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Effect of different font sizes and of spaces between words on eye movement performance: An eye tracker study in dyslexic and non-dyslexic children

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ABSTRACT

The aim of the present study was to explore the possible change in eye movement performance in a group of dyslexic and non-dyslexic children reading four lines of a text with different font sizes and spaces between the words. Fifteen dyslexic children from 7 to 12 years old and two groups of fifteen non-dyslexic children, respectively reading and chronological age-matched group, participated in this study. Horizontal eye movements from both eyes were recorded by a video-system (EyeBrain T2®) while the children were reading a text. Three different texts were used with different font sizes and spaces between words. Results showed that increasing font size and character spacing significantly reduced duration of the fixation and increased the number and amplitude of prosaccades in all groups of children tested. Interestingly, while reading texts in which the letters were larger and more spaced (Texts 2 and 3), the duration of fixations in dyslexic and in non-dyslexic children groups decreased, becoming similar to those reported in the non-dyslexic children group. We suggest that large letter spacing between words could be employed in schools to help dyslexic children in order to ameliorate their reading performance.

1. Introduction

Developmental dyslexia is a learning disability that specifically impairs a person's ability to read, despite his/her normal intelligence. It affects about 10% of children (Peterson & Pennington, 2012). According to the DSM-5 (2013), in order to receive a diagnosis of dyslexia an individual must show difficulties with accurate or fluent word recognition, poor decoding and poor spelling. Currently, there are several theories about the causes of dyslexia, including phonological theory (Ramus, 2003), attentional deficit (Facoetti et al., 2003), cerebellar theory (Stoodley, Fawcett, Nicolson, & Stein, 2005), genetic theory (Becker et al., 2014), and visual theory (Cornelissen, Munro, Fowler, & Stein, 1993). Note, however, that despite intensive research on the subject, its etiology is still unknown.

Eye movements have been widely used as an experimental tool to investigate the mechanisms underlying developmental dyslexia. Specifically, it has been suggested that some individuals with developmental dyslexia have motion-processing disorders, leading to a less stable visual perception (Stein, 2018).

Reading is a complex cognitive process during which several mechanisms are involved, including visual perception, linguistic and semantic capabilities, and ocular movements. Reading requires both saccades (to move the eyes on the words) and fixations (during which subjects maintain their gaze on the word to read and understand its meaning).

One important aspect of reading in dyslexic children is their reduced visual attention span, defined as the amount of distinct visual elements that can be processed concurrently; such limitation leads to a higher number of fixations (and saccades), and to their longer duration (Bosse, Tainturier, & Valdois, 2007). Dyslexic children are also abnormally affected by crowding, which is a perceptual phenomenon with detrimental effects on the recognition of the target letter due to interference from contiguous letters (Bouma, 1970). Bouma and Legein (1977) reported that in dyslexic subjects the crowding effect can be reduced by adding space between letters. Interestingly, spacing between the words influences word comprehension and oculomotor performances (Slattery & Rayner, 2013), and some studies reported that a simple manipulation of letter spacing substantially improved text reading performance of dyslexic children (English and Italian children, see the work of Zorzi et al., 2012). Note, however, that this finding is not accepted by other

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researchers (Skottun & Skoyles, 2012), for whom such an improvement could also be observed among non-dyslexic subjects. Indeed, several other studies observed a reading improvement in terms of speed or accuracy that was not specific to individuals with dyslexia only (see recent work by Hakvoort, van den Boer, Leenaars, Bos, & Tijms, 2017; Sjoblom, Eaton, & Stagg, 2016; van den Boer & Hakvoort, 2015; Perea & Gomez, 2012).

Interestingly, Perea, Giner, Marcet, and Gomez (2016) used an eye tracker to record eye movements in non-dyslexic adult subjects who were reading a text with larger spaces between the letters, and they reported a shortening of the duration of fixations during reading this type of text with respect to the standard interletter spacing but they failed to report any change in the number of fixations, in the total reading time and in the comprehension scores.

Our goal in this study was to gain more insight on such issues, and in order to quantify objectively the effect of different sizes and spaced words on reading in a group of dyslexic children we used an eye tracker to record eye movements. Two groups of non-dyslexic children reading age-, IQ-matched and chronological age-, IQ-matched were also tested for comparison. Indeed, recall that oculomotor performances are age-dependent (Luna, Velanova, & Geier, 2008), and given that in dyslexic children an immaturity of the cortical structures triggering eye movements has been reported (Bucci, Nassibi, Gerard, Bui-Quoc, & Seassau, 2012; Tiadi, Gérard, Peyre, Bui-Quoc, & Bucci, 2016) in studies led on reading and oculomotor capability in dyslexia it is essential to compare dyslexic children with both non-dyslexic reading age- and chronological age-matched children group.

