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Research article

Vertical disconjugacy during reading in dyslexic and non-dyslexic children

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ABSTRACT

Purpose: The objective of this study was to explore vertical binocular coordination in dyslexic and non-dyslexic children during saccades and post-saccadic fixation period while reading a text.

Methods: Binocular eye movements were recorded by an infrared system (Mobile T2®, SuriCog) in thirty-six dyslexic children from 7.3 to 13.6 years of age (mean age: 10.4 ± 0.3 years) who were asked to silently read a four-line text during binocular viewing. Data were compared to those of thirty-six age-matched non-dyslexic children.

Results: Vertical disconjugacy during post-saccadic fixation was higher in dyslexic children with respect to non-dyslexic children group. Vertical disconjugacy was not age-dependent either for dyslexic children or for non-dyslexic children.

Conclusions: The poor binocular vertical coordination observed in dyslexic children while reading could suggest a deficiency in the cerebellum and/or extra-ocular muscles involved in vertical eye alignment. Moreover, the fact that this vertical binocular coordination was not age-dependent could be due to an abnormal eye position and/or to a dysfunction of midbrain structures involved in vertical vergences.

1. Introduction

Reading is a crucial task for social and professional integration. It is based on linguistic and semantic capacities and requires a good control of the ocular motor system [1–3]. While reading, both eyes perform saccadic movements (to reach words), fixations (to read words), and also vergence eye movements (to see words clearly and avoid double vision). Indeed, both eyes need to be well adjusted to the distance of the words by vergence systems to see them in simple vision. Note that while reading a horizontal text, small vertical movements are necessary to properly identify words and also to shift the eyes to the next line. Studies on vertical movements are scarce for technical limitations. Indeed, the most popular method of recording vertical saccades is the search coil-magnetic field method, which eliminates vertical distortions due to eyelid movements [4], but this technique cannot be used in children for ethical reasons.

Our group has previously explored only horizontal eye movements during reading a text [5,6]; in the present study we explored vertical binocular coordination both in non-dyslexic and dyslexic children to further understand vertical binocular vision mechanisms in such patients. Indeed, as we shall see, no studies existing dealing with vertical eye movements during reading in children, and more specifically in children with dyslexia.

Although the term of dyslexia was coined in 1887 by Rudolph Berlin, an ophthalmologist describing reading difficulty, it is still unclear what dyslexia exactly is [7]. Numerous studies have discussed the role of eye movement impairment in this type of population. For years, many authors have documented horizontal saccades towards dots in dyslexic children by recording movements from one eye only [8–14]. Bucci et al. [15] recorded movements from the two eyes simultaneously in dyslexic children. They reported for the first time poor horizontal coordination between the two eyes during and after the saccades, both during saccades towards dots and during reading single words. These authors suggested an impairment of structures involved in ocular motor learning such as the cerebellum or the parietal cortex, allowing interaction between ocular saccades and vergence subsystems. In the 2010s, other studies recorded horizontal binocular eye movements while reading sentences in a dyslexic population. Kirkby et al. [16] reported

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Table 1
Clinical caracteristic of children tested. Mean and stradard error of chronological age, reading age, reading words and pseudo-words (evaluated by using L2MA battery test) and IQ (evaluated with WISC IV).

	Age (years)	Reading age ELFE (years)	Reading word (years)	Reading pseudo-words (years)	IQ	Matrix test	Logical test
Non dyslexic children	10.37 ± 0.3	8.26 ± 0.2	8.5 ± 0.2	8.7 ± 0.2	95.8 ± 1.2		
Dyslexic children	10.4 ± 0.3	10.4 ± 0.3	±	±		10.8 ± 0.3	10.2 ± 0.3

poorer binocular coordination during post-saccadic fixations in dyslexic children than in non-dyslexic children while reading a text in comparison to dot scanning. They hypothesized that poor ocular-motor performances during reading in dyslexic children could be due to attention impairment and/or weaker cognitive performances.

Regarding vertical eye movements, there is only one study exploring vertical saccades in dyslexic children. Tiadi et al. [17] compared vertical visually-guided saccades toward dots in dyslexic and non-dyslexic children. Longer latencies, shorter gain (smaller eye amplitude with respect to target amplitude) and slower mean velocity were found in dyslexic children with respect to non-dyslexic children. This result was interpreted as a possible reflection of the impaired functioning of cortical areas involved in controlling vertical saccades, and also, at a peripheral level, of the extra-ocular oblique muscles [18,19].

