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PEDIATRICS

# Binocular function in school children with reading difficulties

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**Abstract**

*Introduction* Prior findings suggest that poor readers tend to have poor binocular vision skills, but data on the binocular abilities of children with poor reading skills are lacking. Our aim was to characterize distance and near horizontal heterophoria, distance and near horizontal fusional vergence ranges, accommodative convergence/accommodation (AC/A) ratio, near point of convergence, and stereopsis in poor-reading school-age children without dyslexia selected from a non-clinical population.

*Methods* We conducted a cross-sectional study on 87 poor readers and 32 control children (all 8-13 years of age) in grades three to six recruited from eleven elementary schools in Madrid, Spain. With best spectacle correction in each subject, distance and near horizontal heterophoria measurements were obtained using the von Graefe technique, distance and near horizontal fusional vergence ranges were obtained using Risley rotary prisms, the AC/A ratio was measured using the gradient method, near point of convergence (NPC) was evaluated by the standard push-up technique using a transilluminator, and stereoacuity was tested with the Randot stereotest.

*Results* Mean distance base-in break and base-in recovery values were nearly 2 Δ lower ($p<0.01$) in the poor readers than those recorded in the control group. However, mean distance base-out vergences (blur, break and recovery), mean distance and near horizontal heterophoria, mean near horizontal fusional vergence ranges, mean AC/A ratio, mean near point of convergence (NPC), and mean stereoacuity did not differ significantly between the poor readers and controls.

*Conclusions* This study provides information on the binocular ability of children with poor reading skills but without dyslexia. Our findings suggest reduced distance base-in break and base-in recovery, such that distance fusional vergence ranges should always be assessed in children who complain of reading difficulties.

**Keywords** Binocular function · Poor reading school-age children · Heterophoria and fusional vergence ranges · Accommodative convergence/accommodation ratio · Near point of convergence · Stereopsis

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**HUMAN SUBJECTS AND INFORMED CONSENT** The authors declare that this research was performed following the tenets of the Declaration of Helsinki, and that informed consent was obtained from the subjects after the nature of the study had been explained to them in detail. The study protocol was approved by the Clinical Research Ethics Committee of the School of Optometry.

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## Introduction

The role played by vision defects in children's reading problems remains a great concern for optometrists and educators. Children with poor reading skills include those with and without dyslexia, as well as children with a lower intellectual ability or other problems. Most analyses of the relationship between visual function and reading have examined children with dyslexia or unselected readers. However, no reports have provided visual function values for primary school-age poor-readers without dyslexia. In a recent study [1], a large number of high school-age children with poor reading skills were found to show an increased risk of visual skill dysfunction, with more poor-reading students being deficient in binocular fusion range but not in accommodative function or near point of convergence.

Several studies have indicated that children with reading and learning problems show a higher incidence of hypermetropia [2–5] and non-strabismismic binocular vision disorders than normal readers [5–7]. These anomalies include exophoria at near, vertical phoria, lowered fusional vergence reserves, aniseikonia, anisometropia, fixation disparity, and convergence insufficiency. Compromised monocular accommodative amplitude and binocular accommodative facility have been reported for a population of non-dyslexic primary school children with reading difficulties [8]. Nevertheless, other authors have found no relationship between ocular function and academic performance [9–11]. The association between visual skill level and reading outcomes is a source of controversy because of a perceived lack of scientifically rigorous evidence.

Many studies have compared the binocular abilities of school-age children with dyslexia to those of a control group. In one such study comparing 43 control and 39 children with dyslexia, the children with dyslexia had lower positive and negative vergence reserves and vergence instability when the eyes were dissociated at near [12]. In a recent report, binocular coordination during and after saccades was found to be poor in children with dyslexia compared to non-dyslexic children of matched age [13]. Moreover, primary-school-age poor readers without dyslexia show worse binocular horizontal scanning, as assessed by the Developmental Eye Movement (DEM) test, related to a slower reading speed than their normal-reading peers [14]. Another study detected a divergence deficit per se independent of convergence and accommodation relaxation in French children with dyslexia [15]. These authors suggested that the fragility of vergence control is also associated with symptoms of visual fatigue and loss of attention and interest. However, problems of vergence or strabismus were not more prevalent in Swedish children with dyslexia than in control age-matched children [16]. Most of these studies failed to indicate whether their results were adjusted for the effect of visual acuity and refractive error on binocular abilities.

