



**HAL**  
open science

# Effect of comorbid developmental dyslexia on oculomotor behavior in children with developmental coordination disorder: A study with the Developmental Eye Movement test

Stéphanie Bellocchi, Stéphanie Ducrot, Jessica Tallet, Mélanie Jucla,  
Marianne Jover

## ► To cite this version:

Stéphanie Bellocchi, Stéphanie Ducrot, Jessica Tallet, Mélanie Jucla, Marianne Jover. Effect of comorbid developmental dyslexia on oculomotor behavior in children with developmental coordination disorder: A study with the Developmental Eye Movement test. *Human Movement Science*, 2021, 76, pp.102764. 10.1016/j.humov.2021.102764 . hal-03366871

**HAL Id: hal-03366871**

**<https://hal.science/hal-03366871>**

Submitted on 4 Jan 2022

**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.

1 **Special Issue “VSI:DCD”**

2  
3 **Effect of comorbid Developmental Dyslexia on oculomotor behavior in children with**  
4 **Developmental Coordination Disorder: A study with the Developmental Eye Movement test**

5  
6 Stéphanie Bellocchi<sup>1</sup>, Stéphanie Ducrot<sup>2</sup>, Jessica Tallet<sup>3</sup>, Mélanie Jucla<sup>4</sup> & Marianne Jover<sup>5</sup>

7  
8 <sup>1</sup> Univ. Paul Valéry Montpellier 3, Univ. Montpellier, EPSYLON EA 4556, F34000, Montpellier,  
9 France

10 <sup>2</sup>Aix Marseille University, CNRS, LPL, Aix-en-Provence, France

11 <sup>3</sup> ToNIC, Toulouse NeuroImaging Center, Université de Toulouse, Inserm, UPS, France

12 <sup>4</sup>University of Toulouse, Octogone-Lordat, France

13 <sup>5</sup>Aix Marseille University, PSYCLE, Aix-en-Provence, France

14  
15 **Correspondence**

16 Stéphanie Bellocchi

17 Department of Psychology

18 EPSYLON EA 4556

19 University Paul Valéry Montpellier 3

20 Route de Mende

21 F-34199 Montpellier, France

22 E-mail: stephanie.bellocchi@univ-montp3.fr

23 Phone number: 0033 (0) 4 11 75 70 72

24

25

26 **Abstract**

27 Studies have suggested a dysfunction in oculomotor skills in children with developmental  
28 coordination disorder (DCD). It has been proposed that the Developmental Eye Movement  
29 (DEM) test is useful in testing the dyslexics' (DD) oculomotor behavior during reading, in a  
30 simple and indirect manner. The present study aimed at exploring the oculomotor behavior in  
31 children with DCD as assessed with the DEM test. Furthermore, we compared children with  
32 DCD to children with DD and to children with both DCD and DD in order to investigate the  
33 specificity of the oculomotor difficulties, as measured by the DEM test. Results showed that 1)  
34 children with DCD presented mild atypical performances at the DEM test (error z-score only), 2)  
35 children with DD presented particularly poor performance on the DEM test, and 3) the co-morbid  
36 condition (DCD+DD) did not add to the severity of atypical performance obtained on the DEM  
37 test. In sum, children with DCD were the less affected according to the DEM test, and children  
38 with DD (isolated or comorbid) presented the most atypical performance. Results at the DEM test  
39 did not allow making emerge clear oculomotor atypicalities in DCD. We thus conclude that more  
40 research using eye-tracking techniques is needed to explore the nature of oculomotor atypicalities  
41 in DCD children, to distinguish DD and DCD oculomotor behavior, and to understand the profile  
42 of children with dual diagnosis.

43

44 Keywords: DCD; Developmental Dyslexia; DEM test; reading; comorbidity; oculomotor  
45 behavior

46

47           **Introduction**

48           *Developmental Coordination Disorder (DCD)* is a neurodevelopmental disorder  
49 characterized by significant difficulties with the acquisition and execution of motor skill [DSM-5,  
50 American Psychiatric Association (APA), 2013]. Individuals with DCD demonstrate a level of  
51 motor skill out of keeping with their age and intellectual ability, in the absence of other medical  
52 condition (Cerebral Palsy, sensory deficit, etc.). A meta-analysis showed a pattern of deficits  
53 which are characteristic of DCD and involving different areas such as internal (forward)  
54 modelling, rhythmic coordination, executive functions, gait and postural control, catching and  
55 interceptive action, and aspects of sensori-perceptual processing (Wilson, Ruddock, Smits-  
56 Engelsman, Polatajko, & Blank, 2013). Information processing has been shown to be altered in  
57 this developmental disorder (Wilson and McKenzie, 1998). In particular, the authors identified  
58 increased deficits with visuo-spatial processing tasks in the DCD population, regardless of  
59 whether or not the tasks involved a motor component. Later, this last result has been confirmed  
60 by several studies (Bellocchi, Muneaux, Huau, Lévêque, Jover, & Ducrot, 2017; Beery & Beery,  
61 2004; Biotteau, Albaret, Lelong, & Chaix, 2017; Gardner, 1982; Martin, 2006; Prunty, Barnett,  
62 Wilmut, & Plumb, 2016).

63           Additionally, there is an increasing interest in literature over the last decades for eye-  
64 movement behavior in DCD while executing various tasks (Gaymard et al., 2017). Some studies  
65 showed difficulties in pursuit tracking tasks in individuals with DCD, but the analysis of the  
66 results also demonstrated preserved aspects (Langaas, Mon-Williams, Wann, Pascal, &  
67 Thompson, 1998; Lord & Hulme, 1988; Robert , Ingster-Moati, Albuissou, Cabrol, Golse, &  
68 Vaivre-Douret, 2014; Sumner, Hutton, Kuhn, & Hill, 2016). In particular, Langaas et al. (1998)  
69 reported a reduced gain in pursuit eye movements. More recently, Licari et al., (2018) found that  
70 DCD individuals took longer to initiate smooth pursuit but once initiated, these individuals were

71 effectively able to maintain it. Furthermore, Robert et al. (2014) suggested a delay in the  
72 maturation of the ocular pursuit system in children with DCD. They compared horizontal and  
73 vertical pursuit eye movements of children with DCD with those of TD children and showed that  
74 only vertical pursuit gain was significantly lower in children with DCD. In addition to horizontal  
75 smooth pursuit, Sumner et al. (2016) examined fixation stability and performance on pro- and  
76 anti-saccade tasks in children with DCD. In line with Robert et al. (2014), they showed that  
77 horizontal pursuit gains were comparable in DCD and TD children. Moreover, response  
78 preparation in the pro- and anti-saccade tasks were not impaired in children with DCD. The  
79 authors concluded to intact fundamental neural mechanisms underlying pursuit and saccades in  
80 DCD. However, children with DCD had deficits in maintaining engagement in the fixation and  
81 pursuit tasks, and have problems with saccadic inhibition compared to TD controls of the same  
82 age. Therefore, children with DCD would show oculomotor ‘atypicalities’ (Sumner et al., 2016)<sup>1</sup>.

83         The eye-tracking technique has also been used to highlight difficulties in eye-hand  
84 coordination in DCD. Langaas et al. (1998) showed that DCD children had difficulties in  
85 smoothly synchronizing their eye movements with a moving object. Accordingly, Wilmot, Wann  
86 and Brown (2006) observed that children with DCD have difficulties in concatenating the  
87 sequential shifts of gaze and hand in order to complete everyday tasks or assessment items (i.e.,  
88 double-step pointing paradigm ; see also Katschmarsky, Cairney, Maruff, Wilson, & Currie,  
89 2000, for similar results). Similarly, DCD children were found to have slower strategy of fixating  
90 the target prior to initiating a hand movement (Wilmot & Wann, 2008). In the same vein, a

---

<sup>1</sup> Since a huge variety of eye trackers exists, the differences pointed out by the studies could be due to the different characteristics of the eye-tracking system employed.

