Impact of the Ability to Divide Attention on Reading Performance in Glaucoma

Bonnielin K. Swenor,[1] Varshini Varadaraj,[1] Paulomi Dave,[1] Sheila K. West,[1] Gary S. Rubin,[2] and Pradeep Y. Ramulu[1]

[1]The Wilmer Eye Institute, Johns Hopkins University, Baltimore, Maryland, United States
[2]Institute of Ophthalmology, University College of London, London, UK Biomedical Research Centre for Ophthalmology, London, United Kingdom

Correspondence: Bonnielin K. Swenor, The Wilmer Eye Institute, Johns Hopkins University, 600 N. Wolfe Street, Wilmer Room 116, Baltimore, MD 21287, USA;
bswenor@jhmi.edu.

PURPOSE. To determine if the ability to divide attention affects the relationship between glaucoma-related vision loss and reading speed.

METHODS. Better eye mean deviation (MD), contrast sensitivity (CS), and better-eye distance visual acuity (VA) were measured in 28 participants with glaucoma and 21 controls. Reading speeds were assessed using MNRead, IRest, and sustained silent reading tests (words per minute, wpm). The ability to divide attention was measured using the Brief Test of Attention (BTA; scored 0–10). Multivariable linear regression models were used to determine the relationship between visual factors and reading speeds. Effect modification by BTA score (low BTA: <7; high BTA: ≥7) was examined.

RESULTS. Worse CS (per 0.1 log unit) was associated with slower maximum reading speed on MNRead test for participants with low BTA scores ($\beta = -9$ wpm; 95% confidence interval [CI]: -16, -2), but not for those with high BTA scores ($\beta = -2$ wpm; 95% CI: -6, $+2$). Similarly, for the IRest test, worse CS was associated with slower reading speeds ($\beta = -12$ wpm; 95% CI: -20, -4) among those with low, but not high BTA scores ($\beta = -4$ wpm; 95% CI: -10, $+2$). For the sustained silent reading test, glaucoma status (versus controls), worse visual field (VF) MD (per 5 dB), and worse CS were associated with 39%, 21%, and 19% slower reading speeds, respectively, for those with low BTA scores ($P < 0.05$), but these associations were not significant among those with high BTA scores ($P > 0.1$ for all).

CONCLUSIONS. Decreased ability to divide attention, indicated by lower BTA scores, is associated with slower reading speeds in glaucoma with reduced CS and VF defects.

Keywords: reading, glaucoma, low vision, epidemiology

Research has indicated reading performance to be a strong predictor of visual ability[1] and vision-related quality of life,[2] and reading speed has been shown to be strongly associated with an individual's reading performance.[3,4]

Reading speed is partially determined by the ability to divide one's effort between word identification and comprehension simultaneously. Perfetti's Verbal Efficiency theory[5] suggests that the allocation of cognitive resources to both word identification and comprehension differs by reading ability levels. It is hypothesized that less proficient readers need to allocate more resources to word identification, while highly proficient readers use more resources for comprehension and allocate less of these resources to word identification. This reduction in the allocation of cognitive resources for word identification comes with reading automaticity—quick and effortless processing—that new readers gain with practice.[6,7] This automaticity is closely linked to reading speed.

The impetus for the current study is based on the hypothesis proposed by Legge et al.[8] that individuals with decreased vision require cognitive resources, such as the ability to divide attention, above and beyond the levels required in normally sighted individuals in order to gather information for a complex visual task such as reading. Reading models suggest that during a reading task attention is divided between focusing on neighboring words as well as the current word being read.[9–11] This division of attention is deployed to visual field (VF) locations outside of central fixation, without requiring eye saccades.[12] Normally sighted individuals may have a larger visual span than individuals with visual impairment, requiring the latter group to divide their attention between their functioning and deficient VF. In short, visual impairments may increase the demand on attention reserves by requiring the reader to perform the usual cognitive tasks associated with reading, as well as making sense of confusing or distorted visual input.

To test this assumption, we evaluated reading speed, using a variety of reading tests, in a group of glaucoma patients and normally sighted controls in whom we also used a Brief Test of Attention (BTA) to measure attentional reserve. We hypothesized that readers with higher levels of attentional reserves will have a better ability to reallocate resources for word identification, and thus show smaller decrements in reading speed with greater visual impairment compared with readers with lesser attention reserves who will show more significant decrements in reading speed with greater visual impairment. We further postulate that this effect modification will be greatest when evaluating sustained reading (as compared with short-duration reading) because silent reading is quicker, and thus requires persons to devote more attention toward

comprehension, leaving less attention to redirect back toward word identification.

METHODS

Participants were recruited and tested at a subsequent study visit between May 2009 and June 2011 and followed the tenets of the Declaration of Helsinki. Johns Hopkins Medicine institutional review board approval and informed written consent was obtained prior to all study procedures.

