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INTRODUCTION

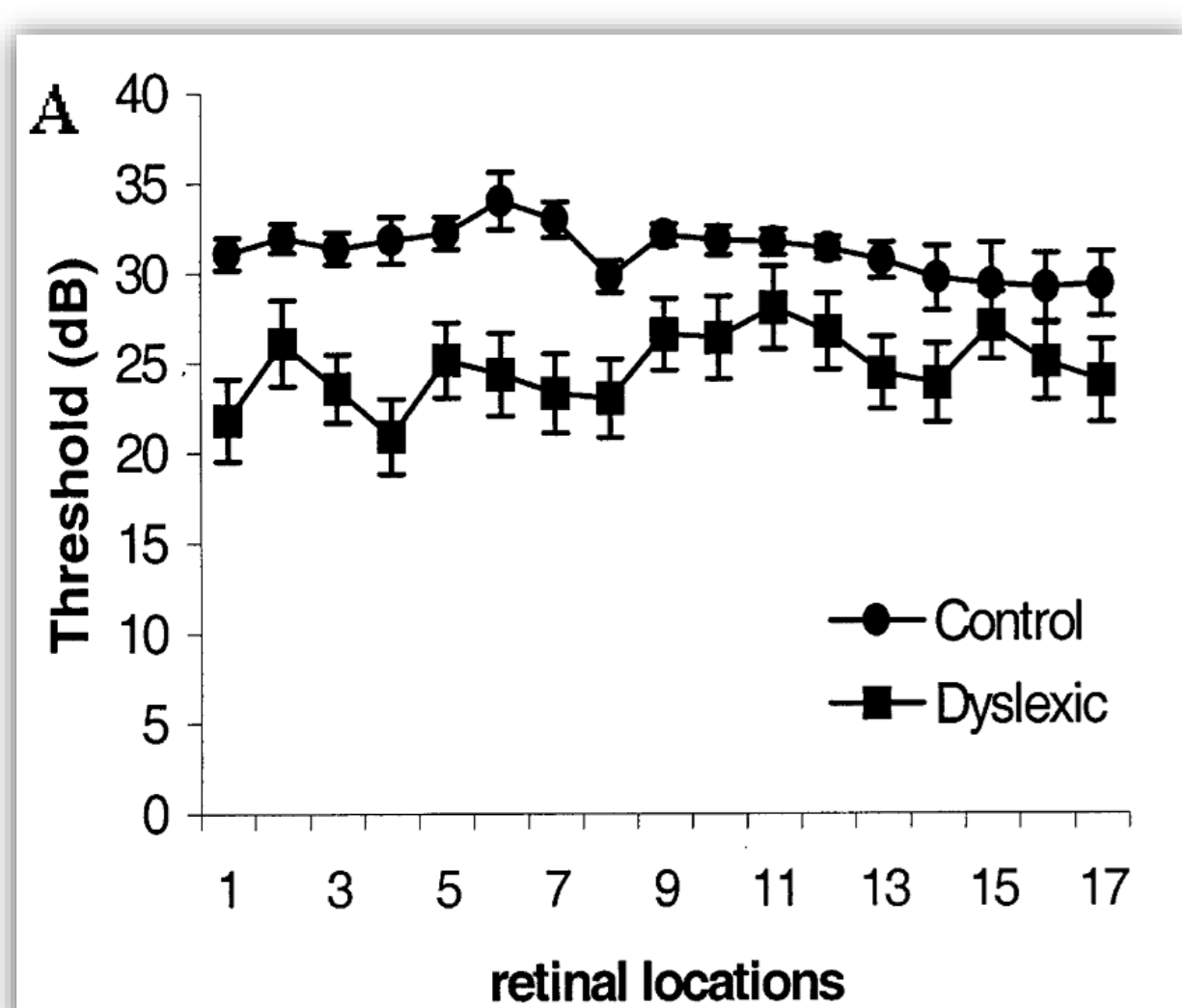


Figure 1. FDT thresholds for dyslexic and normal readers over 17 retinal sections. Source: Pammer & Wheatley (2001).

