**Objective:** To determine if, and at what point, glaucoma affects spoken reading speed.

**Methods:** Data were collected from the Salisbury Eye Evaluation, a population-based evaluation of visual function and disability in the elderly population. Nonscrolling text was displayed on a screen and the rate words were read aloud was measured. Subjects reading slower than 90 words/min were defined as having impairment. Glaucoma status was determined using optic disc appearance and visual field testing.

**Results:** One thousand one hundred fifty-four subjects completed evaluations of spoken reading speed and glaucoma status. Univariate analysis demonstrated reading impairment in 16.0% of subjects without glaucoma, 21.1% of subjects with unilateral glaucoma ($P = .25$), and 28.4% of subjects with bilateral glaucoma ($P = .006$). Multivariable regression demonstrated nonsignificant increases in the odds of reading impairment for subjects with unilateral (odds ratio, [OR], 1.13; $P = .69$) and bilateral glaucoma (OR, 1.25; $P = .43$), though subjects with bilateral glaucoma in the highest quartile of better-eye visual field loss read slower ($\beta = -32$ words/min; $P = .01$) and were more often reading impaired than controls without glaucoma (OR, 3.8; $P = .04$). Race, cognitive ability, education, and visual acuity were important predictors of reading impairment.

**Conclusions:** High rates of spoken reading impairment were found throughout this elderly sample. Glaucoma was associated with slower reading and increased reading impairment with advanced bilateral field loss.

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**G**LAUCOMA AFFECTS 2% OF US adults older than 40 years,¹ and as many as 10% have suspected glaucoma.² Determining who should be treated requires that we understand when and how glaucoma produces disability. Classically, glaucoma was believed to have little functional significance except in advanced disease. However, little direct evidence exists to tell us when glaucoma produces vision-related disability.

Questionnaire-based studies, in which impairment is inferred from self-described visual difficulty, have been the most common approach to evaluate glaucoma-related impairment.³,⁴ Subjects report difficulties in many activities even when field loss is not severe. For example, though reading relies on central acuity more than the peripheral visual field (VF),⁵ one study found self-reported reading impairment with only 6 dB of unilateral VF loss.⁶ Such research offers important insight into perceived impairment, but confirmation of true disability through functional testing is lacking.

The Salisbury Eye Evaluation (SEE) was undertaken among the elderly residents of Salisbury, Maryland, to directly test when eye disease produces disability.³ Previous analysis from this study population, for example, showed little impact of glaucoma on mobility until VF loss was bilateral.³ Herein, we evaluate when and how glaucoma affects spoken reading speed in this population of older Americans.

**METHODS**

The protocol for round 4 of SEE was approved by the Johns Hopkins institutional review board. Data were collected between August 2001 and July 2003. Participants gave written informed consent prior to testing. All subjects had participated in earlier rounds of SEE and were aged 65 to 84 years when the study began in 1993. Further description of subject enrollment is described elsewhere.⁶,⁷

**TESTING OF VISUAL FUNCTION**

Vision testing was performed under binocular conditions using the Early Treatment Diabetic Retinopathy Study chart transillumi-
nated at 130 candelas/m². Habitual correction was selected to most accurately reflect true daily visual function. Visual acuity was converted to logarithm of the minimum angle of resolution (logMAR) units. Contrast sensitivity was measured for each eye as the number of letters correctly read on the Pelli-Robson chart with best correction.

DEFINING GLAUCOMA STATUS

All subjects were first evaluated for glaucoma through a screening examination. Subjects with suspicious findings returned for a definitive examination performed by a glaucoma specialist (D.S.F.). Detailed description of the procedures used to determine glaucoma status have been previously described.9,12

SCREENING EXAMINATION

All subjects able to attend the research site underwent VF testing using the Swedish interactive thresholding algorithm (SITA) fast 24-2 testing algorithm on the Humphrey Field Analyzer II (HFA2; Zeiss-Humphrey Systems, Dublin, California). Visual field testing was repeated for abnormal sensitivity, generally sensitized on glaucoma side, pattern deviation abnormality (P < .05), or borderline or abnormal glaucoma hemifield test classification. Dilated images of the optic nerve were obtained using the Discam camera (Marcher Enterprises Ltd, Hereford, England). Patients who could not be imaged had a vertical cup-disc ratio recorded by the examiner. Recorded cup-disc ratios correlated highly with ratios measured from Discam images.9

DEFINITIVE GLAUCOMA EXAMINATION

Subjects meeting referral criteria returned for a second evaluation, which included repeated SITA fast VF testing on an HFA2, gonioscopy, dilated examination, and optic nerve photographs with a stereo fundus camera (Topcon America Corp, Paramus, New Jersey).

