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Analysis of Eye Movements in Children with Developmental Coordination Disorder During a Handwriting Copy Task

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Abstract. Little is known concerning eye movements during handwriting, especially for children with handwriting disabilities (dysgraphia), because of head movements which limit this kind of analysis. In this paper we present an exploratory study analyzing eye movements during a handwriting copy task using eye-tracking glasses in children with comorbid dysgraphia and Developmental Coordination Disorder (DCD), and in Control (CTL) children. We found that children with DCD spent less time looking at what they were writing than CTL children. Moreover, children with DCD made shorter fixations when writing and these fixations tend to be more numerous, suggesting distinct oculomotor strategies during handwriting copy tasks in these children.

AQ1

Keywords: Developmental Coordination Disorder • Eye-tracking • Dysgraphia

1 Introduction

Handwriting is a complex activity involving cognitive, perceptual and motor skills. Because of its prominence at school, handwriting difficulties, or dysgraphia, can lead to many hardships for children, including lower academic success and loss of self-esteem [16]. Several neurodevelopmental disorders are associated with dysgraphia, namely Developmental Coordination Disorder (DCD), dyslexia, and Attention Deficit Hyperactivity Disorder (ADHD) [16].

DCD is a developmental disorder affecting fine and gross motricity, and concerns 5–6% of school-aged children [6]. Different school activities are impacted by the disorder, such as mathematical learning [7], but handwriting is often the most visible: 50–88% of children with DCD display comorbid dysgraphia [3]. A lot of work has focused on the qualitative and kinematics aspects of handwriting in DCD children, unraveling their underlying motor impairments [3]. Visual motor

skills and visuomotor integration are other essential aspects of handwriting playing a key role in the automation of fine movements [4]. Whereas abnormal eye movements have been reported in DCD children in different tasks such as a high number of fixation before a lifting task [2], unstable fixations [9], less accurate and slower to counting tasks [7] or slower eye-hand coordination when reaching a target [11], little is known concerning the visual strategy implemented by these children during handwriting. This lack of studies is due to the difficulty of studying eye movements during a writing task because of head movements, of posture variations and of the need for visual correction. Several solutions to overcome this problem have been tested [1,5,8]. Among them, eye-tracking glasses were chosen, because they allow to follow eye movements during natural head and torso movements in a copy task with a distant model, and can include corrective lenses without issue for the tracking of gaze [5].

In this pilot study, we set up an experiment aiming at comparing eye movements during a handwriting copy task using eye-tracking glasses in children with DCD and dysgraphia, and in typically developing children (CTL). We had two hypotheses concerning children from the DCD group: (i) a greater number of looks at the model, and (ii) a longer time spent reading the text model, due to the greater need for rereading. More specifically, we analyzed normalized metrics to allow comparison between groups, and we expect a greater number of glances per second, and a higher percentage of time spent looking at the model. These hypotheses rely on the fact that handwriting is not automated in children with dysgraphia in the context of DCD, often leading to dual-task situations. Since handwriting takes more time in DCD children, we hypothesized that the amount of text kept in the working memory will be lower for these children, leading to a quicker forgetting of the text to copy and thus a need for rereading.

2 Materials and Methods

2.1 Participants

Twenty children were included in the study, divided into two groups: the 'DCD' group of 9 children with DCD and dysgraphia, and the 'CTL' group of 11 children without motor or handwriting difficulties. All children were right-handed, and French native speakers. There was no age difference between the groups ($p = .676$; Table 1). As reported in the literature [6], boys were overrepresented in the DCD group compared to the control group ($p = .017$; Table 1). All parents reported that their child had normal hearing, and normal or corrected-to-normal vision. Demographic and clinical profiles of each group are presented in Table 1.