Few studies conducted on primary school-age children with dyslexia have provided mean values of binocular abilities [11, 12]. Only studies in unselected readers have characterized oculomotor, accommodative, and binocular function [17–21]. Most authors have only examined certain visual variables in schoolchildren, such as near point of convergence (NPC) [22, 23], phorias [17, 20, 24], step vergence [25, 26], accommodative convergence/accommodation (AC/A) ratio [19, 27], and stereoacuity [28–30]. The literature lacks mean binocular ability data for a non-clinical population of poor–reading children without dyslexia.

We analyzed the binocular abilities of a population of non-dyslexic primary-school-age children with reading difficulties using accurate methods in an optometrist's office under well-controlled conditions. The objective of the present study was to characterize the binocular vision abilities of these children and identify any deficient binocular variables.

## Methods

*Subjects* The study population consisted of 87 poor readers without dyslexia aged 8 to 13 years (mean age 9.2 years); 30 girls and 57 boys, who at the time of the tests were in the third to sixth grades (third grade =44; fourth grade = 22; fifth grade = 15 and sixth grade = 6). The control group comprised 32 (14 girls and 18 boys) aged-matched normal readers (third grade = 11; fourth grade = ten; fifth grade = nine and sixth grade = two). The participants were recruited from eleven elementary schools in the city of Madrid, Spain, and represented a broad range of socioeconomic backgrounds. School administrations participated in the study by providing us with IQ scores and evaluations of the students' reading performance. The children had been identified as poor readers without dyslexia by their respective school psycho-educational team. For each child, the capacity to read words/pseudowords, the speed of reading, and text comprehension were evaluated using the PROLEC battery of tests for the 3rd and 4th grades [31] and PROLEC-SE for the 5th grade [32]. This is the standard test used in Spain. The test was developed by an applied psychology team, and takes into account the school grade of the child. Only children with scores below the 30th percentile in any of the reading subtests were selected by the school. Also, for a child to be eligible it was required that these scores could not be explained by dyslexia or other psycho-socio-educational or neurological problem (e.g., attention deficit hyperactivity disorder) reported by their parents.

Once the study had been approved by the administrations of the eleven schools, the parents of poor readers were asked if they wanted to participate in the project. The details of the sample recruitment procedure have been described elsewhere [8]. The examination involved a visit to the optometric clinic of the School of Optometry out of school hours.

For all subjects, the selection criteria were: a normal IQ and no dyslexia, a refractive error of less than 2.00 D of myopia or hyperopia, astigmatism less than 1.00 D, no strabismus and a best corrected visual acuity 20/20, to avoid the effect of these factors on the visual abilities evaluated. Twenty-one subjects were excluded from the study group because of: strabismus (six), amblyopia (four), a large refractive error (five), Möebius syndrome (one), misunderstanding the optometric test (two), failure to attend the examination session (two) and lack of reading problems (one).

All subjects in the study and control groups underwent a detailed optometric exam by the same experienced optometrist as part of an extensive study in which several datasets were obtained and analyzed: accommodative function [8], horizontal scanning as determined by the DEM test [14], binocular vision and perception, and reading abilities. As the optometrist knew that the subjects had been identified as poor readers by the school, efforts were made to conduct the exam as normal. The guidelines of the Declaration of Helsinki were adhered to, and the study protocol was approved by the Research Ethics Committee of the School of Optometry. All parents gave their consent to participate after the nature of the study had been explained to them.

