictive of reading performance in school, especially during the  
137 preschool and primary school grades. The initial landing position, the visual-attentional span  
138 and visual-motor skills also explain part of the variance in the reading abilities after one year  
139 of learning (Bellocchi et al., 2017; Bosse & Valdois, 2009; Chung et al., 2004; Ducrot et al.,  
140 2021; Kwon et al., 2007; Valdois et al., 2019). These various findings suggested therefore that  
141 visual and oculomotor processing is highly essential in the development of reading skills.

142

143         **The present study**

144 To sum up, in addition to the well-documented importance of phonological skills in  
145 reading acquisition and dyslexia, visual processes also appear as important factors in learning  
146 to read. Despite the evidence of 1) the importance of the oculomotor and visuo-perceptual  
147 processes in learning to read, and 2) data showing perceptual and oculomotor deficits in  
148 dyslexics, the assessment of these processes is not systematically carried out and many visual  
149 deficits still remain undetected in preschool children. We assume that it is crucial to be able to  
150 assess perceptual, and visuo-attentional prerequisites to reading development, in order to  
151 identify children at-risk for reading disabilities at an early age and increases the chance of  
152 success for charting later developmental trajectories (Jenkins et al., 2007; Shonkoff & Phillips,  
153 2000).

154 It therefore seems important to find a reliable and practical test that could assess visual  
155 processing skills in young children. At the current time, many tools available to professionals  
156 are designed to assess phonological abilities as early as kindergarten, but there are very few  
157 tools for assessing the relations between visual skills and the process of learning to read. In that  
158 context, we have examined the usefulness of the Developmental Eye Movement (DEM) test  
159 (Garzia et al., 1990) that provides an indirect measure of the efficiency of visual processes in a  
160 simulated reading task (horizontal and vertical digit naming task, providing reading time and  
161 errors) . This procedure was not chosen arbitrarily but in reference to previous work using the  
162 DEM-test with and without eye-movement recording (Ayton et al., 2009; Bellocchi et al., 2021;  
163 Facchin et al., 2011, 2014; Hopkins et al., 2019; Moiroud et al., 2018; Raghuram et al., 2019;  
164 Webber et al., 2011). It is important to keep in mind here that all studies on the DEM-test point  
165 agreed that visuo-perceptual and visuo-attentional processes play a major role in this task  
166 (Ayton et al., 2009; Facchin et al., 2011, 2014; Hopkins et al., 2019; Larter et al., 2004; Moiroud  
167 et al., 2018; Northway, 2003; Palomo-Álvarez & Puell, 2009; Portnoy & Gilaie-Dotan, 2020;  
168 Raghuram et al., 2018). Moreover, there is a consensus on the relationship between the DEM-



169 test and reading abilities, both in school-age children (Ayton et al., 2009; Larter et al., 2004;  
170 Palomo-Álvarez & Puell, 2009; Serdjukova et al., 2017; Wood et al., 2018) and in children with  
171 learning difficulties (Bellocchi et al., 2021; Moiroud et al., 2018; Northway, 2003; Raghuram  
172 et al., 2018). Note that Moiroud et al. (2018) with a video-oculography while performing the  
173 DEM-test, even demonstrated that the time taken by the children (dyslexic and non-dyslexic)  
174 to read Text C of the DEM-test was significantly correlated with children fixation ability and  
175 the speed of reading a text. Taken together, these results argue for a strong link between visual  
176 processing, performance of verbalization and the DEM-test to clinically assess the reading  
177 performance of children with and without reading deficiencies<sup>3</sup>.

178         In the present study, we examined the influence of visual processes in kindergarten on  
179 first graders decoding abilities. Specifically, we were interested in showing the importance of  
180 visual processes in a model for predicting emergent literacy in kindergarten and subsequent  
181 reading abilities in first graders. We here address this issue through the longitudinal follow-up  
182 of a cohort of typical children from kindergarten to first grade. The two specific questions  
183 addressed in this study were the following. First, what is the prevalence of visual deficits as  
184 assessed by the DEM test at age 5, before children start formal reading instruction? Secondly,  
185 does kindergarteners' visual skills significantly contribute to emergent literacy abilities and  
186 later reading abilities?

187

## 188         **METHOD**

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<sup>3</sup> Note that only two issues are still being discussed regarding the DEM-test, i.e. (1) is it secure to use the ratio measure (Medland et al. 2010; Raghuram & al., 2018 vs. Ayton & al., 2009; Portnoy & Gilaie-Dotan, 2020; Webber et al., 2011; Wood et al., 2018) and (2) is it possible to use the DEM test as a specific measure of saccadic control (Ayton et al., 2009; Webber et al., 2011 vs. Moiroud et al., 2018; Raghuram et al., 2019). We do not feel concerned here, since investigating eye movement control in children was clearly not the focus of interest of this paper.

189           **Participants.** Fifty-one French-speaking children, enrolled from kindergarten to the 1<sup>st</sup>  
190 grade, took part in this study. All the participants had normal or corrected-to-normal vision.  
191 None of them suffered from any neurological, psychiatric, or emotional disorders or were  
192 educationally disadvantaged. The children were recruited in three kindergartens located in the  
193 Aix-Marseille academy, in the south of France, and we obtained informed consent from their  
194 parents and the agreement of the board of education prior to the beginning of the study. The  
195 task was administered longitudinally. At Time 0, a total of fifty-one kindergarten children (26  
196 females; mean age 5.8 years; range 4.11 to 6.4) participated in the study. One year later,  
197 participants were retested, in May of the first grade, that is, at the end of the school year. The  
198 two testing sessions will hereafter be referred as test 0 (T0) and test 1 (T1). Thirty children (12  
199 females; mean age 6.10 years; range 6.4 to 7.3) were re-assessed in T1.

200

## 201           **Material and method.**

202           *Visual skills.* Visual and oculomotor skills were assessed using the DEM-test  
203 (Developmental Eye Movement Test; Garzia et al., 1990; Richman, 2009), which is composed  
204 by horizontal and vertical digit reading tasks printed on four different sheets of paper: the pre-  
205 test (a horizontal line of ten 0.5 cm high digits) to ensure that the child is familiar with all the  
206 digits presented, two vertical tests (Test A and B; each composed of two vertical lines of twenty  
207 0.5 cm high digits separated by a 10.5 cm horizontal margin and with a 0.5 cm vertical distance  
208 between letters), which are supposed to evaluate the level of automaticity of the naming of  
209 numbers with involving only basic oculomotor skills, and one horizontal test (Test C; sixteen  
210 lines of five irregularly separated 0.5 cm high digits), that requires good oculomotor and visuo-  
211 attentional skills, in addition to number naming skills, due to the variable lines spacing and  
212 numerous line references making the ocular tracking of lines more difficult. Children were  
213 asked to read aloud the digits as fast and as accurately as possible. The task was timed, and

214 errors or omissions were recorded. The DEM test provides four main indices: (1) the vertical  
215 reading time (seconds) (VT) which represents the sum of the time spent on naming the eighty  
216 vertically organized digits of Test A and B (in accordance with the test manual, errors were not  
217 used for scoring purpose) ; (2) the adjusted horizontal time (seconds) (HT) which represents  
218 the time required for reading the eighty horizontally organized digits presented in the Test C;  
219 this score is corrected for omission or addition errors<sup>4</sup>; (3) the total number of errors (HE) which  
220 gives the accuracy on the execution of Test C corresponding to the sum of the 4 possible types  
221 of errors: addition errors (i.e., adding or repeating a digit), omission errors (i.e., forgetting a  
222 digit), transposition errors (i.e., inversion between two digits) and substitution errors (i.e.,  
223 replacing one digit with another); and (4) the Ratio score (R) which is calculated dividing the  
224 HT by the VT ; This ratio is intended to isolate the involvement of oculomotor processes in the  
225 horizontal naming task.

226 *Reading abilities.* The reading abilities of each participant were assessed using the  
227 *Alouette* test (Lefavrais, 1967, 2005). This test is commonly used in France to assess reading  
228 proficiency; it consists of reading aloud a text composed of syntactically correct but  
229 semantically poor sentences. The reader cannot, therefore, use meaning to facilitate access to  
230 lexical representations. Participants were instructed to read the text as fast and as accurately as  
231 possible. The time required for this assessment was 3 min. Three main measures were scored:  
232 the number of words reads, the reading time and the number of errors, thus providing two  
233 indices for each participant: a reading accuracy index (CM) and a reading speed index (CTL).

234

235 **Procedure.** In this longitudinal study, children were tested twice (i.e., T0: kindergarten,  
236 T1: May of the 1<sup>st</sup> grade). All the assessments always occurred in the schools in which the

---

<sup>4</sup> Adjusted Horizontal Time = Test C time x [80/(80-number of omission + number of addition)]

237 children were enrolled. The children were tested individually in a quiet room in their school  
238 during regular school hours. The brightness of the room was adapted according to the support  
239 of the different tasks (i.e., paper or screen). At T0 of the study (i.e., kindergarten), children's  
240 visual skills were assessed from the DEM-test. At T1 (i.e., Grade 1 - May), reading skills were  
241 assessed using the Alouette-test. The administration of the DEM test lasted about 10 minutes,  
242 and that of the Alouette test approximately 5 min.

243         The entire investigation process was conducted according to the principles expressed in  
244 the Declaration of Helsinki (World Health Organisation, 2008), approved by the local Ethics  
245 Committee Review Board (Comité de Protection des Personnes pour la recherche biomédicale,  
246 CNRS, France). The children's parents gave their written consent for participation.

247

248         **Data analysis.** The statistical analyses were carried out using R and GraphPad statistical  
249 software. Distributions for the outcome variables suggested no violations of the normality  
250 assumption. The statistically significant threshold for all the analyses was set at  $p = .05$ .  
251 Descriptive statistics were used to report group means and standard deviations for all the DEM  
252 test parameters, to define the prevalence of visual difficulties in kindergarten. Prevalence data  
253 were based on the threshold of 1 SD above mean<sup>5</sup>. Pearson's correlation analyses were  
254 performed to examine the relationship between the performances on the DEM-test in  
255 kindergarten and the reading level of these children (i.e., reading speed and accuracy) assessed  
256 in the 1<sup>st</sup> grade. Linear regression analyses were subsequently performed in order to integrate

---

<sup>5</sup> In reading or neuropsychological research, it is more often 1.5 or 1.65 (corresponds to 5%), to be able to identify disorders (Ratcliff, 1993; Saksida et al., 2016). But when the question of interest is to track difficulties or delay in the developmental trajectory, the threshold used traditionally is 1 SD below the average (16%), since this is the threshold beyond which the assessed skill can be considered as poor. This cut-off allowed us to identify all poor readers (reading test) and all children with visuo-perceptual difficulties (DEM test) (Lefavrais, 2005; Muneaux, 2018).

