



HAL
open science

Predicting future poor readers from pre-reading visual skills: A longitudinal study

Marie Vernet, Stéphanie Bellocchi, Laurie Leibnitz, Yves Chaix, Stéphanie Ducrot

► To cite this version:

Marie Vernet, Stéphanie Bellocchi, Laurie Leibnitz, Yves Chaix, Stéphanie Ducrot. Predicting future poor readers from pre-reading visual skills: A longitudinal study. *Applied Neuropsychology: Child*, 2022, 11 (3), pp.480-494. 10.1080/21622965.2021.1895790 . hal-03102987v2

HAL Id: hal-03102987

<https://hal.science/hal-03102987v2>

Submitted on 5 Jan 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License

1 **Predicting Future Poor Readers from Pre-reading Visual Skills:**
2 **A Longitudinal Study**

3
4 Marie Vernet^{a,b}, Laurie Leibnitz^d, Stéphanie Bellocchi^e, Yves Chaix^{b,c}, Stéphanie Ducrot^a

5
6 ^aAix Marseille Univ, CNRS, LPL, Aix-en-Provence, France

7 ^bToNIC, Toulouse NeuroImaging Center, Université de Toulouse, Inserm, UPS, Toulouse,
8 France

9 ^cHôpital des enfants, Centre hospitalier universitaire Purpan, Toulouse, France

10 ^dCentre Médico-Psycho-Pédagogique, Association des CMPP, Fort-de-France, Martinique

11 ^eUniv. Paul Valéry Montpellier 3, Univ. Montpellier, EPSYLON EA 4556, Montpellier,
12 France

13
14
15 SHORT RUNNING TITLE: PREREADING VISUAL SKILLS AND FUTURE READING
16 ABILITIES

17
18
19
20 **Correspondence**

21 Marie Vernet

22 Toulouse Neuro-Imaging Center

23 Pavillon Baudot – CHU Purpan

24 Place du Dr Joseph Baylac

25 31024 Toulouse, France

26 E-mail: marie.vernet@inserm.fr

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

28 **A longitudinal study**

29
30 **ABSTRACT**

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

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

52 **INTRODUCTION**

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

60 While a good deal of recent research has focused on the role of phonological skills in
61 learning to perceive written language, little attention has been paid to the development of
62 visual skills¹ in prereaders or about the role that these visual skills play in early reading
63 development. However, reading is a visual task, highly constrained by the anatomical and
64 functional limits of our visual system (for reviews, see Leibnitz et al., 2015, 2017). Whereas it
65 is likely that both phonology and visual processes contribute to skilled reading acquisition and
66 its dysfunction, few studies have been conducted to examine oculomotor and visuo-perceptual
67 processes related to word recognition skills in children as they learn to read. This paper is
68 therefore focused upon those processes and on their potential as explanation of reading
69 behaviour and reading problems in the context of general emergent literacy skills.

70 **The importance of visual processing in reading**

71 Previous researchers have found high overlaps between visual skills and domain-
72 general cognitive skills (e.g., sustained attention, nonverbal reasoning, and inhibitory control)
73 (Buckley et al., 2018; Yang et al., 2019), as well as rapid automatic naming (RAN; Yang et
74 al., 2020). For sighted people, written language is perceived visually. The high visual acuity

¹ 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

75 that is needed to rapidly identify words is spatially limited (Lee et al., 2003; Rayner &
76 Bertera, 1979; Rayner & Morrison, 1981) and most studies today agree about the link
77 between visual attention and oculomotor control during reading: visual attention affects
78 saccadic programming, that is, the position where the eyes land in a word and acts as a filter
79 that enhances letter identification under the attentional focus, thus limiting the detrimental
80 effects of acuity and crowding (Carrasco, 2011; Strasburger, 2005; Tydgate & Grainger, 2009;
81 Yeshurun & Rashal, 2010). One of the first task of the beginning reader is therefore to
82 develop good oculomotor skills to overcome anatomo-functional constraints of the eye and be
83 able to land in the best position within the words to be read, to extract the information being
84 fixated, to program a saccade, to position the eyes on the next word, and so on (Ducrot et al.,
85 2013; O'Regan & Lévy-Schoen, 1987; Rayner, 1986).

86 Furthermore, visual processing shapes the way visual information is extracted from
87 print (Aghababian & Nazir, 2000; Ducrot et al., 2013). In order to process letters within
88 foveal strings and to apply grapheme-to-phoneme conversion rules, beginning readers must be
89 able, at first, to segment the fixated information by shifting from distributed attention to more
90 focused attention. Secondly, the child has to detect and take into account letter orientation
91 (e.g. p becomes q with an orientation change), letter sharpens (e.g. c and e only differ from
92 each other by a visual feature) and letter-in-word order (the same set of letters can make
93 different words, e.g. pat, tap, apt in English). Finally, the child has to develop to inhibit all
94 surrounding letters and words to reduce visual crowding—that is the interference generated
95 by stimuli in close proximity—and optimize letter identification under the attentional focus
96 (Tydgate & Grainger, 2009). It follows that basic aspects of oculomotor control (which
97 provide optimal visual input), the ability to orient the focus of attention as well as the ability
98 to control its size are assumed to play a crucial role in the development of reading skills
99 (Ducrot et al., 2013; Grainger, 2018; Leibnitz et al., 2017; Morris & Rayner, 1991) and that

100 their inadequate development might be one cause of reading disabilities (e.g., Biscaldi et al.,
101 2000; Fischer & Weber, 1990).

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

112 In the same vein, a body of research suggests that deficits in visual-perceptual or
113 oculomotor processing may contribute to reading difficulties (Franceschini et al., 2012; Gori
114 & Facoetti, 2015; Granet et al., 2006; Meng et al., 2011; Vidyasagar & Pammer, 2010; Zhou
115 et al., 2014; see also Bellocchi et al., 2013, for a review). For example, children who have
116 deficits in visual perception often cannot efficiently distinguish words printed in different
117 sizes or colors (Fischer et al., 2000; Visser et al., 2004). In addition to poor performance on
118 tasks requiring phonological awareness, children who had poor reading abilities may present
119 visual perception deficits, e.g. (1) disturbances in contrast sensibility (Lovegrove et al., 1980),
120 weak sensitivity in detecting coherent motion or forms (Cornelissen et al., 1995), letter
121 identity confusions and/or location errors (Pelli et al., 2004; Whitney & Levi, 2011);
122 distortion, blurring, merging or moving of letters or words (Kovács, 2000; Stein & Walsh,
123 1997), (2) oculomotor dysfunction (e.g., increased duration and number of fixations, reduced
124 saccade amplitude, increased ocular regression leading to misread words, missing words and

125 skipping lines (De Luca et al., 2002; Hutzler & Wimmer, 2004) and/or (3) visual attention
126 impairments (e.g. problems focusing attention, Kramer & Hinojosa, 1999; high sensitivity to
127 the crowding effect, Martelli et al., 2009; Zorzi et al., 2012; symmetrical OVP curve,
128 (Bellocchi & Ducrot, 2021; Ducrot et al., 2003) when they attempt to read (see also, Bosse &
129 Valdois, 2009; Ducrot & Lété, 2008, 2020; Lallier et al., 2010; Lété & Ducrot, 2008). It also
130 has been found that remediation based on training of oculomotor and visuo-attentional
131 abilities improves reading abilities in dyslexic children (Caldani et al., 2020; Launay &
132 Valdois, 2004; Lehtimäki & Reilly, 2005).

133

134 **Predictors of reading development**

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

145 As previously stated, the importance of phonological and orthographic skills in
146 learning to read shouldn't overshadow the fact that a written or printed word is, above all, a
147 visual stimulus, and visuo-attentional and oculomotor skills (which provide optimal visual

² 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).

148 input) may play a crucial role in successful reading development. If visual perception is not
149 fully developed by the time a child is in preschool, his or her ability to read (Flax et al., 1984;
150 Kulp & Schmidt, 1996a, 1996b), to spell, and to write (Borsting et al., 2005) may be affected.
151 These visual disorders which often appear in the absence of complaints expressed by the
152 subject or his/her family may lead to eye fatigue, increased tiredness of the child, blurriness,
153 headaches, and/or burning eyes, and then, depending on their severity, to difficulty sustaining
154 attention and focus. All of which may interfere with visual exploration, reading fluency and
155 distract from reading comprehension.

156 Recent research suggests that in addition to skills with language sounds, visual-spatial
157 attention may be an important predictor of reading development. Franceschini et al. (2012)
158 showed that children who had poor reading abilities during the first or second year of reading
159 education made significantly more errors on a visual-search task and a spatial-cueing task
160 than normal readers had when they were in kindergarten. Moreover, poorly developed visual
161 information processing skills, which refer to the cognitive abilities required to extract and
162 organise visual input derived from the environment, have also been associated with poorer
163 learning outcomes (Vinuela-Navarro et al., 2017; Wood et al., 2018). In an earlier study,
164 Kavale (1982) performed a meta-analysis of 161 major studies relating visual perception and
165 reading performance. His results indicated that visual perception is a significant correlate of
166 reading achievement, and is predictive of reading performance in school, especially during the
167 preschool and primary school grades. The initial landing position, the visual-attentional span
168 and visual-motor skills also explain part of the variance in the reading abilities after one year
169 of learning (Bellocchi et al., 2017; Bosse & Valdois, 2009; Chung et al., 2004; Ducrot et al.,
170 2021; Kwon et al., 2007; Valdois et al., 2019). These various findings suggested therefore that
171 visual and oculomotor processing is highly essential in the development of reading skills.

172

The present study

173
174 To sum up, in addition to the well-documented importance of phonological skills in
175 reading acquisition and dyslexia, visual processes also appear as important factors in learning
176 to read. Despite the evidence of 1) the importance of the oculomotor and visuo-perceptual
177 processes in learning to read, and 2) data showing perceptual and oculomotor deficits in
178 dyslexics, the assessment of these processes is not systematically carried out and many visual
179 deficits still remain undetected in preschool children. We assume that it is crucial to be able to
180 assess perceptual, and visuo-attentional prerequisites to reading development, in order to
181 identify children at-risk for reading disabilities at an early age and increases the chance of
182 success for charting later developmental trajectories (Jenkins et al., 2007; Shonkoff &
183 Phillips, 2000).

