Is Reading Performance Impaired in Glaucoma Patients With Preserved Central Vision?

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Precis: Although this sample with glaucoma had preserved central vision, they presented worse reading performance compared with similarly aged controls.

Objective: To determine whether patients with glaucoma with preserved central vision have impaired reading performance compared with healthy controls.

Methods: A cross-sectional study of 35 patients with glaucoma and 32 similarly aged controls with visual acuity better than 0.4 logMAR in both eyes. Each participant had a detailed ophthalmological examination followed by a 5-chart reading performance test using a Portuguese version of the Minnesota Low Vision Reading Test (MNREAD). Correlation between reading performance (reading speed) and ocular parameters was investigated.

Results: Participants had an average age of 63.0 ± 12.6 years. In the glaucoma group, mean deviation in the better and worse eyes was −6.29 ± 6.36 and −11.08 ± 20.23 dB, respectively. There was no significant difference in age, sex, race, education, visual acuity, or systemic comorbidities between groups. Participants with glaucoma had significantly slower reading speeds, with an average of 83.2 ± 25.12 compared with 102.29 ± 29.57 words per minute in controls \( (P = 0.006) \). Reading speed was slower for all 5 charts. Odds of glaucoma increased by 1.29 (95% confidence interval, 1.07–1.56; \( P = 0.009 \)) for each 10 words per minute decrease in average reading speed, with this relationship maintained after accounting for age, schooling, and visual acuity.

Conclusions: Patients with mild to moderate glaucoma had worse reading performance compared with similarly aged controls, despite both having preserved central vision.

Key Words: glaucoma, reading, reading performance, preserved visual acuity, quality of life, contrast

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Glaucoma is a progressive optic neuropathy characterized by degeneration of retinal ganglion cells and consequent loss of visual field, with the potential for blindness. It is expected that by 2040, 111.8 million people will be affected by glaucoma worldwide. Recently, there has been growing recognition of the importance of improved understanding of the impact of glaucoma on quality of life and the ability to perform vision-related tasks of daily living such as driving, shopping for groceries, and reading.

Globally, the ability to read is becoming increasingly important as text is used more often as a method of communication. In addition, due to the prevalence of smartphones, areas of the world with historically high rates of illiteracy, which are also often areas of high glaucoma prevalence, are also becoming more text reliant. Previous studies have indicated patients with glaucoma have impaired reading performance compared with controls, however, these have been predominately conducted in English-speaking populations and have not specifically examined reading performed in patients with preserved central vision.

There are 2 main methods to quantify reading loss in ophthalmological patients: through questionnaires and through reading function tests. Questionnaires are able to evaluate daily life reading issues from the patient’s perspective but lack the objectivity of reading function tests. Several reading function tests have been described including the Bailey-Lovie Near Reading Card, Pepper Visual Skills for Reading Test (VSRT), Minnesota Low-Vision Reading Test (MNREAD), International Reading Test (IReST), and Rapid Serial Visual Presentation (RSVP). These tests have already been applied with success in glaucoma patients, generally showing impaired performance in those with glaucomatous visual field loss. For example, Ramulu et al used the MNREAD to assess loud and silent reading in glaucoma, reporting that reading speed is slower among glaucoma patients with bilateral visual field loss, with the greatest impact present during sustained silent reading.

As reading performance may be influenced by language and potential confounding factors such as age, race, and education, it is important to determine whether similar results are found in different populations. A validated Portuguese version of the MNREAD is now available, providing an appropriate tool to examine reading performance in glaucoma patients in a Brazilian population. The specific purpose of this study was to therefore determine whether patients with glaucoma have impaired reading performance compared with controls, in the presence of preserved central vision.

METHODS

This was a cross-sectional prospective interventional study, approved by the Institutional Review Board of the Federal...
University of São Paulo through the CEP (1154.0089.09/2017). Written informed consent was obtained prospectively from all the participants and all study methods adhered to the tenets of the Declaration of Helsinki.

