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Visual function deficits in dyslexic children: a case-control study

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Abstract

Purpose To compare the ophthalmic findings between dyslexic and non-dyslexic children aged 7–10 years.

Methods A matched case-control study was conducted on 32 dyslexic children as a case group and 32 non-dyslexics as a control group. Both groups underwent complete ophthalmic examinations to measure corrected distance visual acuity, refractive errors, latent and manifest deviations, stereoacuity, near point of accommodation (NPA), and contrast sensitivity (CS).

Results The mean age of the participants in our study was 8.1 ± 0.8 (range 7–10) years. Both dyslexic and non-dyslexic groups consisted of 17(53.1%) boys and 15(46.9%) girls. There was no significant difference in visual functions ($P > 0.05$) except for stereoacuity and contrast sensitivity between the two groups. Contrast sensitivity (CS) was decreased and aggravated in dyslexics versus controls. The mean score of binocular CS in the case and control group was 115.8 ± 40.6 and 175.6 ± 44.3 cycle per degree, respectively ($P < 0.001$). Notably, stereoacuity was increased in dyslexics versus controls (94.2 ± 73.6 vs. 60.94 ± 12.01 s/arc, $P = 0.017$).

Conclusion Dyslexic children exhibited decreased contrast sensitivity and impaired stereoacuity compared to controls. These findings support the theory of magnocellular system deficits in dyslexia. Further research is required to elucidate the role of contrast sensitivity and its impact on dyslexic vision.

Keywords Dyslexia, Contrast sensitivity, Stereo acuity, Visual functions

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Background

Dyslexia refers to a neurodevelopmental condition associated with reading and writing difficulties, but otherwise normal intelligence, socio-economic background, educational opportunity or sensory acuity [1, 2]. As many as around 5–10% of the population is found with dyslexia [3–7]. It seems that dyslexia may affect men more than women [8]. It occurs in approximately 80% of those with a learning disability, implying that it constitutes the most prevalent type of learning disability [9]. Although some researchers reported the dominant theory would be due to phonological impairment [10–15], the cause and mechanism of dyslexia are still unclear and controversial. Deficits in visual attention and temporal sampling have been suggested by Vidyasagar et al. They reported that confusing and misordering of letter and reversal letters in a word cannot be easily defined by phonological deficits [6, 7]. Other studies have also claimed that dyslexia may result from a disturbance in nervous system function and be genetically inherited [16, 17].

There are various theories about the role of visual functions in reading problems in the dyslexic population. Some researchers have concluded that phonological deficits are the cause of dyslexia and that vision does not play a pivotal role in this regard [16]. For example, Wahlberg-Ramsay et al. in a study reported that binocular vision abnormalities in dyslexic children arose from phonological deficits, but not from visual problems [15]. Moreover, Dysli et al. pointed out that phoria is of low importance in dyslexia and correcting small-angle heterophoria fails to help dyslexic children anymore [18]. On the other hand, reading is strongly dependent on vision; thus, it seems obvious that the initial letters must be seen, recognized, and then directed towards the proper location within the brain to be read properly. Aparna Raghuram et al. highlighted that deficits in visual functions are more frequent in dyslexic children than in normal school-age children [19, 20]. Palmo- Alvarez documented an association between reading difficulties and low amplitude accommodation, and Evan explained a significant correlation between the reduced amplitude of accommodation and dyslexia [21, 22].

Also, some have drawn attention towards the role of ocular problems in dyslexia; for instance, Motsch and Mühlendyck reported that prevalent reason reading problems in dyslexic children is hypo accommodation and they emphasized the correction of even small refractions and binocular abnormalities can be very effective in solving reading difficulties [23]. There are some reports have emphasized the presence of a contrast sensitivity deficit in dyslexic individuals [24–29]. Conversely, Williams et al. found no significant difference in CS between dyslexic and control groups to either stimulus [30]. These discrepancies can be attributed to various factors such as variations in diagnostic criteria for dyslexia, demographic and sampling strategies, contrast sensitivity measurement tests, study design and experimental conditions. Therefore, due to these factors, CS in children with dyslexia remains controversial and needs further studies.