91 group-based gaze training intervention has shown to enhance DCD children's general  
92 coordination and perception of their catching ability (Wood et al., 2017). Finally, Warlop and  
93 colleagues (2020) recently found differences in gaze behavior between young adults with DCD  
94 and typically developing individuals in an everyday life task, i.e. walking.

95 As a whole, despite some preserved aspects, a large number of studies concluded on the  
96 presence of oculomotor 'atypicalities' in children with DCD.

97 Even though there is a non-negligible amount of studies investigating DCD individuals'  
98 eye-movements, the exploration of oculomotor control during reading in that specific population  
99 is quite scarce in the literature. Nonetheless, reading difficulties have been observed in 29% to  
100 70% of children diagnosed with DCD (O'Hare & Khalid, 2002). In this context, Bellocchi and  
101 colleagues (2015) investigated the landing position pattern in oculomotor control that take place  
102 in visual word perception in children with DCD. The authors asked children to perform an  
103 oculomotor lateralized bisection task on words, strings of hashes and lines. More precisely, the  
104 children were asked to move their eyes as quickly as possible to a position they thought to be the  
105 middle of the stimulus and to validate this position by pressing a button. Even if the oculomotor  
106 bisection task is not directly a reading task, it elicits saccade targeting which has been proved to  
107 be an integral part of the reading process (Ducrot & Pynte, 2002; see Bellocchi, Massendari,  
108 Grainger, & Ducrot, 2019 for data on Developmental Dyslexia -DD<sup>2</sup>). Results showed that

---

<sup>2</sup> *Developmental dyslexia (DD)* is a neurodevelopmental disorder that is diagnosed when no sensory and intellectual deficits can explain reading and/or writing disorders and when adequate instruction and socio-cultural opportunities are available but fail to result in an adequate level of performance [DSM-5, American Psychiatric Association (APA), 2013; W.H.O., 1992].

109 children with DCD had slower saccade latency compared to TD children in programming their  
110 first saccade and that they were less accurate on saccade targeting. These difficulties particularly  
111 emerged while they had to move their eyes on stimuli presented in the left-visual field (LVF)  
112 which requires programming a right-to-left saccade. These results suggested less automatized  
113 procedures for saccade targeting in children with DCD.

114 To our knowledge, it is unknown whether the oculomotor control atypicalities found in  
115 DCD may be explained or influenced by the presence of a co-occurring neurodevelopmental  
116 disorder (see Smits-Engelsman, Jover, Green, Ferguson, & Wilson, 2017). Indeed, co-occurrence  
117 between neurodevelopmental disorders is a very common condition. Because DCD often co-  
118 occurs with DD, eye movement disorders in this population could rely on reading subclinical  
119 deficits. Indeed, epidemiological studies demonstrate a rate of comorbid diagnosis of DCD and  
120 DD in 16% (Kaplan, Dewey, Crawford, & Wilson, 2001) to 70% of DCD children (Iversen,  
121 Berg, Ellertsen, & Tønnessen, 2005). Similarly, Chaix and colleagues (2007) found an high  
122 percentage of DCD diagnosis in a group of 58 dyslexics, i.e. 40% scored below  $-2$  standard  
123 deviations (SDs) on the Lincoln-Oseretsky Motor Development Scale (Rogé, 1984), and 17.2%  
124 scored between  $-1$  and  $-2$  SDs.

125 Unfortunately, despite the evidence of a frequent association between DCD and DD, this  
126 co-occurrence has not been taken into consideration in the research exploring oculomotor control  
127 in these two clinical populations (i.e., DCD and DD). Bellocchi and colleagues (2015) did not  
128 observe any difference between “DCD+DD” and “isolated DCD” children in the oculomotor  
129 bisection task. However, DCD+DD children differed from DD children, suggesting that the  
130 presence of a motor disorder might induce a dysfunction in saccade programming. Beyond the  
131 question of oculomotor control, recent studies exploring the impact of the co-occurrence between  
132 DCD and DD on visuo-spatial abilities, have pointed out the absence of significant differences

133 between DD+DCD group and DCD or DD isolated groups in the Motor Reduced Visual  
134 Perception and Visual-Motor Integration quotient components of the DTVP-2 (Bellocchi et al.,  
135 2017), but also in visuo-attentional processes involved in word recognition (i.e., *Optimal Viewing*  
136 *Position*<sup>3</sup> - OVP- Bellocchi & Ducrot, submitted). As a whole, these data suggest that the co-  
137 morbid condition does not sharpen difficulties in eye movements or in visuo-spatial processing in  
138 DCD children. Previous studies have reached the same conclusion, with no cumulative impact on  
139 cognitive abilities in the case of a dual diagnosis (see Biotteau et al., 2017, for a detailed review;  
140 Kaplan, Crawford, Cantell, Kooistra, & Dewey, 2006). However, recent findings depict a more  
141 complex framework than what it looks like. Indeed, Bellocchi and Ducrot (under review)  
142 suggested that children with dual diagnosis show an intermediate profile between children with  
143 isolated disorders [see also Maziero, Tallet, Bellocchi, Jover, Chaix & Jucla (2020), for similar  
144 results on working memory capacity]. It is clear that this point deserves a particular attention in  
145 scientific studies. We will thus try to address that question here.

146

### 147 **The present study**

148 Despite the evidence of 1) the importance of the oculomotor control on different cognitive  
149 tasks, and 2) data showing an oculomotor dysfunction in DCD, the assessment of eye movements  
150 is not systematically carried out and widespread in the clinical practice and the consideration of  
151 the comorbidity with dyslexia is neglected (see Bellocchi, Muneaux, Bastien-Toniazzo, &  
152 Ducrot, 2013 for a review on DD). One of the reasons resides on the complexity of the technical

---

<sup>3</sup> The *Optimal Viewing Position (OVP)* effect indicates that words are identified most quickly when the eyes fixate near the word centre in alphabetic languages (e.g., Farid & Grainger, 1996; Nazir, O'Regan, & Jacobs, 1991; O'Regan & Jacobs, 1992; Vitu, O'Regan, & Mittau, 1990).



153 apparatus needed to record on-line oculomotor control during the execution of a cognitive task. A  
154 response to this limit has been represented by the Developmental Eye Movement (DEM) test  
155 (Garzia, Richman, Nicholson, & Gaines, 1990) that provides an indirect measure of oculomotor  
156 abilities involved in a rapid automatized naming (RAN) task. It comprises horizontal and vertical  
157 digit naming tasks and provides reading time and errors norms. Thus, it is a simple and easy  
158 visual-verbal paper-based test used as an oculomotor assessment tool in optometric clinical  
159 practice guideline (e.g., Facchin, Maffioletti, & Carnevali, 2011; Facchin, Ruffino, Facoetti, &  
160 Maffioletti, 2014; Medland, Walter, & Woodhouse, 2010; Tassinari & DeLand, 2005). Another  
161 advantage is that the DEM test provides four behavior profiles, which can disentangle RAN  
162 difficulties from oculomotor dysfunction: 1) Type 1, which represents normal automaticity of  
163 digit naming and oculomotor skills. 2) Type 2, which represents oculomotor dysfunction. 3) Type  
164 3, which represents difficulties in automaticity of digit naming. 4) Type 4, which is a  
165 combination of Type 2 and 3 and represents difficulties in digit naming and oculomotor skills. In  
166 order to validate the structure of the DEM test, Facchin et al. (2011) revealed that the results of a  
167 factorial analysis showed saturation to three main factors. The first factor was linked to the  
168 common naming component between vertical and adjusted horizontal time. This factor has been  
169 thus referred to automatized naming skills. The second factor was related to adjusted horizontal  
170 time and Ratio (i.e. the quotient between horizontal time and vertical time), and it has been  
171 referred to oculomotor skills. They finally found a third factor constituted by Errors. These three  
172 factors account for 99.8% of the total variance of the DEM test data. The authors concluded that  
173 the results of the factorial analysis clearly differentiated naming skills from oculomotor skills and  
174 errors. Accordingly, atypical scores obtained in the first two components could reveal difficulties  
175 in naming and oculomotor skills, respectively.