Study Population

Patients visiting the Glaucoma Clinic at Wilmer Eye Institute aged 50 years and older, and self-identified as literate and a native English speaker, with no history of eye surgery 2 months prior, and no laser procedure 1 week prior, were recruited into the study. All study participants had to have had central 2° VF tests performed in the previous 12 months with the Swedish interactive thresholding algorithm (SITA) standard testing program. Participants with (1) visual impairments not related to glaucoma, (2) an inability to hold a book at a comfortable reading distance for 30 minutes, and (3) or those with uncorrected hearing impairment precluding speed communication at a normal volume were excluded from the study. Study testing was performed on a scheduled nonclinical visit.

Patients with a diagnosis of POAG, angle closure glaucoma (ACG), pseudoexfoliative glaucoma, or pigment dispersion glaucoma, and presenting Early Treatment Diabetic Retinopathy Study (ETDRS) visual acuity (VA) greater than or equal to 20/40 in better seeing eye were recruited as cases. Visual field test results of a mean deviation (MD) worse than −3 dB and a glaucoma hemifield test (GHT) result of "outside normal limits" (in at least one eye), "generalized reduction of sensitivity," or "borderline" in both eyes were considered sufficient to indicate VF damage.

The control group comprised of glaucoma suspects and ocular hypertensives with an ETDRS presenting VA of greater than or equal to 20/40 in both eyes and normal VF test results as per criteria defined previously.[9]

Reading

MNRead acuity chart[8] was used to evaluate out-loud reading speeds and consists of over 19 sentences successively diminishing in size. Maximum reading speed and critical print size (derived from nonlinear mixed-effects model)[13] were the parameters calculated from this test. A 170-word IReST[14] passage excerpt was next presented to participants, who were instructed to read it aloud, and time to read the passage recorded. The 30-minute silent reading test,[15] consisting of a 7300-word nonfiction story booklet, was administered to assess sustained reading speeds and change in reading speed over time. Page turns were timed and used to determine reading speeds for each page. After reading this passage, participants completed a short 16 to 20 question quiz based on the material in the story, intended to discriminate between readers who skimmed the passage without comprehension and those who adequately read for content. Details about the design and administration of these tests,[15] and the calculation of the reading parameters from them, have been described in previously published papers.[16] All reading tests were performed with the participants using their habitual correction, if any. Ambient lighting was standardized using a lux meter and maintained at a luminance between 400 and 600 lux at the level of the reading material. Subjects held the reading tests at a distance they deemed comfortable.

Attention

The Brief Test of Attention measured a participant's ability to divide attention.[17] It included a series of 10 trials requiring the participant to mentally count the number of letters in a sequence of letters interspaced with numbers (e.g., X-U-2-B-4) recited by a prerecorded voice. The sequence of letters and numbers increased in length with each trial. A correct response for each trial sequence received a score of '1' and an incorrect response received a score of '0'. Final score assigned to a participant was a summation of scores from the 10 trials.

Vision and Other Covariates

Cognitive function was measured using a truncated version of the Mini-Mental State Exam (MMSE)[18] that excludes questions requiring unimpaired vision.[19]

All vision tests were performed with the participants using their habitual correction. Distance VA was determined using ETDRS charts. Contrast sensitivity was tested binocularly using the Pelli-Robson chart,[20] and the number of correctly read letters were used to calculate the log of contrast sensitivity. Standardized questionnaires were used to obtain data on participant demographics (age, race, education, etc.), and medical history to ascertain any comorbidities (e.g., stroke, Alzheimer's disease) or prescription drugs (e.g., antidepressants) that may impact reading or cognition.

Statistical Analyses

Group differences in demographic, health, and vision covariates were examined using the Student's *t*-test for continuous variables and χ^2 testing for categorical variables. Maximum reading speed from the MNRead test was calculated based on a previously described model.[13] Sustained silent reading speed was calculated as the average reading speed over the 7300-word passage. Reading speeds for the MNRead, IReST, and sustained silent test were calculated as words read per minute (wpm). Sustained silent reading speeds were not normally distributed, and therefore were log-transformed. Changes in reading speed over the 30-minute sustained silent reading period were defined as reading speed slope, and were calculated as the changes in reading speed over the 30-minute reading period.

Linear regression models were used to determine the association between vision metrics and average reading speed for the MNRead, IRest, and sustained silent reading tests. Coefficients for logged sustained silent reading speeds were converted to percent difference in this speed for ease of interpretation. For models estimating sustained silent reading speed slope, bootstrapped standard errors were obtained to account for the skewed distribution of model residuals. Covariates were included in multivariable models if they demonstrated a significant impact on either sustained or silent reading speed ($P < 0.1$) in age-adjusted regression models, or if they had been shown to impact out loud reading speed in previous research.[16] Factors potentially occurring as a result of glaucoma but also related to reading speed outcomes (i.e., 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.