With the exception of a few, not enough studies have been conducted to examine visual functions in Iranian Farsi spoken students [31, 32]. As Farsi language, unlike many languages such as English, is written and read from right to left, it would be necessary to assess visual functions in Iranian Farsi pupils. This study evaluates and compares visual functions in dyslexic and non-dyslexic children.

Methods

This case-control study was performed on 64 children, including 32 patients suffering from dyslexia as a case group and 32 non-dyslexic children as a control group. The sex and age were matched between the case and control groups. The protocol used in the present study was approved by the Ethical Committee of Mashhad University of Medical Sciences (IR.MUMS.REC.1395.615).

The study followed the principles outlined in the declaration of Helsinki. Moreover, the procedure was explained to the participants and their parents and then informed written consent was obtained from parents or legal guardians before entering the study.

Each dyslexic patient's medical history was reviewed to exclude children with attention deficit and attention-deficit/hyperactivity disorder (ADHD) and borderline personality disorder (BPD). The exclusion criteria included the presence of systemic diseases, and the use of any systemic or ocular medications. The following factors were also excluded from the study: ophthalmic, neurological, emotional or behavioral disorders, and any unusual educational circumstance that could impair the scholastic performance of the participants in reading, spelling and Stanford–Binet IQ test [33, 34]. The minimum IQ score for both dyslexic and non-dyslexic children was 90, indicative of a normal IQ in this study.

The dyslexic participants were selected from two centers for learning disabilities, while the control group consisted of children (both genders) attending two normal primary schools (first to fourth grade) as normal age-appropriate readers. The diagnosis of dyslexia was based on evaluations by a professional team of psychiatrists and speech therapists using globally accepted diagnostic approaches [35–37].

After that, refractive errors were evaluated objectively by auto refractometer (AR-610, Nidek Co, Ltd, Tokyo, Japan) and confirmed by the retinoscope (Beta 200, Heine, Herrsching, Germany). Then, subjective refraction was performed to determine corrected distance visual acuity (CDVA) using an E Snellen chart at 6 m. Myopia was defined as spherical equivalent of -0.50 diopters or more, and hyperopic refractive errors were considered as spherical equivalent of + 0.75 diopters or more [38].

Near point accommodation (NPA) was measured in centimeters using the subjective push-up approach. All participants must focus on the 20/20 line, and letters closed towards the nose until participants reported the blur. This assessment was repeated three times and finally, the mean values were reported. The test was carried out monocularly for the right eye, and then binocular NPA was measured. The TNO test (Laméris Ootech BV, Nieuwegein, Netherlands) was used for evaluating stereoscopic vision. Ocular alignment was evaluated by alternate prism cover test at near and far (40 cm and 6 m).

Monocular and binocular CS were measured with the Cambridge low contrast grating test. The test is set at a spatial frequency of 4 cycles per degree (cpd), which equals 20/150 visual acuity. This test includes 12 pairs of plates with 150 cd/m^2 luminosity. This test is based on a forced-choice procedure, and the subject must choose whether the grating target is at the top or bottom of the page 4 times. The number of pages where the errors happened was counted, and then the final CS score was recorded using a conversion table. All examinations were performed by the same experienced examiner.

Finally, the values of refractive errors, CDVA, heterophoria, heterotropia, NPA, stereopsis, and CS in dyslexic children were compared with non-dyslexic children.

All analyses were performed using SPSS version SPSS 24 (IBM Inc., Chicago, USA). Data are expressed as mean ± standard deviation (SD) for quantitative variables and percentages for qualitative variables. The normal distribution of all data was checked by using the Shapiro–Wilk test. To compare refractive errors, CDVA, heterophoria, heterotropia, NPA, stereopsis, and CS between two groups, we used Student's t-test, and the Chi-square test was used to compare categorical variables. A *P*-value < 0.05 was considered statistically significant.

Results

This study included 64 participants (32 students with dyslexia and 32 control children), with males being slightly predominant (53.1%). As the present study is a matched case control study, age was similar in both groups. The mean age of the dyslexic and control groups was 8.1 ± 0.8 (range 7–10) years, respectively. The two groups were comparable in terms of age, sex and grade ($P > 0.05$). Of all patients, 21.9% were in the first elementary school grade, 62.5% in the second grade, 9.4% in the third grade, and 6.2% in the fourth grade.