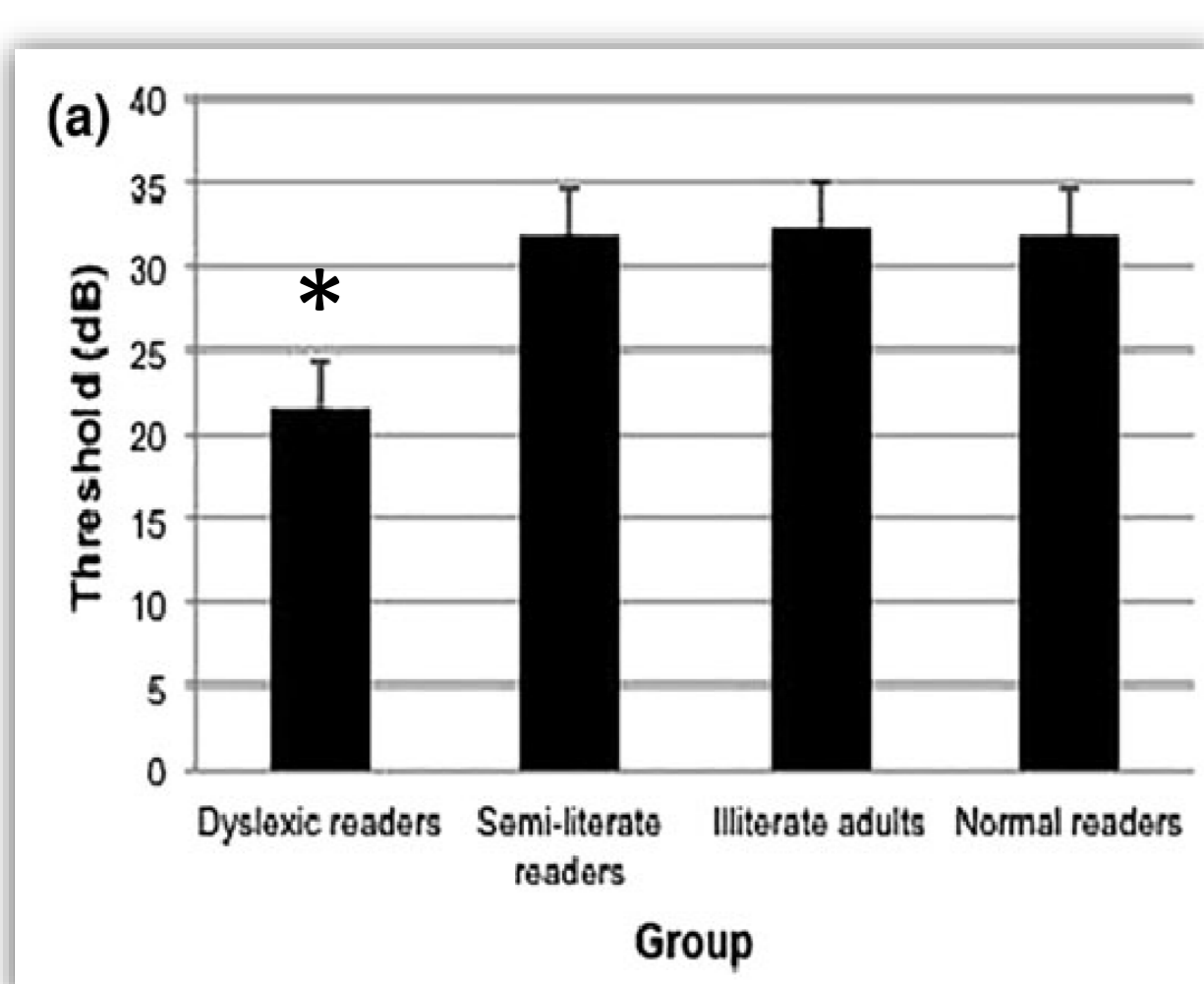


Figure 2. Mean threshold of frequency doubling illusion for the dyslexic, semi-literate, illiterate, and normal readers. Source: Flint & Pammer (2018).

Different studies demonstrate a magnocellular deficit in Developmental Dyslexia, coherent with a deficit in peripheral visual function and in eye movement, while presenting a preserved central visual function. Pammer and Wheatley (2001) verified that a group of 21 dyslexics, performed more poorly on detection of the frequency doubling illusion than the 19 control normal readers, being less sensitive across the retina ($p < 0.005$) (see Figure 1). The Mean Deviation index (MD), averaged over the two eyes, for the Dyslexic Group (MD = -5.007 dB) was significantly less than zero ($t(20) = 3.65$, $p < 0.01$), while the control reading group (MD = -0.46 dB) was non-significantly different than zero ($t(18) = 0.84$, $p = NS$).

