Reading Speed In School-Age Children With Intermittent Exotropia: Evaluated With International Reading Speed Texts

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Research Article

Keywords: Reading performance, school-age children, intermittent exotropia, International Reading Speed Texts

Posted Date: February 25th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1363508/v1>

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Abstract

Purpose: Reading speed in intermittent exotropia (IXT) children has been minimally examined. We assessed reading speed in school-age children with IXT and determined clinical characteristics of IXT that impacted their reading ability.

Methods: A total of 63 school-age (10-16 years) children with intermittent exotropia and a group of 44 age-matched normal children were recruited. All children underwent ophthalmologic and binocular function evaluations. Reading speed was assessed with the International Reading Speed Texts (IReST). We compared reading speed of children with IXT to that of normal counterparts. In addition, the correlation between reading speed and clinical characteristics of IXT (i.e., angle of deviation, binocular function, fusion control) were evaluated.

Results: Reading speed in children with IXT (231 ± 51 CPM) was much slower than their normal counterparts (257 ± 33 CPM, $p=0.002$). For further analysis, we divided the group of IXT patients into slow and non-slow reading groups. The average reading speed in the Slow group was significantly slower than that in the Non-slow group (158 ± 25 CPM vs. 250 ± 37 CPM, $p < 0.001$). After adjusting for the age and gender, we found a significant correlation between the LogTNO and reading speed in IXT group ($r=-0.244$, $p=0.054$). Age, gender and LogTNO were found to be factors associated with reading speed in children with IXT based on a generalized linear model.

Conclusion: Our finding suggests that reading speed was slower in school-age children with IXT assessed with the International Reading Speed Texts. When age and gender were adjusted, poor stereo function at near was found to be related with a slower reading speed, and the stereoacuity at near was found to be associated with reading speed in children with IXT.

Introduction

Intermittent exotropia (IXT) is the most common type of divergent strabismus in children and adolescents¹. The prevalence of IXT varies in different regions; incidence rates in children are 1% in the United States² and 3–4% in Asia^{3,4}. Individuals with IXT are able to maintain ocular alignment and binocular vision for a period of time. However, an abrupt outward deviation of one eye can occur intermittently, thereby disrupting the intact binocular vision⁵. IXT has shown to impact the quality of life for children, including the performance of reading perceived by themselves and their family^{6, 7}, which can be important for a successful academic performance in school-age children.

Previous studies show inconsistent results regarding the reading speed of individuals with strabismus. For instance, Kelly et al (2015) and Birch et al. (2019) reported that strabismus do not reduce reading speed in children with strabismic amblyopia⁸⁻¹⁰. On the other hand, Perrin Fievez et al. (2018) found that strabismus can directly slow the reading rate in children, who either had an impaired eye movement, poor coordination of binocular saccade coordination or the loss of binocular vision¹¹⁻¹³.

Studies on reading performance of children with IXT have been relatively minimal. Since the children with IXT could maintain ocular alignment for some period, the effect of IXT on reading could be obscure. To illustrate, Hirota et al. (2016) used video-oculography to assess the eye movement of eight patients with convergence insufficiency-type IXT and ten normal observers during reading¹⁴. They found a significant saccadic disconjugacy in the patients. Moreover, the patients often found themselves to be reading the same lines repeatedly, thereby increasing the duration of fixation. However, reading speed was not directly measured in the study¹⁴. In a subsequent study, Hirota et al. (2018) recruited 11 patients (aged 13–40 years) with IXT and 15 normal observers to study the relationship between binocular coordination and reading performance using video-oculography¹⁵. They recorded eye movement while the participants read passages from a smartphone at viewing distances of 20, 30 and 50 cm. The proportion of monocular and binocular viewing were also measured from the subjects. They found that the patients had a reduced reading speed and a higher proportion of monocular viewing than the normal controls¹⁵. This phenomenon was more common at a near (i.e. 20 cm) than for viewing distance of 50 cm. In addition, Lions et al. (2013) recorded binocular eye movements using an infrared system (mobile EBT) in 18 strabismic children (including 7 IXT patients) who had been asked to read a four-line text silently (i.e., without verbalizing the text)¹⁶. They found that the strabismic children had a disrupted binocular saccade coordination, which worsened their reading ability, and a longer duration of fixation during reading. These studies show that abnormal ocular alignment in IXT patients could adversely affect the reading performance⁹.