184 It therefore seems important to find a reliable and practical test that could assess visual
185 processing skills in young children. At the current time, many tools available to professionals
186 are designed to assess phonological abilities as early as kindergarten, but there are very few
187 tools for assessing the relations between visual skills and the process of learning to read. In
188 that context, we have examined the usefulness of the Developmental Eye Movement (DEM)
189 test (Garzia et al., 1990) that provides an indirect measure of the efficiency of visual processes
190 in a simulated reading task (horizontal and vertical digit naming task, providing reading time
191 and errors) . This procedure was not chosen arbitrarily but in reference to previous work using
192 the DEM-test with and without eye-movement recording (Ayton et al., 2009; Bellocchi et al.,
193 2021; Facchin et al., 2011, 2014; Hopkins et al., 2019; Moiroud et al., 2018; Raghuram et al.,
194 2019; Webber et al., 2011). It is important to keep in mind here that all studies on the DEM-
195 test point agreed that visuo-perceptual and visuo-attentional processes play a major role in this
196 task (Ayton et al., 2009; Facchin et al., 2011, 2014; Hopkins et al., 2019; Larter et al., 2004;
197 Moiroud et al., 2018; Northway, 2003; Palomo-Álvarez & Puell, 2009; Portnoy & Gilaie-

198 Dotan, 2020; Raghuram et al., 2018). Moreover, there is a consensus on the relationship
199 between the DEM-test and reading abilities, both in school-age children (Ayton et al., 2009;
200 Larter et al., 2004; Palomo-Álvarez & Puell, 2009; Serdjukova et al., 2017; Wood et al.,
201 2018) and in children with learning difficulties (Bellocchi et al., 2021; Moiroud et al., 2018;
202 Northway, 2003; Raghuram et al., 2018). Note that Moiroud et al. (2018) with a video-
203 oculography while performing the DEM-test, even demonstrated that the time taken by the
204 children (dyslexic and non-dyslexic) to read Text C of the DEM-test was significantly
205 correlated with children fixation ability and the speed of reading a text. Taken together, these
206 results argue for a strong link between visual processing, performance of verbalization and the
207 DEM-test to clinically assess the reading performance of children with and without reading
208 deficiencies³.

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

218

³ 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.

219 **METHOD**

220 **Participants.** Fifty-one French-speaking children, enrolled from kindergarten to the
221 1st grade, took part in this study. All the participants had normal or corrected-to-normal
222 vision. None of them suffered from any neurological, psychiatric, or emotional disorders or
223 were educationally disadvantaged. The children were recruited in three kindergartens located
224 in the Aix-Marseille academy, in the south of France, and we obtained informed consent from
225 their parents and the agreement of the board of education prior to the beginning of the study.
226 The task was administered longitudinally. At Time 0, a total of fifty-one kindergarten children
227 (26 females; mean age 5.8 years; range 4.11 to 6.4) participated in the study. One year later,
228 participants were retested, in May of the first grade, that is, at the end of the school year. The
229 two testing sessions will hereafter be referred as test 0 (T0) and test 1 (T1). Thirty children
230 (12 females; mean age 6.10 years; range 6.4 to 7.3) were re-assessed in T1.

231

232 **Material and method.**

233 *Visual skills.* Visual and oculomotor skills were assessed using the DEM-test
234 (Developmental Eye Movement Test; Garzia et al., 1990; Richman, 2009), which is
235 composed by horizontal and vertical digit reading tasks printed on four different sheets of
236 paper: the pre-test (a horizontal line of ten 0.5 cm high digits) to ensure that the child is
237 familiar with all the digits presented, two vertical tests (Test A and B; each composed of two
238 vertical lines of twenty 0.5 cm high digits separated by a 10.5 cm horizontal margin and with
239 a 0.5 cm vertical distance between letters), which are supposed to evaluate the level of
240 automaticity of the naming of numbers with involving only basic oculomotor skills, and one
241 horizontal test (Test C; sixteen lines of five irregularly separated 0.5 cm high digits), that
242 requires good oculomotor and visuo-attentional skills, in addition to number naming skills,
243 due to the variable lines spacing and numerous line references making the ocular tracking of

244 lines more difficult. Children were asked to read aloud the digits as fast and as accurately as
245 possible. The task was timed, and errors or omissions were recorded. The DEM test provides
246 four main indices: (1) the vertical reading time (seconds) (VT) which represents the sum of
247 the time spent on naming the eighty vertically organized digits of Test A and B (in accordance
248 with the test manual, errors were not used for scoring purpose) ; (2) the adjusted horizontal
249 time (seconds) (HT) which represents the time required for reading the eighty horizontally
250 organized digits presented in the Test C; this score is corrected for omission or addition
251 errors⁴; (3) the total number of errors (HE) which gives the accuracy on the execution of Test
252 C corresponding to the sum of the 4 possible types of errors: addition errors (i.e., adding or
253 repeating a digit), omission errors (i.e., forgetting a digit), transposition errors (i.e., inversion
254 between two digits) and substitution errors (i.e., replacing one digit with another); and (4) the
255 Ratio score (R) which is calculated dividing the HT by the VT ; This ratio is intended to
256 isolate the involvement of oculomotor processes in the horizontal naming task.

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

265

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

266 **Procedure.** In this longitudinal study, children were tested twice (i.e., T0:
267 kindergarten, T1: May of the 1st grade). All the assessments always occurred in the schools in
268 which the children were enrolled. The children were tested individually in a quiet room in
269 their school during regular school hours. The brightness of the room was adapted according to
270 the support of the different tasks (i.e., paper or screen). At T0 of the study (i.e., kindergarten),
271 children's visual skills were assessed from the DEM-test. At T1 (i.e., Grade 1 - May), reading
272 skills were assessed using the Alouette-test. The administration of the DEM test lasted about
273 10 minutes, and that of the Alouette test approximately 5 min.

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

279

280 **Data analysis.** The statistical analyses were carried out using R and GraphPad
281 statistical software. Distributions for the outcome variables suggested no violations of the
282 normality assumption. The statistically significant threshold for all the analyses was set at $p =$
283 $.05$. Descriptive statistics were used to report group means and standard deviations for all the
284 DEM test parameters, to define the prevalence of visual difficulties in kindergarten.
285 Prevalence data were based on the threshold of 1 SD above mean⁵. Pearson's correlation
286 analyses were performed to examine the relationship between the performances on the DEM-

⁵ 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).

287 test in kindergarten and the reading level of these children (i.e., reading speed and accuracy)
288 assessed in the 1st grade. Linear regression analyses were subsequently performed in order to
289 integrate the explanatory variables, identified in the correlation analyses, into a model and to
290 isolate the part of the variance explained by these factors. Finally, ROC curve analyses were
291 conducted on the DEM-test indices to determine whether this tool does indeed differentiate
292 children with and without reading difficulties. These analyses allowed us to obtain a measure
293 of the diagnostic test's effectiveness. Indeed, the Area Under the Curve (AUC) is an effective
294 indicator, combining both sensitivity and specificity, which indicates the inherent validity of
295 diagnostic tests (see Hajian-Tilaki, 2013, for more details). The AUC, area under curve, can
296 be a value between 0.5 (chance level) and 1.0 (perfect discrimination) (Swets, 1988); AUCs >
297 0.9 are considered excellent, AUCs between 0.8 – 0.9 are very good, between 0.7 – 0.8 are
298 good, 0.6 – 0.7 are average, and an AUC < 0.6 is poor (Choi, 1998). For this analysis, a child
299 was considered to have poor reading skills if at least one of the two reading indices (i.e., CM
300 and/or CTL) was below the clinical threshold -1 SD (see Footnote 5).

301

302 **RESULTS**

303 *Prevalence of Visual Impairment in Kindergarten and Reading Difficulties in the 1st* 304 *Grade*

305 Mean and standard deviations for VT, adjusted HT (HTaj), HE and R indices
306 according to the schooling level (i.e., kindergarten) are reported in Table 1. A total of 16
307 children had at least one index below-average on the DEM-test in kindergarten, constituting
308 31% of the sample. More precisely, among these 16 children, 5 were below average on the
309 VT index, 5 on the HTaj index, 2 on both VT and HTaj indexes, 10 on the HE index and 5 on
310 the R index. Besides, the 10 children with a deviant performance on the HE index made

311 between 46 and 65 errors in the horizontal layout ($M = 31.57$, $SD = 16.35$). Regarding the
312 nature of these children's errors, on average, 70% were omissions, 25% were addition, 5%
313 were substitution and only 1% were transposition errors, thus confirming the role of visual
314 attention in error scores (Coulter & Shallo-Hoffman, 2001).

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

316

317 Thirty of these children were followed longitudinally⁶, and among them, 6 presented
318 reading difficulties (RD) in the 1st grade including 4 children who already presented
319 difficulties with at least one DEM-test index in kindergarten (i.e., 13.33% of the cohort
320 followed longitudinally). Moreover, 5 children presented a deviant performance in the DEM-
321 test without subsequent reading difficulties (NoRD, i.e., 16.67%) which may indicate purely
322 oculomotor or orthoptic deficits. Note that for these children only the HE index was deviant.
323 When these data were merged together, the distributions of the different DEM-test variables
324 behaved completely differently between children with Reading Difficulties (RD) and without
325 (NoRD), as shown in *Figure 1*. Children with RD differed from children without RD in the
326 VT distributions, with a deviant density peak for the first ones. The HT and HE distributions
327 of the data also confirmed the amplitude of the difficulties encountered by the kindergarten
328 children during this task. Preschool children made a large number of errors, whatever they
329 present RD in grade 1 ($M = 34.50$, $SD = 23.18$) or not ($M = 30.83$, $SD = 14.75$). Note that this
330 result cannot be attributed to poor number knowledge since all children had previously
331 successfully completed the pre-test. As ever observed in other studies, the ratio does not seem
332 an appropriate measure to predict or assess children with RD (e.g., Wood et al., 2018).

333

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

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

335

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

342

343 ***Predictive role of DEM-test outcomes on reading skills***

344 ***Reading accuracy.*** The correlation analyses, provided in *Table 2*, showed a significant
345 relationship between the reading accuracy (i.e., CM index) and all the time and error indexes
346 of the DEM-test (i.e., VT, HTaj and HE). Thus, the longer the vertical and adjusted horizontal
347 time are and the more errors there are at the DEM-test in kindergarten, the less accurate the
348 reading is in 1st grade. The R index did not correlate with the reading accuracy. The
349 regression analyses, as shown in *Table 3*, revealed that the variability in reading accuracy is
350 best explained by a simple linear model taking, as an explanatory variable, the VT index ($\beta =$
351 $-.69$, $p < .001$). More precisely, the reading accuracy is predicted at 37% by the VT index [$R^2 =$
352 $.37$]; $F(1,28) = 18.07$, $p < .001$], at 33% by the HTaj index [$R^2 = .33$]; $F(1,28) = 15.57$, $p <$
353 $.001$] and at 18% by the HE index [$R^2 = .18$]; $F(1,28) = 7.24$, $p < .05$]. The very close
354 predictive properties between the VT and HTaj indices can be explained by the strong
355 correlation maintained between these two factors ($r(28) = .74$; $p < .001$).

356 ***Reading speed.*** The correlation analyses (see *Table 2*) showed a significant
357 relationship between the reading speed (i.e., CTL index) and the VT index only. The HTaj,

358 HE and R indices did not correlate with the reading speed in the 1st grade. The regression
359 analyses, provided in *Table 3*, revealed that the variability in the reading speed is best
360 explained by a simple linear model taking the VT index as an explanatory variable. More
361 precisely, the VT index is the only predictor of the reading speed: it predicts 23 % [(R² = .24);
362 F(1,28) = 9.95, p<.01] of the variance.

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

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

365

366 ***ROC curves analyses.*** In order to better understand the potential role of the DEM-test
367 as an early screening tool for reading difficulties, the group of children was divided into two
368 different groups that separated children with and without RD. As previously mentioned in the
369 previous section, among the 30 children followed longitudinally, 6 presented weaknesses in
370 their reading skills in the 1st grade and 4 of these children already presented difficulties with
371 at least one DEM-test index in kindergarten (i.e., 13.33% of the cohort). The ROC curve
372 analyses, provided in *Figure 2*, were conducted on the basis of the 6 children with RD and the
373 24 children without difficulties in this area of learning. The results showed that the VT index
374 was the only variable of the DEM-test that significantly dissociated children with and without
375 RD. The AUC for VT was $.7917 \pm .1412$ ($p < .05$), 95% CI [0.5169 – 1.000]. For HTaj, the
376 results were in the same direction as for VT with a marginally effect: AUC = $.7569 \pm .1087$ (p
377 = .055), 95% CI [.5439 – .9700]. On the other hand, ROC curve analyses showed that the
378 AUCs for the HE and R indices are not statistically significant (all $p > .10$).

