Difficulty with Out-Loud and Silent Reading in Glaucoma

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Purpose. We evaluated the impact of glaucoma on out-loud and silent reading.

Methods. Glaucoma patients with bilateral visual field (VF) loss and normally-sighted controls had the following parameters measured: speed reading an International Reading Speed Text (IReST) passage out loud, maximum out-loud MNRead chart reading speed, sustained (30 minutes) silent reading speed, and change in reading speed during sustained silent reading.

Results. Glaucoma subjects read slower than controls on the IReST (147 vs. 163 words per minute [wpm], $P < 0.001$), MNRead (172 vs. 186 wpm, $P < 0.001$), and sustained silent (179 vs. 218 wpm, $P < 0.001$) tests. In multivariable analyses adjusting for age, race, sex, education, employment, and cognition, IReST and MNRead reading speeds were 12 wpm (6%–7%) slower among glaucoma subjects compared to controls ($P < 0.01$ for both), while sustained silent reading speed was 16% slower (95% confidence interval [CI] = –24 to –6%, $P = 0.002$). Each 5 decibel (dB) decrement in better-eye VF mean deviation was associated with 6 wpm slower IReST reading (95% CI = –9 to –3%, $P < 0.001$), 5 wpm slower MNRead reading (95% CI = –7 to –2%, $P < 0.001$), and 9% slower sustained silent reading (95% CI = –13 to –6%, $P < 0.001$). A reading speed decline of 0.5 wpm/min or more over the sustained silent reading period was more common among glaucoma subjects than controls (odds ratio [OR] = 2.2, 95% CI = 1.0–4.9, $P < 0.05$).

Conclusions. Reading speed is slower among glaucoma patients with bilateral VF loss, with the greatest impact present during sustained silent reading. Persons with glaucoma fatigue during silent reading, resulting in slower reading over time. (*Invest Ophthalmol Vis Sci.* 2013;54:666–672) DOI:10.1167/iovs.12-10618

Reading is a fundamental part of many daily tasks, including activities related to work, household maintenance, and leisure. In the elderly, vision is a frequent reason for difficulty reading, and reading difficulties are a primary complaint in individuals with eye disease.[1] Therefore, understanding, measuring, and rehabilitating reading difficulty are of significant importance among older adults.

The connection between reading difficulties and visual acuity (VA) is well established,[2] though the connection between visual field (VF) loss and reading ability is less clear. Moreover, the literature describing reading ability in diseases defined by VF loss is limited and often contradictory.[3] For example, nearly half of glaucoma subjects describe difficulty reading in focus groups.[4] However, objective evaluation of out-loud reading speed suggests that significant decreases in reading speed are present only in subjects with advanced bilateral glaucoma.[5]

One possible reason behind the observed discrepancy between self-reported and objectively-measured reading outcomes in glaucoma is that tests of out-loud reading may not capture reading difficulty adequately. In the clinical setting, the most common reading complaints relate to sustained silent reading tasks, such as reading a newspaper or a book over a long duration. Complaints often are focused on "reading fatigue,"[6] which are not measured by out-loud reading tests, which typically evaluate only reading over the course of 1 minute or less.[7–12]

In this study, we hypothesized that VF loss from glaucoma would have little to no effect on out-loud reading, but would significantly reading affect over longer durations. To test these hypotheses, we developed and validated a test of sustained silent reading.[13] Reading outcomes assessed from this test included silent reading speed over a 30-minute duration, and the change in reading speed over this 30-minute period (which may reflect reading fatigue). Here, we evaluated how these sustained silent reading parameters differ between subjects with bilateral VF loss from glaucoma and a group of glaucoma suspects with normal VFs and VA. Additionally, we compared the impact of glaucoma status and VF loss severity on sustained silent reading speed to the impact of glaucoma/VF loss on traditional measures of out-loud reading speed evaluated using the MNRead acuity chart[7] and an International Reading Speed Text (IReST) passage.[8]

Methods

All study procedures were approved by the Institutional Review Board of Johns Hopkins Medicine and adhered to the tenets set forth by the Declaration of Helsinki. Study participants gave written informed consent, and completed the study procedures between July 2009 and April 2011.

Study Subjects

We recruited subjects age 50 and over from the Glaucoma Clinic of the Wilmer Eye Institute at Johns Hopkins Hospital. All patients had to be able to communicate in English, had to be literate by self-report, and were required to have VF testing performed within the last year (HFA2; Carl Zeiss Meditec, Inc., Dublin, CA). VF testing was performed in both eyes over the central 24 degrees using a size III stimulus and the Swedish interactive thresholding algorithm (SITA) standard testing program. VF severity was defined by the higher (less negative) mean

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deviation (MD) among the 2 eyes. Individuals were ineligible for the study if they had any laser procedure in the previous week or any ocular surgery in the previous 2 months, or if chart review raised suspicion of vision loss from causes not related to glaucoma.