However, the findings of the previous studies on reading performance in IXT cannot be generalized to a large clinical population for several reasons. First, these studies have a small sample size. Second, they combine multiple types of strabismus into one treatment group rather than having a separate group for each type of strabismus. Third, reading materials in the previous studies are different and not standardized. For these reasons, reading performance in IXT and the relationship between reading performance and the severity of IXT remain unclear.

In this study, we aimed to resolve the issues of these previous studies by having a large sample size and employing a standardized reading test to assess reading speed in children with IXT and age-matched normal controls. We used the International Reading Speed Texts (IReST). IReST contains linguistically standardized passages (around 130–150 words per text). It mimics the level of reading from daily life, and has similar content and linguistic features in 17 different languages¹⁷. Furthermore, we examined the relationship between the severity of IXT and reading speed of the IXT patients.

Patients And Methods

Participants

63 children with IXT (age range: 10–14 years, including 34 males and 29 females) and 44 cases of age-matched children without strabismus (age range: 10–14 years, including 23 males and 21 females) were enrolled in the study. All subjects gave their assent and a parent gave informed consent.

This prospective case-control study was approved by the ethics committee of the Eye Hospital of Wenzhou Medical University and conformed to the Declaration of Helsinki. All participants were enrolled in the Department of Strabismus from our hospital from June to September 2020. The eligibility criteria were: (1) IXT with a deviation at least 20 prism diopter (PD) at near and distance, (2) an age range of 10–14 years (at least grade 4), (3) normal vision with a best correct visual acuity (BCVA) better than 20/20, (4) no significant anisometropia, (5) no history of eye surgery or binocular vision training. The exclusion criteria were: (1) anisometropia (spherical equivalent difference ≥ 2.0 diopters), (2) amblyopia (best correct visual acuity < 0.8 , or ≥ 2 lines interocular difference by Snellen's vision chart), (3) binocular vision therapy or extraocular muscle surgery history, (4) convergence insufficiency-type IXT (deviation at near larger than at distance for at least 10 PD), (5) a history of surgery for strabismus or other eye disease, such as dyslexia, etc. Age-matched children were enrolled who had normal eye conditions with a possible exception of refractive error.

Clinical evaluation

The following data were recorded for each patient: gender, age, BCVA, angle of deviation, control of the fusion and the binocular function, including the sensory (sensory fusion, stereoacuity) and motor function (fusional vergence amplitude, amplitude of accommodation and accommodative flexibility). The angle of deviation was measured by a prism and alternate cover test (PACT) at near (1/3 m) and far viewing distances (6 m). An office-based scale was used to assess fusion control in IXT patients three times (before examination, before and after the reading task) and the average was obtained as the fusional control score, which ranged from 0 to 5. A high control score indicated a poor control of exodeviation¹⁸. Sensory fusion was evaluated using Worth's 4-dot test at near and far viewing distances. An abnormal sensory fusion was defined when patients reported 2 or 3 dots, or 5 dots. A near stereoacuity was assessed using the TNO test (Lameris Instrumenten, Groenigen, Netherlands, 17th Edition). The scores ranged from 15 to 480 seconds of arc (arcsec). Distance stereoacuity was assessed using the Distance Randot Stereo test (DRS, American Stereo Optical Company); the scores ranged from 63 to 400 arcsec. The scores were transformed into log units for statistical analysis. Stereoacuity was recorded as "nil" if patients did not pass the test at the largest disparity, and was assigned to the next level of the logarithmic scale, i.e. 960 arc seconds for TNO and 800 arc seconds for RDS¹⁹.

