Lança. Int J Ophthalmol Clin Res 2014, 1:1

International Journal of
Ophthalmology and Clinical Research

Research Article: Open Access

Reading Performance in Children with Visual Function Anomalies

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Abstract

Aims: To compare reading performance in children with and without visual function anomalies and identify the influence of abnormal visual function and other variables in reading ability.

Methods: A cross-sectional study was carried in 110 children of school age (6-11 years) with Abnormal Visual Function (AVF) and 562 children with Normal Visual Function (NVF). An orthoptic assessment (visual acuity, ocular alignment, near point of convergence and accommodation, stereopsis and vergences) and autorefraction was carried out. Oral reading was analyzed (list of 34 words). Number of errors, accuracy (percentage of success) and reading speed (words per minute - wpm) were used as reading indicators. Sociodemographic information from parents (n=670) and teachers (n=34) was obtained.

Results: Children with AVF had a higher number of errors (AVF=3.00 errors; NVF=1.00 errors; $p<0.001$), a lower accuracy (AVF=91.18%; NVF=97.06%; $p<0.001$) and reading speed (AVF=24.71 wpm; NVF=27.39 wpm; $p=0.007$). Reading speed in the 3rd school grade was not statistically different between the two groups (AVF=31.41 wpm; NVF=32.54 wpm; $p=0.113$). Children with uncorrected hyperopia ($p=0.003$) and astigmatism ($p=0.019$) had worst reading performance. Children in 2nd, 3rd, or 4th grades presented a lower risk of having reading impairment when compared with the 1st grade.

Conclusion: Children with AVF had reading impairment in the first school grade. It seems that reading abilities have a wide variation and this disparity lessens in older children. The slow reading characteristics of the children with AVF are similar to dyslexic children, which suggest the need for an eye evaluation before classifying the children as dyslexic.

Keywords

Abnormal visual function, Reading performance, Errors, Accuracy, Reading speed

Introduction

Different questions prompt debate within the process of reading, because it demands integration of both visual and phonemic information. Reading is a visuo-cognitive process and single image perception is critical for such process to occur and for successful function in today's society [1]. The act of reading requires the management of a number of visual functions which send coordinated information to the visual cortex, including refraction, accommodation, visual acuity, saccades, convergence and fusion [2]. Subsequently, reading needs to be learned trough repetition, language and assimilation. This means that the reading process includes linguistic processing of words and visuomotor control, all aimed at providing an optimal reading performance [3].

The role of the eyes in reading has led to many misconceptions regarding reading difficulties [4]. If either phonemic or visual processes are impaired, it is plausible that children have particular difficulty in learning to read [5]. Low levels of academic achievement and educational attainment can be related with factors such as health (dyslexia, reduced intellectual ability, binocular vision anomalies and speech sound disorders) [6-8] and the familial, social, physical and economic environment in which children and teenagers live [7].

A consistent relationship between abnormal visual function and academic performance or reading ability has not been shown yet. There are some authors who contend that children without cognitive dysfunctions or speech sound disorders but with abnormal visual function, may be at an educational disadvantage towards their visually normal peers [2,5,7,9-13]. Whilst others report that visual function and academic performance are not positively related [14].

The aims of this study are to:

1). Compare reading performance (errors, accuracy and reading speed) in children with and without visual function anomalies.

2). Compare reading performance per school grade, per different visual function anomalies and refractive error.

3). Identify the influence of abnormal visual function and other variables (e.g. teaching method, parent's academic qualifications) in reading performance.

Methods and Materials

A cross-sectional study was performed in 2012 with data from 11 mainstream primary schools in Lisbon, Portugal. A sample with

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Citation: Lança CC, Serra H, Prista J (2014) Reading Performance in Children with Visual Function Anomalies. Int J Ophthalmol Clin Res 1:001

Received: September 10, 2014: **Accepted:** October 15, 2014: **Published:** October 17, 2014

672 typically developing children (6 to 11 years) of Portuguese origin was collected. Children with reduced intellectual ability, neurocognitive disabilities, dyslexia and speech sound disorders were excluded. Additionally information about teaching method, parent's academic qualifications, school type (private/public), and teacher's age, teacher's number of years of experience and children grade was collected with a questionnaire applied to 670 parents and 34 teachers.