Two study groups were recruited: glaucoma suspect controls and subjects with bilateral VF loss from glaucoma. Controls had a chart diagnosis of glaucoma suspect or ocular hypertension, and also were required to have a presenting Early Treatment Diabetic Retinopathy Study (ETDRS) visual acuity of 20/40 or better in both eyes, and right and left eye VFs meeting the following criteria: MD better than −3 decibels (dB) in at least one eye and better than −4 dB in both eyes on a SITA standard 24-2 test (all but 4 control subjects had a MD ≥−3 dB OU) and a glaucoma hemifield test (GHT) result of "within normal limits," "borderline," or "general reduction of sensitivity." Other GHT results were permitted if the VF test was noted to have "low test reliability" or "excessively high false positives," though at least one eye in each of these 3 subjects had a GHT of either "within normal limits" or "general reduction of sensitivity."

Individuals were eligible for recruitment into the glaucoma group if they had a diagnosis of primary open angle glaucoma, primary angle closure glaucoma, pseudoexfoliation glaucoma, or pigment dispersion glaucoma and a presenting visual acuity of 20/40 or better in at least one eye. Recruited glaucoma subjects also were required to have VFs in both eyes with a MD worse than −3 dB and a GHT result of "outside normal limits," "generalized reduction of sensitivity," or "borderline," including a GHT result of "outside normal limits" in at least one eye. For patients with a recent 24-2 VF in only one eye, and either no recent VF or a 10-2 VF in the second eye, the better-eye MD was taken from the recent 24-2 VF. In 3 patients who had only recent 10-2 VFs, the last 24-2 VFs completed for each eye were identified (occurring within the prior 3 years in all cases), and the better-eye MD was taken from the 24-2 VF with the higher MD.

Evaluation of Reading

Subjects performed, in order, the following tests of reading: evaluation of out-loud reading speed using the sentences presented on the MNRead acuity chart,[7] evaluation of out-loud reading speed while reading an IReST passage,[8] evaluation of sustained silent reading over a 30-minute period,[13] and answering of comprehension questions corresponding to the sustained silent reading material. For all reading tests, subjects wore their habitual reading correction (if any). For the IReST and sustained reading, subjects held the reading material (printed on matte paper) at the distance most comfortable for them, while for the MNRead evaluation, the card was held at a distance of 40 cm. Room lighting was provided by overhead fluorescent lamps and was standardized such that pages were lit uniformly without shadows with an illuminance between 400 and 600 lux at page level. Greater detail regarding the administration of the 3 reading tests is provided in the companion paper to this article.[13]

Reading speeds were calculated in words per minute (wpm) for each of the 3 tests as follows: maximum reading speed was calculated from MNRead times using nonlinear mixed effects models,[14] IReST passage reading speeds were calculated after accounting for reading errors, and sustained silent reading speeds were calculated from the total words read and time required for reading. Additional parameters collected from MNRead testing included critical print size (derived from nonlinear mixed effects models)[14] and reading acuity, while additional parameters collected from sustained silent reading testing included the reading speed slope (expressed in wpm/min), and the percentage of comprehension questions answered correctly. Details regarding the derivation of these parameters are provided in the companion article to this study.[13]

Measurement of Vision and Covariates

VA was measured binocularly with patients' habitual distance correction using the ETDRS chart. For statistical analysis, VA was summarized as the negative logarithm of the minimum angle of resolution (logMAR).[15] Contrast sensitivity was measured as the number of letters read correctly on the Pelli-Robson chart under binocular conditions and converted to a log scale.[16]

Lenticular changes, including nuclear sclerotic, cortical, and posterior subcapsular changes, and posterior capsular opacification, were graded as present or absent as described previously.[17]

Sociodemographic variables, including age, race/ethnicity, and education, were gathered using standardized forms. The presence of depressive symptoms was assessed using the part D of the General Health Questionnaire, with a positive response to any question taken to indicate the presence of depressive symptoms.[18] Cognitive ability was evaluated using the Mini Mental State Exam (MMSE).[19]

Statistical Methods and Programming

Group differences in demographic, health, and vision features were analyzed using the Student's *t*-test for normally-distributed continuous variables, Wilcoxon rank-sum testing for nonnormally distributed continuous variables, and χ^2 testing for categorical variables. Predictors of MNRead, IReST, and log-transformed silent reading speeds also were evaluated using age-adjusted and multivariable linear regression models. Sustained silent reading speeds were log-transformed to produce normally distributed residuals in regression models. Because of the high correlation between better-eye VF loss and contrast sensitivity ($r = 0.63$), a separate multivariable model was constructed to look at the effect of each vision variable on each reading test, adjusted only for nonvisual covariables. Covariates were included in all multivariable models of reading speed if they demonstrated a significant impact on either out-loud or sustained silent reading speed ($P < 0.1$) in age-adjusted regression models, or if they had been shown to impact reading speed in previous research.[5] Factors potentially occurring as a result of glaucoma, but also related to reading speed outcomes (i.e., decreased visual acuity, poor reading comprehension, and depressive symptoms), were not included in primary models, though the sensitivity of major findings to inclusion of these variables was examined.

