Description and Validation of a Test to Evaluate Sustained Silent Reading

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PURPOSE. To construct and validate a test of sustained silent reading.

METHODS. Standardized 7300 and 7600 word passages were written to evaluate sustained silent reading. Two hundred forty subjects validated whether comprehension questions could discriminate subjects who did and did not read the passage. To evaluate test-retest properties, 49 subjects silently read the standardized passages on separate days. Sixty glaucoma suspect controls and 64 glaucoma subjects had their out loud reading evaluated with the MNRead card and an International Reading Speed Texts (IReST) passage, and their silent reading measured using the 7300 word passage. Sustained silent reading parameters included reading speed and reading speed slope over time.

RESULTS. Comprehension questions distinguished individuals who had and had not read passage materials. Bland-Altman analyses of intersession sustained reading speed and reading speed slope demonstrated 95% coefficients of repeatability of 57 words per minute (wpm) and 2.76 wpm/minute. Sustained silent reading speed was less correlated with MNRead ($r = 0.59$) or IReST passage ($r = 0.68$) reading speeds than the correlation of these two measures of out loud reading speed with each other ($r = 0.72$). Sustained silent reading speed was more likely to differ from IReST reading speed by more than 50% in rapid silent readers (odds ratio [OR] = 29, 95% confidence interval [CI] = 10–87), and comparisons of sustained and out loud reading speeds demonstrated proportional error in Bland-Altman analyses.

CONCLUSIONS. Tests of out loud reading do not accurately reflect silent reading speed in individuals with normal vision or glaucoma. The described test offers a standardized way to evaluate the impact of eye disease and/or visual rehabilitation on sustained silent reading. (*Invest Ophthalmol Vis Sci.* 2013; 54:673–680) DOI:10.1167/iovs.12-10617

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Reading is the most frequently mentioned complaint amongst individuals with decreased vision.¹ Many activities of daily living rely on reading, making it an important requirement for independent living, and a highly valued visual ability.² As a result, treatments to restore or rehabilitate visual loss frequently have reading ability as a primary goal.³

Direct tests of reading speed offer an objective method for evaluating the severity of disease and/or the efficacy of ophthalmic care or rehabilitation. Several tests of reading speed have been described toward this end, including the MNRead chart⁴ (Lighthouse Low Vision Products, Long Island, NY), the International Reading Speed Texts (IReST; Precision Vision, La Salle, IL),⁵ and many others.^{6–9} However, all these tests involve reading of short segments of text out loud, which does not represent how the large majority of our reading normally occurs.

Nearly all reading tasks, particularly among individuals with normal vision or mild-to-moderate vision loss, involve reading silently over a sustained period. Indeed, sustained silent reading is essential for numerous tasks, including reading a book, working on a computer, answering email, and handling post mail. Sustained silent reading is also a prerequisite for many types of employment, and is a frequent clinical complaint in conditions such as dry eye, glaucoma, and computer vision syndrome.^{10–12} However, to our knowledge, no standardized test exists to measure the impact of vision on sustained silent reading. Furthermore, the extent to which current tests of out loud reading speed capture the impact of vision loss on sustained silent reading is unclear.

Several challenges exist in constructing a test of sustained silent reading. While reading material is ubiquitous, the material should be of a standardized grade level. Additionally, assessing comprehension may be important to ensure that individuals are reading the material, and not simply skimming over it. Finally, a test of sustained silent reading will, by definition, require greater time for administration, though the requisite time necessary to accurately measure sustained silent speeds or changes in speed over time is unclear.

In the current study, we describe the creation and validation of a standardized test designed to evaluate silent reading over a sustained period of time. We examine how reading performance on this test compares with previously developed tests of out loud reading, and explore the importance of reading comprehension. In our companion paper,¹³ we evaluate the impact of glaucoma on traditional tests of short duration out loud reading speed and sustained silent reading.

METHODS

The study protocol adhered to the tenets set forth by the Declaration of Helsinki. All study procedures were approved by the institutional review board of Johns Hopkins Medicine and all participants gave written informed consent prior to testing. Study participants completed the study testing between May 2009 and June 2011.

Design of a Sustained Silent Reading Test

Two nonfiction passages of 7300 and 7600 words were written to evaluate sustained silent reading, and had 865 ± 36 and 893 ± 36 nonspace characters per page, respectively. The passages tell stories of a young woman starting in her childhood and extending to early adulthood, and would not be known to the reader (passage excerpt included in Appendix). Text from each passage was presented in 12-point Times New Roman font, with 1.5 line spacing, on 5 inch by 8 inch bound pages. Stories were presented such that each page contained exactly 100 or 200 words, and each page had a Flesh-Kincaid grade level between 5.0 and 6.9. Each passage consisted of three sequential chapters containing between 1800 and 3200 words. Each multiple choice comprehension question had four potential answers, and was written to correspond to specific page(s) of the text. Questions were validated as described below.