379 Despite the small size of the present sample, impacting the power of our statistical
380 analyses, the AUCs we found for VT and HTaj remained very similar with other studies such
381 as Hopkins et al. (2019) and Larter et al. (2004). Indeed, for VT, Larter et al. (2004) also
382 found a significant AUC, very close to the current one, at .778. For HTaj, although the current

383 study's AUC (.757) was only marginally significant, other studies such as those by Hopkins et
384 al. (2019) and Larter et al. (2004) have shown that this index was a good indicator
385 discriminating children with and without RD, with AUCs of .72 and .83 respectively. Just to
386 remind, AUCs > 0.9 are considered excellent, AUCs between 0.8 – 0.9 are very good,
387 between 0.7 – 0.8 are good, 0.6 – 0.7 are average, and an AUC < 0.6 is poor (Choi, 1998).
388 Even if these studies differed in terms of experimental design (transversal vs. longitudinal),
389 children age, or tests used to assess reading level, the DEM-test appeared to be an effective
390 test in the screening process for reading difficulties as early as kindergarten.

391

392

[Insert Figure 2 about here]

393

394

DISCUSSION

395

396

397

398

399

400

401

402

403

404

405

406

According to Goswami (2015), phonological processing has been the core area of
focus in the reading research, as phonological deficit was anticipated to link to reading
difficulties, affecting word recognition skills and reading fluency. However, there are certain
parts of reading disabilities that are not entirely explained by phonological skills alone. Early
detection of specific deficits, in any component skills needed for reading is crucial to the
development of targeted instruction to ameliorate the need. As a result, more appropriate and
more effective interventions may be provided to support struggling children. Within this
framework, in the present study we examined the importance of oculomotor and visual
processes for predicting subsequent reading abilities in Grade 1. We addressed this issue
through the longitudinal follow-up of a sample of typical children from kindergarten to first
grade.

407 Prevalence of Visual and Reading Difficulties from Kindergarten to the 1st grade

408 In the early school years as children are learning to read letters and numbers (tasks
409 requiring visual recognition, matching and recall of shapes), adequate oculomotor and visual
410 information processing skills (including visual analysis, visuo-motor integration, eye
411 movement control, attention orienting/focusing) are critical. One of the main objectives of the
412 present study was thus to examine children's visual skills at age 5, before they start formal
413 reading instruction, to assess the occurrence of visual skills difficulties in preschoolers and to
414 study more precisely beyond the linguistic ones, the oculomotor and visuo-attentional
415 mechanisms needed in learning to read.

416 Although data already available for the DEM-test in French school-aged children
417 (Bellocchi et al., 2021; Moiroud et al., 2018, 2020), no research, to the best of our knowledge,
418 has specifically questioned its usefulness in the assessment of visual skills in preschool
419 children. Therefore, the current study provides the first data collected in French kindergarten
420 children. The results corroborate findings from other studies showing that oculomotor and
421 visual processing difficulties are very common among children in kindergarten, with nearly
422 30% of preschool children presented difficulties on this test, in the absence of complaints
423 expressed by the subject or his/her family. In addition to deviant performance on the VT and
424 HT indexes, preschool children made also a large number of errors, whatever they present RD
425 one year later or not (but see, Raghuram et al., 2018, for different results, suggesting an
426 association between reading level and the number of errors made on the horizontal
427 presentation). The nature of these errors is very relevant since most of them are errors of
428 omission (i.e. nearly 70%) resulting mainly from skipping lines and characters. In addition to
429 immature or inaccurate eye movement control, these errors may be due to visuo-attentional
430 factors (Aslin & Ciuffreda, 1983; Coulter & Shallo-Hoffman, 2001).

431 Approximately 14% of the children in the current sample presented difficulties on both
432 the DEM-test in kindergarten and the reading assessment in the 1st grade and it clearly
433 appeared that the performance distribution at the DEM-test in Kindergarten was different
434 between good and poor readers one year later. The results of this study are consistent with
435 those of other investigators who found that children with reading problems have a higher
436 prevalence of associated deficient visual efficiency skills, such as oculomotor (Brodney et al.,
437 2001; Eden et al., 1994; Kulp & Schmidt, 1996b; Maples & Ficklin, 1990), and visuo-
438 attentional skills (Bellocchi & Ducrot, 2021; Bosse & Valdois, 2009; Franceschini et al.,
439 2012), than do children who are proficient readers. In that vein, Portnoy and Gilaie-Dotan
440 (2020) showed in a cross-sectionally study that 14.3% of the children in their total sample
441 (i.e., 4 children out of 28) were both among the slowest on the DEM-test and in difficulty
442 with reading speed, and that 17.9 % of the cohort (i.e., 5 out of 28 children) were both among
443 the least accurate on the DEM-test and had difficulty with reading accuracy.

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

456

457 **Predicting Reading Skills Based on Visual Processes in Kindergarten**

458 Preliminary results regarding prevalence of visual and reading impairments,
459 respectively and jointly, demonstrated that visual information processing ability, based on
460 measures of horizontal and vertical DEM times in preschool children, was significantly
461 associated with reading scores in Grade 1 school children, suggesting that visual information
462 processing plays a significant role in a child's academic performance in Grade 1. These
463 findings are consistent with other studies that have demonstrated associations between
464 delayed visual information processing skills and reduced classroom performance (learning to
465 read in particular, Hopkins et al., 2017, 2019; Kulp, 1999; Oberer et al., 2018; Pienaar et al.,
466 2014; Sortor & Kulp, 2003; White et al., 2017; Yang & Meng, 2020), which justify the need
467 to include visual perceptual skills in the prediction of reading achievement.

468 The question then was to determine whether kindergartners visual skills contribute to
469 emergent literacy skills and later reading abilities. This question is particularly useful for an
470 early identification of children at-risk for reading disabilities. The longitudinal approach of
471 the current study revealed also that the visual skills assessed by the DEM test could partially
472 predict reading outcomes one year later. More precisely, the correlation analyses showed that
473 reading accuracy in Grade 1 was significantly correlated with the HTaj, VT and HE indices
474 assessed in kindergarten, whereas reading speed was only correlated with the VT index. The
475 relationship we found between the DEM-test outcomes and the reading level corroborated
476 previously reported results from several studies, particularly for VT (Ayton et al., 2009;
477 Larter et al., 2004; Raghuram et al., 2018; Serdjukova et al., 2017; Wood et al., 2018) and
478 HTaj (Ayton et al., 2009; Moiroud et al., 2018; Northway, 2003; Palomo-Álvarez & Puell,
479 2009; Raghuram et al., 2018; Serdjukova et al., 2017; Wood et al., 2018). In addition, children
480 with developmental dyslexia have also been shown to perform poorly on the DEM-test than

481 control children (Bellocchi et al., 2021; Moiroud et al., 2018; Raghuram et al., 2018).
482 According to Portnoy and Gilaie-Dotan (2020) and Wood et al. (2018), we found no
483 correlation between the Ratio and reading performances, suggesting that the DEM ratio is
484 poorly associated with academic outcomes (but see Ayton et al., 2009; Raghuram et al.,
485 2018). The distribution of the ratio data was in the same direction, failing to distinguish
486 readers with RD from noRD ones. Moreover, it is important to note that the DEM-test showed
487 a high fidelity as demonstrated by several studies, particularly for the VT and HTaj indices,
488 while the ratio and HE indices, on the other hand, did not reach a consensus (Facchin &
489 Maffioletti, 2018; Orlansky et al., 2011; Tassinari & DeLand, 2005).

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

497 Our finding that the VT index was most strongly associated with the reading
498 performance⁷ of first graders was not in the same direction as the findings of Ayton et al.
499 (2009), or Wood et al. (2018) who reported the strongest correlations between the DEM
500 horizontal subtest and reading test scores in their sample of children, aged 8 to 11 years. This
501 difference may have been because the children in their sample (Grade 3 to 5) were beyond the
502 ‘learning to read’ stage. Indeed, it has been proposed that visual information processing skills

⁷ 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).

503 play a more significant role in the learning process of younger children (kindergarten to Grade
504 2) in the 'learning to read' phase compared to older children (Flax, 2006). The oculomotor
505 system is still not mature in young children (e.g., Kowler & Martins, 1982) and the
506 oculomotor behavior and the visuo-attentional skills undergo substantial changes during
507 reading development, with longer saccade and perceptual span extent, shorter fixation
508 durations, and lower refixation and regression probabilities (Blythe, 2014; Blythe & Joseph,
509 2011; Ducrot et al., 2013; Rayner, 2009). Moreover, other factors such as visuo-attentional
510 and visuospatial factors that are important for performing the DEM test are also developing
511 with the age of the child (Caldani et al., 2020; Coulter & Shallo-Hoffman, 2001; Facchin et
512 al., 2011) and the automatization of this so-called "visuo-attentional" processing is another
513 condition for reading success (see Grainger et al., 2016). In that vein, Ammawat et al. (2019)
514 demonstrated that naming speed (strongly linked with VT performance) was also influenced
515 by visual perception and attention. One of the prominent findings of their study is that visual
516 perception was the most significant factor in predicting naming speed in young children. At
517 the same time, their study provided support for the theory that visual perception has a strong
518 relationship with attention networks, supporting the hypothesis that visual perception and
519 attention networks may combine to affect naming speed or reading readiness in RD children.
520 For Kuperman et al. (2016), the well-established predictive role of RAN for reading
521 performance is in part due to the individual ability to shift attention from one item to the next
522 and to coordinate rapid sequential eye movements to visual nonlinguistic stimuli (see also,
523 Wolf & Bowers, 1999). We argue that the implication of the oculomotor and visuo-attentional
524 mechanisms involved in the DEM horizontal vs. vertical subtests change during reading
525 development and we believe that 5-6 years is a critical window where the weight of these
526 processes are especially strong. Stanovich et al. (1981) showed that digit naming time and
527 errors significantly decreases between 5-and 6-year olds and that automaticity significantly

528 increases in the first grade (see also, Kulp & Schmidt, 1997). According to the perceptual
529 learning account, the visual training associated with the regularity of reading eye movements
530 improves word recognition within a restricted horizontal region close to the fovea and mostly
531 within the regions of the retina that fall on the side of the reading direction (Dehaene et al.,
532 2005). It is therefore likely that the HT index become more strongly associated with the
533 reading performance as children learn to read and take the left-to-right directionality of visual
534 scanning into account (see Ducrot et al., 2020, for a change in landing position distributions
535 between 5 and 6 year-old children, as a result of reading experience).