176 Despite being criticized (e.g., Ayton, Abel, Fricke, & McBrien, 2009; Webber, Wood,  
177 Gole, & Brown, 2011), the DEM test has recently been suggested to be useful in exploring the  
178 oculomotor behavior of children with DD during reading. Moiroud, Gerard, Peyre, and Bucci  
179 (2018) sought to associate the DEM test outcomes with measures of gaze behavior and showed  
180 that children with DD and normal readers of equivalent reading level have significant longer  
181 fixation times and take longer to read the horizontal reading task than normal readers of similar  
182 chronological age. In addition, they found a correlation between the fixation time and the number  
183 of words read in one minute with the total time of the horizontal reading task.

184 As a first goal, our work aimed at exploring oculomotor behavior in children with DCD as  
185 assessed with the DEM test. Particularly, according to the interpretation of the results provided  
186 by the DEM test, we predicted that if children with isolated DCD showed oculomotor difficulties,  
187 they should mainly exhibit Type 2 profile that represents oculomotor dysfunction. In addition,  
188 according to the so-called *phonological hypothesis*<sup>4</sup> (e.g., Snowling, 2000; 2006; Vellutino &  
189 Fletcher, 2005; Vellutino, Fletcher, Snowling, & Scanlon, 2004), children with isolated DD  
190 should be mostly linked to Type 3 profile which represents specific difficulties in RAN.  
191 Subsequently, children with comorbid disorders (DCD+DD) should be mainly characterized by  
192 Type 4 profile, which represents a combination of RAN and oculomotor skills difficulties.

---

<sup>4</sup> One of the most widely accepted explanations of DD posits a core deficit at the phonological level of processing. In particular, the so-called *phonological theory* asserts that dyslexics have a specific impairment in the representation, storage, and/or retrieval of speech sounds that prevents the proper acquisition of the grapheme-phoneme correspondence necessary for learning to read in an alphabetic system.

193 Secondly, we wanted to explore the impact of comorbidity on DCD's oculomotor  
194 behavior. To this aim, we compared children with DD and DCD (DD+DCD) to children with  
195 isolated disorders (DD or DCD) in the DEM task. According to a cumulative hypothesis (e.g.  
196 Pitcher, Piek, & Barrett, 2002), if co-morbid condition adds to the severity of the cognitive  
197 deficit, children with DD and DCD should display more marked oculomotor atypicalities than  
198 children with isolated disorders. On the contrary, if co-morbid condition does not add to the  
199 severity of the cognitive deficit, we should find that no difference between children with isolated  
200 disorders and those with a dual diagnosis (e.g., Bellocchi et al., 2015; Bellocchi et al., 2017;  
201 Biotteau et al., 2017). Moreover, the comparison between co-morbid children (DD+DCD) and  
202 children with isolated disorders (DD or DCD) can provide evidences about the specificity of the  
203 oculomotor difficulties, as measured by the DEM test, to reading or motor impairments. In other  
204 words, if atypicalities at the DEM test are associated with reading deficit, we should find them  
205 more specifically in children with reading impairments (isolated DD and DD+DCD). However, if  
206 atypicalities at the DEM test are associated with motor disorder, we should find them more  
207 specifically in DCD children (isolated DCD and DD+DCD).

208

## 209 **Method**

210 **Participants.** In total, 138 children (57 girls, 81 boys) participated in the study. Four  
211 groups were constituted (see Table 1), one composed of 42 typically developing children (TD),  
212 the other composed of 22 children with developmental coordination disorder (DCD), the third  
213 composed of 47 children with developmental dyslexia (DD), and the last one composed of 27  
214 children with developmental dyslexia and developmental coordination disorder (DD+DCD). The  
215 patients studied were enrolled in the DYSTAC MAP cohort (ANR-13-APPR-0010).

216 All children were aged between 7 years 8 months to 12 years 6 months, right-handed, and  
 217 French native speakers. All parents reported a normal hearing, and normal or corrected-to-normal  
 218 vision of their child. All underwent a full medical and neuropsychological assessment conducted  
 219 by skilled practitioners. They all had normal intellectual functioning level (standard score at least  
 220 above 7 at the Similarities and Pictures Concepts subtest, French-language version of the WISC-  
 221 IV, Wechsler, 2005). Furthermore, children whose oral language skills were in the pathological  
 222 range (scores below -2 SD on the « EVAC » -Flessas & Lussier, 2003- and « Ecosse » -Lecocq,  
 223 1996- tests), or who were diagnosed with ADHD (six or more symptoms of the  
 224 « Hyperactivity/impulsiveness » as « Inattention » checklist of the DSM-5) were excluded from  
 225 the study.

226

227

228

229

[Insert Table 1 about here]

<b>Group</b>	<b>TD</b>	<b>DCD</b>	<b>DD</b>	<b>DCD+DD</b>	<b>Group diff</b>	<b>Post hoc comparison</b>
N (females)	42 (20)	22 (7)	47 (20)	27 (10)	ns	
Age (M ±SD)	10,0 ±1,1	9,8 ±1,3	10,1 ±1,1	10,1 ±1,3	ns	
DSM-5 ADHD questionnaire total score (M ±SD)	0,86 ±1,2	5,41 ±2,6	4,36 ±2,4	5,36 ±2,7	<.001	TD>DD;DCD;DCD+DD
MABC total score (percentiles) (M ±SD)	4,06 ±3,1	20,84 ±4,8	5,45 ±2,7	20,33 ±5,3	<.001	TD;DD>DCD;DCD+DD
Alouette Accuracy Z-score (M ±SD)	0,57 ±0,3	0,32 ±0,4	-2,19 ±1,2	-2,24 ±1,9	<.001	TD>DCD>DD;DCD+DD

Alouette Speed Z-score (M ±SD)	0,95 ±0,8	0,31 ±0,8	-1,43 ±0,6	-1,35 ±0,5	<.001	TD>DCD>DD;DCD+DD
Odedys Irregular word Accuracy (M ±SD)	0,84 ±0,6	0,63 ±0,7	-1,63 ±1	-1,93 ±1,1	<.001	TD;DCD>DD;DCD+DD
Odedys Irregular word Speed (M ±SD)	0,80 ±0,4	0,54 ±0,5	-2,92 ±3,5	-1,94 ±2,1	<.001	TD;DCD>DD;DCD+DD
Odedys Pseudo word Accuracy (M ±SD)	0,51 ±0,6	0,03 ±0,5	-1,8 ±1,3	-1,63 ±1,1	<.001	TD>DCD>DD;DCD+DD
Odedys Pseudo word Speed (M ±SD)	0,54 ±0,6	0,25 ±0,6	-2,17 ±3,3	-1,11 ±1,2	<.001	TD;DCD>DD;DCD+DD

230

231 Table 1: Demographic characteristics and inclusion criteria of each group of children. Sex  
 232 ratio, age, DSM-5 ADHD questionnaire total score, MABC total score (percentiles), Alouette  
 233 Accuracy and Speed z scores and Odedys Accuracy and Speed z scores for Irregular and Pseudo  
 234 word reading. Note. TD = typically developing children; DCD= children with isolated DCD;  
 235 DD= children with isolated DD; DCD+DD= children with both DCD and DD; Group diff=  
 236 Group difference. Group differences were tested with a Kruskal Wallis test and  $\chi^2$ (sex ratio), and  
 237 post-hoc test with Dwass-Steel-Critchlow-Fligner test.