Study Participants

The study included a total of 35 patients with open angle glaucoma and 32 healthy participants as a control group. All patients were recruited from Department of Ophthalmology, Federal University of São Paulo. Participants were required to have a best corrected visual acuity better than 0.4 logMAR in both eyes and to be fluent in speaking, writing, and reading Portuguese by self-report. All participants were refracted, and best-corrected visual acuity was measured in both eyes separately using the Early Treatment Diabetic Retinopathy Study at 4 m. The refraction also ensured an optimal reading correction was worn during the reading assessment.

Glaucoma was defined by presence of repeatable (≥3 consecutive) abnormal standard automatic perimetry (SAP) test results on the 24-2 program of Humphrey Field Analyzer (Carl Zeiss Meditec Inc) or to have progressive glaucomatous optic disc changes noted on masked examination of stereo photographs, regardless of the results of SAP testing. Abnormal SAP was defined by the presence of a pattern SD (PSD) outside the 95% confidence limits of normal, or a glaucoma hemifield test results outside the reference range.

Participants were required to have no ocular comorbidities and no ocular or neurological conditions that may affect the visual field. Other exclusion criteria included; age of below 18 years; corneal and/or retinal diseases; orbital diseases; intracranial or paranasal sinus abnormalities; ametropia with a spherical refractive error > ±3 D or cylindrical > ±3 D; topical or systemic medications that lead to lethargy or decreased reading ability; and dyslexia.

All participants underwent a comprehensive ophthalmologic examination including review of medical history, visual acuity, slit-lamp biomicroscopy, intraocular pressure measurement (using the Goldmann tonometer), gonioscopy, dilated fundoscopic examination, visual field test, and a reading performance test.

Reading Performance Test

The reading procedure was performed using reading sentences from the MNREAD-P reading performance test, translated and validated in Portuguese.24 The table was displayed on a computer screen, using the online tool “Google sheets,” with the MNREAD-P reading tables adjusted to the tool. Font proportions, standard line spacing, color, text box size, and font type were matched to the MNREAD-P protocol.23

Detailed methodology has already been published before.7,19 The sentences were presented on a computer monitor with a resolution of 1024×768 pixels, with a refresh rate of 60 Hz. The lighting in the experiment room was between 400 and 600 lux. The test distance between the participant and the monitor was 40 cm. The phrases in the tables were displayed in Times LT-Roman black font, with logMAR print size unit, on a white background, with a white background luminance set at 140 cd/m², in Brazilian Portuguese.

Five standard texts without alterations or interventions were performed. Patients were asked to read “as if they were reading a novel or newspaper in their daily life, as quickly and accurately as possible.” They were asked to read aloud using both eyes with appropriate refractive corrections. The primary outcome for the study was reading speed, quantified as words per minute (wpm).

Demographic and Socioeconomic Parameters

Socioeconomic and clinical parameters were also evaluated to take account of potential confounding factors. All participants completed a questionnaire to obtain information regarding sex, ethnicity, and educational level (high school or no high school). The presence of systemic diseases was also determined by examination of medical records, medications, and participant recall. Specifically, we recorded comorbidities including systemic hypertension, diabetes mellitus, arthritis, heart disease, stroke, depression, cancers, and asthma. The comorbidity index was calculated by the sum of some scores given to each item.

Statistical Analysis

The descriptive analysis included the mean and SD for variables with a normal distribution, whereas those variables that were not distributed normally were presented as the median. The skewness-kurtosis test was used to confirm for normality or not. The t test was used for multiple comparisons between preoperative and postoperative measurements, and for non-normal variables the corresponding nonparametric test (Wilcoxon rank test) was performed. Percentages were used to describe categorical values and achieve better comparators between the 2 groups. Regression analyses were performed to examine the potential relationship between reading speed and factors including age, sex, race, schooling, comorbidities index, SAP mean deviation (MD) in the better and worse eyes, and SAP PSD in the better and worse eyes. Univariable and multivariable logistic regression analyses were then performed to examine the relationship between changes in reading speed and odds of glaucoma, accounting for potential confounders. All statistical analyses were performed using the available software Stata version 13 (StataCorp LP, College Station, TX). The α level (type I error) was set at 0.05.

