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Slow reading in children with anisometropic amblyopia is associated with fixation instability and increased saccades

Krista R Kelly, PhD^a, Reed M Jost, MS^a, Angie De La Cruz, BS^a, Lori Dao, MD^b, Cynthia L. Beauchamp, MD^b, David Stager Jr, MD^c, and Eileen E Birch, PhD^{a,d}

^aRetina Foundation of the Southwest, Dallas, Texas

^bABC Eyes Pediatric Ophthalmology, PA, Dallas, Texas

^cPediatric Ophthalmology & Adult Strabismus, PA, Plano, Texas

^dDepartment of Ophthalmology, UT Southwestern Medical Center, Dallas, Texas

Abstract

Background—Previous studies show slow reading in strabismic amblyopia. We recently identified amblyopia, not strabismus, as the key factor in slow reading in children. No studies have focused on reading in amblyopic children without strabismus. We examined reading in anisometropic children and evaluated whether slow reading was associated with ocular motor dysfunction in children with amblyopia.

Methods—Anisometropic children (7–12 years) with or without amblyopia were compared to age-similar normal controls. Children silently read a grade-appropriate paragraph during binocular viewing. Reading rate (words/min), number of forward and regressive saccades (per 100 words) and fixation duration were recorded with the ReadAlyzer. Binocular fixation instability was also evaluated (EyeLink 1000).

Results—Amblyopic anisometropic children read more slowly ($n = 25$; mean with standard deviation, 149 ± 42 words/min) than nonamblyopic anisometropic children ($n = 15$; 196 ± 80 words/min; $P = 0.024$) and controls ($n = 25$; 191 ± 65 words/min; $P = 0.020$). Nonamblyopic anisometropic children read at a comparable rate to controls ($P = 0.81$). Slow reading in amblyopic anisometropic children was correlated with increased forward saccades ($r = -0.84$, $P < 0.001$), increased regressive saccades ($r = -0.85$, $P < 0.001$), and fellow eye instability during binocular viewing ($r = -0.52$, $P = 0.019$).

Conclusions—Slow reading in school-age children with anisometropic amblyopia is related to increased frequency of saccades and fixation instability of the fellow eye. Further research should consider the effects of slower reading on academic performance.

Correspondence: Krista R. Kelly, PhD, Crystal Charity Ball Pediatric Vision Evaluation Center Retina Foundation of the Southwest, 9600 N. Central Expressway, Suite 200, Dallas, TX 75231 (kkelly@rfsf.org).

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Amblyopia is the leading cause of monocular visual impairment in children, affecting 3%, or 1–2 children in every classroom in the United States.¹ Previous studies have shown that amblyopia slows reading in adults and school-age children compared with visually normal controls, even under binocular viewing conditions.^{2–5} However, these studies focused on strabismic amblyopia only and used non-natural conditions of either oral reading of one-line sentences or silent reading of text projected on large screens at a far distance. We recently assessed natural, silent reading of grade-appropriate printed paragraphs during binocular viewing in amblyopic children.⁶ Reading rate was slower in amblyopic children, regardless of type (strabismic and combined mechanism vs anisometropic), compared with nonamblyopic children treated for strabismus and normal control children. This finding points to amblyopia, and not strabismus, as the key factor in slow reading in school-age children.

Reading is a vision-reliant ability that requires a coordinated sequence of eye movements, including saccades to move the eyes forward and backward (regressive saccades) through lines of text.^{7,8} Fixations, or pauses, also occur during reading as decoding of phonemes occurs. Ocular motor dysfunction is a hallmark of amblyopia; abnormal saccade initiation and execution⁹ and fixation instability are often present,^{10–13} particularly in the amblyopic eye. Thus, it is likely that slow reading in amblyopic children is at least in part due to associated ocular motor dysfunction. Data showing that slow reading in strabismic amblyopia is related to making more saccades than controls support this hypothesis.^{2,3,6} Other studies of eye movements in normally sighted¹⁴ and visually impaired^{15,16} adults have reported an association between fixation instability and slower reading. However, no studies have assessed the relationship between ocular motor dysfunction and reading in amblyopic children without strabismus (ie, anisometropic amblyopia).

This study examined the relationship between reading rate and ocular motor dysfunction in amblyopic anisometropic children. Using the ReadAlyzer eye movement recording system (Compevo AB, Stockholm, Sweden), children silently read grade-appropriate text during binocular viewing. Binocular fixation instability was also assessed. Consistent with our previous study,⁶ we predicted that, compared with normal control children and nonamblyopic anisometropic children, amblyopic anisometropic children would be slower at reading because of more forward saccades during reading. We further predicted that slow reading in amblyopic anisometropic children would be correlated with fixation instability.