*Clinical Measures* Binocular measurements were carried out with best distance spectacle correction when needed. Interpupillary distance was adjusted for both distances and for each subject. Each subject was compensated for possible ametropia and evaluated by non-cycloplegic static retinoscopic refraction, followed by a subjective refraction test for distance correction. Tests were administered in the same order as described below in both groups.

Distance horizontal heterophoria and distance horizontal fusional vergence ranges were measured using a phoropter with the subject's best refractive correction. Subjects viewed a vertical row of three individual, high-contrast Snellen optotypes, sized 6/7.5, 6/6.5, and 6/6 respectively, projected onto a matte white screen at a viewing distance of 6 m. Heterophoria measurements were obtained using the von Graefe technique [33–35]: a 6 Δ base-up dissociating prism was placed in front of the right eye, and horizontal oculomotor deviation was neutralized using a Risley rotary prism in front of the left eye. Three measurements of heterophoria were obtained and averaged for each subject.

Risley rotary prisms were used to evaluate distance and near horizontal fusional vergence ranges [35, 36]. Approximately equal amounts of prism were slowly introduced in front of each eye at a constant velocity (approximately 2 Δ/s) using the rotary prisms until the subject first reported horizontal diplopia (break value). The amount of prism was then increased by 3 Δ in each eye, and subsequently reduced until the subject was just able to re-fuse the diplopic images (recovery value). As recommended by Rosenfield et al. [37], distance base-in ranges were measured before base-out to avoid vergence adaptation. Although we anticipated that several subjects would fail to report target blur [37], blur base-out was assessed during the study.

Near heterophoria and near fusional vergence ranges were measured using the same technique used for far measurements. Near blur base-out and blur base-in were also assessed. A single column of letters of 20/30 equivalent at 40 cm was used as the target.

AC/A ratios were measured using the gradient method. Following measurement of near horizontal heterophoria, -1.00 D lenses were placed in front of the eyes, noting the new heterophoria value. The change in heterophoria with the additional minus is the AC/A ratio [19, 38].

Near point of convergence (NPC) was evaluated by the standard push-up technique using a transilluminator. Seated in front of the examiner, the subject was asked to visually follow the approaching light presented in free space. For the test, a ruler was held at the center of the forehead of the subject at the level of the brow (used as zero measurement point from which the NPC was taken), and a transilluminator was moved toward the patient at 1-2 cm/s. The break value was defined as the average of three measurements in which either the examiner observed one eye deviate or the subject reported diplopia, whichever occurred first. The recovery value was defined as the average of three measurements in which the subject reported regaining single vision or the examiner observed the patient making a fusional response, whichever occurred first. The break value was measured for each subject, followed immediately by the recovery measurement. The procedure was repeated two additional times, with a rest period of no more than 10 s between each test [19, 23, 39].

Stereoacuity was assessed using the Randot stereotest. The subject wore polarized filters during the testing procedure. The polarized target plate was presented and aligned perpendicular to the subject's face at a distance of 40 cm. The target plate contains simple geometric forms and the familiar E in each area except one (500"–250" of arc stereacuity at 16 in) and hybrid linear targets on a random dot background (animals: 400"–100"; circles: 400"–20" of arc stereoacuity at 40 cm) [19, 29, 40].

*Data Analysis* Statistical analysis was performed using SPSS software for Windows, version 15.00. Normality of data distribution was assessed using the Kolmogorov–Smirnov test, and the Bartlett test was used to check homogeneity of variance. Data were compared by school grade and between groups by analysis of variance (ANOVA). Wilcoxon's signed rank tests were used when the data were not normally distributed or there was inhomogeneity of variance. A *P*-value less than 0.05 were taken to denote statistical significance.

## Results

Bearing in mind the refractive errors used as selection criteria, the study group (poor readers) showed mean spherical equivalent refractive errors for the right and left eyes of 0.20±0.6 and 0.20±0.6 respectively. Fifty-seven children (65.5%) were emmetropic, five (5.7%) were myopic and 25 (28.7%) were hyperopic. Mean spherical equivalent refractive errors for the right and left eyes in the control group were -0.20±0.8 and -0.14±0.8 respectively. Twenty-one children (65.6%) were emmetropic, six (18.8%) were myopic and five (15.6%) were hyperopic.