GLAUCOMA CLASSIFICATION

Two glaucoma specialists (H.D.J. and D.S.F.) reviewed the VF data, optic nerve images, and medical records and independently classified each patient as having definite, probable, possible, or no glaucoma using consensus criteria.13-18 Disagreements were addressed by first having each reviewer reevaluate the case and then by open discussion of the case.

Glaucomatous optic nerve damage (excavation and neuroretinal rim loss) along with a clear VF defect was defined as definite glaucoma. Less certain glaucomatous VF loss and optic nerve features consistent with glaucoma (excavation, thinning of the neuroretinal rim, large cup-disc or cup-disc ratio asymmetry) were classified as probable glaucoma. Lesser findings in the VFs and/or optic nerves were classified as possible or no glaucoma. Eyes were defined as having glaucoma when graded as definite or probable glaucoma. All others were defined as having no glaucoma. Eyes with glaucoma were classified as having open-angle, angle-closure, or secondary glaucoma. Eyes with secondary glaucoma were excluded.12

CLINIC EXAMINATION AND HISTORY

All participants completed standardized forms detailing demographic information (age, sex, race, education). Participants were asked if a physician had diagnosed them with a list of 15 medical conditions. The total number of these conditions was calculated as an overall measure of comorbidity. Depressive symptoms were evaluated using part D of the General Health Questionnaire,20 with a positive response to any depression-related question indicating the presence of depressive symptoms. Cognition was assessed using the Mini-Mental State Examination (MMSE),20 with outputs graded by a possible score between 0 and 30.

EVALUATION OF READING SPEED

Reading speed was tested in room lighting between 400 and 600 lux.8 Reading material was at a sixth- to ninth-grade level. Subjects read aloud short passages of nonscrolling text displayed on a computer screen. Words extended across several lines, and subjects were asked to read the material as quickly as possible. The number of correctly stated words read over 15 seconds was used to calculate the reading speed. Words read incorrectly or out of order were not counted. Reading speed was evaluated for 4 text sizes ranging from 0.131° (pharmacy label print) to 0.525° (small newspaper heading size). Statistical analysis focused primarily on reading speed for 0.26° print (newspaper print size).

STATISTICAL ANALYSIS

Linear associations between reading speed and continuous covariates were verified by superimposing linear fit and lowess models. Binocular acuity required log transformation to achieve a linear relationship with reading speed. Reading speed increased linearly with education levels up to age 14 years but was flat for greater values. Education was analyzed as a simple linear covariate, as nearly identical results were observed when a linear spline term was introduced.

The impact of glaucoma on spoken reading speed and reading impairment was determined through univariate analyses and multivariable linear and logistic regression. Reading impairment was defined as a reading speed less than 90 words/min, lower than which fluent reading is difficult.21 Variables included in multivariable analysis were selected using a predetermined model of factors believed to influence reading speed and incorporating factors identified in age-adjusted bivariable analyses.

Visual field test results were classified as reliable or unreliable using the revised criteria from the Ocular Hypertension Treatment Study.22 The first VF test result was chosen for analysis except when the second, but not the first, VF test result was reliable. Mean deviations of +2 dB or higher were converted to +2 dB in the analysis. Subjects who completed a VF test in only one eye, and who had a best-corrected acuity worse than 20/100 in the second eye, were assigned a mean deviation of −30 dB for the second eye.

RESULTS

One thousand two hundred fifty-three individuals participated in round 4 of SEE, and glaucoma status was defined for 1214 subjects (96.9%). Seventy-six subjects (6.3%) had unilateral glaucoma, and 74 (6.1%) had bilateral glaucoma. The reading evaluation was completed by 1154 subjects with known glaucoma status (95.1%). Subjects not performing the reading test were older, less educated, and more cognitively impaired. Additionally, they had more depressive symptoms, worse acuity, and lower contrast sensitivity and were more often male and African American (Table 1). Subjects with bilateral, but not unilateral, glaucoma completed the reading evaluation less frequently than controls without glaucoma (86.5% vs 95.6%; P = .001). Of the 10 subjects with bilateral glaucoma not participating in the reading evaluation, 7 had binocular acuities of 20/40 or better, while 3 had binocular acuities of 20/100 or worse.
Six subjects (5 with unilateral and 1 with bilateral glaucoma) had secondary glaucoma and were excluded from subsequent analyses.