Changes in reading speed over the sustained silent reading period, also referred to as reading speed slope, were analyzed using multivariable linear regression models. Bootstrapped standard errors were obtained to account for the skewed distribution of model residuals. Declines in reading speed slopes also were dichotomized as being greater than −0.5 wpm/min or ≤−0.5 wpm/min and then analyzed using multivariable logistic regression.

Results

Totals of 60 glaucoma suspect controls and 64 glaucoma subjects were recruited and completed study procedures. One control subject was not analyzed due to poor reading comprehension, and a significant discrepancy between silent and out-loud reading. Glaucoma subjects were older (71.6 vs. 67.0 years, $P = 0.004$) but did not differ with regards to race, sex, education level, employment status, cognitive ability, or depressive symptoms ($P > 0.2$ for all, Table 1). Compared to controls, glaucoma subjects had more severe VF loss in the better-eye (MD of −8.9 vs. +0.2 dB, $P < 0.001$), worse better-eye visual acuity (logMAR of 0.09 vs. 0.00, $P < 0.001$), and worse contrast sensitivity (log of contrast sensitivity = 1.67 vs. 1.93, $P < 0.001$). The observed frequency of significant cataract or posterior capsular opacification (PCO) did not differ by glaucoma status.

In unadjusted analyses, glaucoma subjects read slower than controls on IReST (147 vs. 163 wpm, $P < 0.001$), MNRead (172 vs. 186 wpm, $P < 0.001$), and sustained silent reading (179 vs. 218 wpm, $P < 0.001$) tests (Table 2). Critical print size was larger for glaucoma subjects than controls (0.21 vs. 0.14, $P =$

Table 1. Characteristics of Subjects Completing Reading Testing by Glaucoma Status

	Glaucoma Suspect Controls (n = 59)	Glaucoma (n = 64)	*P* Value
Vision			
Visual field MD, better-eye	0.2 (1.0)	−8.9 (6.8)	<0.001
Better-eye acuity, logMAR	0.00 (0.11)	0.09 (0.11)	<0.001
Binocular log CS	1.93 (0.13)	1.67 (0.19)	<0.001
Sig. cataract/PCO, either eye, %	6.8	10.9	0.41
Demographics			
Age, y	67.0 (8.4)	71.6 (9.1)	0.004
African-American race, %	18.6	20.3	0.82
Female sex, %	62.7	57.8	0.56
Education, y	15.4 (2.1)	15.2 (2.4)	0.58
Employed, %	47.5	42.2	0.56
Health			
MMSE score	27.7 (1.5)	27.4 (1.4)	0.21
Depressive symptoms, %	6.8	7.8	0.83

Values shown for continuous variables reflect means with SD shown in parentheses. CS, Contrast sensitivity; Sig., significant.

0.05), but reading acuity did not differ significantly between groups (logMAR reading acuity of –0.01 vs. –0.05, $P = 0.07$). Reading speed slopes were more negative in glaucoma subjects than controls (median reading speed slope of –0.37 vs. –0.02 wpm/min, $P = 0.06$, Fig. 1), though the difference fell just outside the criteria for statistical significance. Glaucoma subjects were more likely than control subjects to have a decline in reading speed slope greater than 0.5 wpm/min (47 vs. 29%, $P = 0.04$). Glaucoma subjects answered an average of 79% of comprehension questions correctly compared to 84% for control subjects, with group differences falling just outside the cutoff for statistical significance ($P = 0.06$). IReST, MNRead, and sustained silent reading speeds all declined with greater levels of VF loss (Fig. 2).

In separate age-adjusted analyses, all vision variables including glaucoma status, degree of better-eye VF loss, contrast sensitivity, and VA, were associated with slower MNRead, IReST, and sustained silent reading speeds (Table 3, $P < 0.05$ for all). Several nonvisual factors also were associated with slower reading speeds on all 3 reading tests, including older age, African-American race, less education, lower MMSE scores, and depressive symptoms. Employment was associated with faster sustained silent reading, but not with faster IReST or MNRead reading. Neither sex nor the presence of significant cataract/PCO affected reading speed on any of the 3 tests of reading. Higher comprehension on the silent reading material was associated with faster sustained silent reading speeds ($P < 0.001$), and also with faster IReST and MNRead reading speeds ($P \leq 0.01$ for both).