Table 1 compares the means and standard deviations of the distance horizontal heterophoria and distance horizontal fusional vergence ranges recorded in the study group and control group, while Table 2 compares the means and standard deviations of near horizontal heterophoria, near horizontal fusional vergence ranges, AC/A ratio, near point of convergence (NPC), and stereoacuity. In both the study and control groups, ANOVA revealed no significant differences in all distance and near binocular vision variables between school grades (i.e., school grade, or age, had no effect on the binocular variables). Between the two groups, significant differences were detected in distance base-in break ($F=10.0$; $p=0.002$) and base-in recovery ($F=10.9$; $p=0.001$) values. Mean distance base-in breaks and base-in recoveries in the study group were nearly 2 Δ lower than those obtained for the control group. Mean distance base-out measurements (blur, break and recovery), mean distance and near horizontal heterophoria, mean near horizontal fusional vergence ranges, mean AC/A ratio, mean near point of convergence (NPC), and mean stereoacuity failed to differ significantly in the study and control groups.

It should be noted that several subjects were unable to appreciate a subjective blur point: distance and near positive horizontal fusional vergence-blur were reported by 22 and 12 children in the study and control groups respectively, and near negative horizontal fusional vergence-blur was reported only by 27 and eight children in the study and control groups respectively. It seems that during testing, many subjects will fail to report target blur [12, 37].

## Discussion

This study provides binocular vision values for a non-clinical population of Spanish children with poor reading skills without dyslexia. Phoropter tests were used to measure distance and near horizontal heterophorias, and distance and near horizontal vergence ranges. This method provides more accurate values than those obtained during vision screening at schools. Only a few studies have reported phoropter-determined binocular values for unselected school-age children [21] and children with dyslexia [12].

Mean horizontal heterophoria values for distance and near fixation were similar in the study and control groups (Tables 1 and 2), though slightly less exophoric than those reported by Jackson and Goss [21] using the same measuring method. However, when horizontal heterophoria was determined using the Maddox method, mean distance and near horizontal heterophoria values in unselected school-age children were more esophoric [19, 41]. Esophoric values did not differ between children with dyslexia and a control group using the Maddox method [12]. The use of a Maddox rod to measure lateral phorias has the drawback that the subject may view the

**Table 1** Means and standard deviations of distance horizontal heterophoria and distance horizontal fusional vergence ranges recorded in the study (poor readers) and control (normal readers) groups. Units for all measures are prism diopters. Positive numbers represent esophoria while negative numbers indicate exophoria. BI Blur control group $n=8$ and study group $n=27$; BO Blur control group $n=12$ and study group n=22

| Parameters | Control group ($n=32$) | Study group (poor readers) ($n=87$) |
|---|---|---|
| Phoria | −0.0±1.6 | −0.4 ±1.6 |
| BI Break [a] | 11.1±3.4 | 9.1±3.0 |
| BI Recovery [a] | 5.0±2.4 | 3.6±1.9 |
| BO Blur | 11.4±6.0 | 14.2±6.7 |
| BO Break | 17.8±6.1 | 19.0±8.3 |
| BO Recovery | 7.9±3.5 | 6.0±4.1 |

[a] Denotes statistical significance at the level 0.01.

BI = Base In; BO = Base Out.