238

239 Participants with diagnosed neurodevelopmental disorders were recruited at San Salvador  
 240 University Hospital [Center for the diagnosis of learning disabilities] in Marseille, at the Hospital  
 241 of Aix-en-Provence, and at the Purpan University Hospital in Toulouse, France. Children with  
 242 DCD were included in the study if they had a score below the 5<sup>th</sup> percentile on the French version  
 243 of the M-ABC (Soppelsa & Albaret, 2004). Children with DD were included in the study if they  
 244 showed manifested reading deficits in two different tests : at least 1 SDs below the normal level  
 245 on the “Alouette Test-R” (Lefavrais, 2005), a test accounting for speed and accuracy of text  
 246 reading, and at least 1.5 SDs below the normal level on the ODEDYS-2 test- Outil de dépistage

247 des dyslexies, Second Edition (Jacquier-Roux, Valdois, & Zorman, 2002), a test assessing speed  
248 and accuracy of reading isolated irregular words and pseudowords.

249 Children were included in the group of children with isolated DCD only if they had no  
250 reading difficulties [at least -0.5 SDs above the normal level on the “Alouette Test-R” (Lefavrais,  
251 2005) and on the ODEDYS-2 test- Outil de dépistage des dyslexies, Second Edition (Jacquier-  
252 Roux et al., 2002)]. Children were in the group of children with isolated DD only if they had no  
253 motor difficulties [scores above the 15<sup>th</sup> percentile on the M-ABC test]. Children of the group  
254 DCD+DD had a score below the 5<sup>th</sup> percentile on the M-ABC and reading impairments [i.e.,  
255 reading performance respecting the two previously presented criteria - at least 1 SDs below the  
256 normal level on the “Alouette Test-R” and at least 1.5 SDs below the normal level on the  
257 ODEDYS-2 test].

258 Finally, children in the TD group were recruited through announcement in schools and in  
259 the laboratories. They had normal reading abilities [at least -0.5 SDs above the normal level on  
260 the “Alouette Test-R” and on the ODEDYS-2 test] and normal motor abilities [scores above the  
261 15<sup>th</sup> percentile on the M-ABC test]. None of them suffered from any neurological, psychiatric, or  
262 emotional disorders or were educationally disadvantaged. We did not include children who were  
263 considered by parents or by the practitioners’ assessment as having either a specific learning  
264 deficit or cognitive and behavioral problems.

265 This work was conducted in accordance with the Declaration of Helsinki (WHO, 2008),  
266 approved by the French Ethics Committee Review Board (2014-A01239-38 and 2014-A01960-  
267 47). The children and their parents gave their written consent for participation.

268

269 **Materials.** Each participant was given the DEM test (Garzia, et al., 1990) which is  
270 composed by horizontal and vertical digit reading tasks printed on four different sheets of paper:

271 the pre-test (a horizontal line of ten 0,5 cm high digits) , two vertical tests (Test A and B; each  
272 composed of two vertical lines of twenty 0,5 cm high digits separated by a 10.5 cm horizontal  
273 margin and with a 0,5 cm vertical distance between letters) and one horizontal test (Test C;  
274 sixteen lines of five irregularly separated 0,5 cm high digits). Children were asked to read aloud  
275 the digits as fast and as accurately as possible. The task was timed, and errors or omissions were  
276 recorded. The DEM test provides several measures: 1) the vertical reading time (seconds) (VT)  
277 which represents the sum of the time spent on naming the eighty vertically organized digits of  
278 Test A and B (in accordance with the test manual, errors were not used for scoring purpose) ; 2)  
279 the adjusted horizontal time (second) (HT) which represents the time required for reading the  
280 eighty horizontally organized digits presented in the Test C; this score is corrected for omission  
281 or addition errors<sup>5</sup>; 3) the total number of errors which gives the accuracy on the execution of  
282 Test C (errors recorded : omission, addition, substitution, transposition); 4) the Ratio score which  
283 is calculated dividing the HT by the VT.

284 Furthermore, for clinical purposes, the DEM test provides four behavior profiles: 1) Type  
285 1, which represent normal automaticity of digit naming and oculomotor skills. It comprises  
286 essentially normal performance in HT, VT and Ratio. The children were included in this group if  
287 all the scores were  $> -1.5$  SD. 2) Type 2, which represents oculomotor dysfunction. It is  
288 characterized by abnormally increased scores in HT and Ratio but normal scores for VT. The  
289 children were included in this group if HT and Ratio scores were  $\leq -1.5$  SD and VT scores  $> -$   
290  $1.5$  SD. 3) Type 3, which represents difficulties in automaticity of digit naming. It comprises  
291 abnormally increased scores in VT and HT, but normal scores in Ratio. The children were  
292 included in this group if VT and HT scores were  $\leq -1.5$  SD and Ratio scores  $> -1.5$  SD. 4) Type

---

<sup>5</sup> Adjusted Horizontal Time = Test C time x  $[80/(80\text{-number of omission} + \text{number of addition})]$

293 4, is a combination of Type 2 and 3 and represents difficulties in digit naming and oculomotor  
294 skills. It is characterized by abnormally increased scores in VT, HT and Ratio. The children were  
295 included in this group if all the scores were  $\leq -1.5$  SD.

296  
297 **Procedure.** All children were tested individually at the hospital and at the university  
298 laboratories by a neuropsychologist and a psychomotor therapist enrolled in the research project  
299 for their expertise in neurodevelopmental disorders. All the children received a comprehensive  
300 cognitive assessment to evaluate criteria for inclusion in each group. This session lasted about 1  
301 hour and a half. However, the administration of the DEM test lasted about 10 minutes.

302  
303 **Data Analysis.** Data were analysed using the Jamovi statistical computer software [The  
304 jamovi project (2019). jamovi (Version 0.9). Retrieved from <https://www.jamovi.org>]. As  
305 Shapiro-Wilk test demonstrated that the data were not normally distributed, and the group size  
306 were small, all statistics were non-parametric. Group comparisons for the children's test scores  
307 were performed using Kruskal Wallis test a non-parametric version of one-way ANOVA on  
308 ranks which is usually used for comparing more than 2 independent samples. Post-hoc  
309 comparisons were done with Dwass-Steel-Critchlow-Fligner test which compares all pairs of  
310 groups using a pairwise ranking nonparametric method and controls the error rate. The  
311 distribution of the sex ratio and of the DEM types between the groups were tested using  $\chi^2$  tests  
312 and pairwise comparisons were performed with Bonferroni correction ( $p = .008$ ). The  
313 significance threshold was set at  $p = .05$ .