536 These data provided a new contribution to the identification of precursors to reading
537 acquisition and to the understanding of the emergence of associated disorders. The emphasis
538 on the predictive potential of the visual skills assessed by the DEM-test on reading abilities
539 highlights the importance of these processes in the emergence of literacy skills and reading
540 abilities later in the learning process. These results were in line with previous studies that
541 demonstrated the involvement of visual skills such as the visual-attentional span, initial
542 landing position, and/or visual-motor skills and their potential underlying causes of learning
543 difficulties in some children (Bellocchi et al., 2017; Franceschini et al., 2012; Kwon et al.,
544 2007; Valdois et al., 2019; Yang & Meng, 2020). Thus, beyond the already accepted
545 implication of linguistic skills as strong predictors of reading level (Carroll et al., 2003;
546 Lonigan et al., 2000; Piquard-Kipffer & Sprenger-Charolles, 2013; Schatschneider et al.,
547 2004), these findings demonstrate the key role of visual skills in the mechanisms of reading
548 acquisition.

549

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

551 As far as we know, no study analysed the precision of the DEM test at identifying
552 French preschool children at risk/non-risk of reading difficulty. Studies with this purpose are

553 crucial because this information is essential for reading difficulties screening. As pointed out
554 before, a trustworthy screening test can help preventive interventions to begin as soon as
555 possible. The interest of this tool for the early detection of reading difficulties in kindergarten
556 has been investigated in very few studies (Kulp & Schmidt, 1997; Xie et al., 2016), in contrast
557 to the combined association between the visual deficits identified in the DEM-test and the
558 poor reading performance which had already been demonstrated and which supports our
559 results, as demonstrated in the previous section (Ayton et al., 2009; Palomo-Álvarez & Puell,
560 2009; Portnoy & Gilaie-Dotan, 2020; Serdjukova et al., 2017; Wood et al., 2018). Thus,
561 another goal of the present study was to evaluate the precision of the DEM test in predicting
562 children at risk/non-risk of reading as early as possible. A test's precision of classification can
563 be evaluated based on the ROC curve, considering the AUC (Swets, 1988). Although the
564 sample size was small, the results showed that the VT index (and the HTaj, to a lesser extent)
565 were able to dissociate children with and without RD. The AUC for VT was considered as
566 very good (0.80) and that for HTaj as good (comprised between 0.70 and 0.80). This suggests
567 the potential for these measures to be used clinically for identifying children at risk for low
568 academic achievement.

569 These conclusions raise critical perspectives regarding clinical diagnosis and
570 educational approach, by providing the opportunity to gain insight into the visuo-attentional
571 and perceptual difficulties children, in view of establishing thorough and accurate assessment
572 procedures and proposing child-specific guidelines and remediation methods that take into
573 account the particular processes affected. Such information is useful not only for uncovering
574 problems readers have with the different components of reading, but also can help in the
575 development of teaching strategies or methods appropriate for individual children's particular
576 strengths or weaknesses (e.g., implement early oculomotor training programs at school,
577 especially in kindergarten). Almost 70% of a school day is dedicated to learning activities

578 involving visual sensory input (Narayanasamy et al., 2016). This may explain, in part, why
579 children with visual impairment are more likely to fail at school (Goldstand et al., 2005;
580 White et al., 2017). Indeed, if visual processes are not operational and efficient from the
581 beginning of the reading learning process, academic achievements can be considerably
582 impacted. Depending on their severity, these deficits can lead to difficulty tracking, sustaining
583 attention and focus, all of which may interfere with visual exploration, reading fluency and
584 distract from reading comprehension. The importance of early screening then takes on its full
585 meaning, making it possible to intervene very early in children's developmental trajectory. If
586 appropriate interventions are implemented at an early age, academic skill development could
587 be altered, preventing subtle learning difficulties from becoming more pronounced over time.
588 The earlier an intervention is implemented, the better a child's chances of overcoming his or
589 her deficit (Ozernov-Palchik & Gaab, 2016).

590 Currently, reading instruction and reading intervention techniques employed focus
591 primarily on the language components of reading development. Although these programs are
592 based on solid research that identifies phonological processing, vocabulary, and
593 comprehension as core components of reading development, the integration of visual skills
594 assessment from kindergarten onward to limit reading disorder is a real necessity. To do so,
595 the DEM-test can be a useful tool, in particular for the early identification of children at risk
596 for reading difficulties. It provides additional information to existing tools assessing linguistic
597 skills. For clinicians, this tool could improve the diagnostic assessment to better understand
598 the difficulties observed and thus improve the management of children. In that sense, the
599 combined use of investigation tools in early detection can result highly effective for these
600 children. Furthermore, the rehabilitation methods which stimulate both the phonological and
601 the visual-spatial attention skills are proved to be the most effective in children already
602 diagnosed with dyslexia (Facoetti et al., 2003; Gaggi et al., 2012). For example, although eye

603 movement deficits may not be the only contributory factor to reading difficulties, better
604 control of saccadic eye movements can translate to more precise and quicker reading speed
605 and reduce the percentage of reading errors (Fischer et al., 2000; Fischer & Hartnegg, 2008).
606 Training both linguistic and visual skills together before the child begins to learn reading, can
607 help his/her future reading ability.

608 The main limitation of the present study is the size of the sample that could be followed.
609 This limitation is directly related to the longitudinal design since children were followed
610 during 18 months from kindergarten to the first grade, leading inevitably to an attrition effect.
611 But we truly believe this is the best way to better understand the issue of pre-requisites and
612 developmental trajectory in the academic learning process⁸. We also acknowledge that some
613 studies evaluating the validity of the DEM test (Facchin et al., 2011; Garzia et al., 1990) have
614 demonstrated that it did not seem to correlate directly with pure eye movement control
615 parameters; however they also showed that visuo-perceptual and visuo-attentional processes
616 play a major role in this task and that it was strongly correlated with different aspects of
617 reading performance and it is useful in clinical practice (Ayton et al., 2009; Bellocchi et al.,
618 2021; Palomo-Álvarez & Puell, 2009; Powers, 2009). Even though the DEM test does not
619 assess basic components of eye movement control and can be influenced by several cognitive
620 processes, such as sustained attention (Coulter & Shallo-Hoffman, 2001), number recognition
621 and retrieval, visual-verbal integration time, speaking time and visuo-spatial attention
622 (Facchin et al., 2011), the fact remains that the DEM test has been shown to be a measure
623 related to visual and visuo-attentional skills, which in turn are related to ocular movements in
624 a reading-like condition. Furthermore, while eye movement clinically available instruments

⁸ 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).

625 are expensive and hard to use during screening or routine eye examination, the DEM-test is an
626 inexpensive paper-and-pencil test that is performed in only 5 minutes⁹.

627 **CONCLUSION**

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

639

640 **Authors' Notes**

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

642 The authors are grateful to Madame Pascale Olive et Madame Florence Le Borgne De
643 Kaouël, inspectors of French National Education (Aix-Marseille Academy, France) for
644 allowing us to run this research in some of her mainstream elementary schools.

⁹ 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.

645 Additionally, we would like to thank the schools, teachers, parents and children for
646 their interest and involvement in this research. We also want to give a warm thanks to Eve
647 Meiss for her precious help in collecting some of the data presented in this paper and to
648 Abdessadek El Ahmadi for his helpful suggestions in statistics.

649 Support for this research was partly provided by an APEX Research Fellowship from
650 the "Conseil Régional PACA" to the last author (APEX VISALECT, DEB-17-1055) and by a
651 PhD Fellowship from the "Fondation de France" to the first author
652 (VISALECT_NF1_00099576).

653

REFERENCES

- 654 Aghababian, V., & Nazir, T. A. (2000). Developing Normal Reading Skills: Aspects of the
655 Visual Processes Underlying Word Recognition. *Journal of Experimental Child*
656 *Psychology*, 76(2), 123–150. <https://doi.org/10.1006/jecp.1999.2540>
- 657 Ammawat, W., Attanak, A., Kornpetpanee, S., & Wongupparaj, P. (2019). Pre-schoolers’
658 visual perception and attention networks influencing naming speed: An individual
659 difference perspective. *Heliyon*, 5(10), e02587.
660 <https://doi.org/10.1016/j.heliyon.2019.e02587>
- 661 Aslin, R. N., & Ciuffreda, K. J. (1983). Eye movements of preschool children. *Science*,
662 222(4619), 74–77. <https://doi.org/10.1126/science.6623059>
- 663 Ayton, L. N., Abel, L. A., Fricke, T. R., & McBrien, N. A. (2009). Developmental eye
664 movement test: What is it really measuring? *Optometry and Vision Science*, 86(6), 722–
665 730. <https://doi.org/10.1097/OPX.0b013e3181a6a4b3>
- 666 Bellocchi, S., & Ducrot, S. (2021). *The OVP effect in developmental dyslexia, developmental*
667 *coordination disorder and comorbid disorders [Article submitted for publication]*.
- 668 Bellocchi, S., Ducrot, S., Tallet, J., Jucla, M., & Jover, M. (2021). Effect of comorbid
669 developmental dyslexia on oculomotor behavior in children with developmental
670 coordination disorder: A study with the Developmental Eye Movement test. *Human*
671 *Movement Science*, 76, 102764. <https://doi.org/10.1016/j.humov.2021.102764>
- 672 Bellocchi, S., Muneaux, M., Bastien-Toniazzo, M., & Ducrot, S. (2013). I can read it in your
673 eyes: What eye movements tell us about visuo-attentional processes in developmental
674 dyslexia. *Research in Developmental Disabilities*, 34(1), 452–460.
675 <https://doi.org/10.1016/j.ridd.2012.09.002>
- 676 Bellocchi, S., Muneaux, M., Huau, A., Lévêque, Y., Jover, M., & Ducrot, S. (2017).
677 Exploring the Link between Visual Perception, Visual–Motor Integration, and Reading
678 in Normal Developing and Impaired Children using DTVP-2. *Dyslexia*, 23(3), 296–315.
679 <https://doi.org/10.1002/dys.1561>
- 680 Biscaldi, M., Fischer, B., & Hartnegg, K. (2000). Voluntary saccadic control in dyslexia.
681 *Perception*, 29(5), 509–521. <https://doi.org/10.1068/p2666a>
- 682 Blythe, H. I. (2014). Developmental Changes in Eye Movements and Visual Information

- 683 Encoding Associated With Learning to Read. *Current Directions in Psychological*
684 *Science*, 23(3), 201–207. <https://doi.org/10.1177/0963721414530145>
- 685 Blythe, H. I., & Joseph, H. S. S. L. (2011). Children’s eye movements during reading. In S. P.
686 Liversedge, I. Gilchrist, & S. Everling (Eds.), *The Oxford Handbook of Eye Movements*
687 (pp. 634–662). Oxford University Press.
688 <https://doi.org/10.1093/oxfordhb/9780199539789.013.0036>
- 689 Borsting, E., Rouse, M., & Chu, R. (2005). Measuring ADHD behaviors in children with
690 symptomatic accommodative dysfunction or convergence insufficiency: a preliminary
691 study. *Optometry - Journal of the American Optometric Association*, 76(10), 588–592.
692 <https://doi.org/10.1016/j.optm.2005.07.007>
- 693 Bosse, M., & Valdois, S. (2009). Influence of the visual attention span on child reading
694 performance: a cross-sectional study. *Journal of Research in Reading*, 32(2), 230–253.
695 <https://doi.org/10.1111/j.1467-9817.2008.01387.x>
- 696 Brodney, A. C., Pozil, R., Mallinson, K., & Kehoe, P. (2001). Vision Therapy in a School
697 Setting. *Journal of Behavioral Optometry*, 12(4), 99–103.
- 698 Buckley, J., Seery, N., Canty, D., & Gumaelius, L. (2018). Visualization, inductive reasoning,
699 and memory span as components of fluid intelligence: Implications for technology
700 education. *International Journal of Educational Research*, 90(November 2017), 64–77.
701 <https://doi.org/10.1016/j.ijer.2018.05.007>
- 702 Caldani, S., Gerard, C., Peyre, H., & Bucci, M. P. (2020). Visual Attentional Training
703 Improves Reading Capabilities in Children with Dyslexia: An Eye Tracker Study During
704 a Reading Task. *Brain Sciences*, 10(8), 558. <https://doi.org/10.3390/brainsci10080558>
- 705 Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research*, 51(13), 1484–
706 1525. <https://doi.org/10.1016/j.visres.2011.04.012>
- 707 Carroll, J. M., Snowling, M. J., Hulme, C., & Stevenson, J. (2003). The Development of
708 Phonological Awareness in Preschool Children. *Developmental Psychology*, 39(5), 913–
709 923. <https://doi.org/10.1037/0012-1649.39.5.913>
- 710 Case-Smith, J. (2009). *Occupational therapy for children* (6th ed.). Mosby.
- 711 Chen, A. H., Bleything, W., & Lim, Y. Y. (2011). Relating vision status to academic
712 achievement among year-2 school children in Malaysia. *Optometry*, 82(5), 267–273.