This study adhered to the tenets of the Declaration of Helsinki. Ethics approval for the study was obtained from the National School of Public Health in Lisbon. All selected school administrators received information regarding the study and agreed to participate. Informed consent was obtained from the parents to allow inclusion of their child's data in the study. Confidentiality of the given information was guaranteed. All children had an orthoptic assessment and autorefraction done by the same orthoptist:

- Screening for refractive error was done with non-cycloplegic auto-refraction using a SureSightTM WelchAllyn® autorefractometer. Refractive errors were classified as following: hyperopia ≥ + 3.75; myopia ≤ - 0.75 D, astigmatism ≥ 1.75D; anisometropia ≥ 2.75 D [15].

- Distance and near visual acuity was assessed with habitual correction at a distance of 3 m with a Sloan letter linear-spaced Good-Lite® chart and at 40cm with a LogMar Good-Lite® chart. Visual acuity was recorded as the last line on which at least 3 of the 5 letters were identified correctly. Visual acuity (near and distance) was considered abnormal when ≤20/25 (≥0.1 logMAR) or different between the two eyes (two lines of visual acuity) [16-18]. Visual acuity data was converted from decimal notation to logMAR values with the negative of the logarithm [19]:

$$logMAR = -\log\,(decimal\ \ acuity) \tag{1}$$

- Ocular alignment was assessed with a cover test (CT) at distance and near (6 m and 33 cm) to test the presence of heterotropias and heterophorias. The CT was performed with the head held straight and a black paddle occluder as a cover. Detailed fixation objects were used as targets. Manifest strabismus was defined as constant or intermittent tropia of any magnitude at distance or near fixation [20]. A prism cover test was employed to assess the magnitude of the deviation present.

- Near point of convergence (NPC) was assessed with a Royal Air Force (RAF) rule. The mean of three measurements was recorded in cm. The NPC was considered abnormal when >10 cm [21].

- Near point of accommodation (NPA) was assessed with a RAF rule. The mean of three measurements was recorded in diopters. The NPA was considered abnormal when < 14.00D [22].

- Stereoacuity was assessed with the Stereo Butterfly SO-005 test at 40 cm and considered abnormal when >60" [23].

- Vergences (motor fusion) were assessed at distance and near (6 m and 33 cm) with the head held straight. Detailed fixation objects were used as targets. Prisms were employed to assess the magnitude of the motor fusion present. The following criteria were used for classifying convergence insufficiency - NPC >10 cm in conjunction with one of the following: near convergence <25PD; distance convergence <18PD; near divergence <12PD; distance divergence<6PD [21].

- Ocular movements (versions and ductions) were assessed with a pen light in the 9 cardinal positions.

Children were considered to have normal vision function when obtained normal results in the orthoptic assessment and autorefraction. They were examined with optical correction if glasses have been prescribed previously. Children without prescribed glasses were tested without optical correction and when Abnormal Visual Functions (AVF) was detected, they were referred to the ophthalmologist for medical follow-up.

Reading errors, accuracy and reading speed were assessed with a list of 34 Portuguese words that have been used previously to assess reading and its validity is reported [24]. The test was conducted in a quiet room and room illuminance conditions were measured with a TES-1330 luximeter in both groups of subjects. Each child was asked to read the 34 words at a distance of 40 cm. Children were not allowed to get as close to the page as desired. The time taken to complete the task was measured with a stopwatch.

The reading speed is the number of words read by the child per minute (wpm) [25]. The number of incorrect words read was noted and accuracy (A) was calculated with the following equation:

$$A = \frac{NCW}{WR} \times 100 \tag{2}$$

Where NCW is the number of correct words and WR is the total number of words read. The result is a percentage with 3 levels of performance which are published and validated [26]: 1st – independent level reading (accuracy of 96% to 100%); 2nd – instructional level reading (accuracy of 90-95%); 3rd – Frustration level reading (accuracy <90%).

The Mann-Whitney test was used to test for continuous variables and the Kruskal-Wallis test was used to test continuous variables for three or more groups. A p value of less than 0.05 or 0.01 was accepted as significant. We also investigated the data by using a binary logistic regression technique to identify risk factors for having a low reading performance. The criteria forward stepwise (conditional) was used to select the variables to include in the model. The parameters significance were tested with the Wald test at a 5% significance level [27,28].

Results

One hundred and ten children (16.4%) were classified as having visual function anomalies (mean age=7.74 ± 1.17 years) and 562 children as having normal visual function (mean age=7.68 ± 1.19 years). There were no significant age (p=0.675) and sex (p=0.876) differences between the two groups. There were also no significant differences (p=0.987) in illuminance measures, parent's academic qualifications (p=0.458) and the professor number of experience years in teaching (p=0.993). Teaching methods were also similar in the two groups.