257 the explanatory variables, identified in the correlation analyses, into a model and to isolate the  
258 part of the variance explained by these factors. Finally, ROC curve analyses were conducted on  
259 the DEM-test indices to determine whether this tool does indeed differentiate children with and  
260 without reading difficulties. These analyses allowed us to obtain a measure of the diagnostic  
261 test's effectiveness. Indeed, the Area Under the Curve (AUC) is an effective indicator,  
262 combining both sensitivity and specificity, which indicates the inherent validity of diagnostic  
263 tests (see Hajian-Tilaki, 2013, for more details). The AUC, area under curve, can be a value  
264 between 0.5 (chance level) and 1.0 (perfect discrimination) (Swets, 1988); AUCs > 0.9 are  
265 considered excellent, AUCs between 0.8 – 0.9 are very good, between 0.7 – 0.8 are good, 0.6  
266 – 0.7 are average, and an AUC < 0.6 is poor (Choi, 1998). For this analysis, a child was  
267 considered to have poor reading skills if at least one of the two reading indices (i.e., CM and/or  
268 CTL) was below the clinical threshold -1 SD (see Footnote 5).

269

## 270 **RESULTS**

### 271 *Prevalence of Visual Impairment in Kindergarten and Reading Difficulties in the 1<sup>st</sup>* 272 *Grade*

273 Mean and standard deviations for VT, adjusted HT (HTaj), HE and R indices according  
274 to the schooling level (i.e., kindergarten) are reported in Table 1. A total of 16 children had at  
275 least one index below-average on the DEM-test in kindergarten, constituting 31% of the sample.  
276 More precisely, among these 16 children, 5 were below average on the VT index, 5 on the HTaj  
277 index, 2 on both VT and HTaj indexes, 10 on the HE index and 5 on the R index. Besides, the  
278 10 children with a deviant performance on the HE index made between 46 and 65 errors in the  
279 horizontal layout (M = 31.57, SD = 16.35). Regarding the nature of these children's errors, on  
280 average, 70% were omissions, 25% were addition, 5% were substitution and only 1% were

281 transposition errors, thus confirming the role of visual attention in error scores (Coulter &  
282 Shallo-Hoffman, 2001).

283 **[Insert Table 1 about here]**

284

285 Thirty of these children were followed longitudinally<sup>6</sup>, and among them, 6 presented  
286 reading difficulties (RD) in the 1<sup>st</sup> grade including 4 children who already presented difficulties  
287 with at least one DEM-test index in kindergarten (i.e., 13.33% of the cohort followed  
288 longitudinally). Moreover, 5 children presented a deviant performance in the DEM-test without  
289 subsequent reading difficulties (NoRD, i.e., 16.67%) which may indicate purely oculomotor or  
290 orthoptic deficits. Note that for these children only the HE index was deviant. When these data  
291 were merged together, the distributions of the different DEM-test variables behaved completely  
292 differently between children with Reading Difficulties (RD) and without (NoRD), as shown in  
293 *Figure 1*. Children with RD differed from children without RD in the VT distributions, with a  
294 deviant density peak for the first ones. The HT and HE distributions of the data also confirmed  
295 the amplitude of the difficulties encountered by the kindergartner children during this task.  
296 Preschool children made a large number of errors, whatever they present RD in grade 1 ( $M =$   
297  $34.50$ ,  $SD = 23.18$ ) or not ( $M = 30.83$ ,  $SD = 14.75$ ). Note that this result cannot be attributed to  
298 poor number knowledge since all children had previously successfully completed the pre-test.  
299 As ever observed in other studies, the ratio does not seem an appropriate measure to predict or  
300 assess children with RD (e.g., Wood et al., 2018).

301

302 **[Insert Figure 1 about here]**

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<sup>6</sup> Only 30 of the 51 children evaluated in kindergarten could be re-assessed and followed longitudinally to the 1<sup>st</sup> grade.

303

304 All the difficulties identified in the DEM-test in kindergarten were observed without  
305 any clinical complaints from the children. Failure on this test can be attributed to various factors  
306 such as visual fatigability, orthoptic disorders, poor saccadic control, or also a defect in visual-  
307 attentional skills, but in any case the results showed that the visual difficulties observed on this  
308 test are relatively frequent in kindergarten (around 1/3 of the children tested) and can have an  
309 impact on the quality of reading acquisition.

310

### 311 *Predictive role of DEM-test outcomes on reading skills*

312 **Reading accuracy.** The correlation analyses, provided in *Table 2*, showed a significant  
313 relationship between the reading accuracy (i.e., CM index) and all the time and error indexes  
314 of the DEM-test (i.e., VT, HTaj and HE). Thus, the longer the vertical and adjusted horizontal  
315 time are and the more errors there are at the DEM-test in kindergarten, the less accurate the  
316 reading is in 1<sup>st</sup> grade. The R index did not correlate with the reading accuracy. The regression  
317 analyses, as shown in *Table 3*, revealed that the variability in reading accuracy is best explained  
318 by a simple linear model taking, as an explanatory variable, the VT index ( $\beta = -.69$ ,  $p < .001$ ).  
319 More precisely, the reading accuracy is predicted at 37% by the VT index [ $R^2 = .37$ ];  $F(1,28)$   
320  $= 18.07$ ,  $p < .001$ ], at 33% by the HTaj index [ $R^2 = .33$ ];  $F(1,28) = 15.57$ ,  $p < .001$ ] and at 18%  
321 by the HE index [ $R^2 = .18$ ];  $F(1,28) = 7.24$ ,  $p < .05$ ]. The very close predictive properties  
322 between the VT and HTaj indices can be explained by the strong correlation maintained  
323 between these two factors ( $r(28) = .74$ ;  $p < .001$ ).

324 **Reading speed.** The correlation analyses (see *Table 2*) showed a significant relationship  
325 between the reading speed (i.e., CTL index) and the VT index only. The HTaj, HE and R  
326 indices did not correlate with the reading speed in the 1<sup>st</sup> grade. The regression analyses,  
327 provided in *Table 3*, revealed that the variability in the reading speed is best explained by a

328 simple linear model taking the VT index as an explanatory variable. More precisely, the VT  
329 index is the only predictor of the reading speed: it predicts 23 % [ $R^2 = .24$ ];  $F(1,28) = 9.95$ ,  
330  $p < .01$ ] of the variance.

331 **[Insert Table 2 about here]**

332 **[Insert Table 3 about here]**

333

334 ***ROC curves analyses.*** In order to better understand the potential role of the DEM-test  
335 as an early screening tool for reading difficulties, the group of children was divided into two  
336 different groups that separated children with and without RD. As previously mentioned in the  
337 previous section, among the 30 children followed longitudinally, 6 presented weaknesses in  
338 their reading skills in the 1<sup>st</sup> grade and 4 of these children already presented difficulties with at  
339 least one DEM-test index in kindergarten (i.e., 13.33% of the cohort). The ROC curve analyses,  
340 provided in *Figure 2*, were conducted on the basis of the 6 children with RD and the 24 children  
341 without difficulties in this area of learning. The results showed that the VT index was the only  
342 variable of the DEM-test that significantly dissociated children with and without RD. The AUC  
343 for VT was  $.7917 \pm .1412$  ( $p < .05$ ), 95% CI [0.5169 – 1.000]. For HTaj, the results were in the  
344 same direction as for VT with a marginally effect:  $AUC = .7569 \pm .1087$  ( $p = .055$ ), 95% CI  
345 [.5439 – .9700]. On the other hand, ROC curve analyses showed that the AUCs for the HE and  
346 R indices are not statistically significant (all  $p > .10$ ).

347 Despite the small size of the present sample, impacting the power of our statistical  
348 analyses, the AUCs we found for VT and HTaj remained very similar with other studies such  
349 as Hopkins et al. (2019) and Larter et al. (2004). Indeed, for VT, Larter et al. (2004) also found  
350 a significant AUC, very close to the current one, at .778. For HTaj, although the current study's  
351 AUC (.757) was only marginally significant, other studies such as those by Hopkins et al.  
352 (2019) and Larter et al. (2004) have shown that this index was a good indicator discriminating



353 children with and without RD, with AUCs of .72 and .83 respectively. Just to remind, AUCs >  
354 0.9 are considered excellent, AUCs between 0.8 – 0.9 are very good, between 0.7 – 0.8 are  
355 good, 0.6 – 0.7 are average, and an AUC < 0.6 is poor (Choi, 1998). Even if these studies  
356 differed in terms of experimental design (transversal vs. longitudinal), children age, or tests  
357 used to assess reading level, the DEM-test appeared to be an effective test in the screening  
358 process for reading difficulties as early as kindergarten.

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360

[Insert Figure 2 about here]

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## **DISCUSSION**

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### **Prevalence of Visual and Reading Difficulties from Kindergarten to the 1<sup>st</sup> grade**

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In the early school years as children are learning to read letters and numbers (tasks requiring visual recognition, matching and recall of shapes), adequate oculomotor and visual

377 information processing skills (including visual analysis, visuo-motor integration, eye  
378 movement control, attention orienting/focusing) are critical. One of the main objectives of the  
379 present study was thus to examine children's visual skills at age 5, before they start formal  
380 reading instruction, to assess the occurrence of visual skills difficulties in preschoolers and to  
381 study more precisely beyond the linguistic ones, the oculomotor and visuo-attentional  
382 mechanisms needed in learning to read.

383         Although data already available for the DEM-test in French school-aged children  
384 (Bellocchi et al., 2021; Moiroud et al., 2018, 2020), no research, to the best of our knowledge,  
385 has specifically questioned its usefulness in the assessment of visual skills in preschool children.  
386 Therefore, the current study provides the first data collected in French kindergarten children.  
387 The results corroborate findings from other studies showing that oculomotor and visual  
388 processing difficulties are very common among children in kindergarten, with nearly 30% of  
389 preschool children presented difficulties on this test, in the absence of complaints expressed by  
390 the subject or his/her family. In addition to deviant performance on the VT and HT indexes,  
391 preschool children made also a large number of errors, whatever they present RD one year later  
392 or not (but see, Raghuram et al., 2018, for different results, suggesting an association between  
393 reading level and the number of errors made on the horizontal presentation). The nature of these  
394 errors is very relevant since most of them are errors of omission (i.e. nearly 70%) resulting  
395 mainly from skipping lines and characters. In addition to immature or inaccurate eye movement  
396 control, these errors may be due to visuo-attentional factors (Aslin & Ciuffreda, 1983; Coulter  
397 & Shallo-Hoffman, 2001).

398         Approximately 14% of the children in the current sample presented difficulties on both  
399 the DEM-test in kindergarten and the reading assessment in the 1<sup>st</sup> grade and it clearly appeared  
400 that the performance distribution at the DEM-test in Kindergarten was different between good  
401 and poor readers one year later. The results of this study are consistent with those of other

402 investigators who found that children with reading problems have a higher prevalence of  
403 associated deficient visual efficiency skills, such as oculomotor (Brodney et al., 2001; Eden et  
404 al., 1994; Kulp & Schmidt, 1996b; Maples & Ficklin, 1990), and visuo-attentional skills  
405 (Bellocchi & Ducrot, 2021; Bosse & Valdois, 2009; Franceschini et al., 2012), than do children  
406 who are proficient readers. In that vein, Portnoy and Gilaie-Dotan (2020) showed in a cross-  
407 sectionally study that 14.3% of the children in their total sample (i.e., 4 children out of 28) were  
408 both among the slowest on the DEM-test and in difficulty with reading speed, and that 17.9 %  
409 of the cohort (i.e., 5 out of 28 children) were both among the least accurate on the DEM-test  
410 and had difficulty with reading accuracy.

