



# Self-reported visual symptoms in children with developmental dyslexia

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## ABSTRACT

Although there are many anecdotal reports of children with developmental dyslexia complaining of vision symptoms when reading, empirical studies are lacking. The primary aim of the present study was to document self-reported vision-related symptoms in children with developmental dyslexia and typically reading peers. We also explored whether vision symptoms were correlated with sensorimotor measures of vergence, accommodation and ocular motor tracking skills. Using a prospective group comparison observational design, we assessed 28 children with developmental dyslexia (DD) and 33 typically reading children (TR) 7–11 years of age. Participants completed psychoeducational testing, a comprehensive sensorimotor eye examination, and the Convergence Insufficiency Symptom Survey (CISS), which includes 9 items pertaining to vision-related symptoms (CISS-V) and 6 that could have cognitive influence (CISS-C). CISS-V were significantly greater in DD than TR children. Ocular motor tracking, assessed by an infra-red limbal eye tracker while reading text, was most clearly associated with the visual symptoms, but only within the DD group. Vision-related symptom surveys followed by a comprehensive eye examination with detailed evaluation of sensorimotor functioning for those who report a high prevalence of symptoms may be clinically relevant for children with DD.

## 1. Introduction

There are many anecdotal reports of individuals with developmental dyslexia (DD) describing vision symptoms when reading. These symptoms can include words moving around on the page, intermittent blurry vision with print reading, double vision, eye strain, headaches and eye fatigue (Cornelissen, Bradley, Fowler, & Stein, 1991; Evans et al., 1999; Singleton & Henderson, 2007). To date, however, there are no empirical studies that document whether these symptoms are indeed more frequent in children with DD.

The Convergence Insufficiency Symptom Survey (CISS) is a validated questionnaire used to identify patients with convergence insufficiency – a vergence disorder (Borsting et al., 2003; Rouse et al., 2009). It has been successfully used as an outcome measure to monitor improvement in symptoms pre and post vision therapy (eye exercises) to treat convergence insufficiency. The study further explored the extent to which these self-reported symptoms might be correlated with findings from the sensorimotor exam. We previously reported that children with DD have an increased prevalence of visual deficits

relative to typically reading (TR) peers (Raghuram et al., 2018). The primary aim of the present study was to assess the nature and frequency of self-reported vision-related symptoms in children with DD and TR peers using a subset of items from the CISS that reflect visual and not cognitive processes (CISS-V). We also explored whether vision symptoms were correlated with sensorimotor measures of vergence, accommodation and ocular motor tracking skills.

## 2. Methods

Study design: Prospective group comparison observational study.

### 2.1. Participants

Participants were children aged 7–11 years diagnosed with DD by a clinic at Boston Children's Hospital and TR from the population of children receiving standard eye examinations at the same hospital, as well as by flyers and word of mouth. All children in both groups had best corrected visual acuity better than or equal to 20/25 and resided

*Abbreviations:* DD, developmental dyslexia; TR, typically reading children; CISS, Convergence Insufficiency Symptom Survey; CISS-V, vision-related symptoms; CISS-C, cognitive related symptoms; WRMT, Woodcock Reading Mastery Test; WI, Word Identification; WA, Word Attack; DEM, Developmental Eye Movement test

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within 75 miles of the research site. Exclusion criteria included: ADHD documented by questionnaires; IQ < 70; diagnosis of a comorbid neurodevelopmental disorder (e.g., autism spectrum disorder, brain injury or malformation, or neurogenetic disorder) or medical illness; history of eye surgery; structural anomalies of the anterior or posterior segment of the eye or medical condition that could affect the ability to participate in the study; other ocular pathology. The study enrolled 28 children in the DD group and 33 in the TR group.

## 2.2. Procedure

Participants were invited to the laboratory for a visit of approximately two hours, during which they completed psychoeducational testing, a comprehensive eye examination that included a detailed sensorimotor examination, and the CISS.

Informed written assent and consent was obtained from each participant and parent respectively. The Boston Children's Hospital Institutional Review Board approved the research protocol. The entire study was conducted according to the principles of the Declaration of Helsinki.