- 713 <https://doi.org/10.1016/j.optm.2011.02.004>
- 714 Choi, B. C. K. (1998). Slopes of a Receiver Operating Characteristic Curve and Likelihood
715 Ratios for a Diagnostic Test. *American Journal of Epidemiology*, *148*(11), 1127–1132.
716 <https://doi.org/10.1093/oxfordjournals.aje.a009591>
- 717 Chung, S. T. L., Legge, G. E., & Cheung, S. H. (2004). Letter-recognition and reading speed
718 in peripheral vision benefit from perceptual learning. *Vision Research*, *44*(7), 695–709.
719 <https://doi.org/10.1016/j.visres.2003.09.028>
- 720 Cornelissen, P., Richardson, A., Mason, A., Fowler, S., & Stein, J. F. (1995). Contrast
721 sensitivity and coherent motion detection measured at photopic luminance levels in
722 dyslexics and controls. *Vision Research*, *35*(10), 1483–1494.
723 [https://doi.org/10.1016/0042-6989\(95\)98728-R](https://doi.org/10.1016/0042-6989(95)98728-R)
- 724 Coulter, R. A., & Shallo-Hoffman, J. (2001). The Presumed Influence of Attention on
725 Accuracy in the Developmental Eye Movement (DEM) Test. *Optometry and Vision
726 Science*, *78*(1), 8. <https://doi.org/10.1097/00006324-200101010-00007>
- 727 De Luca, M., Borrelli, M., Judica, A., Spinelli, D., & Zoccolotti, P. (2002). Reading words
728 and pseudowords: An eye movement study of developmental dyslexia. *Brain and
729 Language*, *80*(3), 617–626. <https://doi.org/10.1006/brln.2001.2637>
- 730 Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written
731 words: A proposal. *Trends in Cognitive Sciences*, *9*(7), 335–341.
732 <https://doi.org/10.1016/j.tics.2005.05.004>
- 733 Ducrot, S., & Lété, B. (2008). Attention et contrôle oculaire en lecture experte. In G. A.
734 Michael (Ed.), *Les dimensions de l'attention visuelle* (pp. 229–264). SOLAL.
- 735 Ducrot, S., & Lété, B. (2021). *Developmental Changes in the Optimal Viewing Position Effect*
736 *[Article in preparation]*.
- 737 Ducrot, S., Lété, B., Sprenger-Charolles, L., Pynte, J., & Billard, C. (2003). The Optimal
738 Viewing Position Effect in Beginning and Dyslexic Readers. *Current Psychology
739 Letters*, *1*(10), 1–10. <https://doi.org/10.4000/cpl.99>
- 740 Ducrot, S., Massendari, D., Danna, J., Muneaux, M., Bellocchi, S., & Grainger, J. (2021). *An
741 analysis of reading development using landing-position distributions [Article in
742 preparation]*.

- 743 Ducrot, S., Pynte, J., Ghio, A., & Lété, B. (2013). Visual and linguistic determinants of the
744 eyes' initial fixation position in reading development. *Acta Psychologica, 142*(3), 287–
745 298. <https://doi.org/10.1016/j.actpsy.2013.01.013>
- 746 Ducrot, S., & Vernet, M. (2021). *Oculomotor, visual attention abilities and reading: A new*
747 *computerized tool [Article in preparation]*.
- 748 Eden, G. F., Stein, J. F., Wood, H. M., & Wood, F. B. (1994). Differences in eye movements
749 and reading problems in dyslexic and normal children. *Vision Research, 34*(10), 1345–
750 1358. [https://doi.org/10.1016/0042-6989\(94\)90209-7](https://doi.org/10.1016/0042-6989(94)90209-7)
- 751 Facchin, A., & Maffioletti, S. (2018). The reliability of the DEM test in the clinical
752 environment. *Frontiers in Psychology, 9*(JUL). <https://doi.org/10.3389/fpsyg.2018.01279>
- 753 Facchin, A., Maffioletti, S., & Carnevali, T. (2011). Developmental Eye Movement (DEM)
754 test : validity reassessment in Italian population Results : *Optometry and Vision*
755 *Development, 40*(3), 20125.
- 756 Facchetti, A., Corradi, N., Ruffino, M., Gori, S., & Zorzi, M. (2010). Visual spatial attention
757 and speech segmentation are both impaired in preschoolers at familial risk for
758 developmental dyslexia. *Dyslexia, 16*(3), 226–239. <https://doi.org/10.1002/dys.413>
- 759 Facchetti, A., Luisa Lorusso, M., Paganoni, P., Umiltà, C., & Gastone Mascetti, G. (2003). The
760 role of visuospatial attention in developmental dyslexia: evidence from a rehabilitation
761 study. *Cognitive Brain Research, 15*(2), 154–164. [https://doi.org/10.1016/S0926-](https://doi.org/10.1016/S0926-6410(02)00148-9)
762 [6410\(02\)00148-9](https://doi.org/10.1016/S0926-6410(02)00148-9)
- 763 Fischer, B., & Hartnegg, K. (2008). Saccade control in dyslexia: Development, deficits,
764 training and transfer to reading. *Journal of Optometric Vision Development, 39*(4), 181–
765 190.
- 766 Fischer, B., Hartnegg, K., & Mokler, A. (2000). Dynamic visual perception of dyslexic
767 children. *Perception, 29*(5), 523–530. <https://doi.org/10.1068/p2666b>
- 768 Fischer, B., & Weber, H. (1990). Saccadic reaction times of dyslexic and age-matched normal
769 subjects. *Perception, 19*(6), 805–818. <https://doi.org/10.1068/p190805>
- 770 Flax, N. (2006). The relationship between vision and learning: General issues. In M.
771 Scheiman & M. Rouse (Eds.), *Optometric Management of Learning- related Vision*
772 *Problems* (p. 183- 206). Mosby- Elsevier.

- 773 Flax, N., Mozlin, R., & Solan, H. A. (1984). Discrediting the basis of the AAO policy:
774 Learning disabilities, dyslexia and vision. *Journal of the American Optometric*
775 *Association*, 55(6), 399–403.
- 776 Franceschini, S., Gori, S., Ruffino, M., Pedrolli, K., & Facoetti, A. (2012). A causal link
777 between visual spatial attention and reading acquisition. *Current Biology*, 22(9), 814–
778 819. <https://doi.org/10.1016/j.cub.2012.03.013>
- 779 Gaggi, O., Galiazzo, G., Palazzi, C., Facoetti, A., & Franceschini, S. (2012). A Serious Game
780 for Predicting the Risk of Developmental Dyslexia in Pre-Readers Children. *2012 21st*
781 *International Conference on Computer Communications and Networks (ICCCN)*, 1–5.
782 <https://doi.org/10.1109/ICCCN.2012.6289249>
- 783 Garzia, R. P., Richman, J. E., Nicholson, S. B., & Gaines, C. S. (1990). A new visual-verbal
784 saccade test: the development eye movement test (DEM). *Journal of the American*
785 *Optometric Association*, 61(2), 124–135.
- 786 Goldstand, S., Koslowe, K. C., & Parush, S. (2005). Vision, visual-information processing,
787 and academic performance among seventh-grade schoolchildren: A more significant
788 relationship than we thought? *American Journal of Occupational Therapy*, 59(4), 377–
789 389. <https://doi.org/10.5014/ajot.59.4.377>
- 790 González, G. F., Žarić, G., Tijms, J., Bonte, M., Blomert, L., & van der Molen, M. W. (2014).
791 Brain-potential analysis of visual word recognition in dyslexics and typically reading
792 children. *Frontiers in Human Neuroscience*, 8(JUNE), 1–14.
793 <https://doi.org/10.3389/fnhum.2014.00474>
- 794 Goodman, K. S. (1986). *What's Whole in Whole Language?* Heinemann.
- 795 Gori, S., & Facoetti, A. (2015). How the visual aspects can be crucial in reading acquisition:
796 The intriguing case of crowding and developmental dyslexia. *Journal of Vision*, 15(1),
797 1–20. <https://doi.org/10.1167/15.1.8>
- 798 Goswami U. (2015). Sensory theories of developmental dyslexia: three challenges for
799 research. *Nature reviews. Neuroscience*, 16(1), 43–54. <https://doi.org/10.1038/nrn3836>
- 800 Grainger, J. (2018). Orthographic processing: A ‘mid-level’ vision of reading: The 44th Sir
801 Frederic Bartlett Lecture. *Quarterly Journal of Experimental Psychology*, 71(2), 335–
802 359. <https://doi.org/10.1080/17470218.2017.1314515>