Of the 110 children with visual function anomalies, 17 had a manifest strabismus, 66 had visual acuity ≥0.1 logMAR at distance, 2 had convergence insufficiency, 15 presented stereoacuity >60" and 10 had manifest strabismus plus a visual acuity ≥0.1 logMAR at distance. Of the children identified with strabismus 4 had an uncorrected refractive error. Of the children with visual acuity ≥0.1 logMAR at distance 15 had an uncorrected refractive error, mainly hyperopia (10.6%) and astigmatism (9.1%). Only two children had an abnormal visual acuity for near and both had also abnormal visual acuity for distance.

Of the children with manifest strabismus 11 had stereoacuity >60" (median=400"). Of the children with visual acuity ≥0.1 logMAR at distance 17 had a stereoacuity >60" (median=40") and 9 children with strabismus and visual acuity ≥0.1 logMAR had also a stereoacuity >60" (median=600"). We also found that 15 children had a stereoacuity >60" (median=80") and 2 of them had an uncorrected refractive error.

Reading performance

Children in the abnormal visual function group had a higher number of errors (AVF=3.00 errors; NVF=1.00 errors; p<0.001), a lower accuracy (AVF=91.18%; NVF=97.06%; p<0.001) and reading speed (AVF=24.71 wpm; NVF=27.39 wpm; p=0.007) (Table 1).

Only 18.9% of the children with normal visual function had abnormal accuracy (frustration level reading) compared with 40.0% of the children with abnormal visual function.

Table 1: Reading performance per children groups and grade.

Reading performance	Mean ± standard deviation		Median		p
	NVF+	AVF++	NVF+	AVF++	
Number of errors	2.20 ± 3.24	4.40 ± 5.54	1.00	3.00	<0.001*
Number of errors per grade					
1st	3.78 ± 4.36	11.10 ± 8.07	2.00	9.00	<0.001*
2nd	1.67 ± 1.99	4.26 ± 4.78	1.00	3.00	<0.001*
3rd	1.27 ± 1.27	2.53 ± 3.11	1.00	2.00	0.003*
4th	1.17 ± 1.46	2.08 ± 2.74	1.00	1.00	0.034**
Accuracy (%)	91.05 ± 16.81	80.88 ± 26.21	97.06	91.18	<0.001*
Accuracy per grade					
1st	78.71 ± 27.83	53.19 ± 29.03	91.18	60.29	<0.001*
2nd	93.97 ± 9.15	83.48 ± 21.95	97.06	91.18	<0.001*
3rd	95.32 ± 6.33	88.87 ± 22.33	97.06	94.12	0.001*
4th	95.46 ± 8.81	93.99 ± 5.36	97.06	94.12	0.024**
Reading speed (words per minute)	28.32 ± 16.45	23.02 ± 15.40	27.39	24.71	0.007*
Reading speed per grade					
1st	13.87 ± 9.62	5.02 ± 5.04	12.30	3.64	<0.001*
2nd	25.15 ± 12.45	17.45 ± 11.06	24.24	16.40	<0.001*
3rd	34.19 ± 11.93	29.96 ± 12.90	32.54	31.41	0.113
4th	41.94 ± 14.25	38.21 ± 16.20	40.00	35.36	0.031**

+Normal visual function; ++ Abnormal visual function; *Statistically significant differences at 1% significance level; **Statistically significant differences at 5% significance level.

We also compared the three measurements of reading performance by children's grade (1st to 4th). For the number of errors and accuracy there was a statistically significant difference between the results obtained from each group per grade with those subjects in the abnormal visual function group having more errors and a lower accuracy. When comparing the reading speed in the 4 grades, the 3rd grade was the only grade where it was not statistically different between the two groups (AVF=31.41 wpm; NVF=32.54 wpm; *p*=0.113).

Abnormal visual function and uncorrected refractive error

Table 2 shows reading performance per visual function anomalies and uncorrected refractive error. Children with visual acuity ≥ 0.1 logMAR had the lowest reading speed (20.56 wpm). Children with strabismus and visual acuity ≥ 0.1 logMAR had a lower reading speed (26.34 wpm) when compared with children with strabismus and normal visual acuity (30.94 wpm). However there were no significant differences between the groups of visual function anomalies for reading performance (errors=0.994; accuracy=0.922; reading speed=0.652).