411         Visual deficits identified in kindergarten with the DEM-test can have different causes  
412 such as visual fatigability, orthoptic disorders, poor eye movement control, defect in visual-  
413 attentional skills or also insufficient exposure to written language, but whatever their causes,  
414 the visual impairments in kindergarten detected with the DEM-test can have major  
415 consequences on the children's developmental trajectory, particularly in their reading  
416 acquisition leading more generally to academic difficulties (Case-Smith, 2009; Kramer &  
417 Hinojosa, 2010). The vision-related symptoms include distortion, blurring, merging or moving  
418 of letters or words (Stein & Walsh, 1997). Moreover, misread words, missing words and  
419 skipping lines when reading, are also frequently presented, suggesting a consequence of poor  
420 visual processing (Kulp & Schmidt, 1996a). Since visual deficits in preschool children do not  
421 disappear as they grow up, they may continue to struggle visually when reading. This may have  
422 adverse effects on reading motivation and performance.

423

#### 424         **Predicting Reading Skills Based on Visual Processes in Kindergarten**

425         Preliminary results regarding prevalence of visual and reading impairments,  
426 respectively and jointly, demonstrated that visual information processing ability, based on

427 measures of horizontal and vertical DEM times in preschool children, was significantly  
428 associated with reading scores in Grade 1 school children, suggesting that visual information  
429 processing plays a significant role in a child's academic performance in Grade 1. These findings  
430 are consistent with other studies that have demonstrated associations between delayed visual  
431 information processing skills and reduced classroom performance (learning to read in  
432 particular, Hopkins et al., 2017, 2019; Kulp, 1999; Oberer et al., 2018; Pienaar et al., 2014;  
433 Sortor & Kulp, 2003; White et al., 2017; Yang & Meng, 2020), which justify the need to include  
434 visual perceptual skills in the prediction of reading achievement.

435 The question then was to determine whether kindergartners visual skills contribute to emergent  
436 literacy skills and later reading abilities. This question is particularly useful for an early  
437 identification of children at-risk for reading disabilities. The longitudinal approach of the  
438 current study revealed also that the visual skills assessed by the DEM test could partially predict  
439 reading outcomes one year later. More precisely, the correlation analyses showed that reading  
440 accuracy in Grade 1 was significantly correlated with the HTaj, VT and HE indices assessed in  
441 kindergarten, whereas reading speed was only correlated with the VT index. The relationship  
442 we found between the DEM-test outcomes and the reading level corroborated previously  
443 reported results from several studies, particularly for VT (Ayton et al., 2009; Larter et al., 2004;  
444 Raghuram et al., 2018; Serdjukova et al., 2017; Wood et al., 2018) and HTaj (Ayton et al.,  
445 2009; Moiroud et al., 2018; Northway, 2003; Palomo-Álvarez & Puell, 2009; Raghuram et al.,  
446 2018; Serdjukova et al., 2017; Wood et al., 2018). In addition, children with developmental  
447 dyslexia have also been shown to perform poorly on the DEM-test than control children  
448 (Bellocchi et al., 2021; Moiroud et al., 2018; Raghuram et al., 2018). According to Portnoy and  
449 Gilaie-Dotan (2020) and Wood et al. (2018), we found no correlation between the Ratio and  
450 reading performances, suggesting that the DEM ratio is poorly associated with academic  
451 outcomes (but see Ayton et al., 2009; Raghuram et al., 2018). The distribution of the ratio data

452 was in the same direction, failing to distinguish readers with RD from noRD ones. Moreover,  
453 it is important to note that the DEM-test showed a high fidelity as demonstrated by several  
454 studies, particularly for the VT and HTaj indices, while the ratio and HE indices, on the other  
455 hand, did not reach a consensus (Facchin & Maffioletti, 2018; Orlansky et al., 2011; Tassinari  
456 & DeLand, 2005).

457 Linear regression analyses of the current study have shown, more specifically, that the  
458 reading speed and accuracy in the 1<sup>st</sup> grade may be predicted by different indices of the DEM-  
459 test as early as kindergarten. The vertical time (i.e., VT) was the best predictor of reading  
460 accuracy (37%) and speed (23%) in the 1<sup>st</sup> grade. The adjusted horizontal time (i.e., HTaj) also  
461 partially predicts reading accuracy (33%). These results support the view that visual  
462 information processing plays a role in reading achievement, particularly among younger  
463 children in the early school grades (Kavale, 1982; Solan & Mozlin, 1986).

464 Our finding that the VT index was most strongly associated with the reading  
465 performance<sup>7</sup> of first graders was not in the same direction as the findings of Ayton et al. (2009),  
466 or Wood et al. (2018) who reported the strongest correlations between the DEM horizontal  
467 subtest and reading test scores in their sample of children, aged 8 to 11 years. This difference  
468 may have been because the children in their sample (Grade 3 to 5) were beyond the ‘learning  
469 to read’ stage. Indeed, it has been proposed that visual information processing skills play a more  
470 significant role in the learning process of younger children (kindergarten to Grade 2) in the  
471 ‘learning to read’ phase compared to older children (Flax, 2006). The oculomotor system is still  
472 not mature in young children (e.g., Kowler & Martins, 1982) and the oculomotor behavior and

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<sup>7</sup> The possibility that this effect was linked to the small sample of children was ruled out since we obtained similar results, i.e., a superiority of the VT index, in another longitudinal study following 137 preschool children (Ducrot & Vernet, 2021, see also Footnote 8). We assume that this effect is linked to the young age of our participants; as children move through school, the role of language and other higher level cognitive skills become more significant in a child’s reading performance (Flax, 2006; Goldstand et al., 2005).

473 the visuo-attentional skills undergo substantial changes during reading development, with  
474 longer saccade and perceptual span extent, shorter fixation durations, and lower refixation and  
475 regression probabilities (Blythe, 2014; Blythe & Joseph, 2011; Ducrot et al., 2013; Rayner,  
476 2009). Moreover, other factors such as visuo-attentional and visuospatial factors that are  
477 important for performing the DEM test are also developing with the age of the child (Caldani  
478 et al., 2020; Coulter & Shallo-Hoffman, 2001; Facchin et al., 2011) and the automatization of  
479 this so-called "visuo-attentional" processing is another condition for reading success (see  
480 Grainger et al., 2016). In that vein, Ammawat et al. (2019) demonstrated that naming speed  
481 (strongly linked with VT performance) was also influenced by visual perception and attention.  
482 One of the prominent findings of their study is that visual perception was the most significant  
483 factor in predicting naming speed in young children. At the same time, their study provided  
484 support for the theory that visual perception has a strong relationship with attention networks,  
485 supporting the hypothesis that visual perception and attention networks may combine to affect  
486 naming speed or reading readiness in RD children. For Kuperman et al. (2016), the well-  
487 established predictive role of RAN for reading performance is in part due to the individual  
488 ability to shift attention from one item to the next and to coordinate rapid sequential eye  
489 movements to visual nonlinguistic stimuli (see also, Wolf & Bowers, 1999). We argue that the  
490 implication of the oculomotor and visuo-attentional mechanisms involved in the DEM  
491 horizontal vs. vertical subtests change during reading development and we believe that 5-6  
492 years is a critical window where the weight of these processes are especially strong. Stanovich  
493 et al. (1981) showed that digit naming time and errors significantly decreases between 5-and 6-  
494 year olds and that automaticity significantly increases in the first grade (see also, Kulp &  
495 Schmidt, 1997). According to the perceptual learning account, the visual training associated  
496 with the regularity of reading eye movements improves word recognition within a restricted  
497 horizontal region close to the fovea and mostly within the regions of the retina that fall on the

498 side of the reading direction (Dehaene et al., 2005). It is therefore likely that the HT index  
499 become more strongly associated with the reading performance as children learn to read and  
500 take the left-to-right directionality of visual scanning into account (see Ducrot et al., 2020, for  
501 a change in landing position distributions between 5 and 6 year-old children, as a result of  
502 reading experience).

503         These data provided a new contribution to the identification of precursors to reading  
504 acquisition and to the understanding of the emergence of associated disorders. The emphasis  
505 on the predictive potential of the visual skills assessed by the DEM-test on reading abilities  
506 highlights the importance of these processes in the emergence of literacy skills and reading  
507 abilities later in the learning process. These results were in line with previous studies that  
508 demonstrated the involvement of visual skills such as the visual-attentional span, initial landing  
509 position, and/or visual-motor skills and their potential underlying causes of learning difficulties  
510 in some children (Bellocchi et al., 2017; Franceschini et al., 2012; Kwon et al., 2007; Valdois  
511 et al., 2019; Yang & Meng, 2020). Thus, beyond the already accepted implication of linguistic  
512 skills as strong predictors of reading level (Carroll et al., 2003; Lonigan et al., 2000; Piquard-  
513 Kipffer & Sprenger-Charolles, 2013; Schatschneider et al., 2004), these findings demonstrate  
514 the key role of visual skills in the mechanisms of reading acquisition.

515

#### 516         **Usefulness of the DEM-test as an effective screening tool for reading difficulties**

517         As far as we know, no study analysed the precision of the DEM test at identifying French  
518 preschool children at risk/non-risk of reading difficulty. Studies with this purpose are crucial  
519 because this information is essential for reading difficulties screening. As pointed out before, a  
520 trustworthy screening test can help preventive interventions to begin as soon as possible. The  
521 interest of this tool for the early detection of reading difficulties in kindergarten has been  
522 investigated in very few studies (Kulp & Schmidt, 1997; Xie et al., 2016), in contrast to the

523 combined association between the visual deficits identified in the DEM-test and the poor  
524 reading performance which had already been demonstrated and which supports our results, as  
525 demonstrated in the previous section (Ayton et al., 2009; Palomo-Álvarez & Puell, 2009;  
526 Portnoy & Gilaie-Dotan, 2020; Serdjukova et al., 2017; Wood et al., 2018). Thus, another goal  
527 of the present study was to evaluate the precision of the DEM test in predicting children at  
528 risk/non-risk of reading as early as possible. A test's precision of classification can be evaluated  
529 based on the ROC curve, considering the AUC (Swets, 1988). Although the sample size was  
530 small, the results showed that the VT index (and the HTaj, to a lesser extent) were able to  
531 dissociate children with and without RD. The AUC for VT was considered as very good (0.80)  
532 and that for HTaj as good (comprised between 0.70 and 0.80). This suggests the potential for  
533 these measures to be used clinically for identifying children at risk for low academic  
534 achievement.

535         These conclusions raise critical perspectives regarding clinical diagnosis and  
536 educational approach, by providing the opportunity to gain insight into the visuo-attentional  
537 and perceptual difficulties children, in view of establishing thorough and accurate assessment  
538 procedures and proposing child-specific guidelines and remediation methods that take into  
539 account the particular processes affected. Such information is useful not only for uncovering  
540 problems readers have with the different components of reading, but also can help in the  
541 development of teaching strategies or methods appropriate for individual children's particular  
542 strengths or weaknesses (e.g., implement early oculomotor training programs at school,  
543 especially in kindergarten). Almost 70% of a school day is dedicated to learning activities  
544 involving visual sensory input (Narayanasamy et al., 2016). This may explain, in part, why  
545 children with visual impairment are more likely to fail at school (Goldstand et al., 2005; White  
546 et al., 2017). Indeed, if visual processes are not operational and efficient from the beginning of  
547 the reading learning process, academic achievements can be considerably impacted. Depending



548 on their severity, these deficits can lead to difficulty tracking, sustaining attention and focus,  
549 all of which may interfere with visual exploration, reading fluency and distract from reading  
550 comprehension. The importance of early screening then takes on its full meaning, making it  
551 possible to intervene very early in children's developmental trajectory. If appropriate  
552 interventions are implemented at an early age, academic skill development could be altered,  
553 preventing subtle learning difficulties from becoming more pronounced over time. The earlier  
554 an intervention is implemented, the better a child's chances of overcoming his or her deficit  
555 (Ozernov-Palchik & Gaab, 2016).