314

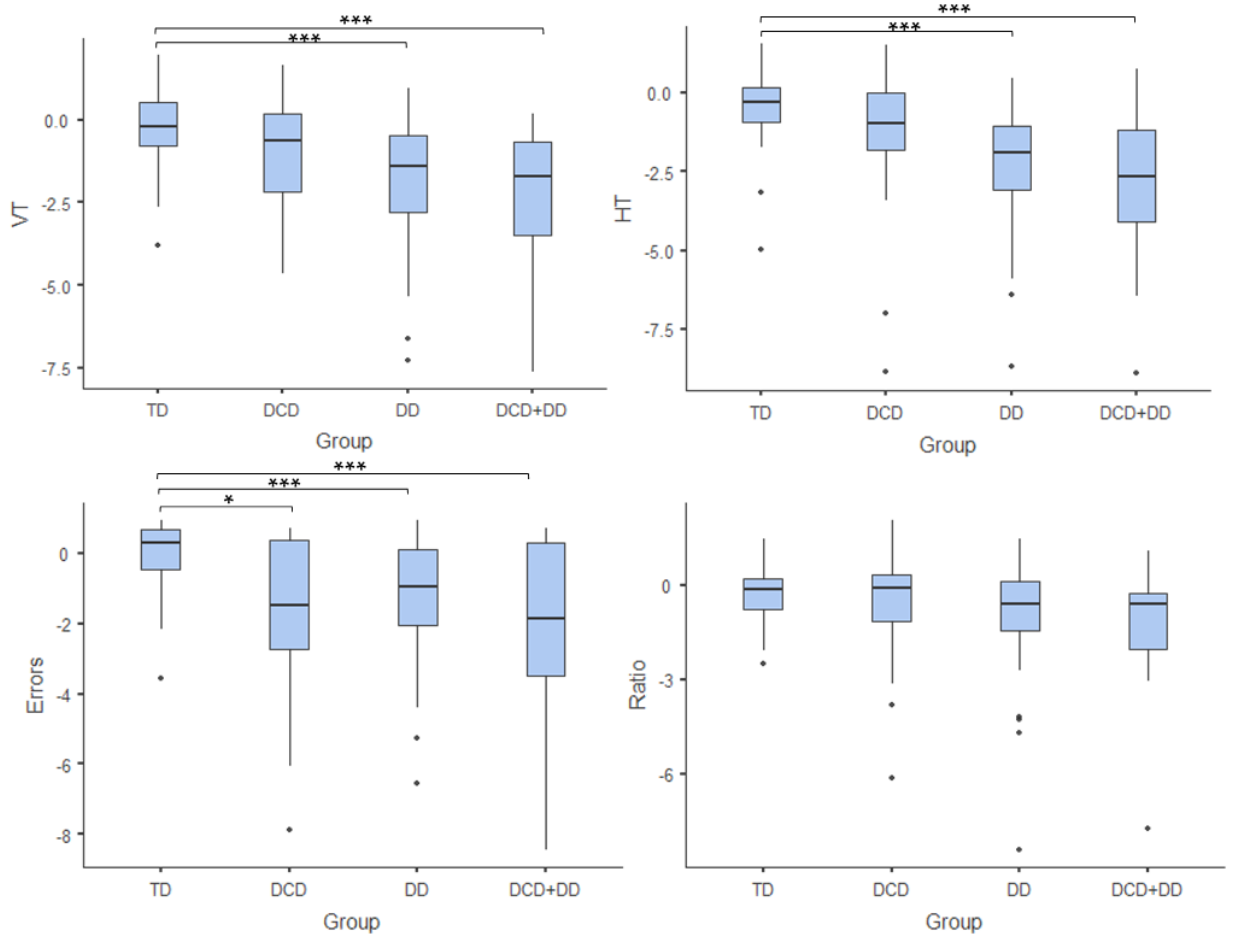
315 **Results**



316 Kruskal-Wallis test showed a significant effect of group for all z-scores (VT,  $H(3) =$   
317  $28.38; p < .001$ ; HT,  $H(3) = 38.85; p < .001$ ; Ratio,  $H(3) = 9.19; p < .05$ ; Errors,  $H(3) = 20.84; p$   
318  $< .001$ ; see Figure 1). Dwass-Steel-Critchlow-Fligner pairwise comparisons demonstrated that  
319 children with isolated DCD differed from TD children only for the errors' z-score ( $p < .039$ ). In  
320 contrast, children with DD had lower z-scores than TD children for the horizontal time, vertical  
321 time and in the errors. Finally, children with DCD+DD had lower z-scores than TD children for  
322 the horizontal time, vertical time, errors and the ratio.

323

324 [Insert Figure 1 about here]



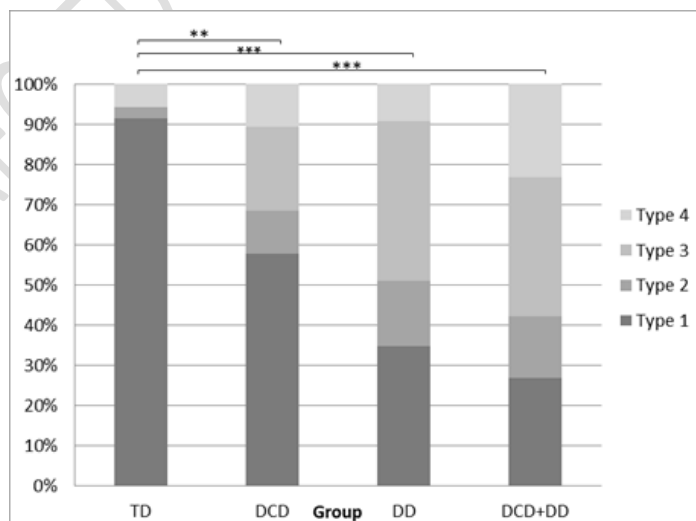
325

326  
 327 Figure 1: Box plot representation of the DEM variables expressed in z scores. VT: vertical time,  
 328 HT: horizontal time, Ratio: ratio HT/VT. Note: \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ . Note. TD =  
 329 typically developing children; DCD= children with isolated DCD; DD= children with isolated  
 330 DD; DCD+DD= children with both DCD and DD.

331  
 332 The distribution of the behavior types differed significantly between the groups of  
 333 children ( $\chi^2 = 37.5, p < .001$ ). Pairwise comparisons showed differences between TD and other  
 334 groups ( $p < .008$ ) but not between DD, DCD and DCD+DD groups. Children with DCD, as did  
 335 DD and DCD+DD children, were more often presenting abnormal behavior response type than  
 336 TD children, but the differences between children with DCD, children with DD and children with  
 337 DCD+DD were never significant.

338

339 [Insert Figure 2 about here]



340

341

342 Figure 2: Distribution of the four behavior types in each group. Note: 1) Type 1: normal  
343 automaticity and oculomotor skills. 2) Type 2: oculomotor dysfunction. 3) Type 3: difficulties in  
344 automaticity of digit naming. 4) Type 4: difficulties in digit naming and oculomotor skills (a  
345 combination of Type 2 and 3). TD = typically developing children; DCD= children with isolated  
346 DCD; DD= children with isolated DD; DCD+DD= children with both DCD and DD.

347

## 348 Discussion

349 The first aim of the present study was to explore oculomotor behavior in children with  
350 DCD as assessed with the DEM test (Garzia et al., 1990). As a whole, results showed that  
351 children with DCD presented slight atypical scores at the DEM test, as attested by the fact that  
352 only one parameter was significantly affected. Particularly, children with isolated DCD made  
353 more errors if compared to TD children. Children with DCD+DD clearly showed a wider range  
354 of difficulties when compared to children with DCD only, and, of course, to TD children: they  
355 had lower z-scores than TD children did for the horizontal time, vertical time, errors and the ratio.  
356 Additionally, the data revealed that DCD and DCD+DD showed less Type 1, more Type 2, and 4  
357 compared to TD children, thus suggesting atypical profile of oculomotor responses in DCD  
358 children (isolated or comorbid)<sup>6</sup>. Contrary to our hypothesis, this result was also observed in  
359 children with isolated DD who showed a pattern of deficit similar to children with DCD and  
360 DCD+DD. Moreover, no significant difference emerged on the percentage of Type 2 profile

---

<sup>6</sup> As a reminder, according to the interpretation provided by the manual of the DEM test, Type 2 and 4 correspond to a wide range of difficulties, going from a specific oculomotor dysfunction (Type 2) to a combination of difficulties in digit naming and oculomotor skills (Type 4).

361 between the isolated DCD group and the two other groups of neurodevelopmental disorders (DD  
362 and DCD+DD), suggesting that isolated DCD group could not be specifically characterized by  
363 oculomotor dysfunction as assessed by DEM test.

364 Contrary to our expectations, the results of the present study showed that atypical scores  
365 at the DEM test were more frequently associated to a diagnosis of DD, both in digit naming and  
366 oculomotor skills. As previously described, children with DCD and DD diagnosis, as well as  
367 children with isolated DD, showed a wider range of difficulties if compared to TD children.  
368 Indeed, they not only made more errors than the DCD only group, but also showed lower scores  
369 for the horizontal time, vertical time, ratio and atypical oculomotor responses if compared to TD  
370 children (i.e., higher presence of Type 2 and 4). In other words, the results at the DEM test were  
371 very sensitive to children's reading abilities or, more specifically, to the presence of a reading  
372 disorder. This is what was found by Moiroud and collaborators (2018) who showed that dyslexic  
373 children and the reading age-matched children took longer time to read Text C of the DEM test if  
374 compared to the chronological age-matched children group. Consistently, in their study, dyslexics  
375 and reading age-matched children had longer fixation time compared to chronological age-  
376 matched children while reading this text. Accordingly, previous important findings showed that  
377 compared to age-matched control readers, dyslexics' eye movements in word, pseudoword, or  
378 sentence reading are characterized by more and longer fixations. Additionally, dyslexics usually  
379 show shorter saccades and more regressions (Bellocchi et al., 2019; Biscaldi, Gezeck, & Stuhr,  
380 1998; Bucci, Nassib, Gerard, Bui-Quoc, & Seassau, 2012; Hawelka, Gagl, & Wimmer, 2010;  
381 Hutzler & Wimmer, 2004; McConkie, Zola, Grimes, Kerr, Bryant & Wolff, 1991; Rayner, 1986;  
382 Seassau, Gerard, Bui-Quoc, & Bucci, 2014).