Separate multivariable models were constructed to assess the impact of glaucoma, VF loss severity, contrast sensitivity, and VA on MNRead, IReST and sustained silent reading speeds (Table 4). When compared to control subjects, glaucoma subjects had slower MNRead (12 wpm slower, 95% confidence interval [CI] = –19 to –5 wpm, $P = 0.001$), IReST (12 wpm slower, 95% CI = –20 to –3 wpm, $P = 0.006$), and sustained silent reading speeds (16% slower, 95% CI = –24 to –6%, $P = 0.002$). Each 5 dB decrement in the better-eye VF also was associated with slower MNRead (5 wpm slower, 95% CI = –7 to –2%, $P < 0.001$), IReST (6 wpm slower, 95% CI = –9 to –3 wpm, $P < 0.001$), and sustained silent reading speeds (9% slower, 95% CI = –13 to –6%, $P < 0.001$, Fig. 2). Slower MNRead, IReST, and sustained silent reading speeds also were associated with lower contrast sensitivity ($P < 0.001$ for all

Table 2. Comparison of Silent and Reading Parameters by Glaucoma Status, Unadjusted Values

	Glaucoma Suspect Controls (n = 59)	Glaucoma (n = 64)	*P* Value*
Out loud reading, IReST passage			
Reading speed, mean wpm	163 (21)	147 (29)	<0.001
Out loud reading, MNRead card			
Max reading speed, mean wpm	186 (20)	172 (19)	<0.001
Critical print size, mean	0.14 (0.16)	0.21 (0.21)	0.05
Reading acuity, mean logMAR	−0.05 (0.11)	−0.01 (0.14)	0.07
Sustained silent reading passage			
Reading speed, median wpm	218 (181–269)	179 (146–230)	<0.001
Log_{10} reading speed, mean	2.34 (0.12)	2.25 (0.15)	<0.001
Slope, wpm/min,† median	−0.02 (−0.67–1.11)	−0.37 (−0.97–0.79)	0.06
Slope less than −0.5 wpm/min	29%	47%	0.04

Standard deviation shown in parentheses for mean values, and interquartile range shown for median values.

* Reflects outcome of *t*-test for values expressed as means, outcome of Mann-Whitney rank sum test for values expressed as medians, and outcome of χ^2 testing for comparison of proportions.

† Slope reflects change in reading speed over time.