556         Currently, reading instruction and reading intervention techniques employed focus  
557 primarily on the language components of reading development. Although these programs are  
558 based on solid research that identifies phonological processing, vocabulary, and comprehension  
559 as core components of reading development, the integration of visual skills assessment from  
560 kindergarten onward to limit reading disorder is a real necessity. To do so, the DEM-test can  
561 be a useful tool, in particular for the early identification of children at risk for reading  
562 difficulties. It provides additional information to existing tools assessing linguistic skills. For  
563 clinicians, this tool could improve the diagnostic assessment to better understand the difficulties  
564 observed and thus improve the management of children. In that sense, the combined use of  
565 investigation tools in early detection can result highly effective for these children. Furthermore,  
566 the rehabilitation methods which stimulate both the phonological and the visual-spatial  
567 attention skills are proved to be the most effective in children already diagnosed with dyslexia  
568 (Facoetti et al., 2003; Gaggi et al., 2012). For example, although eye movement deficits may  
569 not be the only contributory factor to reading difficulties, better control of saccadic eye  
570 movements can translate to more precise and quicker reading speed and reduce the percentage  
571 of reading errors (Fischer et al., 2000; Fischer & Hartnegg, 2008). Training both linguistic and

572 visual skills together before the child begins to learn reading, can help his/her future reading  
573 ability.

574 The main limitation of the present study is the size of the sample that could be followed.  
575 This limitation is directly related to the longitudinal design since children were followed during  
576 18 months from kindergarten to the first grade, leading inevitably to an attrition effect. But we  
577 truly believe this is the best way to better understand the issue of pre-requisites and  
578 developmental trajectory in the academic learning process<sup>8</sup>. We also acknowledge that some  
579 studies evaluating the validity of the DEM test (Facchin et al., 2011; Garzia et al., 1990) have  
580 demonstrated that it did not seem to correlate directly with pure eye movement control  
581 parameters; however they also showed that visuo-perceptual and visuo-attentional processes  
582 play a major role in this task and that it was strongly correlated with different aspects of reading  
583 performance and it is useful in clinical practice (Ayton et al., 2009; Bellocchi et al., 2021;  
584 Palomo-Álvarez & Puell, 2009; Powers, 2009). Even though the DEM test does not assess basic  
585 components of eye movement control and can be influenced by several cognitive processes,  
586 such as sustained attention (Coulter & Shallo-Hoffman, 2001), number recognition and  
587 retrieval, visual-verbal integration time, speaking time and visuo-spatial attention (Facchin et  
588 al., 2011), the fact remains that the DEM test has been shown to be a measure related to visual  
589 and visuo-attentional skills, which in turn are related to ocular movements in a reading-like  
590 condition. Furthermore, while eye movement clinically available instruments are expensive and

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<sup>8</sup> Note that the data we collected in the interim with a computerized version of the DEM-test made us confident that the effects obtained are replicable and generalizable. This experiment was conducted in a larger sample composed by 137 preschoolers, using the same procedure and longitudinal design, with a group of 137 preschool children. The data we obtained support those first obtained in this study, with the paper-based version of the DEM test, that is., the VT and HTaj measures (1) are significantly correlated with reading outcomes one year later and (2) significantly predict children's reading achievement in Grade 1, i.e., 12 months before reading training (Ducrot & Vernet, 2021).

591 hard to use during screening or routine eye examination, the DEM-test is an inexpensive paper-  
592 and-pencil test that is performed in only 5 minutes<sup>9</sup>.

### 593 **CONCLUSION**

594 The current study fills a gap in reading research, by identifying oculomotor and visual  
595 perception skills as overlooked components of prerequisites for word recognition. It is clear  
596 from the current study, that a few of the preschool children who have problems with visual  
597 deficits showed a particularly severe pattern of difficulties, which has significantly impacted  
598 their learning one year later. Based on the key findings in this study, it is essential to raise  
599 awareness among professionals regarding the importance of eye movements and visual  
600 perception in preschool children. Any child who shows signs of visual difficulties should be  
601 referred for more in-depth visual assessment to identify the actual cause of the difficulties.  
602 There is a real challenge in the early identification of additional factors that may contribute to  
603 literacy impairments, both for academic success but also for the quality of life of these children.

604

### 605 **Authors' Notes**

606 The first and the last author contributed equally to this work.

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<sup>9</sup> The creation of an easy-to-use software for clinical practice is in progress in our laboratory, with the aim to assess visuo-perceptual and attentional abilities, taking the children school level into account. This software, called Diaglect, would allow us to obtain an automatic diagnosis and several remedial modules will be proposed according to the child's visual profile.

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## REFERENCES

- 619 Aghababian, V., & Nazir, T. A. (2000). Developing Normal Reading Skills: Aspects of the  
620 Visual Processes Underlying Word Recognition. *Journal of Experimental Child*  
621 *Psychology*, 76(2), 123–150. <https://doi.org/10.1006/jecp.1999.2540>
- 622 Ammawat, W., Attanak, A., Kornpetpanee, S., & Wongupparaj, P. (2019). Pre-schoolers’  
623 visual perception and attention networks influencing naming speed: An individual  
624 difference perspective. *Heliyon*, 5(10), e02587.  
625 <https://doi.org/10.1016/j.heliyon.2019.e02587>
- 626 Aslin, R. N., & Ciuffreda, K. J. (1983). Eye movements of preschool children. *Science*,  
627 222(4619), 74–77. <https://doi.org/10.1126/science.6623059>
- 628 Ayton, L. N., Abel, L. A., Fricke, T. R., & McBrien, N. A. (2009). Developmental eye  
629 movement test: What is it really measuring? *Optometry and Vision Science*, 86(6), 722–  
630 730. <https://doi.org/10.1097/OPX.0b013e3181a6a4b3>
- 631 Bellocchi, S., & Ducrot, S. (2021). *The OVP effect in developmental dyslexia, developmental*  
632 *coordination disorder and comorbid disorders [Article submitted for publication]*.
- 633 Bellocchi, S., Ducrot, S., Tallet, J., Jucla, M., & Jover, M. (2021). Effect of comorbid  
634 developmental dyslexia on oculomotor behavior in children with developmental  
635 coordination disorder: A study with the Developmental Eye Movement test. *Human*  
636 *Movement Science*, 76, 102764. <https://doi.org/10.1016/j.humov.2021.102764>
- 637 Bellocchi, S., Muneaux, M., Bastien-Toniazzo, M., & Ducrot, S. (2013). I can read it in your  
638 eyes: What eye movements tell us about visuo-attentional processes in developmental  
639 dyslexia. *Research in Developmental Disabilities*, 34(1), 452–460.  
640 <https://doi.org/10.1016/j.ridd.2012.09.002>
- 641 Bellocchi, S., Muneaux, M., Huau, A., Lévêque, Y., Jover, M., & Ducrot, S. (2017).  
642 Exploring the Link between Visual Perception, Visual–Motor Integration, and Reading  
643 in Normal Developing and Impaired Children using DTVP-2. *Dyslexia*, 23(3), 296–315.  
644 <https://doi.org/10.1002/dys.1561>
- 645 Biscaldi, M., Fischer, B., & Hartnegg, K. (2000). Voluntary saccadic control in dyslexia.  
646 *Perception*, 29(5), 509–521. <https://doi.org/10.1068/p2666a>
- 647 Blythe, H. I. (2014). Developmental Changes in Eye Movements and Visual Information

- 648        Encoding Associated With Learning to Read. *Current Directions in Psychological*  
649        *Science*, 23(3), 201–207. <https://doi.org/10.1177/0963721414530145>
- 650        Blythe, H. I., & Joseph, H. S. S. L. (2011). Children’s eye movements during reading. In S. P.  
651        Liversedge, I. Gilchrist, & S. Everling (Eds.), *The Oxford Handbook of Eye Movements*  
652        (pp. 634–662). Oxford University Press.  
653        <https://doi.org/10.1093/oxfordhb/9780199539789.013.0036>
- 654        Borsting, E., Rouse, M., & Chu, R. (2005). Measuring ADHD behaviors in children with  
655        symptomatic accommodative dysfunction or convergence insufficiency: a preliminary  
656        study. *Optometry - Journal of the American Optometric Association*, 76(10), 588–592.  
657        <https://doi.org/10.1016/j.optm.2005.07.007>
- 658        Bosse, M., & Valdois, S. (2009). Influence of the visual attention span on child reading  
659        performance: a cross-sectional study. *Journal of Research in Reading*, 32(2), 230–253.  
660        <https://doi.org/10.1111/j.1467-9817.2008.01387.x>
- 661        Brodney, A. C., Pozil, R., Mallinson, K., & Kehoe, P. (2001). Vision Therapy in a School  
662        Setting. *Journal of Behavioral Optometry*, 12(4), 99–103.
- 663        Buckley, J., Seery, N., Canty, D., & Gumaelius, L. (2018). Visualization, inductive reasoning,  
664        and memory span as components of fluid intelligence: Implications for technology  
665        education. *International Journal of Educational Research*, 90(November 2017), 64–77.  
666        <https://doi.org/10.1016/j.ijer.2018.05.007>
- 667        Caldani, S., Gerard, C., Peyre, H., & Bucci, M. P. (2020). Visual Attentional Training  
668        Improves Reading Capabilities in Children with Dyslexia: An Eye Tracker Study During  
669        a Reading Task. *Brain Sciences*, 10(8), 558. <https://doi.org/10.3390/brainsci10080558>
- 670        Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research*, 51(13), 1484–  
671        1525. <https://doi.org/10.1016/j.visres.2011.04.012>
- 672        Carroll, J. M., Snowling, M. J., Hulme, C., & Stevenson, J. (2003). The Development of  
673        Phonological Awareness in Preschool Children. *Developmental Psychology*, 39(5), 913–  
674        923. <https://doi.org/10.1037/0012-1649.39.5.913>
- 675        Case-Smith, J. (2009). *Occupational therapy for children* (6th ed.). Mosby.
- 676        Chen, A. H., Bleything, W., & Lim, Y. Y. (2011). Relating vision status to academic  
677        achievement among year-2 school children in Malaysia. *Optometry*, 82(5), 267–273.