To assess effect modification by BTA score, regression analyses were stratified by BTA score categories: less than 7 or greater than or equal to 7. This cut point was chosen, as it was the mean BTA score within the study population. Linear

TABLE 1. Characteristics of Study Population by Glaucoma Status

Covariates	Control, N = 21 (43%)	Glaucoma, N = 28 (57%)	P Value
Demographics			
Age, y; mean (SD)	70 (7.8)	72 (7.9)	0.297
Female, N (%)	12 (57)	16 (57)	>0.999
African American race, N (%)	4 (19)	7 (25)	0.621
Education, y; mean (SD)	15.3 (2.0)	15.1 (2.3)	0.777
Employed, N (%)	8 (38)	13 (46)	0.560
Vision			
VF in better eye, md; mean (SD)	**−0.07 (0.20)**	**1.54 (1.24)**	**<0.001**
Binocular contrast sensitivity, logUnits; mean (SD)	**−19.0 (1.4)**	**−16.8 (1.3)**	**<0.001**
Distance visual acuity in better eye, logMAR; mean (SD)	**0.008 (0.11)**	**0.096 (0.12)**	**0.013**
Significant cataract/PCO either eye, n (%)	1 (5)	5 (18)	0.166
Reading			
Sustained Reading			
Sustained reading speed, wpm; mean (SD)	**234.6 (61.5)**	**193.0 (75.1)**	**0.044**
Log10 reading speed, mean (SD)	**2.4 (0.1)**	**2.3 (0.2)**	**0.028**
Slope, wpm/min, median (IQR)	1.00 (2.2)	0.06 (1.4)	0.080
MNRead			
Maximum reading speed, wpm; mean (SD)	181.8 (23.3)	171.6 (17.8)	0.089
Critical print size, mean (SD)	**0.13 (0.13)**	**0.24 (0.19)**	**0.026**
Reading acuity, logMAR; mean (SD)	**−0.07 (0.11)**	**0.02 (0.12)**	**0.014**
IReST			
Reading speed, wpm; mean (SD)	155 (23)	144 (30)	0.162
Cognitive			
MMSE score, mean (SD)	27.2 (1.7)	27.3 (1.2)	0.885
BTA score, mean (SD)	7.5 (2.1)	6.5 (2.7)	0.146

Bold font indicates statistically significant difference between glaucoma and control groups (*P* < 0.05). PCO, posterior capsule opacification.

regression models, as described above, were used to determine if estimates differed by BTA score strata.

All analyses were performed using STATA 14 (Stata, College Station, TX, USA).

RESULTS

Of the 49 participants in this study, 21 (43%) were controls and 28 (57%) were glaucoma patients. There was no statistical difference between controls and glaucoma patients for any of the demographic characteristics examined (Table 1). However, VF MD in the better-eye and binocular contrast sensitivity were significantly worse in glaucoma patients than in controls (*P* value ≤ 0.001 for both). Of the reading metrics examined, sustained reading speed was significantly slower among glaucoma patients as compared with controls (*P* = 0.044). Reading measures of MNREAD and IReST did not differ between glaucoma and control groups. Scores on cognitive tests, MMSE and BTA, did not differ by glaucoma status in this study population (*P* > 0.146, for all).

Figures 1A through 1C show the unadjusted relationship between reading speeds from MNRead, IRest, and sustained silent tests with BTA score by glaucoma status. For all three tests, these graphs indicate that there is a linear relationship between reading speeds and BTA score, and suggest that the slope of this relationship differs modestly between glaucoma and controls patients.

Results from the primary regression analyses are shown in Table 2 for the full study population. For all three reading tests, there was no significant difference in reading speeds in models comparing glaucoma participants with controls (*P* = 0.11, 0.20, 0.054 for the MNRead, IRest, and sustained tests, respectively). However, for all three tests, worse VF loss and contrast

sensitivity are associated with slower reading speeds (*P* = 0.03, 0.03, and 0.001 for the MNRead, IRest, and sustained tests, respectively). Worse VA in the better eye was significantly associated with slower reading speeds for the IRest test alone (*P* = 0.009). For the IRest test, but not the MNRead and sustained silent reading tests, worse MMSE score was significantly associated with slower readings speeds. For the sustained silent reading tests, older age and being African-American were associated with slower speeds (*P* = 0.03 and 0.01, respectively).