- 803 Grainger, J., Dufau, S., & Ziegler, J. C. (2016). A Vision of Reading. *Trends in Cognitive*
804 *Sciences*, 20(3), 171–179. <https://doi.org/10.1016/j.tics.2015.12.008>
- 805 Granet, D. B., Castro, E. F., & Gomi, C. F. (2006). Reading: Do the Eyes Have It? *American*
806 *Orthoptic Journal*, 56(1), 44–49. <https://doi.org/10.3368/aoj.56.1.44>
- 807 Hajian-Tilaki, K. (2013). Receiver operating characteristic (ROC) curve analysis for medical
808 diagnostic test evaluation. *Caspian Journal of Internal Medicine*, 4(2), 627–635.
- 809 Hopkins, S., Black, A. A., White, S. L. J., & Wood, J. M. (2019). Visual information
810 processing skills are associated with academic performance in Grade 2 school children.
811 *Acta Ophthalmologica*, 97(8), e1141–e1148. <https://doi.org/10.1111/aos.14172>
- 812 Hopkins, S., Sampson, G. P., Hendicott, P. L., & Wood, J. M. (2017). Vision problems and
813 reduced reading outcomes in Queensland schoolchildren. *Optometry and Vision Science*,
814 94(3), 345–352. <https://doi.org/10.1097/OPX.0000000000001032>
- 815 Hutzler, F., & Wimmer, H. (2004). Eye movements of dyslexic children when reading in a
816 regular orthography. *Brain and Language*, 89(1), 235–242.
817 [https://doi.org/10.1016/S0093-934X\(03\)00401-2](https://doi.org/10.1016/S0093-934X(03)00401-2)
- 818 Jenkins, J. R., Hudson, R. F., & Johnson, E. S. (2007). Screening for At-Risk Readers in a
819 Response to Intervention Framework. *School Psychology Review*, 36(4), 582–600.
820 <https://doi.org/10.1080/02796015.2007.12087919>
- 821 Kavale, K. (1982). Meta-analysis of the relationship between visual perceptual skills and
822 reading achievement. *Journal of Learning Disabilities*, 15(1), 42–51.
823 <https://doi.org/10.1177/002221948201500110>
- 824 Kirby, J. R., Roth, L., Desrochers, A., & Lai, S. S. V. (2008). Longitudinal predictors of word
825 reading development. *Canadian Psychology*, 49(2), 103–110.
826 <https://doi.org/10.1037/0708-5591.49.2.103>
- 827 Kovács, I. (2000). Human development of perceptual organization. *Vision Research*, 40(10–
828 12), 1301–1310. [https://doi.org/10.1016/S0042-6989\(00\)00055-9](https://doi.org/10.1016/S0042-6989(00)00055-9)
- 829 Kowler, E., & Martins, A. J. (1982). Eye movements of preschool children. *Science*,
830 215(4535), 997–999. <https://doi.org/10.1126/science.7156979>
- 831 Kramer, P., & Hinojosa, J. (2010). *Frames of reference for pediatric occupational therapy:*

- 832 *Third Edition*. Wolters Kluwer Health/Lippincott Williams & Wilkins.
- 833 Kulp, M. T. (1999). Relationship between Visual Motor Integration Skill and Academic
834 Performance in Kindergarten through Third Grade. *Optometry and Vision Science*, 76(3),
835 159–163. <https://doi.org/10.1097/00006324-199903000-00015>
- 836 Kulp, M. T., & Schmidt, P. P. (1996a). Effect of Oculomotor and Other Visual Skills on
837 Reading Performance: A Literature Review. *Optometry and Vision Science*, 73(4), 283–
838 292. <https://doi.org/10.1097/00006324-199604000-00011>
- 839 Kulp, M. T., & Schmidt, P. P. (1996b). Visual Predictors of Reading Performance in
840 Kindergarten and First Grade Children. *Optometry and Vision Science*, 73(4), 255–262.
841 <https://doi.org/10.1097/00006324-199604000-00007>
- 842 Kulp, M. T., & Schmidt, P. P. (1997). The Relation of Clinical Saccadic Eye Movement
843 Testing to Reading in Kindergartners and First Graders. *Optometry and Vision Science*,
844 74(1), 37–42. <https://doi.org/10.1097/00006324-199701000-00018>
- 845 Kuperman, V., Van Dyke, J. A., & Henry, R. (2016). Eye-Movement Control in RAN and
846 Reading. *Scientific Studies of Reading*, 20(2), 173–188.
847 <https://doi.org/10.1080/10888438.2015.1128435>
- 848 Kwon, M. Y., Legge, G. E., & Dubbels, B. R. (2007). Developmental changes in the visual
849 span for reading. *Vision Research*, 47(22), 2889–2900.
850 <https://doi.org/10.1016/j.visres.2007.08.002>
- 851 Lallier, M., Donnadieu, S., Berger, C., & Valdois, S. (2010). A case study of developmental
852 phonological dyslexia: Is the attentional deficit in the perception of rapid stimuli
853 sequences amodal? *Cortex*, 46(2), 231–241. <https://doi.org/10.1016/j.cortex.2009.03.014>
- 854 Larter, S. C., Herse, P. R., Naduvilath, T. J., & Dain, S. J. (2004). Spatial load factor in
855 prediction of reading performance. *Ophthalmic and Physiological Optics*, 24(5), 440–
856 449. <https://doi.org/10.1111/j.1475-1313.2004.00219.x>
- 857 Launay, L., & Valdois, S. (2004). Évaluation et prise en charge cognitive de l'enfant
858 dyslexique et/ou dysorthographique de surface. In S. Valdois, P. D. Colé, & D. David
859 (Eds.), *Apprentissage de la lecture et dyslexies développementales. De la théorie à la*
860 *pratique orthophonique et pédagogique* (pp. 209–232). SOLAL.
- 861 Lee, H. W., Legge, G. E., & Ortiz, A. (2003). Is word recognition different in central and

- 862 peripheral vision? *Vision Research*, 43(26), 2837–2846. <https://doi.org/10.1016/S0042->
863 6989(03)00479-6
- 864 Lefavrais, P. (1967). *Test de l'alouette: manuel*. Les éditions du centre de psychologie
865 appliquée.
- 866 Lefavrais, P. (2005). *Alouette-R*. Les éditions du centre de psychologie appliquée.
- 867 Legge, G. E., Klitz, T. S., & Tjan, B. S. (1997). Mr. Chips: An Ideal-Observer Model of
868 Reading. *Psychological Review*, 104(3), 524–553. <https://doi.org/10.1037/0033->
869 295X.104.3.524
- 870 Lehtimäki, T. M., & Reilly, R. G. (2005). Improving eye movement control in young readers.
871 *Artificial Intelligence Review*, 24(3–4), 477–488. <https://doi.org/10.1007/s10462-005->
872 9010-x
- 873 Leibnitz, L., Ducrot, S., Muneaux, M., & Grainger, J. (2015). Spécificité des capacités visuo-
874 attentionnelles et lecture chez l'enfant. *Revue Francophone d'Orthoptie*, 8(1), 45–49.
875 <https://doi.org/10.1016/j.rfo.2015.02.011>
- 876 Leibnitz, L., Grainger, J., Muneaux, M., & Ducrot, S. (2017). Processus visuo-attentionnels et
877 lecture : une synthèse. *L'Année Psychologique*, 116(4), 597–622.
878 <https://doi.org/10.4074/S0003503316000403>
- 879 Lété, B., & Ducrot, S. (2008). Visuo-Attentional Processing by Dyslexic Readers on the
880 Reicher-Wheeler Task. *Current Psychology Letters*, 24(Vol. 24, Issue 1, 2008), 24–40.
881 <https://doi.org/10.4000/cpl.3523>
- 882 Lonigan, C. J. (2006). Development, Assessment, and Promotion of Preliteracy Skills. *Early*
883 *Education & Development*, 17(1), 91–114. https://doi.org/10.1207/s15566935eed1701_5
- 884 Lonigan, C. J., Burgess, S. R., & Anthony, J. L. (2000). Development of emergent literacy
885 and early reading skills in preschool children: Evidence from a latent-variable
886 longitudinal study. *Developmental Psychology*, 36(5), 596–613.
887 <https://doi.org/10.1037/0012-1649.36.5.596>
- 888 Lovegrove, W., Bowling, A., Badcock, D., & Blackwood, M. (1980). Specific reading
889 disability: differences in contrast sensitivity as a function of spatial frequency. *Science*,
890 210(4468), 439–440. <https://doi.org/10.1126/science.7433985>

- 891 Maples, W. C. C., & Ficklin, T. (1990). Comparison of Eye Movement Skills Between Above
892 Average and Below Average Readers. In *Journal of Behavioral Optometry* (Vol. 1, Issue
893 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)
894 [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)
- 895 Martelli, M., Di Filippo, G., Spinelli, D., & Zoccolotti, P. (2009). Crowding, reading, and
896 developmental dyslexia. *Journal of Vision*, 9(4), 1–18. <https://doi.org/10.1167/9.4.14>
- 897 Memiş, A., & Sivri, D. A. (2016). The Analysis of Reading Skills and Visual Perception
898 Levels of First Grade Turkish Students. *Journal of Education and Training Studies*, 4(8),
899 161–166. <https://doi.org/10.11114/jets.v4i8.1663>
- 900 Meng, X., Cheng-Lai, A., Zeng, B., Stein, J. F., & Zhou, X. (2011). Dynamic visual
901 perception and reading development in Chinese school children. *Annals of Dyslexia*,
902 61(2), 161–176. <https://doi.org/10.1007/s11881-010-0049-2>
- 903 Moiroud, L., Gerard, C. L., Peyre, H., & Bucci, M. P. (2018). Developmental Eye Movement
904 test and dyslexic children: A pilot study with eye movement recordings. *PLoS ONE*,
905 13(9), 1–11. <https://doi.org/10.1371/journal.pone.0200907>
- 906 Moiroud, L., Royo, A., & Bucci, M. P. (2020). The Developmental Eye Movement Test in
907 French Children. *Optometry and Vision Science*, 97(11), 978–983.
908 <https://doi.org/10.1097/OPX.0000000000001598>
- 909 Morgan, W. P. (1896). A Case of Congenital Word Blindness. *BMJ*, 2(1871), 1378–1378.
910 <https://doi.org/10.1136/bmj.2.1871.1378>
- 911 Morris, R. K., & Rayner, K. (1991). Eye movements in skilled reading: Implications for
912 developmental dyslexia. In J. F. Stein (Ed.), *Vision and Visual Dyslexia* (pp. 233–242).
913 MacMillan Press.
- 914 Muneaux, M. (2018). *A new practitioners guide for clinical psychometrics*. Paris: De Boeck
915 Supérieur.
- 916 Narayanasamy, S., Vincent, S. J., Sampson, G. P., & Wood, J. M. (2016). Visual demands in
917 modern Australian primary school classrooms. *Clinical and Experimental Optometry*,
918 99(3), 233–240. <https://doi.org/10.1111/cxo.12365>
- 919 Nicolson, R. I., & Fawcett, A. (2010). *Dyslexia, learning, and the brain*. MIT press.

- 920 Northway, N. (2003). Predicting the continued use of overlays in school children - A
921 comparison of the Developmental Eye Movement test and the Rate of Reading test.
922 *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)
923 [1313.2003.00144.x](https://doi.org/10.1046/j.1475-1313.2003.00144.x)
- 924 O'Regan, J. K., & Lévy-Schoen, A. (1987). Eye-movement strategy and tactics in word
925 recognition and reading. In M. Coltheart (Ed.), *Attention and performance 12: The*
926 *psychology of reading* (pp. 363–383). Lawrence Erlbaum Associates, Inc.
- 927 Oberer, N., Gashaj, V., & Roebers, C. M. (2018). Executive functions, visual-motor
928 coordination, physical fitness and academic achievement: Longitudinal relations in
929 typically developing children. *Human Movement Science*, 58(January), 69–79.
930 <https://doi.org/10.1016/j.humov.2018.01.003>
- 931 Orlansky, G., Hopkins, K. B., Mitchell, G. L., Huang, K., Frazier, M., Heyman, C., &
932 Scheiman, M. (2011). Reliability of the Developmental Eye Movement Test. *Optometry*
933 *and Vision Science*, 88(12), 1. <https://doi.org/10.1097/OPX.0b013e318230f03a>
- 934 Ozernov-Palchik, O., & Gaab, N. (2016). Tackling the ‘dyslexia paradox’: reading brain and
935 behavior for early markers of developmental dyslexia. *Wiley Interdisciplinary Reviews:*
936 *Cognitive Science*, 7(2), 156–176. <https://doi.org/10.1002/wcs.1383>
- 937 Palomo-Álvarez, C., & Puell, M. C. (2009). Relationship between oculomotor scanning
938 determined by the DEM test and a contextual reading test in schoolchildren with reading
939 difficulties. *Graefe's Archive for Clinical and Experimental Ophthalmology*, 247(9),
940 1243–1249. <https://doi.org/10.1007/s00417-009-1076-8>
- 941 Parrila, R., Kirby, J. R., & McQuarrie, L. (2004). Articulation rate, naming speed, verbal
942 short-term memory, and phonological awareness: Longitudinal predictors of early
943 reading development? *Scientific Studies of Reading*, 8(1), 3–26.
944 https://doi.org/10.1207/s1532799xssr0801_2
- 945 Pelli, D. G., Palomares, M., & Majaj, N. J. (2004). Crowding is unlike ordinary masking:
946 Distinguishing feature integration from detection. *Journal of Vision*, 4(12), 1136–1169.
947 <https://doi.org/10.1167/4.12.12>
- 948 Pienaar, A. E., Barhorst, R., & Twisk, J. W. R. (2014). Relationships between academic
949 performance, SES school type and perceptual-motor skills in first grade South African
950 learners: NW-CHILD study. *Child: Care, Health and Development*, 40(3), 370–378.