## 2.3. Measures

### 2.3.1. Psychoeducational testing

Psychoeducational testing was carried out to characterize the cognitive and reading profiles of the two groups. It included documentation of IQ (two-subtest version of the Wechsler Abbreviated Scale of Intelligence-II) and of single word reading and spelling (Woodcock Reading Mastery Test (WRMT), Word Identification (WI) and Word Attack (WA) subtests, Test of Written Spelling).

### 2.3.2. Vision testing

Vision testing was conducted to assess the visual functioning of the two groups, with the goal of exploring potential associations between documented visual functioning and self-reported visual symptoms. It included a standard eye examination with cycloplegic refraction. The sensorimotor exam included the following: vergence – near point of convergence; negative and positive fusional vergence ranges at near with prism bars; near vergence facility ( $12^{\Delta}$  Base out/ $3^{\Delta}$  Base in); accommodation – monocular amplitude of accommodation (average of push up – push away); monocular accommodative facility ( $\pm 2.00$  D); and dynamic retinoscopy for accommodation accuracy; (Scheiman & Wick, 2008) visual tracking (detailed below, using both the Developmental Eye Movement test and a Visagraph-tracked reading test) (Colby, Laukkanen, & Yolton, 1998; Palomo-Alvarez & Puell, 2009; Webber, Wood, Gole, & Brown, 2011).

Developmental Eye Movement test (DEM): The DEM is a visual – verbal clinical ocular motor assessment tool. Participants were shown displays of numbers arranged vertically and horizontally and asked to call them out. The test contains three test plates. Test A and Test B contain vertically arranged numbers in two columns. Test C contains horizontally arranged numbers. The time to complete each test plate and the errors were recorded. Test A and B provide an estimate of visual processing speed and the ratio between horizontal to vertical measures tracking. All raw scores were converted to standard scores for analysis.

Eye Movements During Reading – Visagraph: Eye movements (horizontal position of both eyes) while reading standardized text paragraphs (grade 1–5 equivalent) were recorded with a Visagraph eye tracker (Taylor Associates, Huntington, NY), an infrared, limbal-reflection eye movement recording system. The text was chosen based on the child's reading grade level, as estimated by their performance on the WRMT Word Identification task. Children wore goggles containing infra-red sensors and emitters and read the text binocularly at their habitual reading distance in a primary position. The child's reading grade level was estimated by their performance on the WRMT WI subtest, and texts were presented at that level. To assure a stable

baseline, the child first read two practice paragraphs at their reading level after which they read a new paragraph and answered 10 yes/no comprehension questions. Children were instructed to read the paragraphs normally and to pay attention to text details, as they would be tested for comprehension at the end of reading, but they were instructed not to reread. The software automatically calculated values for each parameter, including the following: reading rate in words per minute (wpm), number of progressive saccades as fixations/100 words, number of regressive saccades as regressions/100 words, and comprehension as a percentage of correct answers.

These sensorimotor assessments were performed with appropriate refractive correction in place and in free space.

### 2.3.3. Convergence Insufficiency Symptom Survey (CISS)

The CISS was administered to all children before the start of the comprehensive eye exam. Its 15 items use a Likert-type scale (0–4) for responses, yielding a total score that can range from 0 to 60. Nine of the items directly address vision symptoms (e.g., letters blur) (maximum score,  $9 \times 4 = 36$ ); another six items could reflect visual function, but are equally likely to reflect the cognitive process of reading (e.g., need to re-read lines) (maximum score,  $6 \times 4 = 24$ ) (Barnhardt et al., 2012).

Table 1 shows the items, with the nine vision-related items (CISS-V) grouped at the top and the remaining six items, which could arguably reflect visual or cognitive factors (CISS-C), at the bottom. Children were instructed to respond to the questions regarding symptoms possibly experienced while doing school-related near work on paper, books or e-devices. In order to accommodate the dyslexic readers, the examiner (first author) read the questionnaire aloud to all children.