The CDVA for 93.8% ($n = 30$) of the dyslexic patients and all non-dyslexic participants was 6/6 vision. The mean ± SD of CDVA for the right eye, the left eye, and both eyes were 0.002 ± 0.011, 0.004 ± 0.018, and 0.002 ± 0.011 LogMAR, respectively in the dyslexic group.

Table 1 shows the mean refractive error, stereo acuity, NPA, and CS for both groups. As shown in this table, there was no significant difference in the mean refractive errors between the dyslexic and control children. In both groups, the mean of spherical refractive errors was almost + 0.50.

The dyslexic children showed a significantly higher mean value of stereoacuity (94.2 ± 73.6 s/arc) as compared to the control (60.94 ± 12.01 s/arc) ($P = 0.017$).

The mean NPA in the right eye in the dyslexic and non-dyslexic children were 7.1 ± 0.9 and 7.0 ± 0.8 cm, respectively ($P = 0.585$). In Table 1 the results of obtained CS for the right eye, left eye and both eyes can also be seen. As shown in this table, a significant difference was observed between the two groups for the right eye, left eye and both eyes. (all $P < 0.001$). The mean score of binocular CS in the dyslexics' group was 115.8 ± 40.6 cpd versus control ones (175.6 ± 44.3 cpd) ($P = < 0.001$).

Table 2 illustrates the distribution of refractive errors, stereo acuity, and distribution of strabismus at distance

Table 1 Mean visual findings of the dyslexic and non-dyslexic groups

	Variables		Dyslexia($n = 32$) Mean ± SD	Control($n = 32$) Mean ± SD	Mean difference ± SD	t-static†	*P*-value
Refractive error (diopter)	Spherical equivalent	Right eye	0.50 ± 0.79	0.56 ± 0.56	0.062 ± 0.17	0.363	0.718
		Left eye	0.58 ± 0.93	0.56 ± 0.47	-0.02 ± 018	-0.127	0.900
	Spherical equivalent	Right eye	0.10 ± 0.78	0.37 ± 0.53	0.27 ± 0.17	1.635	0.107
		Left eye	0.12 ± 0.76	0.34 ± 0.49	0.22 ± 0.16	1.362	0.178
Contrast sensitivity (cycle per degree)	Right eye		119.31 ± 44.26	173.97 ± 47.95	54.65 ± 11.54	4.737	< 0.001**
	Left eye		112.25 ± 38.39	177.16 ± 42.12	64.91 ± 10.07	6.442	< 0.001**
	Binocular		115.78 ± 40.59	175.56 ± 44.32	59.78 ± 10.62	5.626	< 0.001**
Other parameters	Near point of accommodation (Right eye, cm)		7.125 ± 0.975	7.0 ± 0.842	-0.12 ± 0.23	-0.549	0.585
	Stereoacuity (second of arc)		94.22 ± 73.60	60.94 ± 12.01	-33.28 ± 13.18	-2.524	0.017*

SD: standard deviation; † Independent t-test; significant at * $P < 0.05$ and ** $P < 0.01$

Table 2 The distribution of refractive errors, stereo acuity, and heterophoria& heterotropia at distance and near in the study groups

		Variables	Dyslexia($n=32$) N(%)	Control($n=32$) N(%)	Chi-square	P-value
Refractive error	Right eye	Myopia	3(9.4%)	0(0.0%)	3.160	0.206
		Hyperopia	23(71.9%)	25(78.1%)		
		Emetropia	6(18.8%)	7(21.9%)		
	Left eye	Myopia	3(9.4%)	1(3.1%)	1.267	0.531
		Hyperopia	21(65.6%)	24(75.0%)		
		Emetropia	8(25.0%)	7(21.9%)		
Ocular deviation	Near	Esotropia	1(3.1)	0(0.0)	6.763	0.080
		Exotropia	0(0.0)	0(0.0)		
		Esophoria	5(15.6)	3(9.4)		
		Exophoria	21(65.6)	15(46.9)		
		Ortophoria	5(15.6)	14(43.8)		
	Far	Esotropia	2(6.3)	0(0.0)	3.217	0.359
		Exotropia	0(0.0)	0(0.0)		
		Esophoria	1(3.1)	0(0.0)		
		Exophoria	3(9.4)	4(12.5)		
		Ortophoria	26(81.3)	28(87.5)		