- 951 <https://doi.org/10.1111/cch.12059>
- 952 Piquard-Kipffer, A., & Sprenger-Charolles, L. (2013). Early predictors of future reading
953 skills: A follow-up of French-speaking children from the beginning of kindergarten to
954 the end of the second grade (age 5 to 8). In *Annee Psychologique* (Vol. 113, Issue 4).
955 <https://doi.org/10.4074/S0003503313014012>
- 956 Plaza, M., & Cohen, H. (2007). The contribution of phonological awareness and visual
957 attention in early reading and spelling. *Dyslexia*, 239(13), 234–239.
958 <https://doi.org/10.1002/dys>
- 959 Pollatsek, A., & Rayner, K. (2005). Reading. In K. Lamberts & R. L. Goldstone (Eds.),
960 *Handbook of cognition* (pp. 276–293). Sage.
- 961 Portnoy, A., & Gilaie-Dotan, S. (2020). *Oculomotor-related measures but not distance visual*
962 *acuity are predictive of reading ability in first graders.*
963 <https://doi.org/10.1101/2020.03.09.983197>
- 964 Powers, M. K. (2009). Paper tools for assessing visual function. *Optometry and Vision*
965 *Science*, 86(6), 613–618. <https://doi.org/10.1097/OPX.0b013e3181a76c7c>
- 966 Raghuram, A., Gowrisankaran, S., Swanson, E., Zurakowski, D., Hunter, D. G., & Waber, D.
967 P. (2018). Frequency of Visual Deficits in Children With Developmental Dyslexia.
968 *JAMA Ophthalmology*, 136(10), 1089.
969 <https://doi.org/10.1001/jamaophthalmol.2018.2797>
- 970 Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers.
971 *Journal of Experimental Child Psychology*, 41(2), 211–236.
972 [https://doi.org/10.1016/0022-0965\(86\)90037-8](https://doi.org/10.1016/0022-0965(86)90037-8)
- 973 Rayner, K. (2009). Eye Movements in Reading: Models and Data. *Journal of Eye Movement*
974 *Research*, 2(5), 1–10. <https://doi.org/10.16910/jemr.2.5.2>
- 975 Rayner, K., & Bertera, J. (1979). Reading without a fovea. *Science*, 206(4417), 468–469.
976 <https://doi.org/10.1126/science.504987>
- 977 Rayner, K., & Liversedge, S. P. (2011). Linguistic and cognitive influences on eye
978 movements during reading. In S. P. Liversedge, I. D. Gilchrist, & S. Everling (Eds.), *The*
979 *Oxford handbook of eye movements.* (pp. 751–766). Oxford University Press.

- 980 Rayner, K., & Morrison, R. E. (1981). Eye movements and identifying words in parafoveal
981 vision. *Bulletin of the Psychonomic Society*, *17*(3), 135–138.
982 <https://doi.org/10.3758/BF03333690>
- 983 Richman, J. E. (2009). Developmental Eye Movement Test, Examiner's manual, version 2.0.
984 *South Bend, IN: Bernell Corp.*
- 985 Schatschneider, C., Fletcher, J. M., Francis, D. J., Carlson, C. D., & Foorman, B. R. (2004).
986 Kindergarten prediction of reading skills: A longitudinal comparative analysis. *Journal*
987 *of Educational Psychology*, *96*(2), 265–282. <https://doi.org/10.1037/0022-0663.96.2.265>
- 988 Serdjukova, J., Ekimane, L., Valeinis, J., Skilters, J., & Krumina, G. (2017). How strong and
989 weak readers perform on the Developmental Eye Movement test (DEM): norms for
990 Latvian school-aged children. *Reading and Writing*, *30*(2), 233–252.
991 <https://doi.org/10.1007/s11145-016-9671-7>
- 992 Shonkoff, J. P., & Phillips, D. A. (2000). *From Neurons to Neighborhoods* (Childhood
993 Development National Research Council (US) and Institute of Medicine (US)
994 Committee on Integrating the Science of Early (ed.)). National Academies Press.
995 <https://doi.org/10.17226/9824>
- 996 Solan, H. A., & Mozlin, R. (1986). The correlations of perceptual-motor maturation to
997 readiness and reading in kindergarten and the primary grades. *Journal of the American*
998 *Optometric Association*, *57*(1), 28–35.
- 999 Sortor, J. M., & Kulp, M. T. (2003). Are the Results of the Beery-Buktenica Developmental
1000 Test of Visual-Motor Integration and Its Subtests Related to Achievement Test Scores?
1001 *Optometry and Vision Science*, *80*(11), 758–763. [https://doi.org/10.1097/00006324-](https://doi.org/10.1097/00006324-200311000-00013)
1002 [200311000-00013](https://doi.org/10.1097/00006324-200311000-00013)
- 1003 Stanovich, K. E., Cunningham, A. E., & West, R. F. (1981). A Longitudinal Study of the
1004 Development of Automatic Recognition Skills in First Graders. *Journal of Reading*
1005 *Behavior*, *13*(1), 57–74. <https://doi.org/10.1080/10862968109547394>
- 1006 Stein, J. F., & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia.
1007 *Trends in Neurosciences*, *20*(4), 147–152. [https://doi.org/10.1016/S0166-](https://doi.org/10.1016/S0166-2236(96)01005-3)
1008 [2236\(96\)01005-3](https://doi.org/10.1016/S0166-2236(96)01005-3)
- 1009 Storch, S. A., & Whitehurst, G. J. (2002). Oral language and code-related precursors to

- 1010 reading: evidence from a longitudinal structural model. *Developmental Psychology*,
1011 38(6), 934–947. <https://doi.org/10.1037/0012-1649.38.6.934>
- 1012 Strasburger, H. (2005). Unfocussed spatial attention underlies the crowding effect in indirect
1013 form vision. *Journal of Vision*, 5(11), 1024–1037. <https://doi.org/10.1167/5.11.8>
- 1014 Swets, J. A. (1988). Measuring the Accuracy of Diagnostic Systems Linked references are
1015 available on JSTOR for this article : Measuring the Accuracy of Diagnostic Systems.
1016 *Science*, 240(4857), 1285–1293.
- 1017 Tassinari, J. T., & DeLand, P. (2005). Developmental Eye Movement Test: reliability and
1018 symptomatology. *Optometry - Journal of the American Optometric Association*, 76(7),
1019 387–399. <https://doi.org/10.1016/j.optm.2005.05.006>
- 1020 Tydgat, I., & Grainger, J. (2009). Serial Position Effects in the Identification of Letters,
1021 Digits, and Symbols. *Journal of Experimental Psychology: Human Perception and*
1022 *Performance*, 35(2), 480–498. <https://doi.org/10.1037/a0013027>
- 1023 Valdois, S., Roulin, J. L., & Line Bosse, M. (2019). Visual attention modulates reading
1024 acquisition. *Vision Research*, 165(October), 152–161.
1025 <https://doi.org/10.1016/j.visres.2019.10.011>
- 1026 Vidyasagar, T. R., & Pammer, K. (2010). Dyslexia: a deficit in visuo-spatial attention, not in
1027 phonological processing. *Trends in Cognitive Sciences*, 14(2), 57–63.
1028 <https://doi.org/10.1016/j.tics.2009.12.003>
- 1029 Vinuela-Navarro, V., Erichsen, J. T., Williams, C., & Woodhouse, J. M. (2017). Saccades and
1030 fixations in children with delayed reading skills. *Ophthalmic and Physiological Optics*,
1031 37(4), 531–541. <https://doi.org/10.1111/opo.12392>
- 1032 Visser, T. A. W., Boden, C., & Giaschi, D. E. (2004). Children with dyslexia: Evidence for
1033 visual attention deficits in perception of rapid sequences of objects. *Vision Research*,
1034 44(21), 2521–2535. <https://doi.org/10.1016/j.visres.2004.05.010>
- 1035 Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994). Development of reading-related
1036 phonological processing abilities: New evidence of bidirectional causality from a latent
1037 variable longitudinal study. *Developmental Psychology*, 30(1), 73–87.
1038 <https://doi.org/10.1037/0012-1649.30.1.73>
- 1039 White, S. L. J., Wood, J. M., Black, A. A., & Hopkins, S. (2017). Vision screening outcomes

- 1040 of Grade 3 children in Australia: Differences in academic achievement. *International*
1041 *Journal of Educational Research*, 83, 154–159.
1042 <https://doi.org/10.1016/j.ijer.2017.03.004>
- 1043 Whitney, D., & Levi, D. M. (2011). Visual crowding: A fundamental limit on conscious
1044 perception and object recognition. *Trends in Cognitive Sciences*, 15(4), 160–168.
1045 <https://doi.org/10.1016/j.tics.2011.02.005>
- 1046 Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental
1047 dyslexias. *Journal of Educational Psychology*, 91(3), 415–438.
1048 <https://doi.org/10.1037/0022-0663.91.3.415>
- 1049 Wolverton, G. S., & Zola, D. (1983). Some thoughts on the temporal characteristics of visual
1050 information extraction during reading. In K. Rayner (Ed.), *Eye movements in reading:*
1051 *Perceptual and language processes* (Academic P, pp. 41–51).
- 1052 Wood, J. M., Black, A. A., Hopkins, S., & White, S. L. J. (2018). Vision and academic
1053 performance in primary school children. *Ophthalmic and Physiological Optics*, 38(5),
1054 516–524. <https://doi.org/10.1111/opo.12582>
- 1055 World Health Organisation. (2008). *59th general assembly* (A. WM (ed.)). WHO.
- 1056 Xie, Y., Shi, C., Tong, M., Zhang, M., Li, T., Xu, Y., Guo, X., Hong, Q., & Chi, X. (2016).
1057 Developmental eye movement (DEM) test norms for mandarin Chinese-speaking
1058 Chinese children. *PLoS ONE*, 11(2), 1–12. <https://doi.org/10.1371/journal.pone.0148481>
- 1059 Yang, X., Chung, K. K. H., & McBride, C. (2019). Longitudinal contributions of executive
1060 functioning and visual-spatial skills to mathematics learning in young Chinese children.
1061 *Educational Psychology*, 39(5), 678–704.
1062 <https://doi.org/10.1080/01443410.2018.1546831>
- 1063 Yang, X., McBride, C., Ho, C. S. H., & Chung, K. K. H. (2020). Longitudinal associations of
1064 phonological processing skills, Chinese word reading, and arithmetic. *Reading and*
1065 *Writing*, 33(7), 1679–1699. <https://doi.org/10.1007/s11145-019-09998-9>
- 1066 Yang, X., & Meng, X. (2020). Visual Processing Matters in Chinese Reading Acquisition and
1067 Early Mathematics. *Frontiers in Psychology*, 11(April), 1–11.
1068 <https://doi.org/10.3389/fpsyg.2020.00462>
- 1069 Yeshurun, Y., & Rashal, E. (2010). Precueing attention to the target location diminishes