## 2.4. Statistical methods

All analyses were performed using IBM SPSS Statistics version 23.0 (IBM Corporation, Armonk, NY). Independent sample student *t*-tests were used to compare group differences for continuous variables with demographic information. Mann-Whitney U tests were used to assess group differences in the distribution of individual CISS items and Fisher's exact tests to assess group differences in the number of individuals reporting symptoms for each item. Pearson correlations were used to assess associations between CISS and findings from the sensorimotor exam. Analysis of covariance was used to investigate differences in CISS-V and CISS-C scores across groups and gender with age as covariate. A two-sided critical value of  $p < 0.05$  was used as criterion for statistical significance.

## 3. Results

Table 2 shows the demographic characteristics of the two groups, mean scores on the literacy and IQ measures, and mean scores on the CISS-V and CISS-C. The TR group was somewhat younger and had a higher proportion of girls and Asian children. Scores of the two groups on the reading measures differed significantly ( $t = 8.62$  (WI);  $t = 8.57$  (WA);  $t = 8.38$  (Spelling), all  $P < 0.001$ ), differences that remained highly significant after adjusting for IQ ( $F = 43.06$  (WI),  $F = 43.41$  (WA),  $F = 40.09$  (Spelling), all  $P < 0.001$ ).

The mean CISS-V and CISS-C scores were both significantly higher in the DD group, after adjusting for the effects of age (covariate) and gender (main effect) (CISS-V,  $F(1,56) = 39.37$ ;  $p < 0.001$ ; CISS-C,  $F(1,56) = 101.57$ ;  $p < 0.001$ ). For both outcomes, moreover, there were significant interaction effects, with DD females reporting more symptoms than DD males (CISS-V,  $F(1,56) = 9.49$ ,  $p = 0.003$ ; CISS-C,  $F(1,56) = 10.28$ ,  $p = 0.002$ ).

Since the focus of this study was the CISS-V items, not the CISS-C items, subsequent analyses pertain only to those items. Table 3 shows the number of children in each group who reported symptom at least "sometimes" for each of the nine CISS-V items, as well as statistical tests of group difference for each item. Children in the DD group reported six

**Table 1**  
Distribution of responses to the CISS questions for Typical Readers (TR) and Developmental Dyslexic (DD).

CISS Survey	Never (0), %		Infrequent (1), %		Sometimes (2), %		Often (3), %		Always (4), %		Mean Likert Rating	
	TR	DD	TR	DD	TR	DD	TR	DD	TR	DD	TR	DD
	<b>CISS-V</b>											
Tired eyes	72.7	53.6	21.2	3.6	6.1	35.7	0.0	7.1	0.0	0.0	<b>0.33</b>	<b>0.96</b>
Uncomfortable eyes	97.0	71.4	3.0	3.6	0.0	25.0	0.0	0.0	0.0	0.0	<b>0.30</b>	<b>0.54</b>
Headaches	93.9	71.4	3.0	3.6	0.0	25.0	0.0	0.0	0.0	0.0	<b>0.06</b>	<b>0.54</b>
Double vision	75.8	64.3	3.0	3.6	0.0	28.6	0.0	3.6	0.0	0.0	<b>0.03</b>	<b>0.71</b>
Words move, float or jump	93.9	75.0	3.0	3.6	0.0	17.9	0.0	3.6	0.0	0.0	<b>0.03</b>	<b>0.50</b>
Eyes hurt	84.8	89.3	15.2	3.6	0.0	3.6	0.0	0.0	0.0	3.6	<b>0.15</b>	<b>0.25</b>
Eyes sore	90.9	85.7	9.1	3.6	0.0	10.7	0.0	0.0	0.0	0.0	<b>0.09</b>	<b>0.25</b>
Pulling feeling around eyes	97.0	89.3	3.0	3.6	0.0	7.1	0.0	0.0	0.0	0.0	<b>0.03</b>	<b>0.18</b>
Words blurring in and out	87.9	50.0	3.0	10.7	9.1	32.1	0.0	7.1	0.0	0.0	<b>0.21</b>	<b>0.96</b>
<b>CISS-C</b>												
Feel sleepy	75.8	50.0	18.2	7.1	6.1	35.7	0.0	7.1	0.0	0.0	<b>0.30</b>	<b>1.00</b>
Lose concentration	72.7	32.1	15.2	3.6	12.1	39.3	0.0	17.9	0.0	7.1	<b>0.39</b>	<b>1.64</b>
Trouble remembering	75.8	50.0	21.2	3.6	3.0	35.7	0.0	7.1	0.0	3.6	<b>0.27</b>	<b>1.11</b>
Reading slowly	84.8	7.1	9.1	0.0	3.0	35.7	3.0	39.3	0.0	17.9	<b>0.24</b>	<b>2.61</b>
Lose place	69.7	10.7	12.1	3.6	18.2	46.4	0.0	17.9	0.0	21.4	<b>0.48</b>	<b>2.36</b>
Re-read	60.6	21.4	27.3	7.1	12.1	35.7	0.0	17.9	0.0	17.9	<b>0.52</b>	<b>2.04</b>