Stratified regression analyses were performed to examine potential effect modification of the relationship between visual metrics and reading speed outcomes by BTA score (<7 or ≥7). These models were adjusted for the same covariates as in Table 2, and results are shown in Figures 2A through 2D and Table 3. For maximum reading speed on MNRead testing, a decline in log contrast sensitivity (logCS) of 0.1 was associated with a 9 wpm (95% confidence interval [CI]: −16, −2) decline in maximum reading speed among those with BTA scores below the median value. However, for those with BTA scores above the median, this effect was smaller and not statistically significant (β = −2; 95% CI: −6, +2 wpm). Similarly, for the IRest reading test, a 0.1 decline in logCS was associated with a 12 wpm (95% CI: −20, −4) reading speed decline among those with low BTA scores, but this effect was smaller and not statistically significant (β = −4; 95% CI: −10, +2 wpm) among those with high BTA scores. Among those with lower BTA scores, sustained silent reading speeds were 39% slower among glaucoma patients, 21% slower among those with worse VF loss, and 19% slower among those with worse CS. However, among those with high BTA scores no such associations were observed with any of the above visual measures (*P* > 0.18 for all). Changes in reading speed can also be calculated for the sustained reading test. Worse VA was associated with a steeper
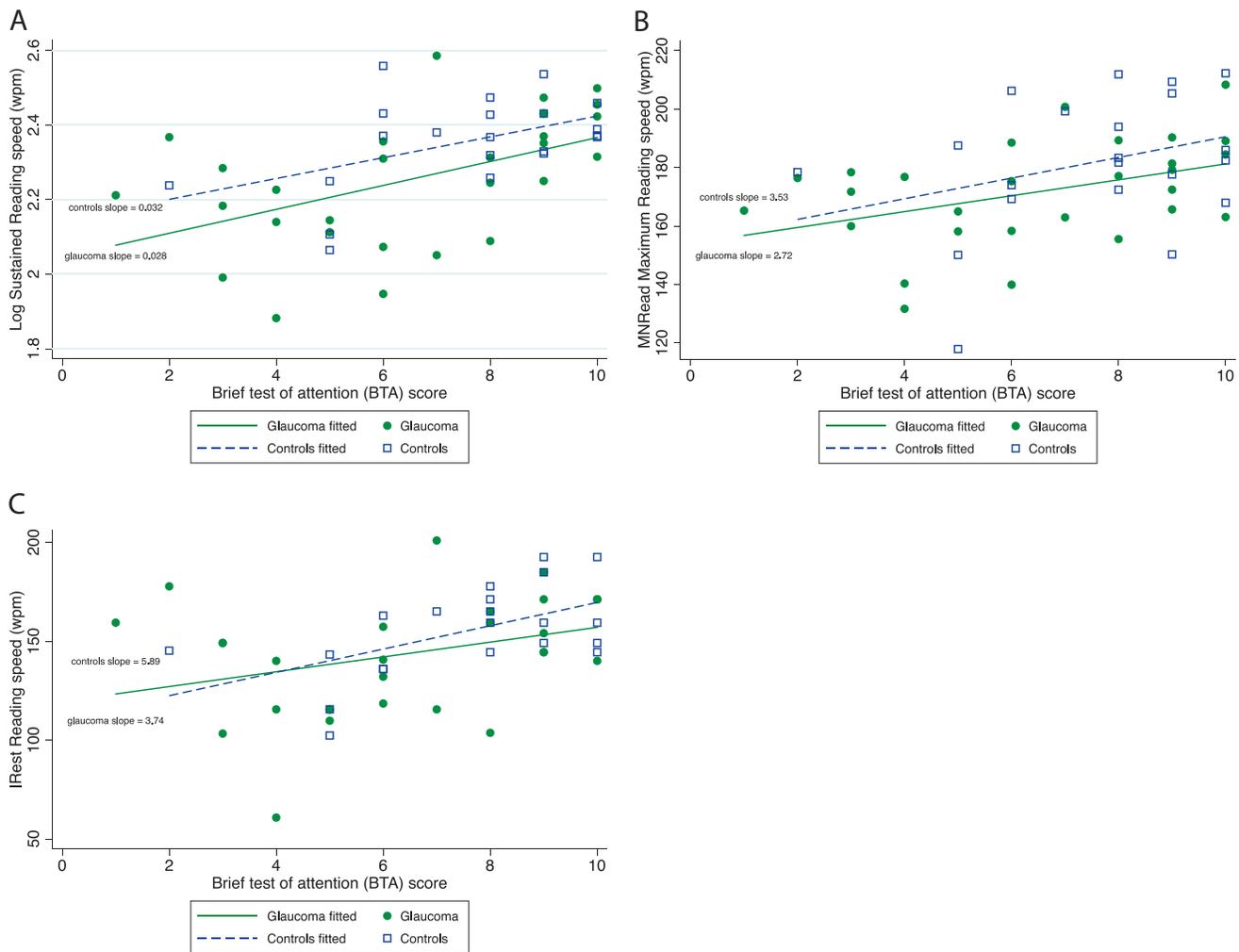
FIGURE 1. Variation of out loud and silent reading speeds with BTA scores for patients with and without glaucoma. (**A**) Variation of MNRead reading speed with BTA scores for patients with and without glaucoma. (**B**) Variation of IRest reading speed with BTA scores for patients with and without glaucoma. (**C**) Variation of sustained silent reading speed with BTA scores for patients with and without glaucoma.