- 678 <https://doi.org/10.1016/j.optm.2011.02.004>
- 679 Choi, B. C. K. (1998). Slopes of a Receiver Operating Characteristic Curve and Likelihood  
680 Ratios for a Diagnostic Test. *American Journal of Epidemiology*, *148*(11), 1127–1132.  
681 <https://doi.org/10.1093/oxfordjournals.aje.a009591>
- 682 Chung, S. T. L., Legge, G. E., & Cheung, S. H. (2004). Letter-recognition and reading speed  
683 in peripheral vision benefit from perceptual learning. *Vision Research*, *44*(7), 695–709.  
684 <https://doi.org/10.1016/j.visres.2003.09.028>
- 685 Cornelissen, P., Richardson, A., Mason, A., Fowler, S., & Stein, J. F. (1995). Contrast  
686 sensitivity and coherent motion detection measured at photopic luminance levels in  
687 dyslexics and controls. *Vision Research*, *35*(10), 1483–1494.  
688 [https://doi.org/10.1016/0042-6989\(95\)98728-R](https://doi.org/10.1016/0042-6989(95)98728-R)
- 689 Coulter, R. A., & Shallo-Hoffman, J. (2001). The Presumed Influence of Attention on  
690 Accuracy in the Developmental Eye Movement (DEM) Test. *Optometry and Vision  
691 Science*, *78*(1), 8. <https://doi.org/10.1097/00006324-200101010-00007>
- 692 De Luca, M., Borrelli, M., Judica, A., Spinelli, D., & Zoccolotti, P. (2002). Reading words  
693 and pseudowords: An eye movement study of developmental dyslexia. *Brain and  
694 Language*, *80*(3), 617–626. <https://doi.org/10.1006/brln.2001.2637>
- 695 Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written  
696 words: A proposal. *Trends in Cognitive Sciences*, *9*(7), 335–341.  
697 <https://doi.org/10.1016/j.tics.2005.05.004>
- 698 Ducrot, S., & Lété, B. (2008). Attention et contrôle oculaire en lecture experte. In G. A.  
699 Michael (Ed.), *Les dimensions de l'attention visuelle* (pp. 229–264). SOLAL.
- 700 Ducrot, S., & Lété, B. (2021). *Developmental Changes in the Optimal Viewing Position Effect*  
701 *[Article in preparation]*.
- 702 Ducrot, S., Lété, B., Sprenger-Charolles, L., Pynte, J., & Billard, C. (2003). The Optimal  
703 Viewing Position Effect in Beginning and Dyslexic Readers. *Current Psychology  
704 Letters*, *1*(10), 1–10. <https://doi.org/10.4000/cpl.99>
- 705 Ducrot, S., Massendari, D., Danna, J., Muneaux, M., Bellocchi, S., & Grainger, J. (2021). *An  
706 analysis of reading development using landing-position distributions [Article in  
707 preparation]*.

- 708 Ducrot, S., Pynte, J., Ghio, A., & Lété, B. (2013). Visual and linguistic determinants of the  
709 eyes' initial fixation position in reading development. *Acta Psychologica, 142*(3), 287–  
710 298. <https://doi.org/10.1016/j.actpsy.2013.01.013>
- 711 Ducrot, S., & Vernet, M. (2021). *Oculomotor, visual attention abilities and reading: A new*  
712 *computerized tool [Article in preparation]*.
- 713 Eden, G. F., Stein, J. F., Wood, H. M., & Wood, F. B. (1994). Differences in eye movements  
714 and reading problems in dyslexic and normal children. *Vision Research, 34*(10), 1345–  
715 1358. [https://doi.org/10.1016/0042-6989\(94\)90209-7](https://doi.org/10.1016/0042-6989(94)90209-7)
- 716 Facchin, A., & Maffioletti, S. (2018). The reliability of the DEM test in the clinical  
717 environment. *Frontiers in Psychology, 9*(JUL). <https://doi.org/10.3389/fpsyg.2018.01279>
- 718 Facchin, A., Maffioletti, S., & Carnevali, T. (2011). Developmental Eye Movement ( DEM )  
719 test : validity reassessment in Italian population Results : *Optometry and Vision*  
720 *Development, 40*(3), 20125.
- 721 Facchetti, A., Corradi, N., Ruffino, M., Gori, S., & Zorzi, M. (2010). Visual spatial attention  
722 and speech segmentation are both impaired in preschoolers at familial risk for  
723 developmental dyslexia. *Dyslexia, 16*(3), 226–239. <https://doi.org/10.1002/dys.413>
- 724 Facchetti, A., Luisa Lorusso, M., Paganoni, P., Umiltà, C., & Gastone Mascetti, G. (2003). The  
725 role of visuospatial attention in developmental dyslexia: evidence from a rehabilitation  
726 study. *Cognitive Brain Research, 15*(2), 154–164. [https://doi.org/10.1016/S0926-](https://doi.org/10.1016/S0926-6410(02)00148-9)  
727 [6410\(02\)00148-9](https://doi.org/10.1016/S0926-6410(02)00148-9)
- 728 Fischer, B., & Hartnegg, K. (2008). Saccade control in dyslexia: Development, deficits,  
729 training and transfer to reading. *Journal of Optometric Vision Development, 39*(4), 181–  
730 190.
- 731 Fischer, B., Hartnegg, K., & Mokler, A. (2000). Dynamic visual perception of dyslexic  
732 children. *Perception, 29*(5), 523–530. <https://doi.org/10.1068/p2666b>
- 733 Fischer, B., & Weber, H. (1990). Saccadic reaction times of dyslexic and age-matched normal  
734 subjects. *Perception, 19*(6), 805–818. <https://doi.org/10.1068/p190805>
- 735 Flax, N. (2006). The relationship between vision and learning: General issues. In M.  
736 Scheiman & M. Rouse (Eds.), *Optometric Management of Learning-related Vision*  
737 *Problems* (p. 183-206). Mosby-Elsevier.



- 738 Flax, N., Mozlin, R., & Solan, H. A. (1984). Discrediting the basis of the AAO policy:  
739 Learning disabilities, dyslexia and vision. *Journal of the American Optometric*  
740 *Association*, 55(6), 399–403.
- 741 Franceschini, S., Gori, S., Ruffino, M., Pedrolli, K., & Facoetti, A. (2012). A causal link  
742 between visual spatial attention and reading acquisition. *Current Biology*, 22(9), 814–  
743 819. <https://doi.org/10.1016/j.cub.2012.03.013>
- 744 Gaggi, O., Galiazzo, G., Palazzi, C., Facoetti, A., & Franceschini, S. (2012). A Serious Game  
745 for Predicting the Risk of Developmental Dyslexia in Pre-Readers Children. *2012 21st*  
746 *International Conference on Computer Communications and Networks (ICCCN)*, 1–5.  
747 <https://doi.org/10.1109/ICCCN.2012.6289249>
- 748 Garzia, R. P., Richman, J. E., Nicholson, S. B., & Gaines, C. S. (1990). A new visual-verbal  
749 saccade test: the development eye movement test (DEM). *Journal of the American*  
750 *Optometric Association*, 61(2), 124–135.
- 751 Goldstand, S., Koslowe, K. C., & Parush, S. (2005). Vision, visual-information processing,  
752 and academic performance among seventh-grade schoolchildren: A more significant  
753 relationship than we thought? *American Journal of Occupational Therapy*, 59(4), 377–  
754 389. <https://doi.org/10.5014/ajot.59.4.377>
- 755 González, G. F., Žarić, G., Tijms, J., Bonte, M., Blomert, L., & van der Molen, M. W. (2014).  
756 Brain-potential analysis of visual word recognition in dyslexics and typically reading  
757 children. *Frontiers in Human Neuroscience*, 8(JUNE), 1–14.  
758 <https://doi.org/10.3389/fnhum.2014.00474>
- 759 Goodman, K. S. (1986). *What's Whole in Whole Language?* Heinemann.
- 760 Gori, S., & Facoetti, A. (2015). How the visual aspects can be crucial in reading acquisition:  
761 The intriguing case of crowding and developmental dyslexia. *Journal of Vision*, 15(1),  
762 1–20. <https://doi.org/10.1167/15.1.8>
- 763 Goswami U. (2015). Sensory theories of developmental dyslexia: three challenges for  
764 research. *Nature reviews. Neuroscience*, 16(1), 43–54. <https://doi.org/10.1038/nrn3836>
- 765 Grainger, J. (2018). Orthographic processing: A ‘mid-level’ vision of reading: The 44th Sir  
766 Frederic Bartlett Lecture. *Quarterly Journal of Experimental Psychology*, 71(2), 335–  
767 359. <https://doi.org/10.1080/17470218.2017.1314515>

- 768 Grainger, J., Dufau, S., & Ziegler, J. C. (2016). A Vision of Reading. *Trends in Cognitive*  
769 *Sciences*, 20(3), 171–179. <https://doi.org/10.1016/j.tics.2015.12.008>
- 770 Granet, D. B., Castro, E. F., & Gomi, C. F. (2006). Reading: Do the Eyes Have It? *American*  
771 *Orthoptic Journal*, 56(1), 44–49. <https://doi.org/10.3368/aoj.56.1.44>
- 772 Hajian-Tilaki, K. (2013). Receiver operating characteristic (ROC) curve analysis for medical  
773 diagnostic test evaluation. *Caspian Journal of Internal Medicine*, 4(2), 627–635.
- 774 Hopkins, S., Black, A. A., White, S. L. J., & Wood, J. M. (2019). Visual information  
775 processing skills are associated with academic performance in Grade 2 school children.  
776 *Acta Ophthalmologica*, 97(8), e1141–e1148. <https://doi.org/10.1111/aos.14172>
- 777 Hopkins, S., Sampson, G. P., Hendicott, P. L., & Wood, J. M. (2017). Vision problems and  
778 reduced reading outcomes in Queensland schoolchildren. *Optometry and Vision Science*,  
779 94(3), 345–352. <https://doi.org/10.1097/OPX.0000000000001032>
- 780 Hutzler, F., & Wimmer, H. (2004). Eye movements of dyslexic children when reading in a  
781 regular orthography. *Brain and Language*, 89(1), 235–242.  
782 [https://doi.org/10.1016/S0093-934X\(03\)00401-2](https://doi.org/10.1016/S0093-934X(03)00401-2)
- 783 Jenkins, J. R., Hudson, R. F., & Johnson, E. S. (2007). Screening for At-Risk Readers in a  
784 Response to Intervention Framework. *School Psychology Review*, 36(4), 582–600.  
785 <https://doi.org/10.1080/02796015.2007.12087919>
- 786 Kavale, K. (1982). Meta-analysis of the relationship between visual perceptual skills and  
787 reading achievement. *Journal of Learning Disabilities*, 15(1), 42–51.  
788 <https://doi.org/10.1177/002221948201500110>
- 789 Kirby, J. R., Roth, L., Desrochers, A., & Lai, S. S. V. (2008). Longitudinal predictors of word  
790 reading development. *Canadian Psychology*, 49(2), 103–110.  
791 <https://doi.org/10.1037/0708-5591.49.2.103>
- 792 Kovács, I. (2000). Human development of perceptual organization. *Vision Research*, 40(10–  
793 12), 1301–1310. [https://doi.org/10.1016/S0042-6989\(00\)00055-9](https://doi.org/10.1016/S0042-6989(00)00055-9)
- 794 Kowler, E., & Martins, A. J. (1982). Eye movements of preschool children. *Science*,  
795 215(4535), 997–999. <https://doi.org/10.1126/science.7156979>
- 796 Kramer, P., & Hinojosa, J. (2010). *Frames of reference for pediatric occupational therapy:*