**Table 2**  
Demographic characteristics, performance on psychoeducational measures and CISS-V and CISS-C scores of Developmental Dyslexia and Typically Reading groups.

	Developmental Dyslexia	Typical Reader
N	28	33
Age in Years, Mean (SD) <sup>*</sup>	10.28 (1.21)	9.43 (1.36)
Male, N (%) <sup>***</sup>	18 (64)	12 (33)
Race <sup>***</sup>		
Caucasian, N (%)	28 (100)	16 (48)
Asian, N (%)	0 (0)	17 (52)
<i>Psychoeducational and CISS Scores, Mean (SD), Median, Range</i>		
WRMT Word Identification <sup>a***</sup>	87.36 (15.80), 88, 55–112	122.58 (15.94), 127, 95–145
WRMT Word Attack <sup>a***</sup>	87.11 (10.00), 86, 63–112	111.33 (11.73), 110, 92–134
Test of Written Spelling <sup>a***</sup>	80.71 (13.63), 81, 45–105	110.91 (14.36), 111, 83–140
WASI-II Estimated IQ <sup>***</sup>	104.97 (12.05), 105, 83–133	117.88 (10.83), 118, 95–138
CISS-V <sup>b***</sup>	4.89 (3.97), 4, 0–16	0.97 (1.36), 0, 0–5
CISS-C <sup>b***</sup>	10.75 (4.85), 10, 3–21	2.21 (1.88), 2, 0–8

<sup>\*</sup>p < 0.05; <sup>\*\*\*</sup>p < 0.001; <sup>a</sup>Adjusted for WASI-II Estimated IQ; <sup>b</sup>Adjusted for age; WRMT = Woodcock Reading Mastery Test; WASI-II = Wechsler Abbreviated Scale of Intelligence – Second Edition.

of the nine CISS-V items more frequently. Three questions that related to ocular discomfort – “eye hurting,” “eyes feeling sore,” and “eyes pulling” – were not significantly different in the two groups. In the DD group, “tired eyes with reading,” “words blurring in and out,” and

**Table 3**  
Number of individuals endorsing symptoms (“sometimes” or more) and medians and ranges for each CISS-V item by group.

	Individuals with Symptoms N(%) <sup>a</sup>	
	Typical Readers (N = 33)	Developmental Dyslexia (N = 28)
Tired eyes <sup>**</sup>	2 (6)	12 (43)
Uncomfortable eyes <sup>**</sup>	0	7 (25)
Headaches <sup>**</sup>	0	7 (25)
Double vision <sup>***</sup>	0	9 (32)
Words move, float or jump <sup>**</sup>	0	6 (21)
Eyes hurt	0	2 (7)
Eyes sore	0	3 (11)
Eye pulling	0	2 (3)
Words blurring in and out <sup>**</sup>	3 (9)	11 (39)
	Median (Range) <sup>b</sup>	
Tired eyes <sup>*</sup>	0 (0–2)	0 (0–3)
Uncomfortable eyes <sup>*</sup>	0 (0–1)	0 (0–2)
Headaches <sup>*</sup>	0 (0–1)	0 (0–2)
Double vision <sup>***</sup>	0 (0–1)	0 (0–3)
Words move, float or jump <sup>**</sup>	0 (0–1)	0 (0–3)
Eyes hurt	0 (0–1)	0 (0–4)
Eyes sore	0 (0–1)	0 (0–2)
Eye pulling	0 (0–1)	0 (0–2)
Words blurring in and out <sup>**</sup>	0 (0–2)	0.5 (0–3)

<sup>a</sup>Fisher’s exact probability test; <sup>b</sup>Mann-Whitney U test.  
<sup>\*</sup>P < 0.05; <sup>\*\*</sup>p < 0.01; <sup>\*\*\*</sup>p < 0.001.