TABLE 2. Visual and Nonvisual Factors Predicting Out Loud and Silent Reading Speeds

Variable	Interval	Outloud MNRead Reading Speed, Δ wpm (95% CI)	Outloud IreST Reading Speed, Δ wpm (95% CI)	Sustained Silent Reading Speed	
				% Difference (95% CI)	Δ wpm/min (95% CI)
Vision*					
Glaucoma	vs. control	−9 (−21, +2)	−10 (−24, +5)	−17 (−32, +1)	−0.73 (−1.93, +0.46)
VF loss MD	5-dB worse	**−5 (−10, −1)**	**−6 (−12, −1)**	**12 (−18, −6)**	−0.38 (−0.80, +0.05)
Contrast sensitivity	0.1-log units worse	**−4 (−8, −1)**	**−6 (−11, −2)**	**−7 (−13, −2)**	−0.12 (−0.44, +0.20)
VA, better eye	0.1-logMAR worse	−4 (−9, +1)	**−8 (−14, −2)**	−7 (−15, +1)	−0.33 (−0.80, +0.13)
Nonvisual†					
Age	5-years older	−1 (−5, +3)	−3 (−8, +2)	**−7 (−12, −1)**	**−0.41 (−0.74, −0.08)**
Male	vs. female	2 (−10, +13)	−1 (−15, +13)	−1 (−18, +18)	0.05 (−1.00, +1.10)
African-American	vs. not African-American	2 (−12, +15)	−4 (−21, +13)	**−24 (−38, −5)**	−0.52 (−1.40, +0.36)
Education	4-years less	−11 (−23, +1)	−6 (−21, +8)	−9 (−24, +10)	0.032 (−0.81, +1.44)
Employed	vs. not employed	−8 (−19, +4)	−10 (−24, +5)	−9 (−24, +9)	−0.51 (−2.45, +1.41)
MMSE	5-points lower	−16 (−40, +8)	**−42 (−71, −12)**	−23 (−47, +12)	−0.52 (−2.45, +1.41)

Bold numbers indicate *P* values < 0.05.

* The association of each vision metric was derived from a separate model including the vision metric and all nonvision metrics shown.

† The association with the nonvisual factors were taken from a single model including the degree of better-eye visual field loss and all nonvisual metrics shown.
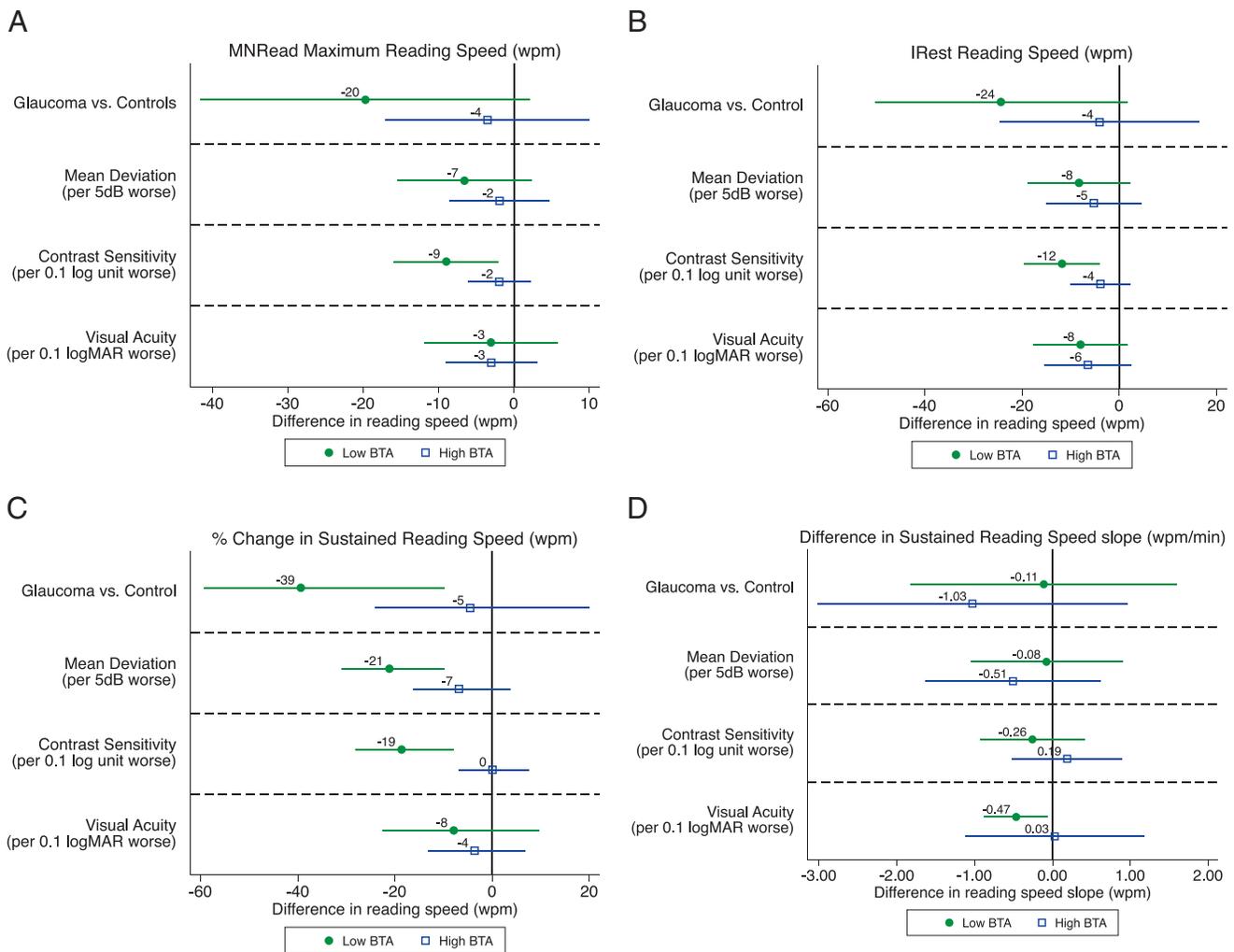
FIGURE 2. Forrest plots demonstrating the association of visual measures with out loud and silent reading speeds stratified by BTA score. (A) The associations of visual measures with MNReading reading speeds stratified by BTA score. (B) The associations of visual measures with IRest reading speeds stratified by BTA score. (C) The associations of visual measures change in percent change in silent reading speeds stratified by BTA score. (D) The associations of visual measures change in silent reading speed slope stratified by BTA score.