The numbers in each cell indicates frequency (percent.; significant at * $P<0.05$

and near. The results showed that in two groups, nearly 70% of participants were hyperopic compared to only about 10% of students which were myopia. According to this table, the frequency of heterophoria in dyslexic patients (65.6%) was higher than the controls (46.9%) ($P=0.080$). While heterotropia was found in 3 patients with dyslexia (2 esotropia at far and 1 esotropia at near), there was no case of manifest strabismus in the non-dyslexic group. The majority of students in the dyslexic ($n=26$, 81.3%) and control ($n=28$, 87.5%) groups were orthophoric at distance ($P=0.359$). The frequency of exophoria at near in case and control groups were 21(65.6%) and 15(46.9%), respectively($P=0.080$).

Discussion

This study aimed to investigate the mean visual functions in dyslexic children versus non-dyslexic children. Farsi language, unlike many languages such as English, is written and read from right to left; therefore, it is necessary to assess visual functions in the Iranian Farsi pupils. Most dyslexia studies focus on European languages, and there is little data on Iranian dyslexic population. Therefore, studying on the ophthalmic findings not only enhances our understanding of dyslexia in Persian, but also helps to the development of better educational and therapeutic programs.

In optometry literature, the role of refractive errors in dyslexia has often been a controversial issue. Consistent with the previous findings in this study dyslexic children showed hyperopia was the most frequent in both groups with the mean value below +o.75 diopter (approximately 70% of dyslexic and control group had hyperopia in both eyes) [17, 39, 40]. Likewise, there was no significant differences in refractive errors between dyslexics and controls. Regarding visual acuity, majority of children in both groups (>90%) had 20/20 vision following correction, which was in line with many previous studies [41–43]. For example, Aasved reported that after studying 3000 first grade schoolchildren, he could not find any correlation between visual acuity and reading problems [44]. Whereas yogg et al. and OGrady highlighted that dyslexic group of children had a lower visual acuity both at distance and at near [40, 45]. The possible reasons for this inconsistency can be attributed to discrepancies in dyslexia diagnostic criteria, VA measurements methods, study designs, and samples.

In the present study the push up test was used as an useful test to assess accommodation and there was no difference between the dyslexic and control groups in terms of NPA, which was corroborated by Ygge et al. However, Wahlberg-Ramsay et al., and Evans, Drasdo and Richards experienced a reduced value of NPA in dyslexic children as opposed to control ones in their studies [15, 32, 40]. These studies stated that this reduction is likely due to deficits in the visual system, increased cognitive load, and visual fatigue. The different results in the available studies may be related to their dyslexic participants, who were selected from distinct age categories, as well as measurement tools applied various settings.

As for stereo acuity, it was found a significant disparity between the study groups so that the dyslexic children displayed higher mean values of stereo acuity than controls. The mean for stereopsis was 94.22 ± 73.60 s/arc for dyslexics while normal readers showed stereopsis 60.94 ± 12.01 s/arc. This was in contrast with findings reported by Yagg et al., Wahlberg-Ramsay et al., and Tokarz-Sawińska, Kozłowska and Karczewicz [32, 40, 46]. We can support this finding by offering an explanation.

Stereopsis is the small horizontal retinal image disparity [46]. Dyslexic individuals with reduced stereo acuity confuse the retinal images because they have defective visuomotor integration. Dyslexics could not locate letters on a page correctly and then are not able to put the retinal and macular motor signals for each eye separately so that this affects reading small letters and violate many motor skills [47, 48]. Likewise, STEIN J et al. observed that one of the most common complaints of dyslexics is that they felt letters move around. They found that this problem could stem from immature vergence control and individuals with impaired vergence control have the potential to show reduced stereo acuity [49].

Akin to the present study, the extant literature has demonstrated no association of dyslexia with latent (phoria) and manifest (tropia) deviations [15, 18, 40, 50]. But the incidence of exophoria at near was higher in both groups and a little more common in dyslexics (21 and 15 students in the dyslexic and control group, respectively). In line with the present findings, Latvala et al. reported that the exophoria type of convergence insufficiency was prevailing among children with dyslexia. They suggested the low ratio of accommodative convergence/accommodation ratio (AC/A) in dyslexia [11].