**Table 4**  
Pearson correlations between vision parameters and CISS-V score for groups combined and separately.

	Combined	DD (N = 28)	TR (N = 33)
<i>Vergence</i>			
Near point of convergence (break)	0.26*	0.10	-0.002
Convergence amplitude break	-0.32*	-0.28	-0.12
Convergence amplitude recovery	-0.31*	-0.24	-0.12
<i>Accommodation</i>			
Amplitude of Accommodation	-0.25*	-0.03	0.15
Monocular accommodative facility	-0.29*	-0.11	-0.10
<i>Ocular motor tracking</i>			
<i>Developmental Eye Movement test</i>			
DEM - Vertical score	-0.40**	-0.39*	-0.09
DEM - Horizontal score	-0.39**	-0.29	0.002
DEM - Errors	-0.52***	-0.39*	0.09
<i>Visagraph (IR eye tracker)</i>			
Reading rate	-0.38**	-0.25	0.073
Fixations	0.47***	0.38*	-0.21
Regressions	0.52***	0.43*	-0.38*

\* p < 0.05; \*\* p < 0.01; \*\*\* p < 0.001; DD = Developmental Dyslexia; TR = Typical Readers.

“double vision” were the top three symptoms, reported by 9 or more children. “Uncomfortable eyes,” “headaches,” and “words moving on the page” were reported by six or more children in the DD group. Vision symptoms were far less frequently reported in the TR group, with “tired eyes” reported by 2 children and words blurring in and out by 3 children.

Of the 28 in the DD group, 16 had high CISS-V scores compared to the TR group (above mean + 2 standard deviation). We compared these DD groups (low vs high CISS-V scores) on the psychoeducational test scores available in our data set as well as age and gender, but found no differences on any of these variables.

**3.1. Correlations between CISS-V and clinical findings**

We next explored whether the prevalence of visual symptoms on CISS-V was related to findings from the clinical examination (Table 4). Correlations between measures of vergence, accommodation and ocular motor tracking and the CISS-V score were in the mild to moderate range.

The most widespread and consistent associations, however, were found with measures of tracking, especially those derived from the Visagraph ocular motor tracking system. Fig. 1 displays a scatterplot of the CISS-V scores in relation to three Visagraph parameters – reading

rate, fixations and regressions – for the two groups. As Table 4 shows, within the DD group, those with more visual problems read at a slower rate and showed more fixations and regressions (all p < 0.05). Visual problems were also associated with the DEM vertical and error scores, findings that were statistically significant for the DD only (p < 0.05). The only statistically significant within-group correlation for the TR group was for Visagraph regressions but it was actually in the opposite direction, suggesting a random finding that is not meaningful. The scatterplot also reveals considerable overlap between the two groups in the CISS-V scores, but also a sizable subgroup of DD with elevated CISS-V scores, well exceeding the range for the TR group.

We also explored potential correlations of the CISS-V with the single-word literacy measures. There were moderate correlations between all three literacy measures and the CISS-V (r = -0.52, -0.49 and -0.49 respectively for Word Identification, Word Attack and Spelling, all p < 0.001) (Fig. 2). However, the within group correlations were not statistically significant for any parameter in either group, suggesting that the overall correlations are accounted for by group membership more than by a meaningful association between CISS-V and single word decoding or recognition.