RESULTS

Thirty-five patients with glaucoma and 32 healthy participants were enrolled. Demographic and clinical characteristics of included participants are shown in Table 1. Participants with glaucoma had an average (±SD) age of 65.7±13.8 years, compared with 60.0±10.7 years in controls (P=0.066). There were similar proportion of males and females between groups and the number of nonocular comorbidities were similar (P=0.958 and P=0.496, respectively). There was also no significant difference in schooling between groups, with a similar proportion completing high school education (P=0.145). Visual acuities in the better and worse eyes were also similar (Table 1). Participants with glaucoma had a MD in the better eye of −6.29±6.35 compared with −11.08±8.43 dB in the worse eye. PSD was 7.77±4.26 dB in the better eye and 4.84±3.64 dB in the worse eye.

Reading speeds were significantly worse in patients with glaucoma compared with controls for each of the 5 MNREAD charts (Table 1, Figs. 1, 2). In addition, the average reading speed for patients with glaucoma was 83.20±25.12 compared with 102.29±29.57 wpm for controls (P=0.006).

Univariable regression analysis examining potential factors affecting reading speed showed no significant association between age, sex, race, schooling, comorbidities, visual acuity in the better and worse eyes, SAP MD in the better and worse eyes, or SAP PSD in the better and worse eyes, and average reading...
TABLE 1. Demographic and Clinical Characteristics of Included Participants

|                        | Glaucoma (n = 35) | Controls (n = 32) | P    |
|------------------------|-------------------|------------------|------|
| Age                    | 65.71 ± 13.80     | 60.03 ± 10.67    | 0.066|
| Sex (female)           | 25                | 23               | 0.592|
| Race (1, 2, 3, 4)      | 8, 7, 1, 19       | 12, 6, 2, 12     | 0.471|
| High school education  | 13 (37.1)         | 18 (56.3)        | 0.145|
| Comorbidities index (yes), n (%) | 9, 12, 10, 11, 11, 7, 0.731 | 2, 2, 0, 2, 0, 1 | 0.092 |
| Visual acuity better eye | 0.11 ± 0.13     | 0.06 ± 0.11      | 0.053|
| Visual acuity worse eye | 0.22 ± 0.17     | 0.14 ± 0.17      | 0.064|
| SAP MD better eye (dB) | −6.29 ± 6.35     | NA               | NA   |
| SAP MD worse eye (dB)  | −11.08 ± 2.13    | NA               | NA   |
| PSD better eye (dB)    | 7.77 ± 4.26      | NA               | NA   |
| PSD worse eye (dB)     | 4.84 ± 3.64      | NA               | NA   |
| Overall average reading speed (wpm) | 83.20 ± 25.12 | 102.29 ± 29.57 | 0.006|
| Average reading speed (slide 1) (wpm) | 81.10 ± 22.50 | 103.01 ± 30.02 | 0.001|
| Average reading speed (slide 2) (wpm) | 83.25 ± 27.64 | 102.31 ± 28.81 | 0.007|
| Average reading speed (slide 3) (wpm) | 85.92 ± 30.25 | 107.83 ± 31.27 | 0.005|
| Average reading speed (slide 4) (wpm) | 83.52 ± 30.98 | 100.33 ± 21.43 | 0.031|
| Average reading speed (slide 5) (wpm) | 82.22 ± 24.51 | 97.96 ± 32.18 | 0.027|

MD indicates mean deviation; NA, not applicable; SAP, standard automatic perimetry.

slower reading speed and increased odds of glaucoma for average reading speed, and reading speeds for slide 1, slide 2, and slide 3, with a similar 1.29-fold (95% confidence interval, 1.03-1.63) increased odds of glaucoma for every 10 wpm decrease in average reading speed. A similar analysis accounting for visual acuity in the better eye, in addition to age and schooling level showed the relationship between slower reading speed and increased odds of glaucoma remained significant for average reading speed and reading speed for slides 1, 2, and 3 (Table 5).

FIGURE 2. Histogram showing the distribution of average reading speeds in patients with glaucoma compared with controls.

