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► 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

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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
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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, L v que, 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)¹.

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

¹ 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 -DD²). Results showed that

² *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*³ - 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

³ 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*⁴ (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.

⁴ 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]

| Group | TD | DCD | DD | DCD+DD | Group diff | Post hoc comparison |
|---|-----------|------------|------------|---------------|-----------------------|----------------------------|
| 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 χ^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 5th 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 15th percentile on the M-ABC test]. Children of the group
254 DCD+DD had a score below the 5th 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 15th 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 errors⁵; 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 ≤ -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 ≤ -1.5 SD and Ratio scores > -1.5 SD. 4) Type

⁵ 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 ≤ -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 χ^2 tests
312 and pairwise comparisons were performed with Bonferroni correction ($p = .008$). The
313 significance threshold was set at $p = .05$.

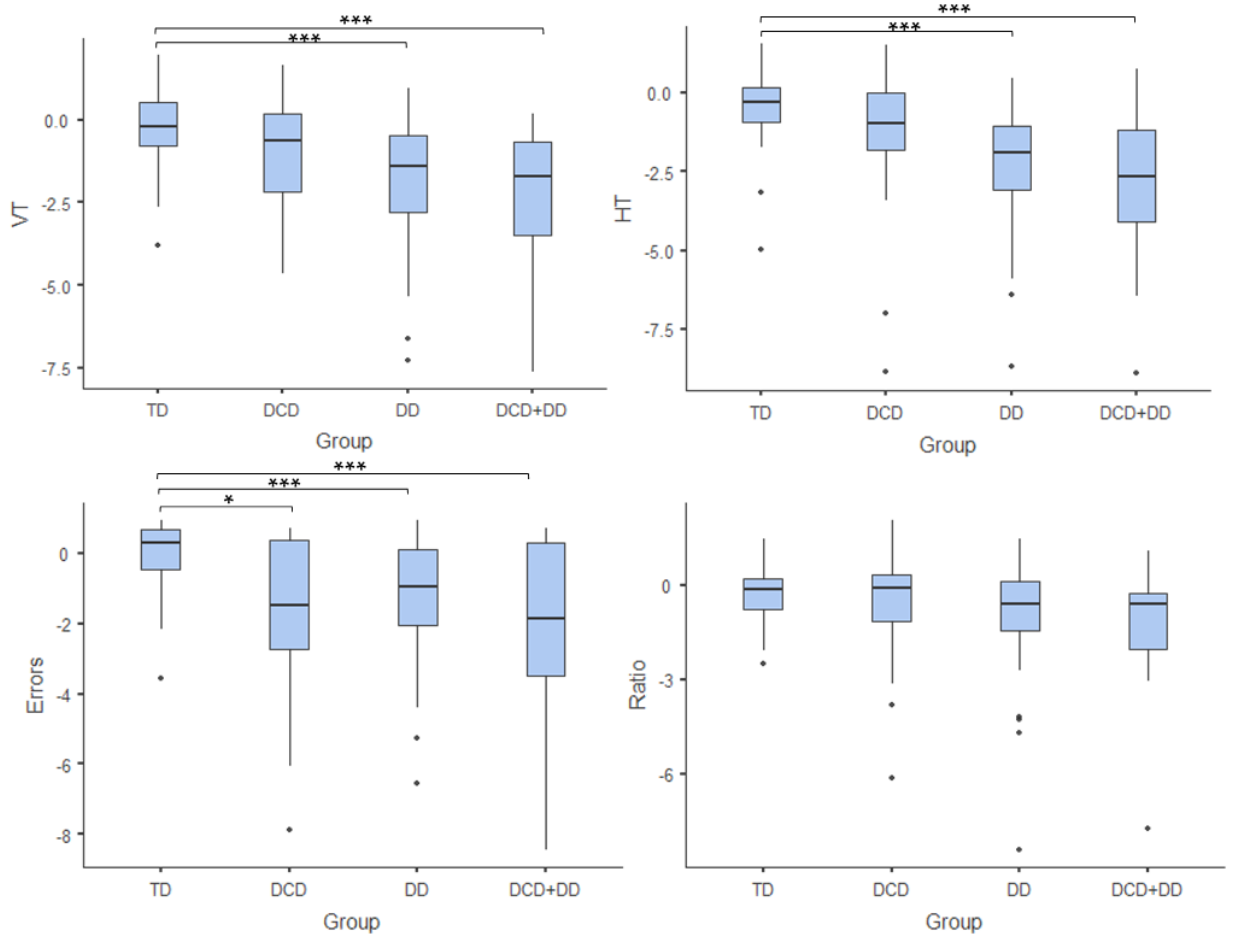
314

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]



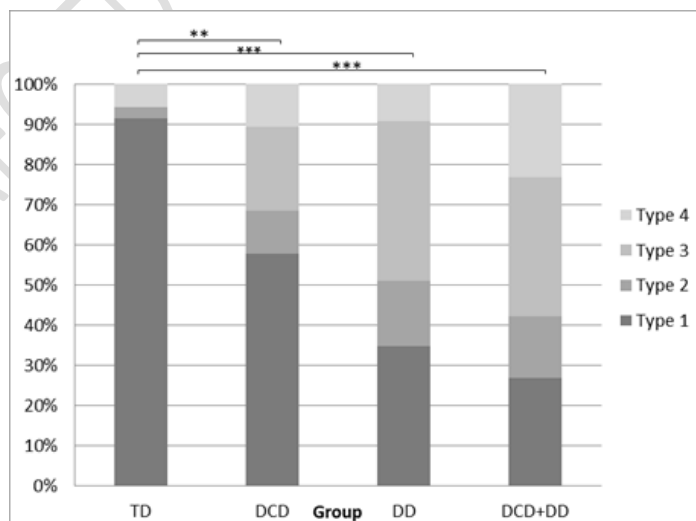
325

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)⁶. 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

⁶ 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).

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