Children from the DCD group underwent complete medical and psychological screening, and all had normal intellectual functioning level (French-language version of the WISC-V [10]) and normal reading skills (Alouette test [17]). Three of them displayed comorbid ADHD, and 2 of them had a suspicion for ADHD (DSM-5 checklist [14]). Motor skills were evaluated using the MABC 1 or 2 (Movement Assessment Battery for Children 1st or 2nd Ed. [18]). Children with DCD scored below the 10th percentile at the MABC1 or 2. Dysgraphia

was diagnosed using the French version of the BHK scale (Brave Handwriting Kinder [15]). Children with DCD all scored below -1.5 SD in at least one of the two scores (i.e. handwriting quality or speed), while both scores were in the norms for the children from the CTL group (Table 1).

Table 1. Demographical and clinical profiles of each group of participants, and comparison of the different means between the two groups. Kruskal-Wallis ANOVAs were used to compare BHK scores and age, and a χ^2 test was applied for the comparison of boys/females ratios between the two groups. Age is shown in years.

Group	N (female)	Mean Age (SD)	MABC Percentile Mean (SD)	Mean BHK Speed Score (SD)	Mean BHK Quality Score (SD)
CTL	11 (7)	10.62 (1.9)	NA	-0.09 (1.17)	1.61 (0.81)
DCD	9 (1)	10.22 (1.39)	4.21 (3.17)	-0.87 (0.93)	-2.2 (1.84)
p-value	0.017*	0.676	NA	0.119	< .001***

Children from the DCD group were recruited via therapists or by mean of public announcement. Children of the CTL group were recruited by mean of public announcements in schools of the Grenoble suburbs. The parents gave written informed consent to participate in the study, and the children gave oral consent just before the beginning of the experiment. This project has been approved by the University Grenoble Alpes Ethics Committee Review Board (CER Grenoble Alpes-Avis-2020-02-18-2).

2.2 The Experiment

Eye-Tracking Apparatus. Each subject was equipped with eye-tracking Tobii Pro Glasses 3, tracking gaze by pupil tracking with two cameras per eye, and a sampling rate of 100 Hz. The children who needed visual correction had additional corrective lenses directly on the Tobii glasses. The recordings were analyzed using the Tobii Pro Lab software to compute the different metrics. As the lighting levels could not be properly controlled during the experiment, no accurate pupil size analysis could be performed.

Task. Children were asked to perform the BHK, a task during which they have to copy a short text during 5 min on a blank paper [15]. The text model was printed on a third of an A4 sheet, and placed close to the child, vertically, so that they can read it easily by raising their head. The instructions given to the children were those of the BHK manual [15]. An example of a text written by a child from each group is shown in Fig. 2.

Procedure. The experiment started with an exploration phase (EXP) during which the text was revealed, and the instructions were given orally to the participant. The duration of this phase was not fixed, because the time necessary to fully understand the instructions may vary between participants. Then came the

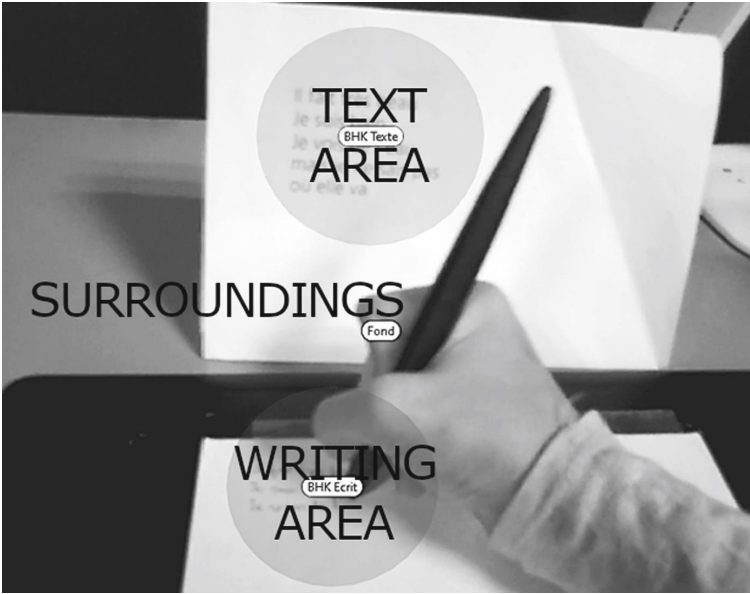


Fig. 1. The three areas of interest of the eye-tracking analysis.