**Table 2** Means and standard deviations of near horizontal heterophoria, near horizontal fusional vergence ranges, AC/A ratio, near point of convergence (NPC), and stereoacuity in the study (poor readers) and control groups.Units: NPC, centimeters: stereoacuity, seconds of arc; all others, prism diopters. Positive numbers represent esophoria, negative numbers represent exophoria. BO Blur control group $n$=12 and study group $n$=22

| Parameters | Control group ($n$=32) | Study group (poor readers) ($n$=87) |
|---|---|---|
| Phoria | −1.7±3.4 | −1.6±3.7 |
| BI Blur | 11.5±6.6 | 13.0±3.8 |
| BI Break | 17.6±5.7 | 18.8±4.7 |
| BI Recovery | 9.0±4.45 | 8.9±3.3 |
| BO Blur | 18.7±7.8 | 18.8±4.6 |
| BO Break | 25.1±7.2 | 26.3±7.7 |
| BO Recovery | 12.4±4.8 | 12.2±7.1 |
| AC/A | 2.8±1.7 | 2.1±1.7 |
| NPC Break | 4.3±2.3 | 3.7±3.2 |
| NPC Recovery | 7.9±3.2 | 9.1±5.2 |
| Stereoacuity | 23.8±8.6 | 25.2±11.3 |

BI = Base In; BO = Base Out.

streak of light as being closer than the light source distance, such that Maddox rod horizontal heterophorias tend to overestimate esophoria [42]. In our study, mean distance and near horizontal heterophoria values did not vary according to school grade in either the study or control groups. This has also been observed in unselected school children populations irrespective of the measurement method [19, 41].

In our group of poor readers, mean distance base-in break and base-in recovery values were nearly 2 Δ lower than those obtained in the control group or those reported by Jackson and Goss (BI break 12±3 and BI recovery 4±2 Δ) using Risley prisms in unselected children [21]. Our children with reading difficulties showed base-in break and recovery at far distance similar to persons aged 51-60 years [43]. In this previous study, we attributed these changes in the vergence system to aging effects on the extraocular muscles. It is difficult, however, to explain the BI break and recovery values recorded in the present poor-reading children. Evans [12] showed that the vergence reserve amplitude was reduced at near vision in their group with dyslexia relative to the control group. It has also been reported that children with dyslexia have poor vergence control, binocular instability [44], and limited divergence at far and near distance [15]. At distance, this divergence limitation is independent of convergence and accommodation relaxation, but a reduced divergence capacity at near distance could reflect abnormal relaxation of convergence and accommodation. In our group of poor readers without dyslexia, near divergence values did not differ significantly from those of the control group. This could be attributed to the influence of accommodation and convergence relaxation. Our subjects showed normal negative and positive relative accommodation [8], AC/A ratio and NPC values.

Mean AC/A ratios were similar in the poor readers and controls. To the best of our knowledge, only three previous studies have measured the stimulus AC/A ratio in school children [19, 27, 45]. Our AC/A ratio (2.1±1.7 poor readers vs 2.8±1.7 controls) is in agreement with that reported by Jimenez et al. and Aring et al., who used the gradient measurement method, but lower than those determined by the calculated [19, 45] or other measurement methods [27]. In children with dyslexia, the AC/A ratio was found to not differ from the ratio recorded in normal readers in the only study reporting this variable [12].

The mean near points of convergence (NPC) determined here were not significantly different between children with reading difficulties and those who had normal reading skills. Our NPC results are similar to those obtained by most authors (Table 3) who examined unselected school-age children, although estimates were made using different methods. The poor NPC break and recovery values obtained by Adler and Jimenez could be explained by the screening measurement conditions. Our NPC values did not differ significantly among the school grades examined and among poor reader and control groups, as found in similar studies [19, 23, 46]. NPC values for children with dyslexia and a control group of children were also found not to significantly differ [12].

Stability occurs in stereopsis by the time a child reaches 9 years of age [47]; adult levels of stereopsis are reached between 3 and 5 years. In our study, stereoacuity values in the poor readers were similar to those recorded in the control children. Mean stereoacuity was in line with values reported by others (Table 4) using the same measurement methods in school-age children [19, 28–30]. Further, we found no statistically significant differences between age groups, either in the poor readers or in controls. Stereoacuities ranged from 70 to 20 seconds of arc; similar values were obtained by Oduntan et al. [28] in children 6 to 12 years of age. Others studies have detected similar stereoacuity values in children with dyslexia and controls [12, 30].