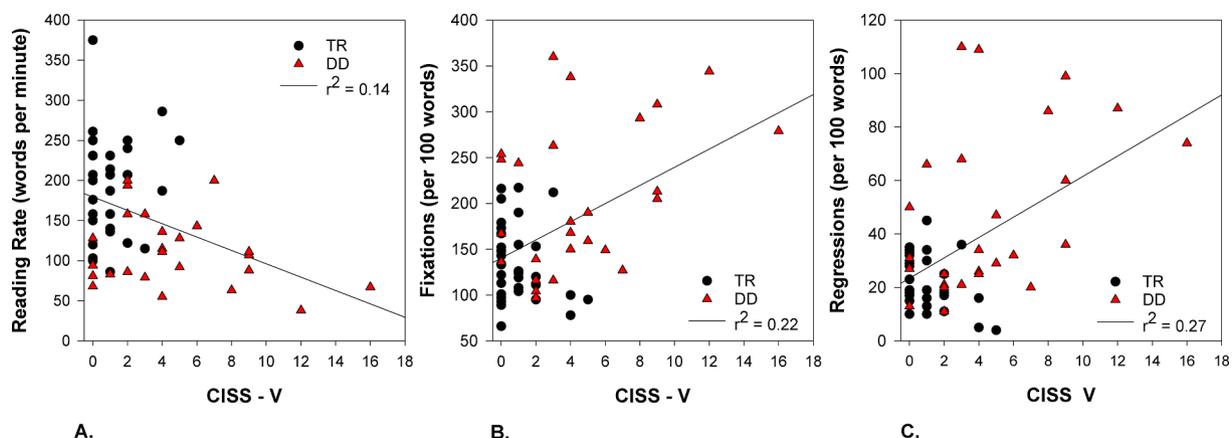
**4. Discussion**

Children with DD report significantly more vision related symptoms while reading than do typical readers, confirming previous anecdotal reports. These symptoms include tired eyes, double vision, intermittent blurring of words, uncomfortable eyes, headaches, and words moving on the page.

These self-reported symptoms, moreover, are validated by their association with findings from vision testing. Ocular motor tracking was most clearly associated with these symptoms. These associations were also evident within the DD group, arguing that the correlation is not accounted for by group membership but represents a true association. There were also associations with vergence (receded near point of convergence and convergence amplitude) and accommodation parameters (amplitude of accommodation and accommodation facility). These associations, however, were weak within groups and so could be attributed to a greater extent to group membership.

We have previously reported that visual abnormalities are more prevalent in children with DD than in their TR peers (Raghuram et al., 2018). The present study extends these findings by documenting not only that children with DD experience more visual symptoms, but also that the severity of the visual problems can be related to the efficiency of ocular motor tracking and possibly to other parameters of visual functioning.

The significance of these visual symptoms is uncertain. While it is plausible that these visual deficits play a causal role in the reading



**Fig. 1.** Scatterplot showing associations between Visagraph ocular motor tracking parameters and CISS-V scores for A. Reading rate, B. Fixations and C. Regressions for Typical Readers (TR) and children with Developmental Dyslexia (DD).

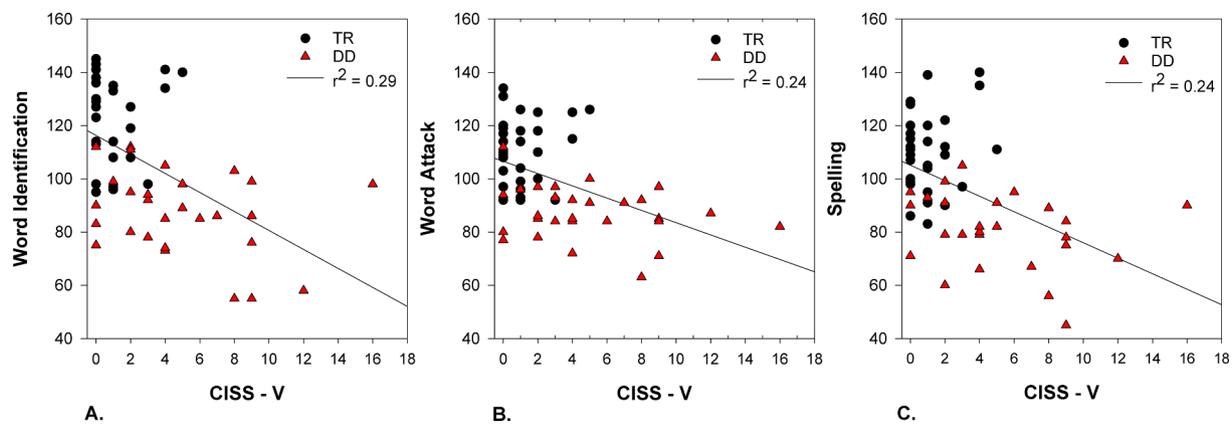


Fig. 2. Scatterplot showing associations between single word reading and spelling and CISS-V scores for A. Word Identification, B. Word Attack and C. Spelling for Typical Readers (TR) and children with Developmental Dyslexia (DD).

disorder, at least for some children and especially for text reading, it is equally plausible that they reflect the effort that children with DD must invest when asked to read.