TABLE 3. Association Between Visual Measures and Reading Speeds, Stratified by BTA Score

Variable	Interval	Outloud MNRead Reading Speed, Δ wpm (95% CI)	Outloud IreST Reading Speed, Δ wpm (95% CI)	Sustained Silent Reading Speed	
				% Change (95% CI)	Δ wpm / min (95% CI)
Low BTA					
Glaucoma	vs. control	−20 (−42, +2)	−24 (−50, +2)	**−39 (−58, −12)**	−0.11 (−1.87, +1.65)
VF loss MD	5-dB worse	−7 (−15, +2)	−8 (−19, +2)	**−21 (−30, −11)**	−0.08 (−1.11, +0.96)
Contrast sensitivity	0.1-log units worse	**−9 (−16, −2)**	**−12 (−20, −4)**	**−19 (−27, −9)**	−0.26 (−0.98, +0.46)
VA, better eye	0.1-logMAR worse	−3 (−12, +6)	−8 (−18, +2)	−8 (−22, +8)	**−0.47 (−0.89, −0.05)**
High BTA					
Glaucoma	vs. control	−4 (−17, +10)	−4 (−25, +16)	−4 (−23, +19)	−1.03 (−3.15, +1.09)
VF loss MD	5-dB worse	−2 (−9, +5)	−5 (−15, +5)	−7 (−16, +3)	−0.51 (−1.59, +0.57)
Contrast sensitivity	0.1-log units worse	−2 (−6, +2)	−4 (−10, +2)	+1 (−7, +7)	+0.19 (−0.50, +0.88)
VA, better eye	0.1-logMAR worse	−3 (−9, +3)	−6 (−15, +2)	−4 (−13, +7)	0.03 (−1.04, +1.09)

Bold numbers indicate P values < 0.05.
* The association of each vision metric was derived from a separate model including the vision metric and adjusting for age (y), sex, race (African Americans vs. whites), years of education, employment status (employed vs. not employed), and Mini-mental state exam score (per 5 point change).

decline in sustained silent reading speed over the 30-minute reading period among those with low BTA scores (−0.47 wpm per 0.1 worsening of logMAR VA; 95% CI: −0.89, −0.05), but not among those with high scores (0.03 wpm per 0.1 worsening of logMAR VA; 95% CI: −1.04, +1.09).

DISCUSSION

In the studied population, our measure of attentional reserve, the ability to divide attention (as measured by the BTA), modified the relationship between glaucoma-related vision loss and reading speed, measured using a variety of reading tests. For the sustained silent reading test, a greater array of visual measures, including glaucoma status, VF loss, and contrast sensitivity demonstrated a significant effect on reading speed among those with low BTA scores but not in those with high BTA scores. The relationship between VA and the change in reading speed over the sustained silent reading test also differed by BTA score strata, with VA having a significant impact on a decrease in reading speed in the low BTA group as compared with no effect in the high BTA group. These results support the hypothesis that when attentional reserve is diminished, the ability of persons with reduced contrast sensitivity or reduction in other vision measures to read quickly is diminished.

Our results echo prior work that showed that older adults with reduced cognitive resources struggle more with functional tasks. Work by Heyl et al.[21] hypothesizes that these available resources are exceedingly important for individuals with sensory impairments, and older adults with vision impairment are forced to rely more intensively on alternative means such as cognitive resources to reach a goal.[22] These authors found that the link between cognitive resources and everyday functioning was stronger for those with sensory impairment as compared with sensory unimpaired older adults. While many tests are available to characterize and quantify cognitive resources, our findings here suggest that a particularly important cognitive resource with regards to reading is the ability to divide one's attention. Indeed, the importance of this ability makes sense, given that reading is inherently a divided attention task, with attention divided between word identification and comprehension.