Subjects and Methods

The research protocol observed the tenets of the Declaration of Helsinki, was approved by the Institutional Review Board of the University of Texas Southwestern Medical Center and conformed to the requirements of the US Health Insurance Portability and Accountability Act of 1996. Informed consent was obtained from a parent or legal guardian and assent was obtained from children 10 years of age prior to testing and after explanation of the nature and possible consequences of the study.

A total of 75 school-age children (7–12 years) treated for anisometropia were diagnosed and referred to the Retina Foundation of the Southwest by 18 pediatric ophthalmologists in the

Dallas-Fort Worth area. Diagnosis, refractive error, ocular alignment motility, and cycloplegic refraction were obtained from medical records. Anisometropia was defined as the presence of a 1.00 D interocular difference in spherical equivalent or 1.50 D interocular difference in astigmatism in any meridian with no measurable heterotropia at distance or near fixation. Amblyopia was defined as an interocular difference in visual acuity of 0.2 logMAR, best-corrected visual acuity in the nonpreferred eye of 0.2 logMAR (20/32), and best-corrected visual acuity in the preferred eye of 0.1 logMAR (20/25). A group of age-similar, normal control children were also enrolled who had normal visual acuity, normal stereoacuity, and no history of vision disorders. Exclusion criteria were prematurity 8 weeks, coexisting ocular or systemic disease, congenital infections/malformations, and developmental delay. Children diagnosed with dyslexia, enrolled in school reading intervention programs, or enrolled in speed reading programs were excluded. English was the primary language for all children.

Study Procedure

Monocular best-corrected visual acuity was obtained using the electronic Early Treatment Diabetic Retinopathy Study (e-ETDRS) protocol.^{17,18} Stereoacuity was assessed using the Randot Preschool Stereoacuity and Stereo Butterfly Tests (Stereo Optical Inc, Chicago, IL).

Our reading protocol has previously been published.⁶ Reading was assessed during binocular viewing using the Readalyzer, an infrared eye movement recording system mounted in goggles worn over the child's habitual optical correction. The child sat eye level at a comfortable, habitual reading distance (35–40 cm) and was required to silently read paragraphs of text from a booklet that averaged 12 lines and 100 words per paragraph. The child first read a grade level 1 passage that served as a practice run then a passage at the last grade level completed. Ten yes/no comprehension questions followed each reading. Recordings were considered acceptable for analyses if comprehension was 80% and tracking reliability was 70%. Tracking reliability may be lowered by 5% artifact time, excessive blinking, too much head movement, and occlusion of one infrared sensor by glasses frames. Outcome measures obtained from the Readalyzer recordings were reading rate (words per minute), number of forward saccades (per 100 words), number of regressive saccades (per 100 words), and mean fixation duration (seconds).

Fixation instability during binocular viewing was obtained using a 500 Hz remote video binocular eye tracker (EyeLink 1000; SR Research, Ontario, Canada) at a viewing distance of 115 cm. Monocular calibration was achieved by presenting a small dot (0.3°) on the screen at 0° and ± 10° vertically and horizontally. Following successful calibration, the child fixated on the small dot in the center of the screen for 20 secs during binocular viewing. Fixation instability was defined by the size of the bivariate contour ellipse area, an area within which 68% of all the x,y coordinates of the approximately 10,000 samples of fixation position that occurred during the 20-second period.¹⁹

Statistical Analyses

Statistical significance of differences among groups (amblyopic anisometropia, nonamblyopic anisometropia, normal control) in reading rate, number of forward saccades,

number of regressive saccades, and fixation duration were evaluated using a one-way analysis of variance (ANOVA). Significant ANOVAs were followed with post hoc pairwise comparisons. Nonparametric Kruskal-Wallis ANOVAs were used to determine group differences for grade completed and comprehension. For amblyopic children, Pearson r correlations were conducted to determine relationships of reading rate with ocular motor measures (number of forward saccades, number of regressive saccades, fellow and amblyopic eye fixation instability during binocular viewing).

Results

Data from 2 children (normal control = 1, amblyopic anisometropia = 1) were excluded in the analysis because of <80% comprehension, and from 8 children (normal control = 3, amblyopic anisometropia = 3, nonamblyopic anisometropia = 2) because of <70% tracking reliability. Low tracking reliability was due to either excessive head movement and/or glasses (occlusion of infrared tracker, bifocals). A total of 65 children met the comprehension and tracking reliability criteria; 25 amblyopic anisometropic children (mean age, standard deviation [SD], 9.8 ± 1.4 years), 15 nonamblyopic anisometropic children (mean age, 10.1 ± 1.8 years), and 25 normal controls (mean age, 9.7 ± 1.5 years). Descriptive statistics for anisometropic and control children for last grade completed, comprehension, and nonpreferred eye visual acuity are provided in Table 1. (See eTable 1 for individual patient information for amblyopic children.)