- 1070 crowding and reduces the critical distance Yaffa Yeshurun. *Journal of Vision*, 10, 1–12.
1071 <https://doi.org/10.1167/10.10.16.Introduction>
- 1072 Zhou, Y., McBride-Chang, C., & Wong, N. (2014). What is the role of visual skills in
1073 learning to read? *Frontiers in Psychology*, 5(July), 1–3.
1074 <https://doi.org/10.3389/fpsyg.2014.00776>
- 1075 Ziegler, J. C., Castel, C., Pech-Georgel, C., George, F., Alario, F. X., & Perry, C. (2008).
1076 Developmental dyslexia and the dual route model of reading: Simulating individual
1077 differences and subtypes. *Cognition*, 107(1), 151–178.
1078 <https://doi.org/10.1016/j.cognition.2007.09.004>
- 1079 Zorzi, M., Barbiero, C., Facoetti, A., Lonciari, I., Carrozzi, M., Montico, M., Bravar, L.,
1080 George, F., Pech-Georgel, C., & Ziegler, J. C. (2012). Extra-large letter spacing
1081 improves reading in dyslexia. *Proceedings of the National Academy of Sciences of the*
1082 *United States of America*, 109(28), 11455–11459.
1083 <https://doi.org/10.1073/pnas.1205566109>
- 1084
- 1085

1086 Table 1. Descriptive analysis of French data for preschool children.

	Kindergarten			
	<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

1087 *Notes.* VT: Vertical Time; HTaj: adjusted Horizontal Time; HE: Horizontal Errors; R: Ratio.

1088

1089

1090 Table 2. Correlation matrix of the DEM indices (z-score) assessed in kindergarten and the
 1091 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

1092 *Notes.* * $p < .05$; ** $p < .01$; *** $p < .001$; VT: Vertical Time; HTaj: adjusted Horizontal Time;
 1093 HE: Horizontal Errors; R: Ratio.

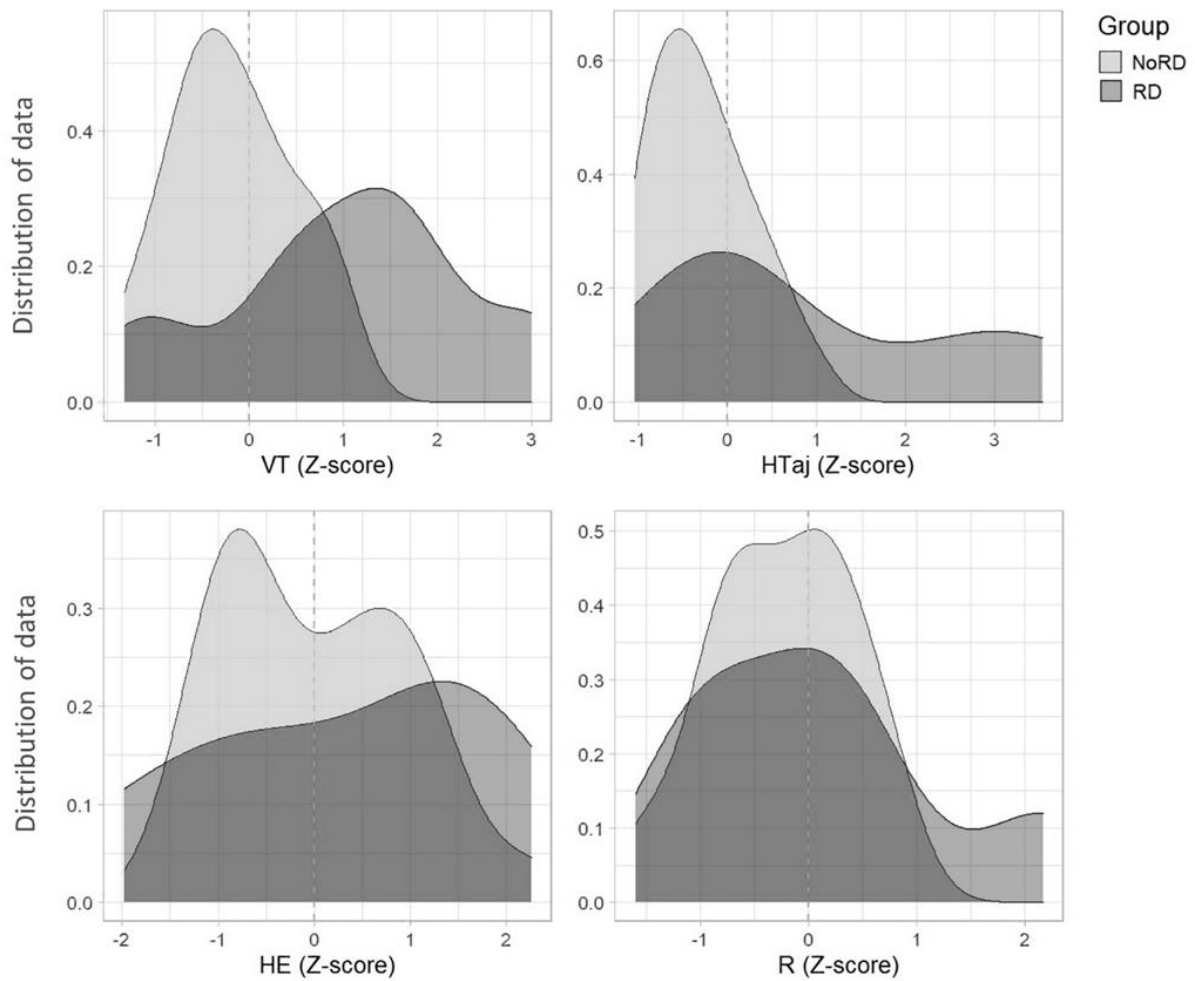
1094

1095 Table 3. Simple linear regression analysis assessing the predictive role of the DEM indices
 1096 (z-score) in kindergarten on the reading outcomes (z-score) in Grade 1

	READING ACCURACY (CM)			READING SPEED (CTL)		
	R ²	B	t	R ²	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*	-	-	-

1097 *Notes.* * p<.05 , ** p<.01 , *** p<.001; VT: Vertical Time; HTaj: adjusted Horizontal Time;
 1098 HE: Horizontal Errors

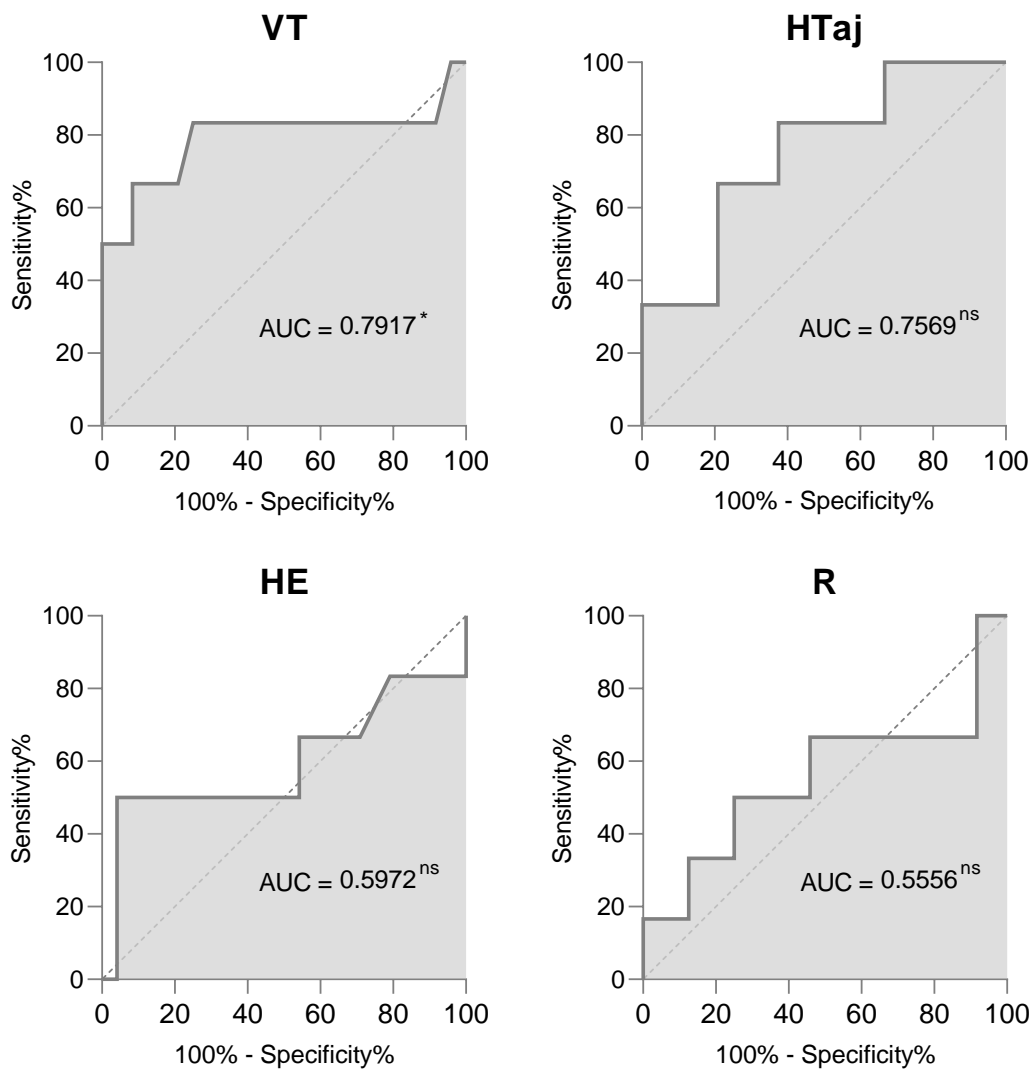
1099



1100

1101 Figure 1. Data distribution for all the DEM-test indices across children with and without
 1102 reading difficulties.

1103 *Notes.* Since the explanatory variables were time, number of errors, or ratio, a high score
 1104 reflects poorer performance than a lower score, thus a negative Z-score represents better
 1105 performance than a positive Z-score; RD: Children with reading disorders; NoRD: Children
 1106 without reading disorders.



1107

1108 Figure 2. ROC curve analyses for each DEM-test index assessed in kindergarten between
 1109 children with and without reading difficulties.

1110 *Notes.* AUC: Area Under the Curve; ns p>.05; * p<.05; ** p<.01; *** p<.001.