2. Methods

2.1. Subjects

Eye movements were recorded in a group of 15 dyslexic children (mean age: 9.4 ± 0.2 years) and two groups of 15 non-dyslexic children each, matched by reading and chronological age, respectively. Note that the group of reading age-matched children has been added in order to compare dyslexic children with a group of children having similar reading skills.

Inclusion criteria for all children were: *(a)* Age between 8 and 12 years; *(b)* Normal visual acuity for distance vision and near vision (both eyes ≥10/10); *(c)* Absence of strabismus, amblyopia or degenerative pathology affecting the eyes (cataract, scotoma, retinopathy); *(d)* Absence of any signs of hyperactivity or lack of coordination related to development; *(e)* Not taking any drugs that could modify their visual behavior or their perception; *(f)* Not suffering from neurological or mental disorders or disabilities that might prevent a proper understanding of the texts.

Dyslexic children were recruited from the Robert Debré pediatric hospital in Paris, where they were referred for a complete evaluation of their dyslexia including psychological and phonological capabilities.

For each dyslexic child, we measured the time required to read a text, the comprehension of the text and the ability to read words and pseudo-words using the L2MA battery (oral Language, written Language, Memory, Attention, Chevrie-Muller, Simon, & Fournier, 1997). Subjects with more than two standard deviations from the normal mean were included in the study.

All children had a mean intelligence quotient (IQ) in the normal range (between 85 and 115). For dyslexic children the IQ was evaluated using the Wechsler Intelligence Scale for Children (fourth edition), while for the two groups of non-dyslexic children the IQ was estimated using two subtests, one assessing the verbal abilities (similarities) and one the non-verbal abilities (matrix reasoning).

For each child the reading age was evaluated by reading aloud the text *Monsieur Petit* taken from Lequette, Pouget, and Zorman (2008). Clinical characteristics of the three children groups are shown in Table 1.

Table 1
Clinical characteristics of the three groups of children tested (mean ± standard errors).

	Dyslexic group (N = 15)	Reading age-matched group (N = 15)	Chronological age-matched group (N = 15)
Chronological age (yrs)	9.4 ± 0.2	7.4 ± 0.1	9.6 ± 0.1
Reading age (yrs)	7.2 ± 0.1	7.5 ± 0.1	9.6 ± 0.1
Verbal IQ	97 ± 2		
Verbal Score	12.4 ± 1	13.6 ± 0.7	13.5 ± 0.7
Logic IQ	95 ± 1		
Logic Score	12.9 ± 0.9	13.9 ± 1	13 ± 0.6

ANOVA reported a significant group effect for age ($F_{(2,42)} = 50.16$, $p < 10^{-3}$); Bonferroni comparison showed that the age of dyslexic children was significantly different from that of the reading age-matched group of non-dyslexic children and that the age of chronological age-matched non-dyslexic children group was significantly different from that of the reading age-matched non-dyslexic children group (both $p < 10^{-3}$).

The investigation adhered to the principles of the Declaration of Helsinki and was approved by the Institutional Human Experimentation Committee of CPP Ile de France I, Hôtel-Dieu Hospital. Written informed consent was obtained from the children's parents after they were given an explanation about the experimental procedure.

2.2. Experimental setup

Stimuli Texts were presented on a 22″ LCD screen with “full HD resolution” (image size of 1920 × 1080 pixels) and the refresh rate was 60 Hz, sufficient to ensure a normal saccade performance (Kennedy, Brysbaert, & Murray, 1998).

The children read passages that were presented in three different sizes. Each text contained 40 words and 174 characters (extract from ‘Jojo Lapin fait des farces,’ Gnid Bulton, Hachette). Text was written in black using the Century Schoolbook font, a specific serif font for those who have difficulty in reading, since it was designed for books used in primary school to teach reading; the interline was always double corpus size for all three texts used. The three texts were different in terms of corpus and/or inter-letter space:

Text 1: Corpus: 25 pt; Inter-letter space: 1 pt.
Text 2: Corpus: 25 pt; Inter-letter space: 2.5 pt.
Text 3: Corpus: 30 pt; Inter-letter space: 2.5 pt.

Children were asked to read aloud so that it was possible to count the number of errors they made, and after each text two questions were asked to assess the comprehension abilities of the child.

2.3. Eye movement recordings

Eye movements were recorded using the Mobile Eyebrain Tracker (Mobile EBT®, e(ye)BRAIN, SuriCog), a CE-marked medical eye-tracking device. The Mobile EBT® benefits from cameras that capture the movements of each eye independently. Recording frequency was set up to 300 Hz. The precision of this system is typically 0.25°. There is no obstruction of the visual field with this recording system.

2.4. Procedure

Each child was seated in a chair in a dark room, his/her head stabilized by a headrest supporting both the forehead and chin. Viewing was binocular; the viewing distance was 60 cm. Calibration of the eye tracker was done at the beginning of each block.