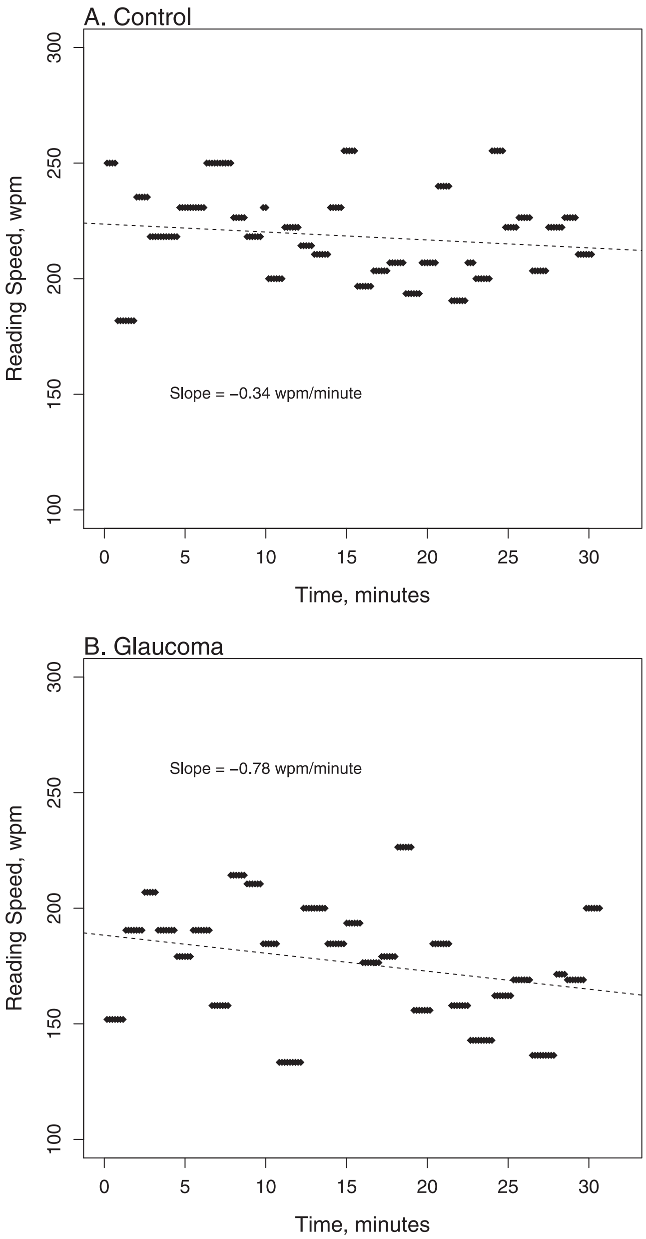

Figure 1. Pattern of reading speed time for representative glaucoma and control patients. The reading speed at each examined time point (chosen at 10-second intervals) was inferred from the reading speed for the page of text being read at that time. Change in reading speed over time (i.e., reading speed slope) then was calculated by plotting reading speed against time. Representative patterns of reading speed are shown for: (**A**) the control subject at the 51st percentile for reading speed and 36th percentile for reading speed slope, and (**B**) the glaucoma subject at the 47th percentile for reading speed and 36th percentile for reading speed slope.

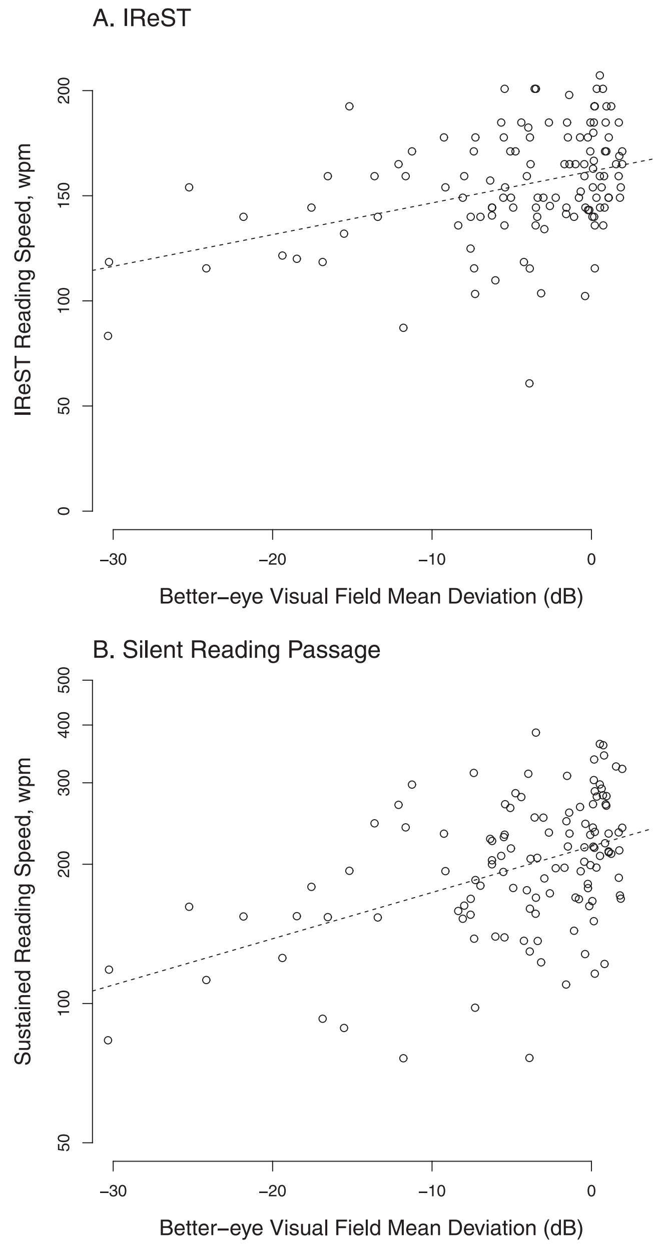

Figure 2. Change in IReST and sustained silent reading speeds with severity of visual field loss. (**A**) Out-loud reading speed of an IReST passage shown across the spectrum of VF loss severity. (**B**) Sustained silent reading speed shown across the spectrum of VF loss severity. Reading speed is displayed on an logarithmic scale.

reading tests) and worse binocular visual acuity ($P \leq 0.06$ for all reading tests).

The association between glaucoma and decreased reading speed in all 3 tests of reading persisted when any combination of the following variables were included in multivariable models: depressive symptoms, reading comprehension, and visual acuity ($P < 0.05$ in all models). The association between severity of better-eye VF loss and slower MNRead, IReST, and sustained silent reading speeds also persisted when depressive symptoms, reading comprehension, visual acuity, or any combination of these covariates were added to regression models ($P \leq 0.001$ for all).