DISCUSSION

The results of this study demonstrate patients with glaucoma may have significantly reduced reading speed compared with similarly aged controls, with an average reading speed of 19.1 wpm less in patients with glaucoma compared with controls. This represented an 18.7% lower average reading speed in those with glaucoma. The lower reading speed was consistent across all 5 MNREAD slides. In addition, slower reading speed was associated with higher odds of glaucoma, even after taking account of age and schooling as potential confounders (Table 4). Overall, there was a 1.29-fold increased odds of glaucoma for every 10 wpm decrease in average reading speed. These findings strongly suggest that glaucoma can have a serious impact on reading, even in patients with preserved central visual acuity, and even after accounting for potential confounding factors.

Although there are many aspects of reading performance, we opted to study reading speed, to allow comparison with other studies.8,25 Our results are in agreement with previous work showing patients with glaucoma have worse reading speed compared with controls but are particularly interesting given the study was restricted to patients with preserved central visual acuity. As part of the Salisbury Eye Evaluation, Ramulu et al.8 reported reduced reading speed in patients with glaucoma, however this was only observed in patients with advanced bilateral visual field loss. In contrast, the present study included patients with mainly mild to moderate glaucoma, with an average MD in the better eye of only −6.29 ± 6.35 dB.

We examined the relationship between MD in the better and worse eyes and reading speed but surprisingly found no association, with R² values of only 0.034 and 0.077, respectively (Table 2). This was in contrast to...
Altangerel et al25 who found correlation between reading speed and visual field loss, despite the findings not being assessed in a multivariable analysis. Ramulu et al2 also found slower out-loud reading speeds using the MNRead and IRest, with a relationship between slower reading and worse visual field loss, however, this association was independent of visual acuity. It is possible that the present study was underpowered to detect an association between MD and reading, particularly due to the relatively few patients with advanced glaucoma in both eyes. Alternatively, a summary metric such as MD may not be a good index for assessing the component of visual field important for reading, which may be affected more by localized types of field loss. As we excluded patients with poor central acuity, glaucoma patients in this study likely had relatively preserved central visual field. Unfortunately, we were not able to examine the impact of particular patterns of visual field loss given the relatively small sample size and diversity of field loss in those included. We also did not examine the repeatability of the reading assessment, however, by using 5 slides, it was possible to demonstrate consistent results across tests.

Swenor et al26 have previously examined the importance of the peripheral visual field when reading with the aim of determining why patients with normal central vision may have difficulty. During reading, attention is divided between focusing on the word being read as well as neighboring words, and therefore reading speed may be affected by attention reserves. Readers with higher levels of attentional reserves were found to have smaller decrements in reading speed with worsening visual impairment compared with readers with lower attention reserves, suggesting that higher attentional reserves may help compensate for visual loss. Glaucomatous optic nerve damage and loss of visual field may affect attentional reserves, explaining why glaucoma patients have more trouble reading compared to controls with the same visual acuity.

Reading speed is also affected by contrast, which was not varied in the current study. Moreover, it has been demonstrated that the reading performance of patients with glaucoma is more affected by reduction in contrast sensitivity than in healthy subjects, with similar cognitive and reading activity than in healthy subjects, with similar cognitive and reading ability.27 Reading speed also differs depending on whether a person is reading silently or out-loud and it has been found that glaucoma may affect silent reading to a greater extent.9 It is therefore possible that the differences between glaucoma patients and controls observed in the present study may be accentuated if the study repeated using silent reading.