383 The Type 3 profile of the DEM test is supposed to refer to specific difficulties in RAN. In  
384 the present study, children with DCD +DD and children with isolated DD tended to be more

385 linked to this profile, if compared to others profiles and to DCD group. This tendency could be in  
386 accordance with the so-called *phonological hypothesis* (e.g., Snowling, 2000; 2006; Vellutino &  
387 Fletcher, 2005; Vellutino et al., 2004). Although non-significant, these differences are interesting  
388 anyhow because they show a specific pattern of profile regarding children with a DD, associated  
389 or not with a DCD. In other words, the DEM test seemed to be sensitive in highlighting RAN  
390 deficits in children with reading disorders. These descriptive results deserve to be replicated in  
391 future studies.

392         Until now very few studies have investigated whether the oculomotor control atypicalities  
393 found in DCD may be, or not, influenced by the presence of a co-occurring DD. Considering the  
394 evidence of a frequent association between these two neurodevelopmental disorders (Iversen et  
395 al., 2005; Kaplan et al., 2001), our second aim here was to explore the impact of comorbidity of  
396 DD on DCD's oculomotor skills, particularly the oculomotor skills measured by the DEM test.  
397 As a whole, results showed no significant differences between comorbid and isolated groups at  
398 the DEM test. This means that no additional impact on DEM performance is associated with a  
399 dual diagnosis. Therefore, these data do not support the cumulative hypothesis according to  
400 which if co-morbid condition add to the severity of the cognitive deficit, children with DCD and  
401 DD should revealed more marked atypical DEM test results than children with isolated disorders  
402 (e.g., Pitcher et al., 2002). These results are in line with other recent studies suggesting that the  
403 comorbid condition does not systematically add to the severity of associated cognitive disorders  
404 (e.g., Bellocchi & Ducrot, submitted; Bellocchi et al., 2017; Biotteau et al., 2017; Kaplan et al.,  
405 2006; Maziero et al., 2020). Note that, as previously mentioned, children with DCD and DD  
406 diagnosis, showed atypicalities on a wider range of parameters when compared to isolated  
407 disorders. Accordingly to what it has been stated above, this result can be mainly explained by  
408 the presence of a co-occurred DD.

409 Even if the differences between the three groups of children with neurodevelopmental  
410 disorders (DCD, DCD+DD, and DD) were not statistically significant, it does not mean that these  
411 groups had comparable performance on the DEM test. Indeed, if we look at the distribution of the  
412 behavior types (Figure 2), it appears that the profiles that emerged are quite heterogeneous.  
413 Particularly, we can observe that DCD+DD group showed higher percentage of Type 4 profile  
414 compared to the other two profiles (Type 2 and 3) and compared to isolated DD and DCD. Again,  
415 it is important to notice that these differences were not statistically significant but they highlight a  
416 variability that researchers need to explore more deeply as it could depict a more complex  
417 framework of the DCD+DD comorbid profile.

418 Finally, results at the DEM test did not reveal clear oculomotor atypicalities in DCD. For  
419 instance, the percentage of Type 2 profile, indicating an oculomotor dysfunction, wasn't higher in  
420 children presenting a DCD isolated or comorbid, compared to the other neurodevelopmental  
421 groups. Rather than concluding that DCD children do not encounter eye-movements difficulties,  
422 we assume that the DEM test is not as sensitive to oculomotor than to RAN difficulties. Indeed,  
423 first of all, the vast majority of researches observed oculomotor difficulties in DCD (e.g.,  
424 Bellocchi et al., 2015; Gaymard et al., 2017; Gonzalez et al., 2016; Langaas et al., 1998;  
425 Katschmarsky et al., 2000; Licari et al., 2018; Lord & Hulme, 1988; Robert et al., 2014; Sumner,  
426 et al. 2016; Warlop et al., 2020 ; Wilmut, Wann, & Brown, 2006; Wilmut & Wann, 2008).  
427 Furthermore, Ayton et al. (2009), as well as Webber et al. (2011), did not find any link between  
428 the DEM test and saccadic parameters (accuracy, latency, speed), thus questioning the validity of  
429 the DEM test as a measure of oculomotor behavior during reading, but not as a measure of  
430 reading performance and speed of visual processing. Taking into account all these observations,  
431 some precautions are needed while using the DEM test as a measure of DCD's oculomotor  
432 behavior during reading. Alternatively, it is possible that oculomotor difficulties in DCD are

433 revealed depending on the task and the measures used. Thereby, it is worth to mention that  
434 studies reporting these atypicalities used different tasks and measures compared to what is asked  
435 for the execution of the DEM test. The former employed tasks such as pro- and anti-saccades,  
436 smooth pursuit, eye-hand coordination, walking, etc., and direct measures of saccadic parameters  
437 such as latency, speed, saccade targeting, number and duration of fixations and regressions, etc.  
438 Differently, as previously described, the DEM test is based on a RAN task and uses indirect  
439 measures such as errors and speed. Future studies should thus take into consideration the impact  
440 of the type of cognitive task on oculomotor control in DCD and develop more researches  
441 comparing indirect and direct measures of DCD children's eye-movements.

442

#### 443 **Limitations of the study**

444 The present study unfortunately cannot disentangle the origin of the oculomotor  
445 difficulties in DCD between low-level processes or higher-level cognitive tasks (e.g., reading).  
446 As a matter of fact, our results showed that 1) performance at the DEM test are clearly associated  
447 to reading abilities, particularly to reading disorder and 2) the validity of the DEM test as a  
448 measure of oculomotor behavior is questionable. Consistently, it is also reasonable to observe  
449 that children with DCD made more errors in the DEM test because they have attentional  
450 difficulties which are frequently associated to this disorder (e.g., Dewey et al., 2002; Goulardins  
451 et al. 2017). Even if a more complete assessment of attentional functions should be necessary, we  
452 compared the scores at the ADHD questionnaire total score used for inclusion criteria between  
453 DCD, DCD+DD and DD groups. No differences emerged between DCD and other  
454 neurodevelopmental groups in terms of clinical attentional problems, suggesting that attentional  
455 problems could not explain DCD's performances at the DEM test. Surely, the question of

456 attention should be explored in more depth and deserves more consideration in future studies  
457 exploring eye-movements in DCD.

458 Finally, we relied on parental report, on a neuropsychological and on a medical  
459 assessment to check the visual functioning of the children in the present study. As children with  
460 neurodevelopmental disorders usually suffer from various debilitating visual impairments, it  
461 would be recommended to systematically test visual capability before testing visual perceptual  
462 skills.

463

#### 464 **Conclusions**

465 Our study showed that 1) children with DCD presented mild atypical performances at the  
466 DEM test (error z-score only), 2) children with DD presented particularly poor performance on  
467 the DEM test, and 3) the co-morbid condition (DCD+DD) did not add to the severity of atypical  
468 performance obtained on the DEM test. In sum, children with DCD were the less affected  
469 according to the DEM test, and children with DD (isolated or comorbid) presented the most  
470 atypical performance. To go further, follow up research with direct measures of oculomotor  
471 control are required to 1) explore on-line oculomotor control during reading and/or visual word  
472 recognition in DCD (e.g., Bellocchi et al., 2015) and 2) measure the impact of DCD's oculomotor  
473 deficits on reading. In that sense, eye tracking should help researchers to explore the nature of  
474 oculomotor disorder in DCD children, distinguish DD and DCD oculomotor behavior and better  
475 apprehend DCD+DD performance variability.