**Table 3** Means and standard deviations of near point of convergence (NPC) values recorded in our study (for 87 poor readers and 32 normal readers) compared to other studies performed on unselected readers. Units: NPC, centimeters

| Author | *N* | Age | Method | Break point/recovery point |
|---|---|---|---|---|
| Hayes et al. (1998) | 297 | Kindergarten | Push-up with accommodative task (three measurements) | 3.3±2.6 / 7.3±4.8 |
| | | Third grade | | 4.1±2.4 / 8.7±4.2 |
| | | Sixth grade | | 4.3±3.4 / 7.2±3.9 |
| Rouse et al. (1998) | 206 | 8–13 | Push-up with accommodative task (three measurements) | 2.7±3.7 / 6.9±7 |
| Borsting et al. (1999) | 14 | 8–13 | Push-up with accommodative task (three measurements) | 3±2 (break point) |
| Borsting et al. (2003) | 392 | 8–15 | Penlight push-up technique | 3.9±3.9 / 6.7±5.1 |
| Jimenez et al. (2004) | 1,015 | 6–12 | Penlight push-up technique | 5.2±4.4 / 11.4±7.2 |
| Adler et al. (2007) | 20 | 6–9 | Penlight push-up technique (three measurements by the same examiner) | 6.5±5.4 / 10.9±5.6 |
| | 17 | 11–13 | | 6.3±3.5 / 11.3±4.7 |
| Maples et al. (2007) | 132 | 6 | Push-up with accommodative task (three measurements) | 2.6±2.7 / 7.0±5.9 |
| | 162 | 7 | | 3.1±6.1 / 7.9±8.4 |
| | 164 | 8 | | 2.7±3.3 / 6.9±7.2 |
| | 63 | 9 | | 3.3±6.7 / 7.1±6.7 |
| Present study | 87 | Poor readers 8–13 | Penlight push-up technique (three measurements by the same examiner) | 3.7±3.2 / 9.1±5.2 |
| | 32 | Controls 8–13 | | 4.3±2.3 / 7.9±3.2 |

In a previous study conducted on the same population, we reported reading speed values that were significantly related to horizontal DEM times [14]. However, no significant correlation between reading speed and binocular abilities was detected here.

The present study provides data on the binocular abilities of a population of children with poor reading skills. According to our findings, poor readers show reduced distance base-in vergence, as has been found in children with dyslexia [15]. Distance and near base-out vergence, near base-in vergence, AC/A ratio, near point of convergence, and stereopsis values were similar to those obtained in an unselected reader population or in children with dyslexia. It has been suggested that monocular occlusion seems to help children with dyslexia and unstable binocular fixation to gain stability more quickly [48]. It is important to identify any divergence limitation early on so that, through training, convergence and divergence subsystems can be balanced to reduce the symptoms of visual fatigue and loss of attention and interest that often occur in children with reading difficulties. This has been suggested by Kapoula et al. [15]. Although there are no data to support this proposal, it has been observed that orthoptic training may improve some oculomotor abnormalities in children with vertigo [49, 50]. Future work should include well-conducted studies in

**Table 4** Mean stereoacuity values obtained in our study compared to other studies. Units: stereoacuity, seconds of arc.

| Author | *N* | Age | Stereoacuity |
|---|---|---|---|
| Buzzelli (1991) | 13 | Normal readers 13 | 24±8.77 |
| | 13 | Children with dyslexia 13 | 23.46±15.46 |
| Evans et al. (1994) | 43 | Normal readers 7–12 | 20 (median) |
| | 38 | Children with dyslexia 7–12 | 25 (median) |
| Oduntan et al. (1998) | 791 | 6-12 | 25.32±9.93 |
| Kulp & Schmidt (2002) | 36 | 8-9 | 25 (median) |
| Jimenez et al. (2004) | 1,016 | 6-12 | 25±10 |
| Present study | 87 | Poor readers 8–13 | 25.2±11.3 |
| | 32 | Normal readers 8–13 | 23.8±8.6 |

poor-reading children designed to assess the impacts of visual therapy on reading tasks.

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