The study has several limitations. First, although there was no significant difference in age, sex, race, education, systemic comorbidities, or visual acuity between patients with glaucoma and controls, it is possible that other confounders may have influenced the results. The MNREAD-P test also has limitations, as it cannot measure sustained reading, which may be a better reflection of real-world

| TABLE 2. Univariable Regression Analyses Examining Potential Effects on Reading Speed (Average of 5 Slides) in Patients With Glaucoma |
|-----------------------------|-----------------|---------------|-----------------|---------------|
| Coefficient/Odds Ratio | 95% CI | P | R²/Pseudo R² |
| Age (per year older) | −0.19 | −0.83 to 0.45 | 0.549 | 0.011 |
| Sex (male vs. female) | 1.00 | 0.97-1.03 | 0.814 | 0.001 |
| Race (white vs. non-white) | −5.90 | −12.41 to 0.61 | 0.074 | 0.093 |
| Schooling (high school vs. no high school) | 1.02 | 1.00-1.05 | 0.907 | 0.065 |
| Comorbidities index (per unit higher) | −0.48 | −8.53 to 7.56 | 0.904 | 0.001 |
| Visual acuity better eye (per 0.1 logMAR better) | −3.22 | −10.04 to 3.60 | 0.344 | 0.027 |
| Visual acuity worse eye (per 0.1 logMAR better) | −2.14 | −7.22 to 2.94 | 0.397 | 0.032 |
| SAP MD better eye (per dB higher) | −0.73 | 02-1.0-65 | 0.288 | 0.034 |
| SAP MD worse eye (per dB higher) | −0.82 | −1.84 to 0.19 | 0.107 | 0.077 |
| PSD better eye (per dB higher) | 1.00 | −1.06 to 3.06 | 0.331 | 0.029 |
| PSD worse eye (per dB higher) | 0.18 | −2.27 to 2.63 | 0.882 | 0.001 |

CI indicates confidence interval; MD, mean deviation; PSD, pattern SD; SAP, standard automatic perimetry.

FIGURE 3. Scatter plots showing the relationship between average reading speed and MD in the better (A) and worse (B) eyes. MD indicates mean deviation.
reading behavior. Although we found patients with glaucoma had worse reading performance during testing, it is uncertain whether a difference would persist with reading of longer texts. Most people are likely to spend more time silently reading than reading out loud and therefore further studies assessing silent reading of longer texts would be interesting. A further limitation was that we did not attempt to measure eye movement patterns. A previous study examining reading speed in glaucoma using eye tracking software showed that patients with advanced glaucoma read slower than controls, and that those glaucoma patients that read slower exhibited greater text saturation (distance between first and last fixations on lines of text) during reading.28 Owing to the limited sample, we were not able to evaluate the relationship between the location of glaucomatous visual field loss and reading performance. It is likely that central visual field loss has a greater effect on reading than peripheral loss, and although MD includes a weighting for the central visual field, summary indices do not allow full exploration of the effect of visual field defects on ability to perform vision-related tasks. Another potential problem of a small sample size is that results may be affected by outliers, however, an examination of scatter plots of reading speed showed no apparent outliers (Fig. 3), and the distribution of reading speeds was clearly different between those with glaucoma and controls (Fig. 2). It is however possible that the complex activity of reading was affected by potential confounding factors not examined in this study.

In summary, this study demonstrated significantly slower reading speeds in patients with glaucoma compared with controls, despite preserved central visual acuity, similar age, and similar levels of education between groups. Further studies are needed to assess the real impact of worsened reading performance on daily tasks and to explore whether interventions may be possible to improve reading performance in such patients.

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TABLE 3. Univariable Logistic Regression Showing the Change in Odds of Glaucoma Associated With a 10 wpm Decrease in Reading Speeds for Average Reading Speed and Each of the 5 MNREAD Slides

| Odds Ratio | 95% CI      | P    |
|------------|-------------|------|
| Slide 1    | 1.37        | 1.11-1.68 | 0.003|
| Slide 2    | 1.27        | 1.06-1.52 | 0.011|
| Slide 3    | 1.26        | 1.06-1.50 | 0.008|
| Slide 4    | 1.19        | 1.01-1.40 | 0.036|
| Slide 5    | 1.22        | 1.02-1.46 | 0.032|
| Average    | 1.29        | 1.07-1.56 | 0.009|

CI indicates confidence interval.