With regard to sex, no difference in reading rate was found for amblyopic anisometropia, nonamblyopic anisometropia, or normal control groups (P values = 0.07). Groups did not differ in last grade completed ($H_{2,65} = 1.89$, $P = 0.40$) or comprehension ($H_{2,65} = 0.50$, $P = 0.78$).

Reading rate was significantly different among the three groups of children ($F_{2,62} = 3.85$, $P = 0.027$; Figure 1). Amblyopic anisometropic children read 24% slower (mean, 149 ± 42 words/min) than nonamblyopic anisometropic children (mean, 196 ± 80 words/min; $P = 0.024$), and 22% slower than normal control children (mean, 191 ± 65 words/min; $P = 0.020$). Nonamblyopic anisometropic children and normal control children did not differ significantly in reading rate ($P = 0.81$). For nonamblyopic anisometropic children, there was no significant difference in reading rate between those who were previously amblyopic ($n = 9$; mean, 194 ± 66) and those who were never amblyopic ($n = 6$; mean, 199 ± 105 ; $t_{13} = 0.12$, $P = 0.91$).

The number of forward saccades was significantly different among the three groups ($F_{2,62} = 5.37$, $P = 0.007$; Figure 1). Amblyopic anisometropic children made significantly more forward saccades (mean, 111 ± 26 forward saccades/100 words) than nonamblyopic anisometropic children (mean, 94 ± 25 forward saccades/100 words; $P = 0.040$) and normal control children (mean, 88 ± 26 forward saccades/100 words; $P = 0.002$). Nonamblyopic anisometropic children and normal control children did not differ significantly in the number of forward saccades ($P = 0.52$).

The number of regressive saccades did not differ significantly between groups (mean, 24 ± 13 regressive saccades/100 words for amblyopic anisometropic children; 19 ± 11 regressive saccades/100 words for nonamblyopic anisometropic children; 17 ± 9 regressive saccades/100 words for normal control children; $F_{2,62} = 2.92$, $P = 0.06$; Figure 1). Mean fixation duration did not differ significantly between groups (mean, 0.32 ± 0.03 seconds for amblyopic anisometropic children; 0.31 ± 0.06 seconds for nonamblyopic anisometropic children; 0.33 ± 0.06 seconds for normal control children; $F_{2,62} = 1.29$, $P = 0.28$; Figure 1).

Prior to conducting correlational analyses for reading rate and ocular motor measures, possible modifying variables of slow reading (grade completed, amblyopic eye best-corrected visual acuity, stereoacuity) were evaluated for amblyopic anisometropic children. There was no significant correlation between reading rate and last grade completed ($n = 25$; $r = 0.35$; $P = 0.09$; 95% CI, -0.05 to 0.65), amblyopic eye best-corrected visual acuity ($n = 25$; $r = -0.06$; $P = 0.78$; 95% CI, -0.44 to 0.34), or stereoacuity ($n = 25$; $r_s = 0.22$; $P = 0.28$; 95% CI, -0.19 to 0.57).

In the amblyopic anisometropic group, reading rate was significantly correlated with the number of forward saccades ($n = 25$; $r = -0.84$; $P < 0.001$; 95% CI, -0.93 to -0.67), number of regressive saccades ($n = 25$; $r = -0.85$; $P < 0.001$; 95% CI, -0.93 to -0.69), fellow eye fixation instability during binocular viewing ($n = 20$; $r = -0.52$; $P = 0.019$; 95% CI, -0.78 to -0.10). See Figure 2. Reading rate was not significantly correlated with amblyopic eye fixation instability during binocular viewing ($n = 20$; $r = -0.32$; $P = 0.17$; 95% CI, -0.67 to 0.14).

Discussion

Reading rate was significantly slower in amblyopic anisometropic children compared with nonamblyopic anisometropic children and normal controls. Slow reading was related to ocular motor dysfunction. The relationship of reading rate and the number of saccades is consistent with previous studies of reading in strabismic amblyopia^{2,3,6} and with simulated central scotomas.²⁰ The increase in saccades during reading in our study may be due to a suppression scotoma associated with anisometropic amblyopia.²¹ Central scotomas have been shown to reduce the visual span, and they may cause inaccurate, more frequent saccades during reading.²²

Fellow eye fixation instability was also related to slower reading in amblyopic anisometropic children. Fellow eye fixation instability increases with poorer amblyopic eye acuity.^{12,13} Fixation instability is related to slower reading in adults with macular disease.^{15,16,22} In the present study, reading rate was associated with fellow eye instability, not with amblyopic eye instability, during binocular viewing conditions. Fixation instability may decrease the accuracy of forward saccades, causing the reader to miss the preferred landing position of the eye, the center of the word.²³ In turn, this may require secondary forward and regressive corrective saccades to acquire the optimal position.⁹ Because amblyopic anisometropic children showed a significant increase in the number of forward but not regressive saccades compared with controls, it is likely that they are most often undershooting the preferred

landing position with their primary saccade. The Readalyzer may not differentiate between secondary corrective saccades and primary saccades during reading.