No study about vertical eye movements during reading in dyslexic and non-dyslexic children has been reported so far. Only a few studies examined vertical binocular eye movement during reading, and they were limited to healthy adult subjects. Nuthmann and Kliegl [20], for example, analyzed vertical binocular coordination while reading sentences (of 5–11 words) in a large population of 245 healthy adults. They focused on the post-saccadic fixation period, and found that vertical binocular coordination was good enough: the left eye tends to fixate slightly above the right eye. Unfortunately, these results were purely descriptive. Indeed, their study was exploratory, without experimental manipulation. Recently, Nikolova et al. [21] showed that when a vertical misalignment (offset of 0.05°, of 0.11° and of 0.16°) was induced while reading single words, healthy adults did not compensate this vergence disconjugacy. They suggested that the vertical motor fusional mechanisms showed limited activation, even in the presence of a vertical misalignment designed to elicit a vergence response. These vertical limits could be caused by the reduced capacity of the visual system to compensate for vertical misalignments [22,23]. Jainta et al. [23] studied binocular vertical disconjugacy between the two eyes in sixteen healthy adults while reading english sentences. Results showed that, while vertical binocular disconjugacy was smaller at the beginning of a fixation (0.05°), there was no significant difference between disparity at the beginning and at the end of fixations (0.04°). They suggested that minimal vertical vergence responses arise because the eyes are anatomically separated by only a small distance in the horizontal dimension. While vertical eye movements in humans seem to be insufficient for misalignment correction, it appears that a good vertical alignment is necessary to an efficient horizontal fusional response. These studies showed that in healthy young adults, small differences were observed between horizontal and vertical disparities and that the second one will allow to success the first one leading to a minim disparity during reading (avoid double vision).

Based on these findings dyslexia is a good model to explore further these assumptions given that in this population horizontal as well as vertical eye movements had been reported to be poorly controlled [15,24,25].

Moreover, regarding lack of knowledge and lack of treatment options on binocular mechanisms in adults as well as in children, it seems to be important to take an interest in vertical binocular coordination, especially during a daily activity as reading. The goal of the present study was to explore vertical binocular coordination during saccades and during post-saccadic fixation periods while reading in dyslexic and non-dyslexic children. Based on previous studies of [25], Quercia [18] and Quercia et al. [19], we hypothesized that vertical binocular coordination during reading could be impaired in dyslexic children.

2. Materials and methods

2.1. Subjects

The investigation adhered to the principles of the Declaration of Helsinki and was approved by our institutional Human Experimentation Committee. Informed parental consent was obtained for each subject after the nature of the procedure had been explained.

Thirty-six dyslexic children between 7.3–13.6 years of age (mean age: 10.4 ± 0.3 years) participated in the study. Dyslexic children were recruited from the Robert Debré children's hospital in Paris where they were subjected to a complete evaluation of their dyslexia (neurological/psychological and phonological capabilities). Thirty-six age-matched control children (mean age: 10.4 ± 0.3 years) were also tested. They were all native French speakers.

For each dyslexic child the time of reading a text, its comprehension, and the capacity of reading word/pseudo-words were evaluated by using the L2MA battery [26] (see Table 1). This is the standard test developed by the "*Centre de Psychologie appliquée de Paris*", often used in France and already employed in previous studies for selecting dyslexic populations [15,27]. Inclusion criteria were: test scores beyond 2 standard deviations; a normal mean intelligence quotient (IQ, evaluated with WISC-IV). The mean reading age was 8.2 years (from 6 to 11 years). The mean reading words and pseudo-words were 8.5 and 8.7, respectively. Mean IQ was 95.8, ranging to 80–110.

Non-dyslexic children had to satisfy the following criteria: no known neurological or psychiatric abnormalities, no history of reading difficulty, no visual impairment or difficulty with near vision. Also, their reading capabilities were within normal range. Both the WISC IV similarities subtest assessing verbal ability, and the WISC IV matrix reasoning subtest assessing spatial and logical abilities were performed. The normal range for both tests is 10 ± 3 [28]. All non-dyslexic children had a reading age similar to their chronological age. The mean matrix test and logical test scores were 10.8 and 10.2, respectively.

2.2. Ophthalmological and orthoptic examination

All dyslexic children underwent an ophthalmological and orthoptic examination to evaluate their visual function. All participants had normal binocular vision (< 60 s of arc), which was evaluated with the TNO random dot test. Visual acuity was normal (≥ 20/20) for all participants. No patient had strabismus or any oculomotor abnormality.

2.3. Reading task

The reading paradigm used was described previously by Bucci et al. [5] and consisted in reading a four-line paragraph. The paragraph contained 40 words and 174 characters. The size of the text was 29° wide and 6.4° high; mean character width and height were 0.5°, and the text was written in black 'Courier' font on a white background (see Fig. 1). Children had to read a different text according to their age (7–9, 10–12, and beyond 13 years old). To ensure that all words were well-know and easily understood by the children, all texts come from three different books that usually are used by French teachers in different