Fusional vergence amplitudes were measured with a horizontal prism bar while the participants fixated on an accommodative target at near (1/3 m) and far viewing distances (6 m). The base-out prism was gradually increased for a positive vergence (BO) and the base-in prism was gradually increased for a negative vergence (BI). The patients were asked to identify the point at which the target image appeared to be doubled; this prism power was designated as the breakpoint²⁰. BI was first measured before BO to avoid errors caused by the prism requirement of a positive fusion vergence.

Near point of convergence (NPC): Participants were asked to focus on an accommodative target at 40 cm. The target was gradually moved closer to the eyes until they saw double images. The distance between the parallel point of the patient's lateral canthal and the break point was the NPC.

Accommodative flexibility (AF): Participants were asked to read the "E" visual acuity chart at 40 cm with a ± 2.00 D flipper. During the clinical assessment, the patients were asked to focus on letters of the chart. After reading the letter successfully, they were asked to turn the flipper and focus on the next letter. This procedure was performed consecutively for 1 minute.¹⁴

Reading material

The International Reading Speed Texts (IReST) is a standardized test to assess reading speed. The IReST is printed on white paper at a high contrast, with a letter-size of 10-point Times New Roman font. The level of difficulty is appropriate to children who are 10-12 years old and has been linguistically standardized²¹. It was first developed in Europe and has been translated to 17 different languages. The Chinese version of IReST consists of 10 essays, each of which contains 153 words. The Chinese version of IReST has been proved useful for assessing reading performance²².

Procedures

The Chinese version of international reading speed texts was performed under the same viewing and luminance conditions for all subjects. The participants were asked to be seated comfortably in front of a desk on which the reading card was placed at a distance of 40 cm. Participants were instructed to read each text, loudly and as quickly as possible. Reading speed was measured using a stopwatch that began its count when the participants began to read the first word of each text and stopped when they read the last word. Words read incorrectly or missed were also counted. The reading speed, in character per minute, was calculated using this formula (words read correctly/seconds) * 60 = character count per minute (CPM)²³. During the training of the reading test, participants were asked to read Text 5 first, then, they received instruction that explained the test procedure. Then, for the actual experiment, they were asked to read out loud Texts 1 and 6. The average reading speed across those from Texts 1 and 6 was then taken as the reading speed of the subjects.

Data analysis

Patients with IXT were divided into two groups based on the reading speed of children. The reading speed was categorized as slow group (< 189CPM) and non-slow group (≥ 189 CPM) (we defined the mean reading speed of normal children ± 2 SD of controls as the normal range, and anyone less than mean - 2SD as slow, so that would be 189CPM). The statistical analysis was performed using SPSS software for Windows version 25.0 (SPSS Inc, Chicago, Illinois, USA). Difference of reading speed and basic data in IXT and normal control was compared with an independent t-test. The differences in Slow and Non-slow groups in IXT were analyzed by independent t-test and Mann-Whitney U test were used. A Spearman correlation test was used to calculate the correlation coefficient between the reading speed and the severity of IXT. A generalized linear model was used to evaluate factors associated with the reading speed in IXT. We select reading speed as the dependent variable, gender as a factor, other parameters such as deviation angle and control score were used as covariables. The results of the generalized linear model suggest that age and gender are related to reading speed. Therefore, we did a partial correlation analysis after controlling for age and gender. A p-value < 0.05 was deemed as statistically significant.

Results

Comparison of binocular functions between children with IXT and normal controls

63 children with IXT and 44 cases of age-matched normal children were enrolled in the study. No significant difference in age and gender between the IXT group and the normal control (Table 1). Table 1 shows that the IXT group had a poor binocular function than normal control children; this is represented by convergence reserve (BO), negative vergence (BI), sensory fusion, near point of convergence (NPC). Near stereoacuity (LogTNO) and distance stereoacuity LogRDS were worse in IXT than that in normal ($p < 0.05$).