There is evidence that dyslexia, a language-based learning disability that affects reading, is associated with substantially longer fixation duration (during which phoneme decoding occurs) and a large increase in regressive saccades used to recheck words for decoding.^{24,25} Altered eye movements during reading in dyslexia are secondary to the impairment in the phonological decoding of text.²⁴ In our study, there were no group differences in fixation duration and or the number of regressions, indicating that slow reading in amblyopic anisometropic children was due to amblyopia and its associated ocular motor dysfunction, rather than a learning disability.

Consistent with our previous study,⁶ the lack of relationship between reading rate and amblyopic eye visual acuity suggests that the presence, not severity, of amblyopia was sufficient to cause slower reading in anisometropic children. This is also supported by the finding that nonamblyopic anisometropic children read at a similar rate compared with controls, especially since 9/15 children in this group were previously amblyopic. This finding is encouraging as it suggests that treatment of amblyopia can remediate reading speed without the need for eye movement-specific interventions. Nonetheless, our range of amblyopia was moderate (0.2–0.7 logMAR [20/32–20/80] best-corrected visual acuity), and our study may not have been sufficiently powered to ascertain any relationship with acuity. Therefore, it is possible that slower reading may be related to severity of the visual acuity deficit. Future studies should include a larger range of amblyopic eye visual acuity.

In conclusion, reading is fundamental to academic achievement and slow reading can hinder academic success. Slower reading in amblyopic anisometropic children appears to be a consequence of ocular motor dysfunction; yet, parents of amblyopic children may be unaware that their child's reading could be affected by amblyopia and the associated ocular motor dysfunction because the child has 20/20 vision in the fellow eye. Whether recovery of normal visual acuity with amblyopia treatment improves reading speed is yet to be determined. Academic performance associated with longer times for reading warrants further study.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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FIG 1.

Bar graphs depicting group means for reading rate, number of forward saccades, number of regressive saccades, and fixation duration for amblyopic anisometropic children (light gray bars), nonamblyopic anisometropic children (white bars), and normal control children (dark gray bars). Amblyopic anisometropic children were significantly slower at reading and produced more forward saccades compared with nonamblyopic anisometropic children and normal control children. No significant group differences were found for number of regressive saccades or fixation duration. Error bars represent $\pm$ standard error of the mean. * $P < 0.05$; ** $P < 0.01$.

FIG 2.

Scatterplots depicting significant correlations between reading rate and ocular motor outcomes measured with the Readalyzer during binocular reading (no. forward saccades, no. of regressive saccades), fellow eye fixation instability during binocular viewing and amblyopic eye best-corrected visual acuity for amblyopic anisometropic children.

Table 1

Last grade completed, comprehension, and best corrected visual acuity for amblyopic anisometropic children, nonamblyopic anisometropic children, and normal control children

Group	Age, years	Last grade completed	Comprehension, %	Non-preferred eye BCVA, logMAR ^a
	Mean $\pm$ SD (range)	Mean $\pm$ SD (range)	Mean $\pm$ SD (range)	Mean $\pm$ SD (range)
Amblyopic anisometropia (n = 25)	9.8 $\pm$ 1.4 (7.7–12.4)	3.2 $\pm$ 1.4 (1–6)	91 $\pm$ 8 (80–100)	0.4 $\pm$ 0.1 [20/50] (0.2 to 0.7)
Nonamblyopic anisometropia (n = 15)	10.1 $\pm$ 1.8 (7.4–12.9)	3.7 $\pm$ 1.6 (1–6)	91 $\pm$ 8 (80–100)	0.0 $\pm$ 0.1 [20/20] (–0.1 to 0.2)
Normal control (n = 25)	9.7 $\pm$ 1.5 (7.4–12.5)	3.0 $\pm$ 1.5 (1–6)	93 $\pm$ 7 (80–100)	–0.1 $\pm$ 0.1 [20/16] (–0.1 to 0.1)

BCVA, best-corrected visual acuity; LogMAR, logarithm of the minimum angle of resolution; SD, standard deviation.

^aFor nonamblyopic anisometropic children, either the previously amblyopic eye or the right eye (if the child was never amblyopic) is listed for nonpreferred eye visual acuity. For normal control children, the right eye is listed for nonpreferred eye visual acuity.