TABLE 4. Multivariable Logistic Regression Showing the Change in Odds of Glaucoma Associated With a 10 wpm Decrease in Reading Speeds for Average Reading Speed and Each of the 5 MNREAD Slides Accounting for Visual Acuity in the Better Eye, Age (Per Year Older) and Schooling (High School or No High School)

| Odds Ratio | 95% CI   | P   |
|------------|----------|-----|
| Average    |          |     |
| Age        | 0.97     | 0.93-1.01 | 0.124|
| Schooling  | 0.86     | 0.25-2.99 | 0.812|
| Reading speed | 1.29   | 1.03-1.63 | 0.028|
| Slide 1    |          |     |
| Age        | 0.97     | 0.93-1.01 | 0.168|
| Schooling  | 0.87     | 0.26-2.88 | 0.817|
| Reading speed | 1.36   | 1.08-1.72 | 0.009|
| Slide 2    |          |     |
| Age        | 0.97     | 0.93-1.01 | 0.127|
| Schooling  | 0.96     | 0.28-3.23 | 0.943|
| Reading speed | 1.26   | 1.01-1.56 | 0.037|
| Slide 3    |          |     |
| Age        | 0.97     | 0.93-1.01 | 0.116|
| Schooling  | 0.90     | 0.27-3.02 | 0.864|
| Reading speed | 1.26   | 1.03-1.54 | 0.023|
| Slide 4    |          |     |
| Age        | 0.97     | 0.93-1.01 | 0.106|
| Schooling  | 1.09     | 0.32-3.67 | 0.895|
| Reading speed | 1.17   | 0.96-1.43 | 0.110|
| Slide 5    |          |     |
| Age        | 0.97     | 0.93-1.01 | 0.126|
| Schooling  | 1.09     | 0.32-3.69 | 0.893|
| Reading speed | 1.19   | 0.96-1.48 | 0.115|

Statistically significant values are in bold. CI indicates confidence interval.

TABLE 5. Multivariable Logistic Regression Showing the Change in Odds of Glaucoma Associated With a 10 wpm Decrease in Reading Speeds for Average Reading Speed and Each of the 5 MNREAD Slides Accounting for Visual Acuity in the Better Eye, Age (Per Year Older) and Schooling (High School or No High School)

| Odds Ratio | 95% CI   | P   |
|------------|----------|-----|
| Average    |          |     |
| Visual acuity | 0.06 | 0.001-6.53 | 0.240|
| Age        | 0.97     | 0.93-1.01 | 0.136|
| Schooling  | 0.75     | 0.21-2.59 | 0.654|
| Reading speed | 1.27  | 1.01-1.61 | 0.042|
| Slide 1    |          |     |
| Visual acuity | 0.03 | 0.00-4.03 | 0.166|
| Age        | 0.97     | 0.93-1.01 | 0.186|
| Schooling  | 0.70     | 0.20-2.44 | 0.377|
| Reading speed | 1.36  | 1.08-1.72 | 0.010|
| Slide 2    |          |     |
| Visual acuity | 0.05 | 0.00-4.88 | 0.196|
| Age        | 0.97     | 0.93-1.01 | 0.138|
| Schooling  | 0.79     | 0.22-2.81 | 0.714|
| Reading speed | 1.25  | 1.00-1.55 | 0.046|
| Slide 3    |          |     |
| Visual acuity | 0.99 | 0.00-12.21 | 0.347|
| Age        | 0.97     | 0.93-1.01 | 0.126|
| Schooling  | 0.83     | 0.24-2.83 | 0.762|
| Reading speed | 1.36  | 1.00-1.51 | 0.043|
| Slide 4    |          |     |
| Visual acuity | 0.04 | 0.00-4.33 | 0.178|
| Age        | 0.97     | 0.93-1.01 | 0.123|
| Schooling  | 0.90     | 0.25-3.17 | 0.868|
| Reading speed | 1.17  | 0.96-1.23 | 0.129|
| Slide 5    |          |     |
| Visual acuity | 0.06 | 0.00-5.98 | 0.227|
| Age        | 0.97     | 0.93-1.01 | 0.141|
| Schooling  | 0.96     | 0.27-3.34 | 0.944|
| Reading speed | 1.17  | 0.94-1.45 | 0.172|

Statistically significant values are in bold. CI indicates confidence interval.
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