Compared with controls of similar age without glaucoma, subjects with bilateral glaucoma had lower acuity, more comorbid illness, and lower MMSE scores and were twice as likely to be African American (Table 2). Subjects with unilateral, but not bilateral, glaucoma were more frequently male than controls without glaucoma. Both subjects with unilateral and bilateral glaucoma were older and had worse contrast sensitivity and VF loss than controls. Subjects with unilateral and bilateral glaucoma were not significantly different than controls with regard to education and depressive symptoms.

Reading speed for newspaper-sized text was first calculated by glaucoma status in a univariate analysis (Table 3). Subjects with unilateral glaucoma showed similar reading speeds and odds of reading impairment when compared with subjects without glaucoma. Subjects with bilateral glaucoma read 29 words/min slower than those without glaucoma (P < .001) and had roughly twice the odds of reading impairment (P = .006). In all subjects, reading speed increased across evaluated text sizes (Figure 1). To confirm that differences in reading speed were not specific for a single text size, univariate analyses were repeated using individual subjects’ best reading speed (the highest reading speed for all tested text sizes). Lower reading speeds and higher odds of impairment were again observed for subjects with bilateral, but not unilateral, glaucoma (Table 3). Reading speed also decreased with African American race, lower education, impaired cognition (lower MMSE score), more medical comorbidities, depressive symptoms, and lower binocular acuity (Table 4).

Multivariable regression models evaluating reading speed as a function of glaucoma, age, race, education, and MMSE score demonstrated no difference in reading speed for subjects with unilateral (95% confidence interval [CI], −18 to 6 words/min; P = .30) or bilateral glaucoma (95% CI, −22 to 4 words/min; P = .16) when compared with subjects without glaucoma (Table 5). Subjects with unilateral or bilateral glaucoma demonstrated similar odds of reading impairment when compared with subjects without glaucoma (P = .39 for both).

To assess whether impairment might occur only in those with severe bilateral glaucoma, regression models were created to assess the effect of better-eye mean deviation on reading speed. Because VF loss may affect reading through acuity, models were constructed with and without visual acuity. Reading speed decreased with better-eye mean deviation (β = −2.9 words/min/DB VF loss; P = .004) without acuity in the model (Figure 2). This effect disappeared (P = .83) with acuity in the model, suggesting that the effect of field loss on reading speed is mediated through loss of visual acuity. We also analyzed reading speed in subjects with bilateral glaucoma by quartile of better-eye VF loss. In order of most severe to least severe, reading speeds were 74, 118, 120, and 147 words/min while average better-eye mean deviations were −22.5, −8.5, −3.6, and −0.7 dB. Multivariable regression models demonstrated that, for the most severely affected quartile of subjects with bilateral glaucoma, reading speed was 32 words/min slower than subjects without glaucoma (95% CI, −56 to −7 words/min; P = .01), and the odds of reading impairment were 3.8-fold higher (95% CI, 1.1 to 13.1; P = .04). Small nonsignificant effects on reading speed were noted when binocular acuity was added to the model, when subjects in the middle 2 quartiles of VF