BHK copy phase (BHK) during which the child began to copy the text, after a signal from the examiner. Once the copy was finished, the recordings were stopped and the child was de-equipped.

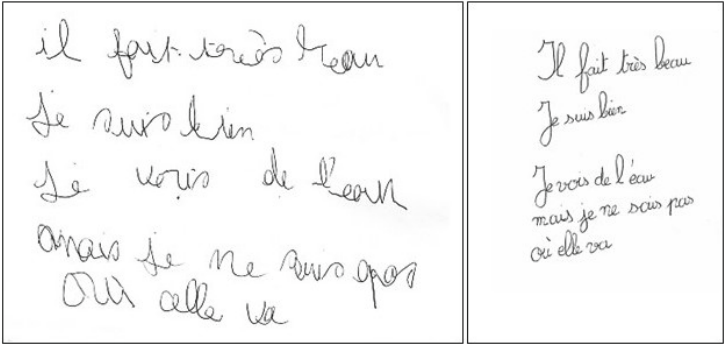


Fig. 2. Examples of the 5 first lines of a BHK written by two 3rd-grade children : one from the DCD group (left) and one from the CTL group (right).

Metrics Analyzed. Eye movements were analyzed using Tobii Pro Lab. For the BHK phase, we analyzed eye movements only during the copy of the 5 first lines of the BHK, to work on comparable materials between children. Three areas

of interest were defined: the Writing Area (WA), the Text Area (TA) and the Surroundings Area (SA) (Fig. 1). The WA is a circle centered on the pen tip, the TA is a circle including the whole text copied (i.e. the 5 lines of the BHK), and the SA consists in the rest of the window. Different eye-tracking metrics were computed in each area. They focused on the analysis of fixations and of glances, which are the time intervals during which the gaze is in the same area. A glance starts when the gaze enters an area and ends when it leaves the area. Because of the definition of the SA, it means that the gaze is always in an area, so each glance is directly followed by a new one.

The absolute number of fixations can be misleading, because any difference between the groups may only be due to a different time spent to copy the 5 first lines, in particular in children with dysgraphia. To overcome this problem, we computed the percentage of total fixation for each area (normalization by the total number of fixations). The same reasoning was applied to the number of fixations per second in the area and the percentage of time doing fixations (both normalized by the total time spent in the area), the number of glances per second and the percentage of total time spent (both normalized by the total time of the phase - EXP or BHK). For each area, we thus ended up with 8 metrics: the percentage of total time in the area, the number of fixations per second in the area, the average duration of a fixation, the percentage of total fixations made in the area, the percentage of time in area doing fixations, the number of glances per second, the total duration of glances, and the average duration of a glance.

Statistical Analysis. Because of the reduced number of children in each group, comparisons between groups for the different metrics were performed with a Kruskal-Wallis test. Effect sizes were expressed using partial η^2 .

3 Results

3.1 Eye Movements During the Exploration Phase.

Results of eye movements' analysis during the EXP phase are shown in Table 2. The percentage of total time spent in each area attests that the main focus of attention during this phase was first on the text (44% of their time for the DCD group, 49.7% for CTL), then on the surroundings (where the examiner was), and last on the writing area. Although the difference is not significant ($p = .076$), the average duration of a fixation in the text area is smaller in the DCD group. The % of time doing fixation in the Writing Area is significantly lower for the DCD group ($p < 0.05$). There is no difference in the time spent reading the text or paying attention to the surroundings for this phase.

3.2 Eye Movements During the BHK Copying Phase

The results of eye movements' analysis of the BHK copying phase are shown in Table 3. Both groups spent the most time looking at the WA (68% for DCD,

Table 2. The eye-tracking metrics for each area are presented in the form of Mean (SD). The p-values and η^2 are the result of a Kruskal-Wallis test. The average duration of a fixation and the average duration of a glance were not computed for the Surroundings Area. + = $p < .1$; * = $p < .05$.