The CS score was measured by the Cambridge low-contrast test at a spatial frequency of 4 cpd under photopic condition. The dyslexic group was significantly different from the non-dyslexic group in CS for the right eye, left eye, and both eyes. The findings of the present study in line with previous reports have emphasized the presence of a contrast sensitivity deficit in dyslexic individuals [24–29]. The magnocellular theory is of the utmost importance so that almost 75% of dyslexic disorders result from a deficit in the magnocellular pathway [51]. Some studies have provided evidence in support of this theory [27, 29, 51]. Pina Rodrigues et al. in a study performed on 33 dyslexic children and 34 controls showed that dyslexics had impairment in the speed discrimination task, involving the M system, whereas no deficit was observed in the chromatic contrast sensitivity task controlled by the P system [27]. In another study, CS was investigated by Lovegrove et al. using nine stimuli with various durations at four levels of spatial frequencies (2, 4, 12, and 16 cpd) in dyslexics and controls. They found that sensitivity was lower in dyslexics than controls and the largest reduction was related to a spatial frequency of 4 cpd [26]. Additionally, Yap and Boon stated that 4 cpd is the most suitable frequency to use because it closely aligns with the peak of the normal contrast sensitivity function [52]. On the other hand, some researchers, such as Stuart et al. and Gilchrist et al., confirmed no relationship between dyslexia and spatial/temporal frequency [2, 53]. It is noteworthy that the Cambridge Low Vision Grating Test was conducted in only one orientation, and gratings in different orientations may yield different results [54]. This variation occurs because neurotypical children often exhibit a bias when processing gratings in horizontal or vertical orientations [55]. Probably, our findings put stress on a theory of the link between low-level visual functions and reading, implying the higher mechanism involving the magnocellular-dorsal (M-D) stream in reading related tasks. Since the M-D stream is identified as a selective activator for stimuli with low spatial and high temporal frequencies, and dyslexic individuals suffer from problems related to the M-D stream [56]. Most of dyslexic individuals with the poor M system present with reduced sensitivity to visual motion, are slower, and make more errors in the correct recognition of letters in words during reading [51]. In some studies, it has been revealed that the M-D stream training considerably improves reading comprehension and reading fluency in dyslexia [57] and supports a hypothesis of a causal relationship between the M-D processing deficits and dyslexia.

The finding of this study showed that there were defects in stereo acuity and contrast sensitivity in dyslexics versus controls. The reduced contrast sensitivity in dyslexic group in our study emphasized the presence of deficits in the M system and visuospatial perception in dyslexics. Indeed, further studies with detailed design are required to determine the precise role of CS in the reading process. In addition, it is recommended that visuals factors be evaluated in dyslexic individuals to recognize and treat any eye problems.

Abbreviations

ADHD	Hyperactivity disorder
BPD	Borderline personality disorder
CDVA	Corrected distance visual acuity
CS	Contrast sensitivity
NPA	Near point of accommodation

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Author contributions

Azam Darvishi and Masoud Khorrami-Nejad wrote the main manuscript text. Javad Heravian Shandiz and Davood Sobhani Rad made substantial contributions to the conception and design of the work. Negar Sangsefidi and Foroozan Narooie-Noori made contributions to data acquisition. Javad Heravian Shandiz and Davood Sobhani Rad made contributions to data interpretation. Foroozan Narooie-Noori and Masoud Khorrami-nejad have drafted the work. Azam Darvishi and Masoud Khorrami-Nejad revised the manuscript. All authors reviewed the manuscript. All authors approved the submitted version.

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Data availability
The database used and/ or analyzed during the current study is available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The protocol used in the present study was approved by the Ethical Committee of Mashhad University of Medical Sciences (IR.MUMS.REC.1395.615). The study followed the principles outlined in the declaration of Helsinki. Moreover, the procedure was explained to the participants and their parents and then informed written consent was obtained from parents or legal guardians before entering the study.

Consent for publication
Not applicable.

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