### Table 1. Characteristics of Salisbury Eye Evaluation Round 4 Subjects by Participation in Reading Evaluation

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Participated (n = 1154)</th>
<th>Did Not Participate (n = 60)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y&lt;sup&gt;a&lt;/sup&gt;</td>
<td>79.7 (4.5)</td>
<td>80.9 (4.7)</td>
<td>.04</td>
</tr>
<tr>
<td>Male, %</td>
<td>39.9</td>
<td>50.0</td>
<td>.03</td>
</tr>
<tr>
<td>African American, %</td>
<td>22.1</td>
<td>50.0</td>
<td>.02</td>
</tr>
<tr>
<td>Last grade completed</td>
<td>11.8 (3.2)</td>
<td>8.2 (4.5)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>MMSE score</td>
<td>26.0 (3.3)</td>
<td>20.2 (5.6)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Depressive symptoms, %</td>
<td>6.9</td>
<td>15.0</td>
<td>.02</td>
</tr>
<tr>
<td>No. of comorbid conditions</td>
<td>3.5 (2.1)</td>
<td>3.5 (1.9)</td>
<td>.98</td>
</tr>
<tr>
<td>Contrast sensitivity&lt;sup&gt;c&lt;/sup&gt;</td>
<td>33.0 (4.3)</td>
<td>27.5 (10.7)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Glaucoma status, %</td>
<td>None</td>
<td>1017 (95.6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unilateral</td>
<td>73 (96.1)</td>
<td>.76</td>
</tr>
<tr>
<td></td>
<td>Bilateral</td>
<td>64 (86.5)</td>
<td>.003</td>
</tr>
</tbody>
</table>

**Table 2. Characteristics of Salisbury Eye Evaluation Round 4 Subjects Who Completed the Reading Evaluation Analyzed by Glaucoma Status**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No Glaucoma (n = 1017)</th>
<th>Unilateral Glaucoma (n = 68)</th>
<th>Bilateral Glaucoma (n = 64)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y&lt;sup&gt;a&lt;/sup&gt;</td>
<td>79.5 (4.5)</td>
<td>80.8 (4.3)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>81.2 (4.6)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Male, %</td>
<td>39.3</td>
<td>51.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>37.5</td>
</tr>
<tr>
<td>African American, %</td>
<td>20.0</td>
<td>25.0</td>
<td>51.6&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Last grade completed</td>
<td>11.9 (3.1)</td>
<td>11.7 (3.2)</td>
<td>11.2 (3.8)</td>
</tr>
<tr>
<td>MMSE score</td>
<td>26.1 (3.2)</td>
<td>26 (2.8)</td>
<td>24.5 (3.8)&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Depressive symptoms, %</td>
<td>6.8</td>
<td>10.3</td>
<td>4.7</td>
</tr>
<tr>
<td>No. of comorbid conditions</td>
<td>3.4 (1.9)</td>
<td>3.4 (1.9)</td>
<td>4.0 (2.2)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>LogMAR acuity&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.05 (0.20)</td>
<td>0.11 (0.26)</td>
<td>0.13 (0.27)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>CS, worse eye&lt;sup&gt;f&lt;/sup&gt;</td>
<td>30.2 (7.5)</td>
<td>26.1 (10.1)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>24.5 (10.5)&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>CS, better eye&lt;sup&gt;f&lt;/sup&gt;</td>
<td>33.4 (3.9)</td>
<td>31.6 (4.9)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>29.4 (6.4)&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>MD, worse eye, dB</td>
<td>−4.0 (6.2)</td>
<td>−8.5 (7.6)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>−12.7 (9.5)&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>MD, better eye, dB</td>
<td>−1.6 (3.8)</td>
<td>−3.4 (4.8)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>−8.8 (9.1)&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

**Abbreviations:** logMAR, logarithm of the minimal angle of resolution; MMSE, Mini-Mental State Examination.

<sup>a</sup>Age was tested using the t test; all others reflect P values for odds of participation in bivariate logistic regression model with age.
<sup>b</sup>Acuity refers to binocular acuity with habitual correction.
<sup>c</sup>Contrast sensitivity expressed as number of letters correctly read on Pelli-Robson chart in better eye with best correction.
<sup>d</sup>Values for odds of reading impairment are adjusted for age and sex.
<sup>e</sup>Acuity refers to binocular acuity with habitual correction.
<sup>f</sup>Contrast sensitivity expressed as number of letters correctly read on Pelli-Robson chart in better eye with best correction.
loss were analyzed, or when the most severely affected quartile of subjects with unilateral glaucoma were affected (P > .40 for all).

An additional multivariable model was constructed to define the most important predictors of reading speed and impairment (Table 5). This model included all variables believed to be predictive of reading speed from the age-adjusted analysis, including those that did not necessarily confound the association between glaucoma and reading. In this model, African American race, education level, MMSE score, medical comorbidities, and visual acuity were important predictors of reading speed and reading impairment.