476



477 **Acknowledgements**

478           The authors are very grateful to the children and their parents who accepted to participate  
479 in this research. Additionally, we would like to thank all the members of the research team of the  
480 DYSTAC MAP project (PI: Y. Chaix; 2014-2018).

481           Funding: This work was promoted by a grant from the French National Research Agency  
482 (ANR DYSTAC-MAP, ANR-13-APPR-0010).

UNCORRECTED PROOF \_pre-print version

483           **References**

- 484    American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders*  
485           (5th ed.). Washington, DC: Author.
- 486    Ayton, L.N., Abel, L.A., Fricke, T.R., & McBrien, N.A. (2009). Developmental eye movement  
487           test: What is it really measuring? *Optometry and Vision Science*, 86, 722-30.
- 488    Beery, K., & Beery, N. (2004). *The beery-buktenica developmental test of visual-motor*  
489           *integration (manual)*. Bloomington, MN: Pearson Assessments.
- 490    Bellocchi, S. & Ducrot, S. (submitted). “Same, same but different”: The OVP effect in  
491           developmental dyslexia, developmental coordination disorder and comorbid disorders.
- 492    Bellocchi, S., Huau, A., Jover, M., Brun-Hénin, F., Mancini, J., & Ducrot, S. (2015). Oculomotor  
493           control in DCD children with and without developmental dyslexia: What is the impact of  
494           co-occurrence between neurodevelopmental disorders? *Journal of Comorbidity*, 5, 48.  
495           Proceedings of the 11th International Conference on Developmental Coordination Disorder  
496           (DCD11), Toulouse, France, July 2–4, 2015.
- 497    Bellocchi, S., Massendari, D., Grainger, J., & Ducrot, S. (2019). Effects of inter-character  
498           spacing on saccade programming in beginning readers and dyslexics. *Child*  
499           *Neuropsychology. A Journal on Normal and Abnormal Development in Childhood and*  
500           *Adolescence*, 25(4), 482-506.
- 501    Bellocchi, S., Muneaux, M., Bastien-Toniazzo, M., & Ducrot, S., (2013). I can read it in your  
502           eyes: What eye movements tell us about visuo-attentional processes in developmental  
503           dyslexia. *Research in Developmental Disabilities*, 34, 452-460.
- 504    Bellocchi, S., Muneaux, M., Huau, A., Lévêque, Y., Jover, M., & Ducrot, S. (2017). Exploring  
505           the Link between Visual Perception, Visual-Motor Integration, and Reading in Normal

506           Developing and Impaired Children using DTVP-2. *Dyslexia. An International Journal of*  
507           *Research and Practice*, 23(3), 296-315.

508   Biotteau, M., Albaret, J.M., Lelong, S., & Chaix, Y. (2017). Neuropsychological status of French  
509           children with developmental dyslexia and/or developmental coordination disorder: Are  
510           both necessarily worse than one? *A Journal on Normal and Abnormal Development in*  
511           *Childhood and Adolescence*, 23 (4), 422-441.

512   Biscaldi, M., Gezeck, S., & Stuhr, V. (1998). Poor saccadic control correlates with dyslexia.  
513           *Neuropsychologia*, 36,1189–202.

514   Bucci, M.P., Nassibi, N., Gerard, C.L., Bui-Quoc, E., Seassau, M. (2012). Immaturity of the  
515           oculomotor saccade and vergence interaction in dyslexic children: evidence from a reading  
516           and visual search study. *PlosOne*, 7(3):e33458.

517   Chaix, Y., Albaret, J.M., Brassard, C., Cheuret, E., de Castelnau, P., Bénesteau, J., Karsenty, C.,  
518           & Démonet, J.F. (2007). Motor impairment in dyslexia: The influence of attention disorders.  
519           *European Journal of Paediatric Neurology*, 11, 368–374.

520   Ducrot, S., & Pynte, J. (2002). What determines the eyes' landing position in words? *Perception*  
521           & *Psychophysics*, 64, 1130–1144.

522   Facchin, A., Maffioletti, S., & Carnevali, T. (2011). Validity reassessment of Developmental Eye  
523           Movement (DEM) test in the Italian population. *Optometry & Vision Development*, 42(3),  
524           155-167.

525   Facchin, A., Ruffino, M., Facoetti, A., & Maffioletti, S. (2014). Modified direction of DEM test  
526           suggests differences in naming and eye movements. *Optometry & Vision Development*, 2,  
527           103–111.

528   Farid, M., & Grainger, J. (1996). How initial fixation position influences visual word recognition:  
529           A comparison of French and Arabic. *Brain and Language*, 53, 681–690.

530 Flessas J. & Lussier, F. (2003). *EVAC - Épreuve Verbale d'Aptitudes Cognitives*. Paris : ECPA.

531 Gardner, M. (1982). *TVPS: Test of visual-perceptual skills (non-motor)-manual*. Seattle, WA:  
532 Special Child Publications.

533 Garzia, R.P., Richman, J.E., Nicholson, S.B., & Gaines, C.S. (1990). A new visual-verbal  
534 saccade test: The development eye movement test (DEM). *Journal of the American*  
535 *Optometric Association*, 61, 124–135.

536 Gaymard, B., Giannitelli, M., Challes, G., Rivaud-Péchoux, S., Bonnot, O. et al. (2017).  
537 Oculomotor Impairments in Developmental Dyspraxia. *The Cerebellum*, 16 (2), 411 -420.

538 Gonzalez, C.C., Mon-Williams, M., Burke, S., & Burke, M.R. (2016). Cognitive Control of  
539 Saccadic Eye Movements in Children with Developmental Coordination Disorder.  
540 *PLoS ONE*, 11(11), e0165380. doi:10.1371/journal.pone.0165380

541 Hammill, D. D., Pearson, N. A., & Voress, J. K. (1993). *Developmental test of visual perception*  
542 (2nd. ed). Austin, TX: Pro-Ed.

543 Hawelka, S., Gagl, B., Wimmer, H. (2010). A dual-route perspective on eye movements of  
544 dyslexic readers. *Cognition*, 115, 367-379.

545 Hutzler, F., & Wimmer, H. (2004). Eye movements of dyslexic children when reading in a  
546 regular orthography. *Brain and Language*, 89, 235-242.

547 Iversen, S., Berg, K., Ellertsen, B., & Tønnessen, F. E. (2005). Motor coordination difficulties in  
548 a municipality group and in a clinical sample of poor readers. *Dyslexia*, 11(3), 217-231.

549 Jacquier-Roux, M., Valdois, S., & Zorman, M. (2002). *Outil de dépistage des dyslexies [Dyslexia*  
550 *screening tool]*. Grenoble, France: Laboratoire de Cogni-Sciences IUFM.

551 Kaplan, B. J., Dewey, D. M., Crawford, S. G., & Wilson, B. N. (2001). The term comorbidity is  
552 of questionable value in reference to developmental disorders: Data and theory. *Journal of*  
553 *Learning Disabilities*, 34(6), 555-565.

554 Kaplan, B., Crawford, S., Cantell, M., Kooistra, L., & Dewey, D. (2006). Comorbidity, co-  
555 occurrence, continuum: What's in a name? *Child: Care, Health and Development*, 32(6),  
556 723-731.

557 Katschmarsky, S., Cairney, S., Maruff, P., Wilson, P. H. & Currie, J. (2001). The ability to  
558 execute saccades on the basis of efference copy: Impairments in double-step saccade  
559 performance in children with Developmental Coordination Disorder. *Experimental Brain*  
560 *Research*, 136, 73–78.

561 Langaas, T., Mon-Williams, M. P., Wann, J., Pascal, E., & Thompson, C. (1998). Eye  
562 movements, prematurity and developmental co-ordination disorder. *Vision Research*, 38,  
563 1817–1826.