Area of interest	Surroundings			Text Area			Writing Area		
	DCD	CTL	p-value (η^2)	DCD	CTL	p-value (η^2)	DCD	CTL	p-value (η^2)
% of total time	41.3 (14.1)	38.1 (15.2)	0.741 (0.01)	44.0 (14.1)	49.7 (17.4)	0.409 (0.036)	13.8 (12.6)	10.1 (5.6)	0.869 (0.001)
Number of Fixations per s	2.14 (0.69)	1.96 (0.49)	0.563 (0.02)	3.62 (0.64)	3.31 (0.79)	0.215 (0.081)	4.51 (1.96)	3.94 (1.30)	0.934 (0.0)
Average duration of a fixation (ms)	NA	NA	NA	174.88 (60.34)	223.91 (64.16)	0.076+ (0.166)	154.63 (77.19)	220.82 (101.43)	0.215 (0.081)
% of total Fixations	30.6 (13.3)	28.5 (13.7)	0.869 (0.001)	53.9 (11.5)	58.1 (16.6)	0.869 (0.001)	15.5 (11.7)	13.4 (6.7)	0.934 (0.0)
% of time on Fixations	31.8 (12.7)	40.1 (14.9)	0.186 (0.092)	60.9 (14.8)	71.5 (14.4)	0.160 (0.104)	59.0 (16.5)	75.7 (16.8)	0.039* (0.224)
Number of Glances per s	0.041 (0.011)	0.044 (0.015)	0.509 (0.023)	0.255 (0.098)	0.272 (0.101)	0.62 (0.013)	0.163 (0.125)	0.164 (0.092)	0.68 (0.009)
Total duration of Glances (s)	10.71 (3.29)	10.33 (5.03)	0.741 (0.006)	11.95 (5.88)	13.97 (6.86)	0.62 (0.013)	3.47 (3.46)	2.43 (1.32)	1.0 (0.0)
Average duration of a Glance (s)	NA	NA	NA	2.067 (1.099)	1.936 (0.713)	0.869 (0.001)	0.787 (0.478)	0.665 (0.269)	0.934 (0.0)

77.2% for CTL), but the difference between groups is not significant ($p = .16$). The DCD group tended to do more fixations (2.96 fixations per second in the area for the DCD group vs. 2.37 for the CTL group; $p = 0.099$), but shorter (206 ms mean duration of a fixation for the DCD group vs. 349 ms for the CTL group; $p = 0.023$), in this area. Moreover, they spent less overall time doing fixation during writing (59.3% of the time spent looking at the WA is spent doing fixations for the DCD group vs. 75.3% for the CTL group; $p = 0.01$). There is no significant difference between groups for the number of fixations per second, the average duration of fixations, and the percentage of the time spent on fixations in the TA. The number of glances in the TA, normalized by the total time of the task, is also not significantly different between groups. These results are in disagreement with our hypotheses.

4 Discussion

In this pilot study, eye movements during a copying handwriting task were explored in a group of children with DCD in comparison to a group of typically developing children. The Exploration phase was first analyzed, to ensure that the focus of the children on the examiner (present in the Surroundings) and the text did not differ between groups. The time taken looking at the text model was similar in the two groups, and there are no other attention point in the TA than the text itself, suggesting that both groups had a comparable reading time of the text beforehand. This finding is in disagreement with our initial hypotheses: children with DCD did not need to read the text for longer than CTL children

During the BHK copying phase, although spending a comparable time in the writing area, children with DCD tend to make more fixations in this area than the CTL group, but these fixations are shorter. Thus, the total fixation time during writing is shorter for children with DCD than for CTL. Their patterns of eye movements seem to differ from that of typical children: they do more fixations in the writing area but each fixation is shorter.

The number and duration of fixations is related to the focus in costly cognitive tasks. Our results in children with DCD may be due to the fact that they

Table 3. The eye-tracking metrics for each area are presented in the form of Mean (SD). The p-values and η^2 are the result of a Kruskal-Wallis test. The average duration of a fixation and the average duration of a glance were not computed for the Surroundings Area. + = $p < .1$; * = $p < .05$.