It is important to note that we did not observe any significant differences in MMSE or BTA score by glaucoma status (Table 1). Prior work suggests that older adults with glaucoma are more likely to be cognitively impaired than their normally sighted counterparts,[23–25] but we did not observe this difference within our study population. This is possibly a result of our convenience sampling strategy. It is possible that participants with higher levels of cognitive functioning were more willing to participate in this study than those with cognitive difficulties. These group differences in cognitive measures might have appeared if our study sample included those with a full spectrum of cognitive functioning.

Our results indicate that the ability to divide attention modified the impact of vision loss, as judged by glaucoma status and VF loss, on the sustained silent reading test, but did not significantly modify the impact of vision loss on short-duration out-loud reading tests, such as MNRead and IRest tests. It may be that for out loud reading tests, even a limited ability to divide attention is adequate to effectively complete the task because speaking takes longer than the associated time to mentally process those words being read, such that persons reading out loud are not working at their maximum cognitive capacity. But, for the sustained reading test, the silent reading and mental processing are done simultaneously, and subjects read as fast as they can process the words, and significantly greater attention must be devoted to comprehension.

We found that patients' ability to divide attention affected the relationship between a single measure of vision, distance VA, and the change or slope of sustained reading speed. Brief Test of Attention did not affect the association of contrast sensitivity on change in reading speed unlike the results observed for mean reading speeds on all three tests. It is possible that contrast sensitivity and peripheral vision are needed to establish a baseline or threshold reading speed, but good central VA is important for maintaining that speed over sustained reading periods, at least in those with less attentional reserve. Previous literature examining the relationship between contrast sensitivity and reading performance in glaucoma showed that patients with glaucoma had greater reductions in reading speed with decreasing text-contrast than visually healthy controls with similar cognitive/reading ability.[26] Further research is warranted to determine which aspects of visual functioning are most important for maintaining sustained reading speeds.

Also, while not assessed here, additional research investigating eye movement behavior during the performance of reading tasks and its relationship to the ability to divide attention is needed. A prior study examining reading speed in glaucoma using eye tracking software reported that some patients with advanced glaucoma read slower than controls while other patients did not, and that those glaucoma patients that did read slower exhibited greater text saturation (distance between first and last fixations on lines of text) during reading.[27] They hypothesized that this variability among patients with glaucoma may in part be due to differences in eye movements. Eye movement behavior could be an important paradigm to consider when studying attention in future studies.

There are limitations to this study that should be considered when interpreting the results. First, this study has a small sample size that limited our ability to test effect modification by examining the interaction between glaucoma-related vision measures and BTA score. While results from stratified analyses do support effect modification by level of ability to divide attention, including interaction terms would provide a more robust test of this hypothesis. Additionally, as indicated above, our results may be biased by the convenience sample used in this study. It is possible that participants with higher levels of both reading and cognitive ability were more willing to participate. If this was the case and our research was biased toward recruiting good readers, we likely underestimated the difference in the modification by BTA score. Lastly, our measure of one's ability to divide attention may not fully capture the cognitive reserve that enable reading even in the context of visual impairment. Studies have used multiple cognitive tests to assess cognitive resources, including tests of processing speed, working memory, and ability to divide attention, though all of these were not tested here. In this population, we chose to focus on the measure most likely to capture cognitive reserve, the ability to divide attention, and were able to use a nonvisual test to best assess the ability to divide attention in glaucoma cases and controls. Further work is needed to more fully characterize cognitive reserve among those with more visual impairment to determine if other cognitive domains also modify the impact of vision loss on reading ability. Despite these limitations, this is among the first studies to examine the relationship between attentional reserves and reading performance among older adults. Our results highlight the possibility that reduced cognitive resources, particularly difficulty with divided attention, exacerbates the visual impact on reading abilities among those with glaucoma.

In summary, we conclude that one's ability to divide attention affects the relationship between glaucoma-related vision loss and reading speeds. Findings from this study suggest that this cognitive ability is an important modifier of the effect of vision factors on reading. More work is needed to further examine the interaction between cognitive measures and vision loss on completing other functional tasks, such as walking and other daily tasks. It is possible that interventions aimed at strengthening specific cognitive abilities can maximize functional potential, and enable some visually impaired older adults to gain greater results from low-vision rehabilitation.

References

1. McClure M, Hart P, Jackson A, Stevenson M, Chakravarthy U. Macular degeneration: do conventional measurements of impaired visual function equate with visual disability? *Br J Ophthalmol*. 2000;84:244–250.

2. Hazel CA, Petre KL, Armstrong RA, Benson MT, Frost NA. Visual function and subjective quality of life compared in subjects with acquired macular disease. *Invest Ophthalmol Vis Sci*. 2000;41:1309–1315.