Table 1
Clinical characteristics of 107 subjects

Parameter	IXT(n = 63)	Control(n = 44)	P value
Age (year,mean(SD))	11.5 ± 1.2	11.2 ± 1.0	0.12
Gender (male:female)	34:29	23:21	0.863
NPC (cm)	5.7 ± 3.6	4.3 ± 1.7	0.002
PRA (diopter)	7.2 ± 1.5	6.5 ± 1.7	0.021
AF (circle/min)	7.4 ± 3.5	7.1 ± 3.3	0.410
BI@N (prism diopter)	21.7 ± 10.9	15.0 ± 5.2	< 0.001
BO@N (prism diopter)	17.0 ± 11.7	28.4 ± 9.69	< 0.001
BI@D (prism diopter)	12.4 ± 10.0	11.2 ± 5.5	0.07
BO@D (prism diopter)	8.8 ± 10.1	20.0 ± 11.6	< 0.001
Abnormal sensory fusion@N	26.70%	0	
Abnormal sensory fusion@D	63.30%	0	
LogTNO	2.26 ± 0.44	2.15 ± 0.39	0.05
LogRDS	2.36 ± 0.45	2.21 ± 0.47	< 0.001
Reading speed in text1 (CPM)	228.7 ± 51.7	254.4 ± 33.6	0.003
Reading speed in text6 (CPM)	233.4 ± 53.0	259.1 ± 37.0	0.008
Average reading speed (CPM)	231.0 ± 51.2	256.8 ± 33.2	0.002
NPC = near point of convergence; PRA = positive relative accommodative			
BI = base in prism power for fusional vergence amplitudes;			
BO = base out prism power for fusional vergence amplitudes;			
AF = accommodative facility; CPM = character per minute; *p < 0.05 statistically significant			

Comparison of reading speed between children with IXT and normal controls

Interestingly, we found that the average reading speed in the IXT group was 231 ± 51 CPM, whereas that in the normal control group was 257 ± 33 CPM. There was a significant difference between the reading speeds of the two groups ($p = 0.002$). There was no significant difference in reading speed between Texts 1 and 6, both in the IXT group ($p = 0.865$) nor in the control group ($p = 0.735$). Reading speed was significantly correlated with age both in IXT ($r = 0.49$, $p < 0.001$) and normal controls ($r = 0.42$, $p = 0.005$) (Fig. 1). Interestingly, male's reading speed was significant faster than that of females in IXT group ($p = 0.03$), while it was not so in normal control ($p = 0.32$).

In our study, 69.8% (46/63) IXT patients had a slower mean reading speed than the normal children. Furthermore, based on the normal mean reading speed, we divided the IXT group into Slow and Non-slow group. 13 patients were defined as the Slow reading group (158 ± 25 CPM) and 50 patients were defined as Non-slow reading group (250 ± 37 CPM) (Table 2).

Table 2
Comparison of slow and non-slow reading group in IXT patients

Parameter	Slow group (n = 13)	Non-slow group (n = 50)	P
Age	10.5 ± 0.8	11.8 ± 1.2	< 0.001
Gender (male:female)	4:9	30:20	0.06
Average reading speed (CPM)	158 ± 25	250 ± 37	< 0.001
Reading speed in text1 (CPM)	157 ± 22	247 ± 39	< 0.001
Reading speed in text6 (CPM)	159 ± 32	253 ± 38	< 0.001
Deviation angle @N (PD)	34.8 ± 13.6	35.3 ± 12.4	0.89
Deviation angle @D (PD)	31.2 ± 11.9	32.5 ± 12.3	0.73
Fusional control score @N	1(1, 3)	1(0, 2)	0.52
Fusional control score @D	3(1.5, 4)	2(1, 4)	0.57
BO @N (PD)	12(4, 20)	16(11, 25)	0.10
BO @D (PD)	2(2, 9)	6(2, 12)	0.23
LogTNO	2.17 ± 0.41	2.28 ± 0.45	0.42
LogRDS	2.17 ± 0.34	2.41 ± 0.47	0.09
NPC	4.8 ± 3.0	6.0 ± 3.8	0.30
AF (circle/min)	7.0 ± 4.4	7.5 ± 3.3	0.66
Abnormal sensory fusion @N	31% (4/13)	22% (11/50)	0.51
Abnormal sensory fusion @D	62% (8/13)	62% (31/50)	0.98
NPC = near point of convergence			
BI = base in prism power for fusional vergence amplitudes			
BO = base out prism power for fusional vergence amplitudes			
AF = accommodative facility			
CPM = character per minute			