Children with uncorrected hyperopia had more errors in reading (median=3.00), a lower accuracy (median=88.24%) and reading speed (median=16.20 wpm) when compared with children without or corrected refractive error (Table 2). The differences were significant for the number of errors and accuracy between the children with uncorrected hyperopia and the children without refractive error (*p*=0.003) and the children with uncorrected astigmatism and the children without a refractive error (*p*=0.019).

We also compared children regarding spherical refractive status score (1.00D, 2.00D, 3.00D and >3.00D) and cylindrical refractive status score (0.50D, 1.00D, 2.00D and >2.00D). Children with a spherical refractive score >3.00D presented a higher number of errors (median=3.00), a lower accuracy (median=91.18%) and reading speed (median=24.25 wpm). Children with cylindrical refractive score >2.00D presented a lower reading speed (median=18.42 wpm). However both groups did not differ significantly from children without or corrected refractive error.

Influence of abnormal visual function and other variables in reading performance

Direct logistic regression was performed to assess the impact of 7 factors on the likelihood that children would have a low reading performance: visual function (normal/abnormal), teaching method, parents academic qualifications, school type (private/public), teacher's age, teacher's number of years of experience and children grade. Low reading performance was considered when children had an accuracy <90%. [26].

The full logistic regression model was statistically significant, indicating that it was able to distinguish between children who have a low reading performance and children who have not. Sensitivity of the model was of 39.3% and specificity was of 94.3%. Positive predictive value was of 67.1% and negative predictive value was of 84.00%. At a 5% level of significance visual function [OR=4.29; $C.I._{95\%}$ (2.49; 7.38)] was identified as risk factor or predictor (p<0.001). The risk of having a low reading performance is higher in children with visual function anomalies. However, children grade was identified as a protector factor (p<0.001): [OR 2nd=0.17; C.I.95% (0.09; 0.29); OR 3rd=0.08; C.I. 95% (0.04; 0.16); OR 4th=0.04; C.I. 95% (0.02; 0.09)]. The 2nd, 3rd, and 4th grade presented a lower risk for having a low reading performance when compared with the 1st grade. The variables teaching method, parent's academic qualifications, school type (private/public), and teacher's age, teacher's number of years of experience and children grade were not factors statistically significant to explain the reading performance, when the effect of the visual function was contemplated in the model.

Discussion and Conclusions

Is this study we compared reading performance in children with normal vision function with children with abnormal visual function. Impaired reading performance was detected in children with visual function anomalies (higher number of errors, a lower accuracy and reading speed). The variables teaching method, parent's academic qualifications, school type (private/public), teacher's age and number of years of experience and children grade were not factors statistically significant to explain the reading performance.

Our findings are comparable with previous reports suggesting that children with visual function anomalies could be at disadvantage in reading, writing and academic performance [5,12,13,25,29-34]. Some studies support the possibility that children with unstable binocular control commit more phonological spelling errors, even when age, IQ and phonemic awareness were taken into account [29]. Monocular viewing reduces the proportion of non-word errors [5], which supports the idea that reading is affected by interference between the two eyes.

There were no significant differences between the groups of visual function anomalies for reading performance, although reading speed seems to be lower in children with visual acuity ≥ 0.1 logMAR and children with strabismus plus visual acuity ≥ 0.1 logMAR. However, our findings support previous results showing that there is a relationship between reading performance and an uncorrected refractive error. Children with uncorrected hyperopia and astigmatism had more errors in reading, a lower accuracy and reading speed when compared with other children. There were no significant differences between lower and higher values of spherical and cylindrical refractive scores.

Table 2: Reading performance per visual function anomalies and uncorrected refractive error.