In this population-based sample of elderly Americans, spoken reading speed was not affected by glaucoma until disease was bilateral with advanced field loss (mean deviation ≤ −17 dB) in both eyes. This level of glaucoma damage occurred in roughly 10% of subjects with glaucoma and nearly 1% of all participants. The effect of VF loss on spoken reading speed did not persist independent of visual acuity, suggesting that glaucoma affects reading through visual acuity lost from central field damage.

In the present study, reading impairment occurred at a higher level of glaucomatous VF loss than suggested by questionnaire-based studies.4,23–32 Such studies evaluated subjects with broadly distributed unilateral and bilateral VF loss and consistently reported statistically significant correlations between the presence and/or extent of glaucoma and self-reported reading impairment. Two large population-based studies, one from the current cohort23 and one from the Los Angeles Latino Eye Study,24 both reported that near-vision tasks, such as reading, were affected in persons with bilateral glaucoma, with little24 or no23 impairment in those with unilateral glaucoma. Our results, however, suggest that spoken reading is only affected in those with advanced bilateral disease.

In deciding when reading is truly affected by glaucoma, we feel that our findings deserve more weight, as direct measurement of reading function avoids many of the problems inherent in questionnaire-based research. Questionnaire-based studies generally group reading with other near-vision activities, whereas reading was studied as an isolated activity in our study. Additionally, the clinical relevance of self-reported visual disability is difficult to gauge in questionnaire-based work, as score values hold little inherent meaning. In contrast, our work provides direct measures of reading speed and impairment, allowing for a more meaningful comparison between groups. Finally, direct functional assessment avoids the potential for information bias inherent in questionnaire-based studies, in which awareness of an eye disease or blurry vision from an undiagnosed condition may result in poorer ratings of visual function even when performance remains unaffected.

Our finding that glaucoma only affects reading speed when field loss is bilateral and severe corroborates the idea that reading is primarily a task of central vision and would be unlikely to be affected except in patients with VF loss near fixation. Indeed, studies in normal subjects have found normal reading speeds with central windows of vision only 4 characters wide.6 Decreased contrast sensitivity resulting from glaucoma may also worsen reading, though normal individuals tolerate contrast reduction up to 10-fold with little effect on reading speed, suggesting that only the most advanced glaucoma would affect reading speed through contrast sensitivity loss.33

Our evaluation of reading does not fully recapitulate reading under normal conditions, leaving open the possibility that physiological reading is more affected by glaucoma than observed in the current study. Patients read straight ahead instead of looking down toward a page, which may minimize the impact of inferior VF loss. Additionally, material was presented as dark letters against a bright white screen,
Reading Impairment

quently had characteristics of slower readers, suggesting
Finally, nonparticipants in the reading test more fre-
ing and might result in self-reported reading difficulties.

greater functional field of vision than straight-ahead read-
tion of information. Performing these tasks may require a

relevant text and skimming documents for quick assimila-

dard reading tests, such as scanning documents for rel-

Values were derived from multiple logistic regression analysis.

Values were derived from a univariate regression for age and from bivariable linear regression analyses including age for all other variables.

d Effect eliminated (β = 0; P = .99) when visual acuity is incorporated into the regression model.

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multivariable analysis demonstrated more significant impacts for age-related variables, such as cognition and medical comorbidity. Lower levels of education were associated with slower reading speeds, and race persisted as a significant predictor of reading speed even after adjusting for education. Elderly African American individuals likely received a lower-quality education, possibly accounting for the slower reading in African American individuals independent of education level. As reading out loud was necessary to measure reading speed, racial differences in speaking rates could account for the difference in the measured reading rate, though patients were asked to read passages as quickly as they could. As previously reported, visual acuity remained the most significant predictor of reading speed, with reading speed decreasing 15 words/min and the odds of reading impairment increasing nearly 3-fold for each 0.1 logMAR unit (corresponding to roughly 1 line of Snellen acuity).

These data from a population-based, elderly sample demonstrate high overall rates of reading impairment, with 1 in 8 white subjects and 1 in 3 African American subjects having impaired reading. Regression analyses demonstrate no impact of glaucoma on spoken reading speed until the disease is bilateral with severe VF loss in both eyes. Future work should evaluate reading in subjects with glaucoma under more realistic conditions to further explore if reading impairment is more prevalent than reported herein.

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