Area of interest	Surroundings			Text Area			Writing Area		
	DCD	CTL	p-value (η^2)	DCD	CTL	p-value (η^2)	DCD	CTL	p-value (η^2)
% of total time	15.7 (9.9)	10.0 (4.5)	0.117 (0.13)	16.0 (12.3)	12.6 (8.0)	0.62 (0.013)	68.0 (14.5)	77.2 (7.5)	0.16 (0.104)
Number of Fixations per s	0.27 (0.36)	0.15 (0.20)	0.611 (0.014)	4.47 (0.83)	4.82 (1.25)	0.684 (0.009)	2.96 (0.63)	2.37 (0.61)	0.099+ (0.144)
Average duration of a fixation (ms)	NA	NA	NA	167.86 (47.80)	148.91 (44.28)	0.441 (0.033)	206.13 (68.36)	349.27 (132.81)	0.023* (0.272)
% of total Fixations	2.3 (3.3)	0.6 (0.7)	0.309 (0.054)	23.0 (14.3)	23.4 (13.7)	1.0 (0.0)	74.7 (13.0)	76.0 (13.6)	0.869 (0.001)
% of time on Fixations	10.3 (18.6)	4.9 (4.7)	0.934 (0.0)	71.3 (6.8)	68.5 (13.8)	0.821 (0.003)	59.3 (15.8)	75.3 (14.2)	0.01* (0.345)
Number of Glances per s	0.011 (0.003)	0.013 (0.004)	0.322 (0.052)	0.186 (0.091)	0.194 (0.088)	0.934 (0.0)	0.216 (0.075)	0.206 (0.078)	0.68 (0.009)
Total duration of Glances (s)	16.00 (10.68)	8.37 (4.20)	0.16 (0.104)	17.79 (14.61)	11.84 (8.85)	0.509 (0.023)	64.69 (13.87)	65.86 (17.38)	0.934 (0.0)
Average duration of a Glance (s)	NA	NA	NA	0.804 (0.448)	0.610 (0.291)	0.39 (0.041)	4.095 (3.051)	4.626 (2.555)	0.364 (0.043)

look more back-and-forth in order to check for potential mistakes in their writing. Alternatively, it may reflect a lower stability of the gaze, perhaps related to deficits in oculomotor control. Indeed, we did not discriminate the different sub-types of DCD among our participants, and some may have visuo-spatial deficits. These results are in line with previous findings showing that children with DCD had deficits in maintaining engagement and attention on a visual target [9].

During the copying phase, children from the DCD group did not spend more time looking at the model. This observation is again in disagreement with our hypotheses. However, although the difference between groups is not significant, children with DCD seem to look away from the writing area more often. This may be due to the presence of different strategies among the DCD group for the copy task. It may be difficult for some of them to maintain their gaze in the focus area, either because of a lower stability of the gaze or of a difficulty in maintaining their attention on the task [9]. This latter hypothesis is further supported by the fact that at least one third of our DCD children displayed or were suspected of comorbid ADHD. Indeed, ADHD affects eye movements [12]. In addition, the overrepresentation of boys in the DCD group may also affect our results, although recent findings contradict this assumption and support the Gender Similarities Hypothesis regarding cognitive functions [13]. However, for others it seems that they memorized the entire text during the EXP phase, and did not once look back at the model during the BHK phase. The diversity of strategies used by children with DCD could explain the difficulty to see a precise tendency in their pattern of visual exploration.

Although our study is exploratory, our results are in line with previous findings showing that children with DCD have abnormal eye-movements [2,7,9,11], and add new insights into eye movements and visual strategies used by children with DCD during handwriting copy tasks, a field that has never been investigated before. Further analyses of the position of fixations on the writing and text model areas would help to better understand the visual strategies used by DCD children during a copy task. Also, gathering more data, and separating children with DCD between groups based on their visual strategy could help to better understand the needs and particularity of each strategy. It would also be very informative to concomitantly analyze eye movements and handwriting

kinematics to investigate the visuomotor relationship between the visual strategy used and the motor impairments in handwriting in these children. All these informations would lead to a better understanding of handwriting deficits in DCD children, and could eventually lead to new tools for the diagnosis and/or remediation of these deficits.

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Chapter 3

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