- 797           *Third Edition*. Wolters Kluwer Health/Lippincott Williams & Wilkins.
- 798   Kulp, M. T. (1999). Relationship between Visual Motor Integration Skill and Academic  
799           Performance in Kindergarten through Third Grade. *Optometry and Vision Science*, 76(3),  
800           159–163. <https://doi.org/10.1097/00006324-199903000-00015>
- 801   Kulp, M. T., & Schmidt, P. P. (1996a). Effect of Oculomotor and Other Visual Skills on  
802           Reading Performance: A Literature Review. *Optometry and Vision Science*, 73(4), 283–  
803           292. <https://doi.org/10.1097/00006324-199604000-00011>
- 804   Kulp, M. T., & Schmidt, P. P. (1996b). Visual Predictors of Reading Performance in  
805           Kindergarten and First Grade Children. *Optometry and Vision Science*, 73(4), 255–262.  
806           <https://doi.org/10.1097/00006324-199604000-00007>
- 807   Kulp, M. T., & Schmidt, P. P. (1997). The Relation of Clinical Saccadic Eye Movement  
808           Testing to Reading in Kindergartners and First Graders. *Optometry and Vision Science*,  
809           74(1), 37–42. <https://doi.org/10.1097/00006324-199701000-00018>
- 810   Kuperman, V., Van Dyke, J. A., & Henry, R. (2016). Eye-Movement Control in RAN and  
811           Reading. *Scientific Studies of Reading*, 20(2), 173–188.  
812           <https://doi.org/10.1080/10888438.2015.1128435>
- 813   Kwon, M. Y., Legge, G. E., & Dubbels, B. R. (2007). Developmental changes in the visual  
814           span for reading. *Vision Research*, 47(22), 2889–2900.  
815           <https://doi.org/10.1016/j.visres.2007.08.002>
- 816   Lallier, M., Donnadieu, S., Berger, C., & Valdois, S. (2010). A case study of developmental  
817           phonological dyslexia: Is the attentional deficit in the perception of rapid stimuli  
818           sequences amodal? *Cortex*, 46(2), 231–241. <https://doi.org/10.1016/j.cortex.2009.03.014>
- 819   Larter, S. C., Herse, P. R., Naduvilath, T. J., & Dain, S. J. (2004). Spatial load factor in  
820           prediction of reading performance. *Ophthalmic and Physiological Optics*, 24(5), 440–  
821           449. <https://doi.org/10.1111/j.1475-1313.2004.00219.x>
- 822   Launay, L., & Valdois, S. (2004). Évaluation et prise en charge cognitive de l'enfant  
823           dyslexique et/ou dysorthographique de surface. In S. Valdois, P. D. Colé, & D. David  
824           (Eds.), *Apprentissage de la lecture et dyslexies développementales. De la théorie à la*  
825           *pratique orthophonique et pédagogique* (pp. 209–232). SOLAL.
- 826   Lee, H. W., Legge, G. E., & Ortiz, A. (2003). Is word recognition different in central and

- 827 peripheral vision? *Vision Research*, 43(26), 2837–2846. <https://doi.org/10.1016/S0042->  
828 6989(03)00479-6
- 829 Lefavrais, P. (1967). *Test de l'alouette: manuel*. Les éditions du centre de psychologie  
830 appliquée.
- 831 Lefavrais, P. (2005). *Alouette-R*. Les éditions du centre de psychologie appliquée.
- 832 Legge, G. E., Klitz, T. S., & Tjan, B. S. (1997). Mr. Chips: An Ideal-Observer Model of  
833 Reading. *Psychological Review*, 104(3), 524–553. <https://doi.org/10.1037/0033->  
834 295X.104.3.524
- 835 Lehtimäki, T. M., & Reilly, R. G. (2005). Improving eye movement control in young readers.  
836 *Artificial Intelligence Review*, 24(3–4), 477–488. <https://doi.org/10.1007/s10462-005->  
837 9010-x
- 838 Leibnitz, L., Ducrot, S., Muneaux, M., & Grainger, J. (2015). Spécificité des capacités visuo-  
839 attentionnelles et lecture chez l'enfant. *Revue Francophone d'Orthoptie*, 8(1), 45–49.  
840 <https://doi.org/10.1016/j.rfo.2015.02.011>
- 841 Leibnitz, L., Grainger, J., Muneaux, M., & Ducrot, S. (2017). Processus visuo-attentionnels et  
842 lecture : une synthèse. *L'Année Psychologique*, 116(4), 597–622.  
843 <https://doi.org/10.4074/S0003503316000403>
- 844 Lété, B., & Ducrot, S. (2008). Visuo-Attentional Processing by Dyslexic Readers on the  
845 Reicher-Wheeler Task. *Current Psychology Letters*, 24(Vol. 24, Issue 1, 2008), 24–40.  
846 <https://doi.org/10.4000/cpl.3523>
- 847 Lonigan, C. J. (2006). Development, Assessment, and Promotion of Preliteracy Skills. *Early*  
848 *Education & Development*, 17(1), 91–114. [https://doi.org/10.1207/s15566935eed1701\\_5](https://doi.org/10.1207/s15566935eed1701_5)
- 849 Lonigan, C. J., Burgess, S. R., & Anthony, J. L. (2000). Development of emergent literacy  
850 and early reading skills in preschool children: Evidence from a latent-variable  
851 longitudinal study. *Developmental Psychology*, 36(5), 596–613.  
852 <https://doi.org/10.1037/0012-1649.36.5.596>
- 853 Lovegrove, W., Bowling, A., Badcock, D., & Blackwood, M. (1980). Specific reading  
854 disability: differences in contrast sensitivity as a function of spatial frequency. *Science*,  
855 210(4468), 439–440. <https://doi.org/10.1126/science.7433985>

- 856 Maples, W. C. C., & Ficklin, T. (1990). Comparison of Eye Movement Skills Between Above  
857 Average and Below Average Readers. In *Journal of Behavioral Optometry* (Vol. 1, Issue  
858 4, pp. 87–91). [http://www.oepf.org/journal/pdf/jbo-volume-1-issue-4-comparison-eye-](http://www.oepf.org/journal/pdf/jbo-volume-1-issue-4-comparison-eye-movement-skills-between-above-average-and-below-aver)  
859 [movement-skills-between-above-average-and-below-aver](http://www.oepf.org/journal/pdf/jbo-volume-1-issue-4-comparison-eye-movement-skills-between-above-average-and-below-aver)
- 860 Martelli, M., Di Filippo, G., Spinelli, D., & Zoccolotti, P. (2009). Crowding, reading, and  
861 developmental dyslexia. *Journal of Vision*, 9(4), 1–18. <https://doi.org/10.1167/9.4.14>
- 862 Memiş, A., & Sivri, D. A. (2016). The Analysis of Reading Skills and Visual Perception  
863 Levels of First Grade Turkish Students. *Journal of Education and Training Studies*, 4(8),  
864 161–166. <https://doi.org/10.11114/jets.v4i8.1663>
- 865 Meng, X., Cheng-Lai, A., Zeng, B., Stein, J. F., & Zhou, X. (2011). Dynamic visual  
866 perception and reading development in Chinese school children. *Annals of Dyslexia*,  
867 61(2), 161–176. <https://doi.org/10.1007/s11881-010-0049-2>
- 868 Moiroud, L., Gerard, C. L., Peyre, H., & Bucci, M. P. (2018). Developmental Eye Movement  
869 test and dyslexic children: A pilot study with eye movement recordings. *PLoS ONE*,  
870 13(9), 1–11. <https://doi.org/10.1371/journal.pone.0200907>
- 871 Moiroud, L., Royo, A., & Bucci, M. P. (2020). The Developmental Eye Movement Test in  
872 French Children. *Optometry and Vision Science*, 97(11), 978–983.  
873 <https://doi.org/10.1097/OPX.0000000000001598>
- 874 Morgan, W. P. (1896). A Case of Congenital Word Blindness. *BMJ*, 2(1871), 1378–1378.  
875 <https://doi.org/10.1136/bmj.2.1871.1378>
- 876 Morris, R. K., & Rayner, K. (1991). Eye movements in skilled reading: Implications for  
877 developmental dyslexia. In J. F. Stein (Ed.), *Vision and Visual Dyslexia* (pp. 233–242).  
878 MacMillan Press.
- 879 Muneaux, M. (2018). *A new practitioners guide for clinical psychometrics*. Paris: De Boeck  
880 Supérieur.
- 881 Narayanasamy, S., Vincent, S. J., Sampson, G. P., & Wood, J. M. (2016). Visual demands in  
882 modern Australian primary school classrooms. *Clinical and Experimental Optometry*,  
883 99(3), 233–240. <https://doi.org/10.1111/cxo.12365>
- 884 Nicolson, R. I., & Fawcett, A. (2010). *Dyslexia, learning, and the brain*. MIT press.

- 885 Northway, N. (2003). Predicting the continued use of overlays in school children - A  
886 comparison of the Developmental Eye Movement test and the Rate of Reading test.  
887 *Ophthalmic and Physiological Optics*, 23(5), 457–464. [https://doi.org/10.1046/j.1475-](https://doi.org/10.1046/j.1475-1313.2003.00144.x)  
888 [1313.2003.00144.x](https://doi.org/10.1046/j.1475-1313.2003.00144.x)
- 889 O'Regan, J. K., & Lévy-Schoen, A. (1987). Eye-movement strategy and tactics in word  
890 recognition and reading. In M. Coltheart (Ed.), *Attention and performance 12: The*  
891 *psychology of reading* (pp. 363–383). Lawrence Erlbaum Associates, Inc.
- 892 Oberer, N., Gashaj, V., & Roebers, C. M. (2018). Executive functions, visual-motor  
893 coordination, physical fitness and academic achievement: Longitudinal relations in  
894 typically developing children. *Human Movement Science*, 58(January), 69–79.  
895 <https://doi.org/10.1016/j.humov.2018.01.003>
- 896 Orlandy, G., Hopkins, K. B., Mitchell, G. L., Huang, K., Frazier, M., Heyman, C., &  
897 Scheiman, M. (2011). Reliability of the Developmental Eye Movement Test. *Optometry*  
898 *and Vision Science*, 88(12), 1. <https://doi.org/10.1097/OPX.0b013e318230f03a>
- 899 Ozernov-Palchik, O., & Gaab, N. (2016). Tackling the ‘dyslexia paradox’: reading brain and  
900 behavior for early markers of developmental dyslexia. *Wiley Interdisciplinary Reviews:*  
901 *Cognitive Science*, 7(2), 156–176. <https://doi.org/10.1002/wcs.1383>
- 902 Palomo-Álvarez, C., & Puell, M. C. (2009). Relationship between oculomotor scanning  
903 determined by the DEM test and a contextual reading test in schoolchildren with reading  
904 difficulties. *Graefe's Archive for Clinical and Experimental Ophthalmology*, 247(9),  
905 1243–1249. <https://doi.org/10.1007/s00417-009-1076-8>
- 906 Parrila, R., Kirby, J. R., & McQuarrie, L. (2004). Articulation rate, naming speed, verbal  
907 short-term memory, and phonological awareness: Longitudinal predictors of early  
908 reading development? *Scientific Studies of Reading*, 8(1), 3–26.  
909 [https://doi.org/10.1207/s1532799xssr0801\\_2](https://doi.org/10.1207/s1532799xssr0801_2)
- 910 Pelli, D. G., Palomares, M., & Majaj, N. J. (2004). Crowding is unlike ordinary masking:  
911 Distinguishing feature integration from detection. *Journal of Vision*, 4(12), 1136–1169.  
912 <https://doi.org/10.1167/4.12.12>
- 913 Pienaar, A. E., Barhorst, R., & Twisk, J. W. R. (2014). Relationships between academic  
914 performance, SES school type and perceptual-motor skills in first grade South African  
915 learners: NW-CHILD study. *Child: Care, Health and Development*, 40(3), 370–378.