Factors associated with changes in reading speed over 30 minutes of sustained reading were evaluated with linear regression models that evaluated slope as continuous metric, or logistic regression models that evaluated the likelihood of a decline in reading speed of –0.5 wpm/min or worse. The factors considered were glaucoma status, better-eye VF MD, visual acuity, significant cataract/PCO, African-American race, education, and employment status. In multivariable models, glaucoma was associated with a non-statistically significant decrease in reading speed slope (–0.49 wpm/min, 95% CI = –1.08–0.09, $P = 0.10$), and a greater likelihood of a reading

Table 3. Predictors of MNRead, IReST, and Sustained Silent Reading Speeds, Age-Adjusted Analyses

Variable	Interval	Out Loud (MNRead) Reading Speed Δ wpm (95% CI)	Out Loud (IreST) Reading Speed Δ wpm (95% CI)	Sustained Silent Reading Speed % Change (95% CI)
Vision				
Glaucoma	vs. Suspect glaucoma	−12 wpm (−20 to −5)*	−13 wpm (−22 to −4)*	−17% (−22 to −7)*
VF loss MD, better-eye	5 dB worse	−6 wpm (−8 to −3)*	−7 wpm (−11 to −4)*	−11% (−14 to −7)*
Contrast sensitivity	0.1 log units worse	−3 wpm (−5 to −2)*	−5 wpm (−7 to −3)*	−6% (−8 to −3)*
VA, binocular	0.1 logMAR worse	−4 wpm (−7 to −1)*	−6 wpm (−9 to −2)*	−5% (−10 to 0)*
Cataract/PCO	Present, either eye	+3 wpm (−9 to +13)	−1 wpm (−14 to +12)	−8% (−23 to +10)
Demographics				
Age	5 y older	−2 wpm (−4–0)*	−3 wpm (−5 to −1)*	−4% (−6 to −1)*
Male	vs. Female	+3 wpm (−4 to +10)	+2 wpm (−7 to +10)	+3% (−7 to +16)
African-American	vs. Not African-American	−12 wpm (−21 to −3)*	−18 wpm (−29 to −8)*	−25% (−34 to −13)*
Education	4 y less	−10 wpm (−16 to −4)*	−11 wpm (−18 to −4)*	−18% (−25 to −10)*
Employed	vs. Not employed	+6 wpm (−1 to +13)	+8 wpm (−1 to +16)	+15% (+2 to +28)
Health				
MMSE score	5 points lower	−27 wpm (−38 to −16)*	−37 wpm (−50 to −25)*	−32% (−43 to −18)*
Depressive symptoms	Present	−17 wpm (−29 to −5)*	−25 wpm (−39 to −11)*	−27% (−40 to −12)*

* $P \leq 0.05$.

speed decline ≥0.5 wpm/min (odds ratio [OR] = 2.2, 95% CI = –1.0–4.9, $P < 0.05$, Table 5). In separate multivariable models, declines in reading speed over time were associated with more better-eye VF loss (–0.19 wpm/min per 5 dB decrement in MD, 95% CI = –0.36 to –0.01, $P = 0.04$) and worse visual acuity (–0.31 wpm/min per 0.1 logMAR increment, 95% CI = –0.58 to –0.05, $P = 0.02$). Reading speed declines ≥0.5 wpm/min were more common with worse visual acuity (OR = 1.6 per 0.1 logMAR increment, 95% CI = 1.1–2.2, $P = 0.008$), but not with severity of better-eye VF loss (OR = 1.1 per 5 dB decrement in MD, 95% CI = 0.8–1.4, $P = 0.67$). The presence of significant cataract/PCO was associated with a more negative reading speed slope (β = –0.87 wpm/min, 95% CI = –1.61 to –0.12, $P = 0.02$), but not with a greater likelihood of a reading speed decline ≥0.5 wpm/min (OR = 3.1, 95% CI = 0.8–11.7, $P = 0.10$). No other tested variables were associated with change in reading speed.

Discussion

Individuals with bilateral VF loss from glaucoma read slower than glaucoma suspect controls, particular when reading silently over prolonged durations. Slower out-loud and silent reading speeds were associated with greater levels of VF loss, and this association was independent of visual acuity. Furthermore, declines in reading speed over time are more common among glaucoma subjects compared to glaucoma suspect controls, a feature captured uniquely by sustained silent reading testing. Testing of sustained silent reading also demonstrates a greater impact of glaucomatous VF loss on reading speed than tests of out-loud reading. Given that most daily reading is done silently, results from sustained reading testing best represent the true impact of glaucoma on reading speed.