Comparisons of clinical characteristics between IXT patients with slow or non-slow reading speed

The average reading speed in the Slow group was 158 ± 25 CPM, which was significantly slower than that in the Non-slow group (250 ± 37 CPM, $P < 0.001$). Deviation angles were no significant difference between the two groups, as well as the fusional vergence amplitudes. No significant difference in the fusion control score at distance ($p = 0.57$) or at near ($p = 0.52$), in stereopsis at near (LogTNO, $p = 0.42$) or at distance (LogRDS, $p = 0.09$). Age was found a significant difference between the Slow and Non-slow Groups ($p < 0.001$) (Table 2).

Correlations between reading speed and clinical characteristics in IXT patients

Correlations between reading speed and clinical factors were analyzed in the IXT patients. It is commonly believed that stereoacuity is an important factor that describes the severity of IXT^{24,25}. Interestingly, we found a negative correlation between the reading speed and LogTNO after adjusting for the age and gender ($r = -0.244$, $p = 0.054$). We also found that LogTNO was associated with the reading speed using generalized linear model. It implied worse TNO measurement correlated with slower reading speed (Table 3 and Fig. 2).

Table 3
Factors associated with the reading speed in IXT patients

Parameter	B	Std.Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	9.482	52.7849	-93.975	112.939	.032	1	.857
Age	19.382	4.8572	9.862	28.902	15.923	1	.000
Gender	33.790	10.2060	13.786	53.793	10.961	1	.001
Deviation angle @N	-.098	1.4841	-3.007	2.811	.004	1	.947
Deviation angle @D	.369	1.5707	-2.709	3.448	.055	1	.814
Control score @N	-.953	5.4029	-11.542	9.637	.031	1	.860
Control score @D	-.575	4.0786	-8.569	7.419	.020	1	.888
BO@N	-.318	.5161	-1.329	.694	.379	1	.538
BO@D	-.405	.6626	-1.704	.893	.374	1	.541
NPC	1.962	1.3816	-.746	4.670	2.016	1	.156
AF	.837	1.5682	-2.236	3.911	.285	1	.593
LogTNO	-39.691	16.1554	-71.355	-8.027	6.036	1	.014
LogRDS	22.546	16.2451	-9.293	54.386	1.926	1	.165
Sensory fusion @N	.943	13.1229	-24.777	26.663	.005	1	.943
Sensory fusion @D	.752	12.3699	-23.493	24.996	.004	1	.952
BI = base in prism power for fusional vergence amplitudes							
BO = base out prism power for fusional vergence amplitudes							
NPC = near point of convergence							
AF = accommodative facility							

Discussion

IXT is the most common type of divergent strabismus in children and adolescents, with a prevalence of 3–4% in Asia^{3,4}. To our knowledge, our study is the first to examine the reading speed in children with

IXT in detail. In our study, we found that children with IXT read more slowly than the age matched normal participants. As is the case in a previous study²⁶, reading speed was found to be correlated with age in IXT children (aged 10–14 year) and those with normal vision. Moreover, stereopsis at near was associated with reading speed in IXT group according to a generalized linear model.

Stereopsis was correlated with reading performance in children with strabismus. Kelly et al. (2020) evaluated motor skills in children with strabismus. They found that strabismic children had a poorer stereoacuity and a stronger suppression, both of which could disrupt the development of reading and motor ability²⁷. Our results found there was a worse stereopsis in the IXT group compared with the control group. Furthermore, we also showed a negative correlation between reading speed and LogTNO ($r=-0.244$, $P = 0.054$) in IXT patients after adjusting for age and gender. Moreover, LogTNO was found as the factors associated with reading speed in the IXT group. This suggests that stereopsis at near might be related with reading speed in children with IXT.