The contrast between the correlations between self-reported visual symptoms and single word reading on the one hand and ocular motor tracking on the other are of potential interest. Although visual symptoms were meaningfully associated with ocular motor tracking during text reading within the DD group, they were not similarly associated with single word reading. Text reading likely makes a greater demand on visual functioning since the eyes need to track a complex visual array. Reading isolated words, however, may depend more on cognitive factors, especially phonological processing, since the visual stimuli are relatively simple and the eyes do not need to track. Visual functioning, therefore, may become more relevant developmentally as the emphasis in reading acquisition shifts from reading single words to reading more visually complex texts printed in smaller and denser fonts, with potential impact on reading rate and fluency.

Ocular motor tracking measures have been used as indicators of cognitive processes underlying text reading (Rayner, 1998; Schad, Risse, Slattery, & Rayner, 2014). However, our observation that tracking parameters are associated with visual symptoms, such as blurring of print or headaches, in individuals with DD suggests that visual skills may also play a functional role in the process of text reading.

Along these lines, children with dyslexia have shown improved text reading when visual crowding is minimized by altering the text to expand the spacing between letters (Zorzi et al., 2012). This effect is documented for dyslexic readers in both phonologically transparent (Italian) and opaque (French) languages. A recent study showed that a subset of dyslexic individuals had elevated sensitivity to visual crowding (even with non-linguistic stimuli) and that these individuals benefited most from increased text spacing (Joo, White, Strodtman, & Yeatman, 2018). Since this effect is not observed in typical readers (Pelli & Tillman, 2008), the findings in dyslexic readers suggest that at least for a subset, visual deficits render them more vulnerable to effects of spacing between the letters. Visual crowding could thus be relevant to the visual symptoms seen in the DD children in our study as well as to their tracking deficits, even when they are reading texts geared to their reading level.

Another related consideration is visual attention span, that is, the number of elements in a visual array that is processed in a single glance. Visual attention span is reported to be reduced in many individuals with dyslexia, affecting reading acquisition and performance (Bosse, Tainturier, & Valdois, 2007). A reduced visual span could account for the increased number of fixations, as observed in our study, and perhaps symptoms of letters moving on the page. There is also substantial evidence that visual attention deficits play a causal role in dyslexia

(Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012). Surprisingly, experience with action based videogames has led to improved visual spatial attention and reading fluency in children with DD (Franceschini et al., 2013) as well as reducing the effects of visual crowding in typical readers (Green & Bavelier, 2007). In another study, changes induced in visual attention span were found to mediate the relationship between videogame exposure and improved reading fluency (Antzaka et al., 2017). In contrast to these findings, however, a controlled trial failed to demonstrate that action based video games and phonological non-action based video games led to improved reading (Luniewska et al., 2018).

This study has several limitations. The examiner read the questions to the child and was not masked to group membership and thus could have influenced their responses. The association between the CISS-V scores and performance on the tracking measures, however, would argue for a true association that cannot be attributed to bias introduced by the examiner. Also, the findings are correlational, and it is thus not appropriate to attribute causation.

## 5. Conclusion

Vision-related symptoms are more frequent in children with dyslexia. Our findings suggest that it could be beneficial to administer the CISS more routinely to children diagnosed with DD. Those who report high levels of symptoms on the vision items could warrant a comprehensive eye exam with detailed sensorimotor evaluation. It remains to be seen, however, whether correcting sensorimotor deficits could facilitate reading in these individuals. Moreover, further research is needed to investigate potential relationships of these visual symptoms to visual crowding, visual attentional span, and visual spatial attention, as well as their complex relationships to ocular motor tracking and potentially to vergence and accommodation.

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Drafting of the manuscript: Raghuram and Waber.

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