Two previous studies measured reading speed in glaucoma. Altangerel et al. noted a correlation between binocular VF loss

Table 4. Predictors of MNRead, IReST, and Sustained Silent Reading Speeds, Multivariable Analyses

Variable	Interval	Out Loud (MNRead) Reading Speed Δ wpm (95% CI)	Out Loud (IreST) Reading Speed Δ wpm (95% CI)	Sustained Silent Reading Speed % Change (95% CI)
Vision*				
Glaucoma	vs. Suspect glaucoma	−12 wpm (−19 to −5)†	−12 wpm (−20 to −3)†	−16% (−24 to −6)†
VF loss MD, better-eye	5 dB worse	−5 wpm (−7 to −2)†	−6 wpm (−9 to −3)†	−9% (−13 to −6)†
Contrast sensitivity	0.1 log units worse	−3 wpm (−5 to −1)†	−4 wpm (−6 to −2)†	−5% (−7 to −3)†
VA, better-eye	0.1 logMAR worse	−3 wpm (−6 to 0)†	−5 wpm (−8 to −1)†	−4% (−9 to 0)‡
Non-visual§				
Age	5 y older	−2 wpm (−4 to 0)†	−3 wpm (−5 to −0)†	−4% (−7 to −1)†
Male	vs. Female	+2 wpm (−5 to +9)	+1 wpm (−7 to +9)	−1% (−10 to +10)
African-American	vs. Not African-American	−4 wpm (−13 to +5)	−10 wpm (−20 to 0)	−16% (−26 to −4)†
Education	4 y less	−4 wpm (−11 to +3)	−1 wpm (−10 to +7)	−10% (−19 to 0)†
Employed	vs. Not employed	−2 wpm (−9 to +6)	+0 wpm (−9 to +9)	−4% (−14 to +7)
MMSE score	5 points lower	−14 wpm (−27 to −1)†	−30 wpm (−46 to −14)†	−17% (−32 to +1)

* The impact of different metrics of vision each derived from a separate model including the visual metric and all non-visual metrics shown.
† $P \leq 0.05$.
‡ $P = 0.06$.
§ The impact of nonvisual variables taken from a single model including the degree of better-eye VF loss and all nonvisual metrics shown.

Table 5. Predictors of Reading Speed Slope during Sustained Silent Reading, Multivariable Analyses

Variable*	Interval	Reading Speed Slope Δ wpm/min (95% CI)	Likelihood of a Slope ≤−0.5 wpm/min† OR (95% CI)
Glaucoma	vs. Suspect glaucoma	−0.49 (−1.08–0.09)	2.2 (1.0–4.9)‡
VF loss MD, better-eye	5 dB worse	−0.19 (−0.36–0.00)‡	1.1 (0.8–1.4)
VA, binocular	0.1 logMAR worse	−0.31 (−0.58 to −0.05)‡	1.6 (1.1–2.2)‡
Cataract/PCO	Present	−0.87 (−1.61 to −0.12)‡	3.1 (0.8–11.7)
Age	5 y older	−0.11 (−0.26–0.04)	0.8 (0.7–1.0)
African-American	vs. Not African-American	−0.46 (−1.03–0.12)	1.6 (0.7–4.0)
Education	4 y less	−0.01 (−0.56–0.53)	1.6 (0.9–3.1)
Employed	vs. Not employed	−0.16 (−0.71–0.39)	0.7 (0.3–1.5)

* Regression coefficients for glaucoma, better-eye MD and VA taken from separate multivariable models, including cataract/PCO, age, race, education, and employment status as covariates. Regression coefficients for all other variables taken from a single model including better-eye VF MD in addition to cataract/PCO, age, race, education, and employment status.

† Implies a decline in reading speed ≥0.5 wpm/min of reading.

‡ $P \leq 0.05$.

and reading speed, though findings were not evaluated in multivariable analyses.[20] The Salisbury Eye Evaluation (SEE) found no association between glaucoma and reading speed except among subjects with advanced bilateral VF loss.[5] The association between glaucoma and severity of VF loss with reading speed did not persist after adjusting for visual acuity, suggesting that lower reading speed was not a function of VF loss. The results from our study differ from these previous findings in that bilateral glaucoma was associated with lower reading speeds irrespective of the reading test used. Additionally, the observed associations were independent of visual acuity, suggesting that VF loss alone impairs reading speed. The reasons behind these discrepant findings are unclear. Bilateral glaucoma subjects had similar levels of VF damage in both populations, though subjects were younger in our study. Subjects in our study population also were better educated and read faster, such that changes in reading speed due to disease may have been more detectable. It also is likely that the reading test used in SEE, which tested reading out-loud over brief, 15-second intervals, was not well suited to pick up VF-related declines in reading speed when compared to the three tests of reading used in our study.

Studies assessing reading through self-report provide compelling evidence that reading is, indeed, affected by glaucoma, corroborating the findings from our study. In a focus group conducted by Nelson et al., over 40% of glaucoma subjects described difficulty with reading.[4] Several other studies demonstrate greater difficulty with near vision tasks with greater glaucoma-related VF loss.[5,21–23] In one study, greater VF loss was associated with greater self-reported difficulty finding the next line of text, providing a possible explanation for why reading difficulties may be notable particularly in reading tests of longer duration, which require the reading of multiple lines of text.[24] Indeed, VF loss may impair one's ability to bring new text effectively into fixation by decreasing saccade size and/or accuracy, providing a plausible mechanism for reading speed decline (Burton R, *IOVS* 2012, ARVO Program 175).