In a more recent study, Flint and Pammer (2018) verified that a group of illiterate adults perform as well as normal and semi-illiterate readers on specific temporal and spatial tasks of the visual magnocellular system, with all three groups performing better than the dyslexic reader group (see Figure 2). The authors concluded that this functional failure is probably not a consequence of lack of reading and points to a causal role of magnocellular processing.

RESULTS

 Table 1. Demographic, central and peripheral visual function, eye movement and Reading from a Group of 74 Dyslexics and 74 Matched-control group. [Mean \pm Standard Deviation]

	Parameters	Dyslexic Group	Control Group	<i>p</i>	<i>d</i>
Demographic	Sample size	74	74	-	-
	Age range	7-51	7-51	-	-
	Mean age	14.9 \pm 7.7	15.8 \pm 7.7	=0.51	0.12
	Male (%)	74	74	-	-
Central visual function (Optec 6500)	Left-handed (%)	39	39	-	-
	Monocular visual acuity*	.05 \pm .13	-.03 \pm .12	=0.024	0.30
	Binocular visual acuity*	.01 \pm .14	-.10 \pm 0.11	=0.029	0.71
	20/12.5 – 20/16 (n)	34	43	<0.05	-
	20/20 – 20/25 (n)	31	30	-	-
	20/30 – 20/50 (n)*	9	1	<0.05	-
	Stereopsis (logmar)*	.25 \pm .37	0.03 \pm 0.16	=0.012	0.77
Peripheral visual field function – FDT (MD, mean deviation index)	Lateral phorias*	2.9 \pm 2.4	1.5 \pm 1.6	=0.046	0.68
	Both eyes*	-3.4 \pm 3.2	-0.7 \pm 1.7	<0.0001	1.05
	Left eye*	-3.3 \pm 2.9	-0.6 \pm 1.6	<0.0001	1.15
	Right eye*	-3.4 \pm 3.5	-0.8 \pm 1.8	<0.0001	0.93
	Dominant Eye*	-3.2 \pm 2.9	-0.7 \pm 1.8	<0.0001	1.04
	Not Dominant Eye*	-3.5 \pm 3.5	-0.6 \pm 1.6	<0.0001	1.07
	Best eye*	-2.5 \pm 2.7	-0.1 \pm 1.5	<0.0001	1.10
Worst eye*	-4.3 \pm 3.5	-1.3 \pm 1.6	<0.0001	1.10	
Eyes worse than -2.0*	66%	26%	<0.0001	-	
Eye movement (Visagraph III)	Fixations*	207 \pm 137	162 \pm 30	<0.0001	0.45
	Regressions*	66 \pm 67	47 \pm 14	<0.0001	0.39
	Span of Recognition (%)*	65 \pm 31	83 \pm 26	=0.0003	0.63
	Relative Efficiency*	99 \pm 117	146 \pm 117	<0.0001	0.40
Text reading	Text-related visual distortions symptoms*	1.7 \pm 1.5	1.1 \pm .9	<0.05	0.49
	Visual reading difficulty*	10.6 \pm 3.7	2.9 \pm .9	<0.0001	2.86
	Visual reading discomfort*	6.1 \pm 4.2	2.7 \pm 2.3	<0.0001	1.00
	Words per minute*	158 \pm 94	212 \pm 117	<0.0001	0.51
	Text comprehension (%)	78 \pm 16	79 \pm 16	=0.88	-

*: $p < 0.05$. FDT = Frequency Doubling Technology; *d* = Cohen's Effect Size: 0.2–0.4 small effect; 0.5–0.7 medium effect; >0.8 large effect.

DISCUSSION

The current study hypothesized that peripheral visual field and eye-tracking technology could objectively identify physical evidence of visual-related reading difficulties. For the central visual function, DD patients had statistically worse monocular and binocular visual acuity ($p < 0.05$); stereopsis (depth perception, $p = 0.012$); and lateral phorias (binocular integration, $p = 0.046$). However, only 12% of DD had poor visual acuity, being between 20/30 to 20/50. It is recommended a more constant/annually ophthalmic evaluations to verify the need for refractive correction. Important to highlight that most DD had good visual acuity (88%), essential to extract refined spatial information.