Visual function anomalies	Reading performance	Mean ± Standard deviation	Median
Visual acuity ≥0.1 logMAR (n=66)	Errors	4.63 ± 5.84	3.00
	Accuracy	81.46 ± 24.49	91.18
	Reading speed	21.94 ± 15.44	20.56
Strabismus (n=17)	Errors	4.25 ± 5.35	1.50
	Accuracy	82.35 ± 26.12	94.12
	Reading speed	26.25 ± 16.66	30.94
Strabismus and visual acuity ≥0.1 logMAR (n=10)	Errors	5.00 ± 7.78	3.00
	Accuracy	68.82 ± 40.18	91.18
	Reading speed	20.71 ± 14.27	26.34
Convergence insufficiency (n=2)	Errors	3.00 ± 0.00	3.00
	Accuracy	91.18 ± 0.00	91.18
	Reading speed	29.30 ± 0.99	29.30
Stereoacuity >60” (n=15)	Errors	3.64 ± 3.27	3.00
	Accuracy	83.33 ± 24.85	91.18
	Reading speed	24.85 ± 16.14	23.86
Children with normal visual function	Errors	2.20 ± 3.32	1.00
	Accuracy	91.05 ± 16.81	97.06
	Reading speed	28.32 ± 16.45	27.39
Uncorrected refractive error	**Reading performance**	**Mean ± Standard deviation**	**Median**
Hyperopia (n=11)	Errors	5.11 ± 5.33	3.00
	Accuracy	70.32 ± 35.53	88.24
	Reading speed	16.18 ± 12.99	16.20
Astigmatism (n=9)	Errors	4.75 ± 5.87	2.00
	Accuracy	71.57 ± 33.82	91.18
	Reading speed	19.34 ± 17.07	20.64
Anisohyperopia (n=5)	Errors	2.40 ± 2.70	2.00
	Accuracy	92.94 ± 7.95	94.12
	Reading speed	30.42 ± 12.14	26.56

Previous research suggests that hyperopia is related to poor reading progress and its correction seems to result in improved performance [9,10,35-39]. One study reports that 34% of the hyperopes aged 4-15 years had the lowest level of school performance, compared to 14% of the emmetropes and 12% of the myopes [37]. Other study in the UK concluded that a high proportion of the fogging test failures (16%) confirmed the presence of 29% of hyperopes aged 8 years, which had been referred to an educational psychologist [35]. Previous research on refractive status and reading performance suggested that myopic children are better readers than hyperopic children [10,38]. However, other studies [25,40] do not found any association between refractive error and reading in children.

The evidence linking mild-moderate hyperopia and lack of progress in school continues to be insufficient. Although myopia is correlated to high reading ability in some studies, a correlation does not necessarily imply causation. In the present study there were no children with uncorrected myopia. The age range could be an explanation for the absence of uncorrected myopia as older children are more likely to be myopic.

Thurston and Thurston [2] in a recent review about reading and refractive error show some concern about the studies reporting correlations between reading performance and visual problems. These authors warn that studies have not established a relationship of cause and effect. This relationship may be relational or directional, but not causal. On the other hand, there are several limitations to refractive error estimates.

A potential source of error in the present study is the use of non-cyclopegic auto-refraction as a method of refractive error assessment. One study [41] report that noncycloplegic measurements of equivalent spheres were consistently more negative or less positive than those after cyclopegia. The use of non-cyclopegic auto-refraction is more accurate in the detection of astigmatism and abnormally high levels of hyperopia. However, as reported by Williams et al. [42] these measurements could be important to identify subgroups with children who truly have the refractive error in question, as well as some who not. It is true that, in the present study, the level of refractive error in subjects with latent hyperopia could be underreported, nevertheless we found out that children with hyperopia of +3.00D or more presented a higher number of errors, a lower accuracy and reading speed. This means that the level of refractive error could have an important impact in reading performance, being this performance more affected in higher levels of hyperopia. Other potential source of data interference is the uncorrected refractive error, which can lead to changes in accommodation, ocular alignment and vergence system.

Our findings also demonstrate that school grade is a protective factor. Reading impairment is better appreciated in the first two school grades. In the third grade reading performance of children with visual function anomalies, specifically reading speed begins to approach reading in children with normal visual function. We can assume that as one gets older the reading problems of a younger age due to visual anomalies appears to be overcome or somehow compensated by other strategies. It seems that reading abilities have a wide variation even for normal children. We found outliers that are considered extreme points and standard deviation was very high showing a great dispersion between children. This effect/disparity lessens in older children.

Previous studies concluded that as a child progresses through school, the relationship between vision and reading changes, with the role of vision being more significant among younger children in the early school grades [3,30].

We also found out that the slow reading characteristics of the children with abnormal visual function are similar to dyslexic children [24], which lead us to conclude that students with poor reading performance should be sent for eye evaluation before being classified as dyslexic.

The results of the present study need to be analysed carefully because the design was cross-sectional and the model sensitivity was only 39.3%. Therefore, it’s necessary to develop clinical trials to better understand these findings.

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