Previous studies have shown that binocular fusion maintenance (i.e. the vergence function) is related to reading performance^{28,29}. Convergence reserve was reported reduced in IXT than in normal observers³⁰. Besides, Perrin Fievez et al. (2018) and Clotuche B et al. (2016) found that asymmetric accommodative responses between the dominant eye and the non-dominant eye during binocular viewing in IXT^{11, 13}. The asymmetric accommodative response was suggested would impact reading performance in patients with IXT³¹. Our study found that vergence and accommodative functions as well as the stereopsis are reduced in individuals with IXT compared with the normal control. While no significant correlation was found between the binocular functions and the reading speed in IXT patients. Moreover, a similar level of the deviation angle, convergence function, stereopsis and fusion control ability were found between the IXT group with a reading speed below the normal range and those with normal reading speed. It implies that the deviation angle, fusion control and vergence functions may not cause a difference in reading speed between the children with IXT and normal controls. Reading speed could be evaluated again with exotropia correction so that the role of deviation and binocular functions on the reading speed to children with IXT could be studied.

Defining and evaluation the severity of IXT is difficult because there are too many parameters that are associated with the severity^{32,33}. The deviation angle, fusional control score, and stereoacuity are commonly considered as the main factors that affect the severity of IXT^{24,25}. We found no significant correlation between the reading speed and the mentioned characters of clinical “severity”; however, LogTNO may associated with the reading speed after adjusted the age and gender. It seems that a slower reading speed is not correlated with a more severe IXT in children population. Also, our findings suggest that the severity of IXT could not indicate a slower reading speed. Reading performance is important for children’s academic performance in school^{6,7}. Although our findings indicate that the severity of IXT is not correlated with reading speed, we still show that children with IXT have a slower reading speed. Therefore, it might be important to assess reading speed as part of routine clinical examination in children with IXT.

Our study has a few limitations. First, reading speed alone cannot fully reflect reading performance because one can read quickly without comprehension⁹. Second, we asked the participants to read out loud. The children's speaking rate could differ from the speed of reading comprehension; extracting meaning from a text could be achieved without verbalizing the text³⁴. Furthermore, we used the same reading distance for all the subjects, as well as the same distance for assessing the clinical characteristics (i.e., stereoacuity). This study design of using the same distance for all subjects enabled us to easily compare the relationship between reading speed and clinical characteristics¹⁵. Lastly, saccadic and fixation function have been shown to be associated with reading performance. Disconjugacy saccadic and longer fixation have been found in children with strabismus because the patients often found themselves rereading the same passage to achieve comprehension. The role of fixation and saccadic parameters in reading performance for subjects with IXT should be investigated in the future by using an eye-tracking device^{14, 16}.

In conclusion, reading speed seems to be slower in school-age children with IXT based on the International Reading Speed Texts. After adjusting for the age and gender, we found that poor stereo function at near was related with a slower reading speed and that stereoacuity at near was associated with reading speed in children with IXT.

Declarations

Acknowledgments

We thank the children who participated in this study and Seung Hyun (Sam) Min (www.ses21.com) for revising the manuscript.

Funding Supported by the National Natural Science Foundation of China grant NSFC (subject number: 82070995) and Zhejiang Provincial Natural Science Foundation of China (subject number: LY19H120004) and the Medical Health Science and Technology Project of the Zhejiang Provincial Health Commission (subject number: 2019KY110).

Authors' contributions Xinping Yu and Chongling Chen contributed to the study conception and design and manuscript modified. Material preparation, data collection and analysis were performed by Cheng Fang, Yidong Wu, Tingting peng, Chunxiao Wang, Jiangtao Lou, Meiping Xu, Jinhua Bao. The first draft of the manuscript was written by Cheng Fang and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

Comparison of Reading speed by age between IXT and normal

Figure 2

Correlations between Reading speed and LogTNO in IXT patients