A significant finding from our study was that reading speed declines were significantly greater (on an absolute and percentage basis) for sustained silent reading than for out-loud reading over shorter durations. Specifically, the 16% decline associated with glaucoma in testing of sustained silent reading was over twice the 7% decline associated with glaucoma in tests of out-loud reading (i.e., MNRead and IReST). This finding likely reflects that out-loud reading is determined by one's ability to process the read material (visually and cognitively) and also one's ability to speak the words out loud, while silent reading is limited only by one's ability to process the read material visually and cognitively. Most individuals read significantly faster when reading silently,[25] suggesting that when they are reading aloud they are not maximally challenging their visual and cognitive processing systems due to limitations in how fast they can, or are inclined to, speak. In this scenario, the impact of vision on reading would be underestimated when reading out loud, and captured more completely with testing of sustained silent reading.

A small pilot study of 5 glaucoma patients suggested previously that VF loss may be associated with decreasing reading speed over time,[6] and a unique feature of the sustained silent reading test used here is that it allowed us to examine this possibility formally in a much larger group of patients. Glaucoma subjects were more likely than controls to have declines in reading speed slopes greater than 0.5 wpm/min. The magnitude of these effects was modest, with the median glaucoma subject demonstrating a decline in reading speed of 10 wpm (roughly 5%) over a 30-minute period. Additionally, evidence for a dose-response relationship between VF loss severity and reading speed decline was mixed, with severity of VF loss associated with change in reading speed expressed as a continuous, but not a dichotomized, outcome. Reading speed decline may be a marker for "reading fatigue," which often is described among glaucoma patients in the clinical setting, and indicates that the effect of glaucoma on reading measured in the first minute of reading likely underestimates the true impact of the disease. Further study will be needed to corroborate our current findings, quantify reading fatigue through self-report, and examine the association between change in reading speed over time and the report of reading fatigue.

An additional finding of interest was that reading comprehension was lower in the glaucoma group than the control group, though the finding fell just outside the chosen cutoff for statistical significance ($P = 0.06$). Nonetheless, it certainly is possible that material read by glaucoma subjects was understood more poorly because it was not read and processed as clearly as it would be in an individual with normal vision. Further study is required to evaluate whether this association is indeed true, and to investigate whether it is a result of visual defects or coexisting cognitive defects.

VF loss was investigated as the primary disease severity metric predicting reading speed in our study, and the impact of VF loss on out-loud and silent reading speed was, indeed, independent of visual acuity. VF loss severity also impacted the maximum rate of reading for the different text sizes presented on the MNRead card, suggesting that text size is not by itself limiting reading. Rather, it is likely that the impact of glaucoma on reading is a result of several visual features, including VF loss, decreased contrast sensitivity, and decreased visual acuity. However, given the sample size, and the fact that many of these metrics for vision loss are correlated strongly (particularly VF loss and contrast sensitivity), the relative contributions of these visual metrics is difficult to define from the current data. Furthermore, we did not assess the impact of VF loss in particular locations within the field of vision, or of overlapping VF defects, on reading speed.

Limitations to our study include the fact that the population studied represented a convenience sample, and that poor readers may have been less likely to participate, biasing our findings in a conservative direction. Additionally, we chose glaucoma suspects as controls and not individuals with any signs of eye disease, possibly biasing our findings towards the null hypothesis of no impact of glaucoma on reading ability. However, we felt that glaucoma suspects represented an appropriate comparison group as their degree of VF loss and contrast sensitivity was the same as or even slightly better than normal older adults described in population based studies,[26] and because recruitment of normal controls (i.e., spouses or friends accompanying patients to clinic) is likely to exclude individuals who are less likely to venture outside the home due to poorer general health, mood, or cognitive ability, thus producing a "supranormal" group of controls. In addition, controls who also attend the same clinic as cases are more likely to be similar on unmeasured factors. Finally, our findings pertain to a specific set of office-based environmental testing conditions, and the effect of glaucoma on reading may differ under other conditions.

In summary, our findings showed that patients with bilateral VF glaucoma read slower, particularly when reading silently for long periods of time, and are more likely to have their reading speed decrease over time, possibly as a result of reading fatigue. At the same time, many individuals with advanced levels of VF loss were able to read silently at rates exceeding 200 wpm, suggesting that normal reading speed remains possible in more advanced glaucoma. Further research is necessary to distinguish the mechanism behind slower reading speed in glaucoma, understand why some individuals are able to maintain normal reading speeds despite their visual impairment, and design rehabilitative strategies to improve reading ability in individuals with VF loss.

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