564 Lecocq, P. (1996). *L'É.co.s.se une épreuve de compréhension syntaxico-sémantique (manuel et*  
565 *épreuve)*. Villeneuve d'Ascq : Presses Universitaires du Septentrion

566 Lefavrais, P. (2005). *Test de l'Alouette-R*. Paris : ECPA.

567 Licari, M.K., Reynolds, J. E., Tidmand, S., Ndiaye, S., Sekaran, S. N., Reid, S.L., & Lay, B.S.  
568 (2018). Visual tracking behaviour of two-handed catching in boys with developmental  
569 coordination disorder. *Research in Developmental Disabilities*, 83, 280-286.

570 Lord, R., & Hulme, C. (1988). Patterns of rotary pursuit performance in clumsy and normal  
571 children. *The Journal of Child Psychology & Psychiatry*, 29(5), 691–701.

572 Martin, N. (2006). *Test of visual perceptual skills (3rd ed.)*. USA: Academic Therapy  
573 Publications.

574 Maziero, S., Tallet, J., Bellocchi, S., Jover, M., Chaix, Y. & Jucla, M. (under review). Influence  
575 of Comorbidity on Working Memory Profile in Dyslexia and Developmental Coordination  
576 Disorder. *Journal of Clinical and Experimental Neuropsychology*.

577 McConkie, G.W., Zola, D., Grimes, J., Kerr, P.W., Bryant, N.R., & Wolff, P.M. (1991).  
578 Children's eye movements during reading. In J.F. Stein (Ed.), *Vision and visual dyslexia*  
579 (pp.251-262). London: Macmillan Press.

580 Medland, C., Walter, H., & Woodhouse, M. J. (2010). Eye movements and poor reading: does the  
581 Developmental Eye Movement test measure cause or effect? *Ophthalmic and Physiological*  
582 *Optics*, 30, 740–747.

583 Moiroud, L., Gerard, C.L., Peyre, H., & Bucci, M.P. (2018). Developmental Eye Movement test  
584 and dyslexic children: A pilot study with eye movement recordings. *PLoS ONE*, 3(9),  
585 e0200907.

586 Nazir, T. A., O'Regan, J. K., & Jacobs, A. M. (1991). On words and their letters. *Bulletin of the*  
587 *Psychonomic Society*, 29, 171–174.

588 O'Hare, A., & Khalid, S. (2002). The association of abnormal cerebellar function in children with  
589 developmental coordination disorder and reading difficulties. *Dyslexia*, 8(4), 234-248.

590 O'Regan, J. K., & Jacobs, A. M. (1992). Optimal viewing position effect in word recognition: A  
591 challenge to current theory. *Journal of Experimental Psychology. Human Perception and*  
592 *Performance*, 18, 185–197.

593 Pitcher, T. M., Piek, J. P., & Barrett, N. C. (2002). Timing and force control in boys with  
594 attention deficit hyperactivity disorder: Subtype differences and the effect of comorbid  
595 developmental coordination disorder. *Human Movement Science*, 21(5–6), 919–945.

596 Rayner, K. (1979). Eye guidance in reading: Fixation location within words. *Perception*, 8, 21-  
597 30.

598 Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers.  
599 *Journal of Experimental Child Psychology*, 41, 211-236.

600 Robert, M.P., Ingster-Moati, I., Albuissou, E., Cabrol, D., Golse, B., & Vaivre-Douret, L. (2014).  
601 Vertical and horizontal smooth pursuit eye movements in children with developmental  
602 coordination disorder. *Developmental Medicine & Child Neurology*, 56, 595–600.

603 Rogé, B. (1984). *Manuel de l'échelle de développement moteur de Lincoln-Oseretsky*. Paris:  
604 ECPA.

605 Seassau, M., Gerard, C.L., Bui-Quoc, E., & Bucci, M.P. (2014). Binocular saccade coordination  
606 in reading and visual search: A developmental study in typical reader and dyslexic children.  
607 *Frontiers in Integrative Neuroscience*, 8:85.

608 Smits-Engelsman, B. C., Jover, M., Green, D., Ferguson, G., & Wilson, P. (2017). DCD and  
609 comorbidity in neurodevelopmental disorder: How to deal with complexity? *Human*  
610 *Movement Science*, 53 1-4.

611 Snowling, M. J. (2006). Language skills and learning to read: The dyslexia spectrum. In M. J.  
612 Snowling e J. Stackhouse (a cura di), *Dyslexia- Speech and Language* (pp 1-14). Chichester  
613 (West Sussex): Whurr Publishers.

614 Snowling, M.J. (2000). *Dyslexia*. Oxford: Blackwell.

615 Sumner, E., Hutton, S.B., Kuhn, G., & Hill, E.L. (2016). Oculomotor atypicalities in  
616 developmental coordination disorder. *Developmental Science*, 21(1),1-12.

617 Tassinari, J.T., & DeLand, P. (2005). Developmental Eye Movement Test: Reliability and  
618 symptomatology. *Optometry*, 76, 387-99.

619 Tsai, C.L. (2009). The effectiveness of exercise intervention on inhibitory control in children  
620 with developmental coordination disorder: Using a visuospatial attention paradigm as a  
621 model. *Research in Developmental Disabilities*, 30(6), 1268-80.

622 Vellutino, F.R., & Fletcher, J.M. (2005). Developmental Dyslexia. In M. J. Snowling & C.  
623 Hulme (Eds.), *The Science of Reading. A Handbook*. Oxford: Blackwell Publishing.

624 Vellutino, F.R., Fletcher, J.M., Snowling, M.J., & Scanlon, D.M. (2004). Specific reading  
625 disability (dyslexia): What have we learned in the past four decades? *Journal of Child*  
626 *Psychology and Psychiatry*, 45 (1), 2-40.

627 Vitu, F., O'Regan, J. K., & Mittau, M. (1990). Optimal landing position in reading isolated words  
628 and continuous text. *Perception & Psychophysics*, 47, 583–600.

629 Warlop, G., Vansteenkiste, P., Lenoir, M., Van Causenbroeck, J., & Deconinck, F. (2020). Gaze  
630 behaviour during walking in young adults with developmental coordination disorder. *Human*  
631 *Movement Science*, 71, 102616.

632 Webber, A., Wood, J., Gole, G., & Brown, B. (2011). DEM test, visagraph eye movement  
633 recordings, and reading ability in children. *Optometry and Vision Science*, 88(2), 295-302.

634 Wechsler, D. (2005). WISC-IV. Echelle d'intelligence de Wechsler pour enfants (4e ed.).  
635 Paris:ECPA.

636 Wilmut, K., & Wann, J. (2008). The use of predictive information is impaired in the actions of  
637 children and young adults with developmental coordination disorder. *Experimental brain*  
638 *research* 191 (4), 403-418.

639 Wilmut, K., Wann, J. P., & Brown, J. H. (2006). Problems in the coupling of eye and hand in the  
640 sequential movements of children with Developmental Coordination Disorder. *Child Care*  
641 *Health and Development*, 32(6), 665-678.

642 Wilson, P.H., & McKenzie, B.E. (1998). Information processing deficits associated with  
643 developmental coordination disorder: A meta-analysis of research findings. *Journal of*  
644 *Child Psychology and Psychiatry*, 39, 829-840.

645 Wilson, P.H., Ruddock, S., Smits-Engelsman, B., Polatajk, H., & Blank, R. (2013).  
646 Understanding performance deficits in developmental coordination disorder: A meta-  
647 analysis of recent research. *Developmental Medicine and Child Neurology*, 55(3), 217-228.



648 Wood, G., Miles, C.A.L., Coyles, G., Alizadehkhayat, O., Vine, S.J., Vickers, J.N., & Wilson,  
649 M.R. (2017). A randomized controlled trial of a group-based gaze training intervention for  
650 children with Developmental Coordination Disorder. *PLoS ONE*, 12(2), e0171782.

UNCORRECTED PROOF \_pre-print version