3. Legge GE, Pelli DG, Rubin GS, Schleske MM. Psychophysics of reading—I. Normal vision. *Vision Res*. 1985;25:239–252.

4. Legge GE, Rubin GS, Pelli DG, Schleske MM. Psychophysics of reading—II. Low vision. *Vision Res*. 1985;25:253–265.

5. Perfetti CA. Reading Ability. New York: Oxford University Press; 1985.

6. Kuhn MR, Schwanenflugel PJ, Meisinger EB. Aligning theory and assessment of reading fluency: automaticity, prosody, and definitions of fluency. *Read Res Q*. 2010;45:230–251.

7. Hudson RF, Isakson C, Richman T, Lane HB, Arriaza-Allen S. An examination of a small-group decoding intervention for struggling readers: comparing accuracy and automaticity criteria. *Learn Disabil Res Pract*. 2011;26:15–27.

8. Legge GE, Ross JA, Luebker A, Lamay JM. Psychophysics of Reading. VIII. The Minnesota Low-Vision Reading Test. *Optom Vis Sci*. 1989;66:843–853.

9. Reichle ED, Pollatsek A, Fisher DL, Rayner K. Toward a model of eye movement control in reading. *Psychol Rev*. 1998;105:125.

10. Legge GE, Ahn SJ, Klitz TS, Luebker A. Psychophysics of reading—XVI. The visual span in normal and low vision. *Vision Res*. 1997;37:1999–2010.

11. Engbert R, Longtin A, Kliegl R. A dynamical model of saccade generation in reading based on spatially distributed lexical processing. *Vision Res*. 2002;42:621–636.

12. Lee H-W, Kwon M, Legge GE, Gefroh JJ. Training improves reading speed in peripheral vision: is it due to attention? *J Vis*. 2010;10(6):18.

13. Cheung S-H, Kallie CS, Legge GE, Cheong AM. Nonlinear mixed-effects modeling of MNREAD data. *Invest Ophthalmol Vis Sci*. 2008;49:828–835.

14. Hahn G, Penka D, Gehrlich C, et al. New standardised texts for assessing reading performance in four European languages. *Br J Ophthalmol*. 2006;90:480–484.

15. Ramulu PY, Swenor BK, Jefferys JL, Rubin GS. Description and validation of a test to evaluate sustained silent readingtesting sustained silent reading. *Invest Ophthalmol Vis Sci*. 2013;54:673–680.

16. Ramulu PY, Swenor BK, Jefferys JL, Friedman DS, Rubin GS. Difficulty with out-loud and silent reading in glaucomareading in glaucoma. *Invest Ophthalmol Vis Sci*. 2013;54:666–672.

17. Schretlen D, Bobholz JH, Brandt J. Development and psychometric properties of the Brief Test of Attention. *Clin Neuropsychol*. 1996;10:80–89.

18. Folstein MF, Robins LN, Helzer JE. The Mini-Mental State Examination. *Arch Gen Psychiatry*. 1983;40:812.

19. Busse A, Sonntag A, Bischkopf J, Matschinger H, Angermeyer MC. Adaptation of dementia screening for vision-impaired older persons: administration of the Mini-Mental State Examination (MMSE). *J Clin Epidemiol*. 2002;55:909–915.

20. Elliott D, Bullimore M, Bailey I. Improving the reliability of the Pelli-Robson contrast sensitivity test. *Clin Vis Sci*. 1991;6:471–475.

21. Heyl V, Wahl H-W. Managing daily life with age-related sensory loss: cognitive resources gain in importance. *Psychol Aging*. 2012;27:510.

22. Lang FR, Rieckmann N, Baltes MM. Adapting to aging losses do resources facilitate strategies of selection, compensation, and optimization in everyday functioning? *J Gerontol B Psychol Sci Soc Sci*. 2002;57:P501–P509.

23. Yochim BP, Mueller AE, Kane KD, Kahook MY. Prevalence of cognitive impairment, depression, and anxiety symptoms among older adults with glaucoma. *J Glaucoma*. 2012;21:250–254.

24. Helmer C, Malet F, Rougier MB, et al. Is there a link between open-angle glaucoma and dementia? *Ann Neurol*. 2013;74:171–179.

25. Lin I-C, Wang Y-H, Wang T-J, et al. Glaucoma, Alzheimer's disease, and Parkinson's disease: an 8-year population-based follow-up study. *PLoS One*. 2014;9:e108938.

26. Burton R, Crabb DP, Smith ND, Glen FC, Garway-Heath DF. Glaucoma and reading: exploring the effects of contrast lowering of text. *Optom Visi Sci*. 2012;89:1282–1287.

27. Burton R, Smith ND, Crabb DP. Eye movements and reading in glaucoma: observations on patients with advanced visual field loss. *Graefes Arch Clin Exp Ophthalmol*. 2014;252:1621–1630.