- 916 <https://doi.org/10.1111/cch.12059>
- 917 Piquard-Kipffer, A., & Sprenger-Charolles, L. (2013). Early predictors of future reading  
918 skills: A follow-up of French-speaking children from the beginning of kindergarten to  
919 the end of the second grade (age 5 to 8). In *Annee Psychologique* (Vol. 113, Issue 4).  
920 <https://doi.org/10.4074/S0003503313014012>
- 921 Plaza, M., & Cohen, H. (2007). The contribution of phonological awareness and visual  
922 attention in early reading and spelling. *Dyslexia*, 239(13), 234–239.  
923 <https://doi.org/10.1002/dys>
- 924 Pollatsek, A., & Rayner, K. (2005). Reading. In K. Lamberts & R. L. Goldstone (Eds.),  
925 *Handbook of cognition* (pp. 276–293). Sage.
- 926 Portnoy, A., & Gilaie-Dotan, S. (2020). *Oculomotor-related measures but not distance visual*  
927 *acuity are predictive of reading ability in first graders.*  
928 <https://doi.org/10.1101/2020.03.09.983197>
- 929 Powers, M. K. (2009). Paper tools for assessing visual function. *Optometry and Vision*  
930 *Science*, 86(6), 613–618. <https://doi.org/10.1097/OPX.0b013e3181a76c7c>
- 931 Raghuram, A., Gowrisankaran, S., Swanson, E., Zurakowski, D., Hunter, D. G., & Waber, D.  
932 P. (2018). Frequency of Visual Deficits in Children With Developmental Dyslexia.  
933 *JAMA Ophthalmology*, 136(10), 1089.  
934 <https://doi.org/10.1001/jamaophthalmol.2018.2797>
- 935 Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers.  
936 *Journal of Experimental Child Psychology*, 41(2), 211–236.  
937 [https://doi.org/10.1016/0022-0965\(86\)90037-8](https://doi.org/10.1016/0022-0965(86)90037-8)
- 938 Rayner, K. (2009). Eye Movements in Reading: Models and Data. *Journal of Eye Movement*  
939 *Research*, 2(5), 1–10. <https://doi.org/10.16910/jemr.2.5.2>
- 940 Rayner, K., & Bertera, J. (1979). Reading without a fovea. *Science*, 206(4417), 468–469.  
941 <https://doi.org/10.1126/science.504987>
- 942 Rayner, K., & Liversedge, S. P. (2011). Linguistic and cognitive influences on eye  
943 movements during reading. In S. P. Liversedge, I. D. Gilchrist, & S. Everling (Eds.), *The*  
944 *Oxford handbook of eye movements.* (pp. 751–766). Oxford University Press.

- 945 Rayner, K., & Morrison, R. E. (1981). Eye movements and identifying words in parafoveal  
946 vision. *Bulletin of the Psychonomic Society*, *17*(3), 135–138.  
947 <https://doi.org/10.3758/BF03333690>
- 948 Richman, J. E. (2009). Developmental Eye Movement Test, Examiner's manual, version 2.0.  
949 *South Bend, IN: Bernell Corp.*
- 950 Schatschneider, C., Fletcher, J. M., Francis, D. J., Carlson, C. D., & Foorman, B. R. (2004).  
951 Kindergarten prediction of reading skills: A longitudinal comparative analysis. *Journal*  
952 *of Educational Psychology*, *96*(2), 265–282. <https://doi.org/10.1037/0022-0663.96.2.265>
- 953 Serdjukova, J., Ekimane, L., Valeinis, J., Skilters, J., & Krumina, G. (2017). How strong and  
954 weak readers perform on the Developmental Eye Movement test (DEM): norms for  
955 Latvian school-aged children. *Reading and Writing*, *30*(2), 233–252.  
956 <https://doi.org/10.1007/s11145-016-9671-7>
- 957 Shonkoff, J. P., & Phillips, D. A. (2000). *From Neurons to Neighborhoods* (Childhood  
958 Development National Research Council (US) and Institute of Medicine (US)  
959 Committee on Integrating the Science of Early (ed.)). National Academies Press.  
960 <https://doi.org/10.17226/9824>
- 961 Solan, H. A., & Mozlin, R. (1986). The correlations of perceptual-motor maturation to  
962 readiness and reading in kindergarten and the primary grades. *Journal of the American*  
963 *Optometric Association*, *57*(1), 28–35.
- 964 Sortor, J. M., & Kulp, M. T. (2003). Are the Results of the Beery-Buktenica Developmental  
965 Test of Visual-Motor Integration and Its Subtests Related to Achievement Test Scores?  
966 *Optometry and Vision Science*, *80*(11), 758–763. [https://doi.org/10.1097/00006324-](https://doi.org/10.1097/00006324-200311000-00013)  
967 [200311000-00013](https://doi.org/10.1097/00006324-200311000-00013)
- 968 Stanovich, K. E., Cunningham, A. E., & West, R. F. (1981). A Longitudinal Study of the  
969 Development of Automatic Recognition Skills in First Graders. *Journal of Reading*  
970 *Behavior*, *13*(1), 57–74. <https://doi.org/10.1080/10862968109547394>
- 971 Stein, J. F., & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia.  
972 *Trends in Neurosciences*, *20*(4), 147–152. [https://doi.org/10.1016/S0166-](https://doi.org/10.1016/S0166-2236(96)01005-3)  
973 [2236\(96\)01005-3](https://doi.org/10.1016/S0166-2236(96)01005-3)
- 974 Storch, S. A., & Whitehurst, G. J. (2002). Oral language and code-related precursors to



- 975 reading: evidence from a longitudinal structural model. *Developmental Psychology*,  
976 38(6), 934–947. <https://doi.org/10.1037/0012-1649.38.6.934>
- 977 Strasburger, H. (2005). Unfocussed spatial attention underlies the crowding effect in indirect  
978 form vision. *Journal of Vision*, 5(11), 1024–1037. <https://doi.org/10.1167/5.11.8>
- 979 Swets, J. A. (1988). Measuring the Accuracy of Diagnostic Systems Linked references are  
980 available on JSTOR for this article : Measuring the Accuracy of Diagnostic Systems.  
981 *Science*, 240(4857), 1285–1293.
- 982 Tassinari, J. T., & DeLand, P. (2005). Developmental Eye Movement Test: reliability and  
983 symptomatology. *Optometry - Journal of the American Optometric Association*, 76(7),  
984 387–399. <https://doi.org/10.1016/j.optm.2005.05.006>
- 985 Tydgat, I., & Grainger, J. (2009). Serial Position Effects in the Identification of Letters,  
986 Digits, and Symbols. *Journal of Experimental Psychology: Human Perception and*  
987 *Performance*, 35(2), 480–498. <https://doi.org/10.1037/a0013027>
- 988 Valdois, S., Roulin, J. L., & Line Bosse, M. (2019). Visual attention modulates reading  
989 acquisition. *Vision Research*, 165(October), 152–161.  
990 <https://doi.org/10.1016/j.visres.2019.10.011>
- 991 Vidyasagar, T. R., & Pammer, K. (2010). Dyslexia: a deficit in visuo-spatial attention, not in  
992 phonological processing. *Trends in Cognitive Sciences*, 14(2), 57–63.  
993 <https://doi.org/10.1016/j.tics.2009.12.003>
- 994 Vinuela-Navarro, V., Erichsen, J. T., Williams, C., & Woodhouse, J. M. (2017). Saccades and  
995 fixations in children with delayed reading skills. *Ophthalmic and Physiological Optics*,  
996 37(4), 531–541. <https://doi.org/10.1111/opo.12392>
- 997 Visser, T. A. W., Boden, C., & Giaschi, D. E. (2004). Children with dyslexia: Evidence for  
998 visual attention deficits in perception of rapid sequences of objects. *Vision Research*,  
999 44(21), 2521–2535. <https://doi.org/10.1016/j.visres.2004.05.010>
- 1000 Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994). Development of reading-related  
1001 phonological processing abilities: New evidence of bidirectional causality from a latent  
1002 variable longitudinal study. *Developmental Psychology*, 30(1), 73–87.  
1003 <https://doi.org/10.1037/0012-1649.30.1.73>
- 1004 White, S. L. J., Wood, J. M., Black, A. A., & Hopkins, S. (2017). Vision screening outcomes

- 1005 of Grade 3 children in Australia: Differences in academic achievement. *International*  
1006 *Journal of Educational Research*, 83, 154–159.  
1007 <https://doi.org/10.1016/j.ijer.2017.03.004>
- 1008 Whitney, D., & Levi, D. M. (2011). Visual crowding: A fundamental limit on conscious  
1009 perception and object recognition. *Trends in Cognitive Sciences*, 15(4), 160–168.  
1010 <https://doi.org/10.1016/j.tics.2011.02.005>
- 1011 Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental  
1012 dyslexias. *Journal of Educational Psychology*, 91(3), 415–438.  
1013 <https://doi.org/10.1037/0022-0663.91.3.415>
- 1014 Wolverton, G. S., & Zola, D. (1983). Some thoughts on the temporal characteristics of visual  
1015 information extraction during reading. In K. Rayner (Ed.), *Eye movements in reading:*  
1016 *Perceptual and language processes* (Academic P, pp. 41–51).
- 1017 Wood, J. M., Black, A. A., Hopkins, S., & White, S. L. J. (2018). Vision and academic  
1018 performance in primary school children. *Ophthalmic and Physiological Optics*, 38(5),  
1019 516–524. <https://doi.org/10.1111/opo.12582>
- 1020 World Health Organisation. (2008). *59th general assembly* (A. WM (ed.)). WHO.
- 1021 Xie, Y., Shi, C., Tong, M., Zhang, M., Li, T., Xu, Y., Guo, X., Hong, Q., & Chi, X. (2016).  
1022 Developmental eye movement (DEM) test norms for mandarin Chinese-speaking  
1023 Chinese children. *PLoS ONE*, 11(2), 1–12. <https://doi.org/10.1371/journal.pone.0148481>
- 1024 Yang, X., Chung, K. K. H., & McBride, C. (2019). Longitudinal contributions of executive  
1025 functioning and visual-spatial skills to mathematics learning in young Chinese children.  
1026 *Educational Psychology*, 39(5), 678–704.  
1027 <https://doi.org/10.1080/01443410.2018.1546831>
- 1028 Yang, X., McBride, C., Ho, C. S. H., & Chung, K. K. H. (2020). Longitudinal associations of  
1029 phonological processing skills, Chinese word reading, and arithmetic. *Reading and*  
1030 *Writing*, 33(7), 1679–1699. <https://doi.org/10.1007/s11145-019-09998-9>
- 1031 Yang, X., & Meng, X. (2020). Visual Processing Matters in Chinese Reading Acquisition and  
1032 Early Mathematics. *Frontiers in Psychology*, 11(April), 1–11.  
1033 <https://doi.org/10.3389/fpsyg.2020.00462>
- 1034 Yeshurun, Y., & Rashal, E. (2010). Precueing attention to the target location diminishes