For the peripheral visual function, DD had a decreased sensitivity on detection of the frequency doubling illusion (FDT, $p=0.0001$), even if we divided the data by eye dominance or best/worse eye. The FDT has been developed based on particular neural magnocellular characteristics and can examine the magnocellular dysfunction hypothesis in Dyslexia. FDT provides a mean deviation (MD) index to generally summarize the visual field results for threshold tests. MD represents the average sensitivity deviation from a normal healthy person of the same age (based on the normative database). The MD is an indication of the overall visual field sensitivity, and can either be a negative or positive value depending on if the individual's general contrast sensitivity is below or above the average for that same age group. Overall, the results show that patients with dyslexia have less visual field sensitivity than normal controls in both eyes, with very strong statistical effect size.

Concerning eye-movement recorded while reading texts (Visagraph-III), DD had a significantly worse number of Fixations, Regressions, Span of Recognition, and Relative Efficiency ($p < 0.01$). Participants with DD reported more symptoms of visual reading difficulty, visual reading discomfort, and more text-related visual distortions, compared to control ($p < 0.05$). Participants with DD had moderate reduction in the number of words read per minute, but had normal text comprehension.

These findings are in agreement with both reference studies (Flint & Pammer, 2018; Pammer & Wheatley). The poorer magnocellular efficiency can be in the core of some patients with Developmental Dyslexia, having a causal relation to the reading difficulty. The retino-cortical/subcortical magnocellular visual pathway is mainly involved in temporal processing, object/word location (where), controls eye movement and direct our attention. Essential cognitive features during reading activities, as the eyes have to systematically and sequentially make horizontal saccades, followed by eye fixations of 200 to 400msec (to extract and process the content via parvocellular pathway), while coordinated binocular eye activity track line-by-line along a text. Over a sustained reading of a book, for example, the accumulated visual activity can lead to visual stress symptoms of visual distortions, reading difficulties and discomfort, frequently reported by DD. These visual stressing conditions may hinder the development of a proficient, comfortable and sustained reading.

CONCLUSION

The parvo, as well as magnocellular visual pathways, are directly involved in proficient reading, as they are parallel and partially dependent systems. DD presented a markedly worse performance in visual variables related to magnocellular visual pathway (ie., peripheral visual function, eye movement, visual stress symptoms), when compared to a matched-Control Group.

AIM

Verify if participants with Developmental Dyslexia present deficits in central and/or peripheral visual function, when compared to a matched-Control Group.

MÉTODODO

Participants

Research Ethics Committee of UFMG: #49765115.0.0000.5149.

We retrospectively reviewed records of reading and ophthalmic variables of all patients who had been assessed from January 2007 to April 2018 at the NeuroVision Department of the *Hospital de Olhos de Minas Gerais*.

We only selected the records of 74 patients with formal diagnosis of Developmental Dyslexia, according to DSM-5th edition. The Control Group consisted of 74 typically developing participants without dyslexia, matched for age, gender and handedness.

Instruments

- **Optec 6500:** Monocular and binocular visual acuity. The stereopsis test verified the difficulty to identify the “floating” circle at far in an increased nine discrete steps of 20, 25, 30, 40, 50, 70, 100, 200, 400 arcsec. Lateral foria was evaluated with the simultaneous presentation of an arrow in the left eye and numbers from 1 to 15 in right eye.
- **Frequency Doubling Technology (FDT, Humphrey Instruments):** Verify the integrity of the visual field. Each eye were measured separately at all 19 retinal regions using a full threshold analysis program (N-30). Each stimulus is formed by a low spatial frequency (0.25 cycles per degree) vertical sinusoidal grid, with a high temporal frequency (flicker counter-phase of 25 Hz).
- **Eye Movement:** Ocular motor skills and reading parameters were measured using a Visagraph III Eye-Movement Recording System (Taylor Associates, New York). Consists of lens-free goggles with inbuilt infra-red sensors. Parameters:
 - Fixations: Number of eye pauses in a left-to-right reading per 100 words.
 - Regressions: Number eye movements directed from right-to-left per 100 words.
 - Span of Recognition: Number of words read divided by the number of fixations.
 - Relative Efficiency: Reading Rate divided by fixations and regressions.
- **Reading:**
 - Number of text-related visual distortions symptoms.
 - Questionnaire of text-related visual difficulty and discomfort.
 - Words per minute: Number of words read in one minute without re-reading.
 - Comprehension: Percentage of correct answers in a ten yes/no questions.

REFERENCES

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