- 1035 crowding and reduces the critical distance Yaffa Yeshurun. *Journal of Vision*, 10, 1–12.  
1036 <https://doi.org/10.1167/10.10.16.Introduction>
- 1037 Zhou, Y., McBride-Chang, C., & Wong, N. (2014). What is the role of visual skills in  
1038 learning to read? *Frontiers in Psychology*, 5(July), 1–3.  
1039 <https://doi.org/10.3389/fpsyg.2014.00776>
- 1040 Ziegler, J. C., Castel, C., Pech-Georgel, C., George, F., Alario, F. X., & Perry, C. (2008).  
1041 Developmental dyslexia and the dual route model of reading: Simulating individual  
1042 differences and subtypes. *Cognition*, 107(1), 151–178.  
1043 <https://doi.org/10.1016/j.cognition.2007.09.004>
- 1044 Zorzi, M., Barbiero, C., Facoetti, A., Lonciari, I., Carrozzi, M., Montico, M., Bravar, L.,  
1045 George, F., Pech-Georgel, C., & Ziegler, J. C. (2012). Extra-large letter spacing  
1046 improves reading in dyslexia. *Proceedings of the National Academy of Sciences of the*  
1047 *United States of America*, 109(28), 11455–11459.  
1048 <https://doi.org/10.1073/pnas.1205566109>
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- 1050

1051 Table 1. Descriptive analysis of French data for preschool children.

	<b>Kindergarten</b>			
	<i>n = 51</i>			
	VT	HTaj	HE	R
Mean	105,51	193,00	30,35	1,85
Standard deviation	32,16	77,14	15,34	0,51

1052 *Notes.* VT: Vertical Time; HTaj: adjusted Horizontal Time; HE: Horizontal Errors; R: Ratio.

1053

1054

1055 Table 2. Correlation matrix of the DEM indices (z-score) assessed in kindergarten and the  
 1056 Alouette-test indices (z-score) assessed in Grade 1.

	READING ACCURACY (CM)	READING SPEED (CTL)
VT	-0.626***	-0.512**
HTaj	-0.598***	-0.318
HE	-0.453*	-0.229
R	-0.150	-0.097

1057 *Notes.* \*  $p < .05$ ; \*\*  $p < .01$ ; \*\*\*  $p < .001$ ; VT: Vertical Time; HTaj: adjusted Horizontal Time;  
 1058 HE: Horizontal Errors; R: Ratio.

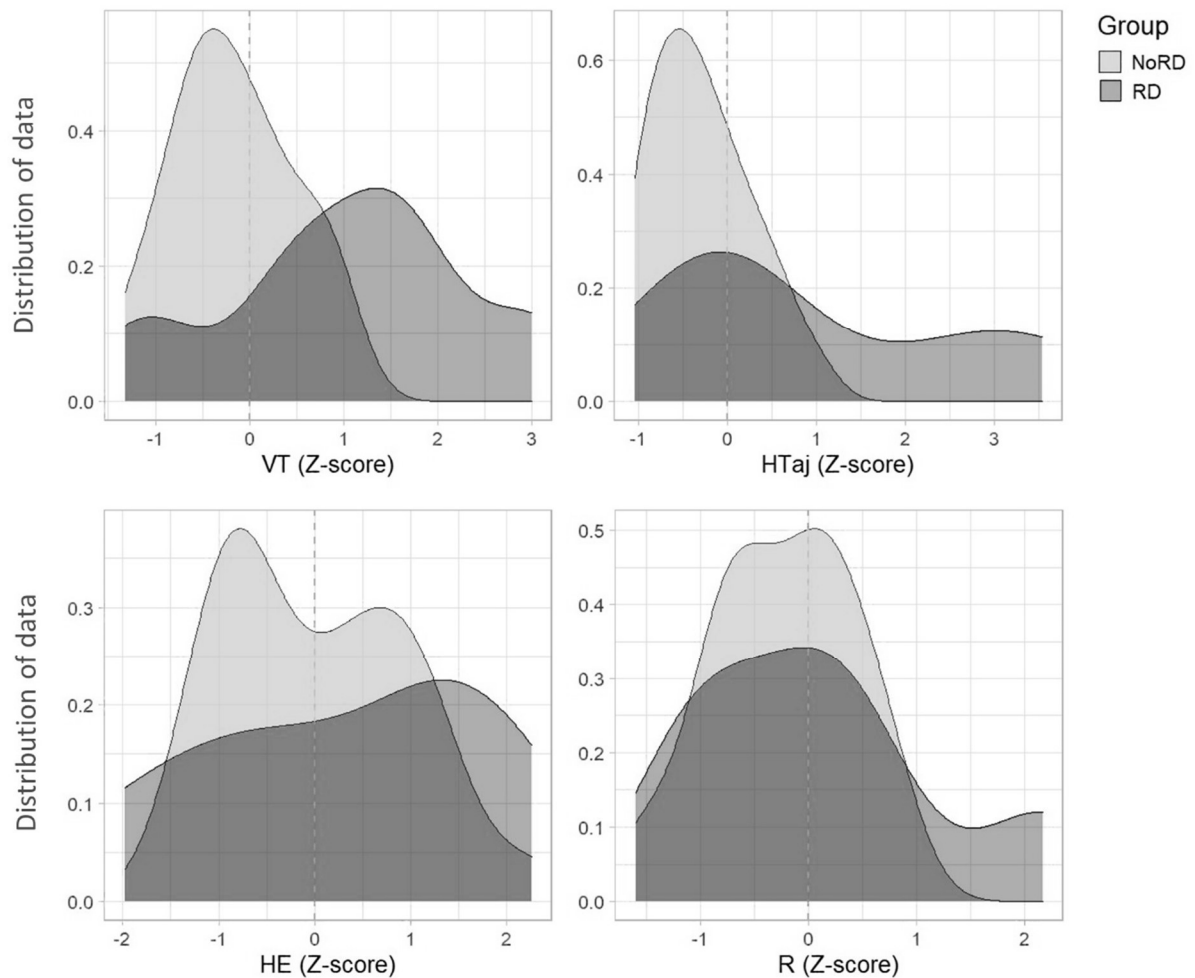
1059

1060 Table 3. Simple linear regression analysis assessing the predictive role of the DEM indices  
 1061 (z-score) in kindergarten on the reading outcomes (z-score) in Grade 1

	READING ACCURACY (CM)			READING SPEED (CTL)		
	R <sup>2</sup>	B	t	R <sup>2</sup>	β	t
VT	0.370	-0.558	4.249***	0.235	-0.426	-3.147**
HTaj	0.334	-0.485	3.946***	-	-	-
HE	0.178	-0.320	-2.694*	-	-	-

1062 *Notes.* \* p<.05 , \*\* p<.01 , \*\*\* p<.001; VT: Vertical Time; HTaj: adjusted Horizontal Time;  
 1063 HE: Horizontal Errors

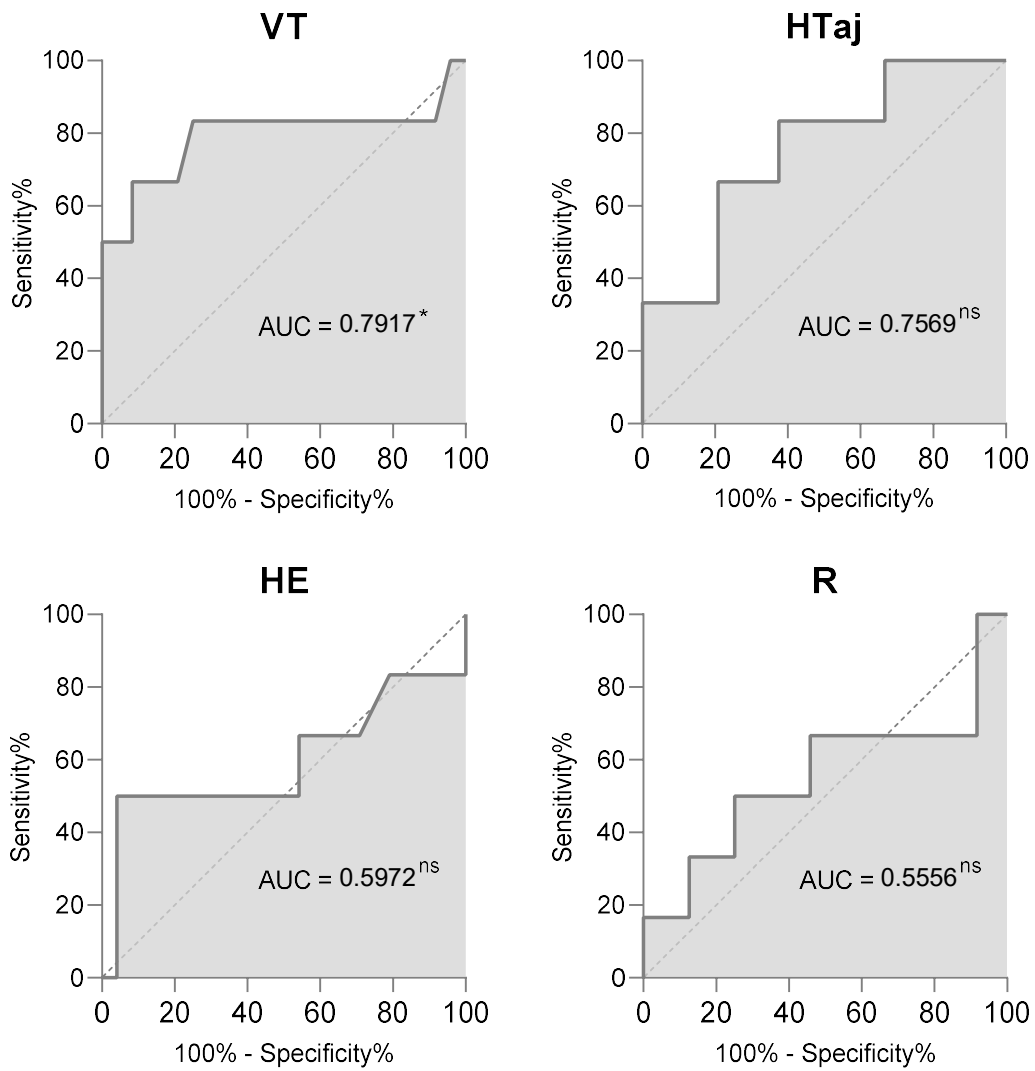
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1065

1066 Figure 1. Data distribution for all the DEM-test indices across children with and without  
 1067 reading difficulties.

1068 *Notes.* Since the explanatory variables were time, number of errors, or ratio, a high score reflects  
 1069 poorer performance than a lower score, thus a negative Z-score represents better performance  
 1070 than a positive Z-score; RD: Children with reading disorders; NoRD: Children without reading  
 1071 disorders.



1072

1073 Figure 2. ROC curve analyses for each DEM-test index assessed in kindergarten between  
 1074 children with and without reading difficulties.

1075 Notes. AUC: Area Under the Curve; ns  $p > .05$ ; \*  $p < .05$ ; \*\*  $p < .01$ ; \*\*\*  $p < .001$ .