Overall Approach

Psychometric properties of the sustained silent reading test were tested using three distinct sets of study subjects, each of whom performed a different set of testing designed to:

1. Validate comprehension questions by comparing the accuracy of comprehension question responses across two groups of subjects who either did or did not read the corresponding material from the sustained silent reading passage;
2. Evaluate the test-retest properties of the sustained reading test by comparing sustained silent reading parameters from the two passages, which were read on separate days; and
3. Compare sustained silent reading speed to short duration out loud reading speed in glaucoma suspects with normal vision and glaucoma patients with bilateral visual field (VF) loss.

Comprehension Question Validation

For this portion of the study, subjects age 18 and older were recruited from patients and the friends/family of patients at the Wilmer Eye Institute of Johns Hopkins University. Subjects were excluded from this portion of the study only (comprehension question validation) if they described difficulty reading for any reason (vision-related or not).

Two hundred forty subjects were recruited to validate reading comprehension questions, with 40 subjects reading each of the six chapters contained within the two sustained reading passages (3 chapters per passage). In each group of 40 subjects, 20 answered the comprehension questions after reading the passage chapter, while 20 subjects answered the comprehension questions without reading the passage chapter. Subjects answering the questions after reading were given enough time to complete the reading material, but were not allowed to reference the material while answering the questions. Subjects answering the questions without having read the passage were told that the purpose of the study was to determine if the correct questions to the passage could be guessed without having read the material. All subjects answered comprehension questions to only one passage. Differences between subjects who did and did not read the passage were investigated by collecting data regarding age, race/ethnicity, and highest level of completed education. Sixteen questions well distributed throughout the passage corresponding to the 7300 word passage and 22 questions corresponding to the 7600 word passage were chosen, and used to assess comprehension in subjects reading the full passage(s) (described below). A sample passage excerpt along with the corresponding comprehension question and potential responses is provided in the Appendix.

Test-Retest Evaluation

Forty-nine subjects age 50 and older were asked to read the two sustained reading passages and answer the comprehension questions chosen for the respective passage. Subjects were eligible for this

portion of the study if they: (1) self-described themselves as literate in English, (2) had at least some high school education, (3) had a reading acuity of 20/40 or better (assessed using the MNRead card), and (4) had no illness or recent surgeries that would impair reading or reading comprehension. Subjects read the two sustained reading passages on different days to avoid fatigue. After reading the passage, subjects read and answered the reading comprehension questions corresponding to the material they had read. On the day the first sustained reading passage was read, subjects also read two 77 word passages taken from the IReST. One IReST passage was read immediately before the sustained reading period, while the second was read immediately after the sustained reading period. Subjects also self-reported their age, sex, race/ethnicity, and level of education.

Comparison of Sustained Silent Reading and Short Duration Out Loud Reading

Reading was formally evaluated using three tests of reading in two groups of subjects recruited from the Wilmer Eye Institute Glaucoma service: (1) glaucoma suspects with normal visual acuity and minimal or no VF loss, and (2) glaucoma patients with bilateral VF loss. Subjects were recruited into these groups based on their visual characteristics, and independent of whether or not they described difficulty reading. A detailed description of the inclusion/exclusion criteria for these subjects and their characteristics are provided in the companion paper to this article.¹³ The two study groups were selected in order to choose one set of individuals in whom reading would be expected to be normal, and a second set of individual with vision loss in whom reading would be affected. All subjects had their reading evaluated, in order, by reading: (1) the MNRead card, (2) a 77 word IReST passage, (3) the 7300 word reading passage described above, and (4) the questions chosen to assess passage comprehension (and answering the questions corresponding to the portion of the passage they had completed reading). Subjects read the MNRead and IReST materials aloud, while the sustained reading passage was read silently.

Administration of Reading Tests

All tests of reading were performed with subjects wearing their habitual near correction. For the MNRead testing, subjects were asked to hold the reading material at a distance of 40 cm. For IReST and sustained reading testing, subjects were allowed to hold the reading materials at a comfortable distance. Room lighting was standardized to fall between 400 and 600 lux at page level.

Subjects were asked to read the MNRead card one sentence at a time out loud as quickly and accurately as possible. Participants began reading the sentence corresponding to a reading acuity of 20/200. Subjects were shown only one sentence at a time, with upcoming sentences of smaller print covered. Subjects continued to read sentences of smaller print until they were not able to recognize any words of the passage. Reading errors were recorded, and mistaken or skipped words were accounted for when calculating reading speeds.

IReST passages were read out loud. The time required to read the passage was recorded, and errors, including skipped words, incorrectly read words, and words read out of order, were not counted. Reading of the passage was audio taped to permit a more detailed review of reading errors.

Subjects read the sustained silent reading passages until they had completed the passage, or until they completed a page of reading at least 30 minutes after their start time. Subjects turned the pages of the standardized passages on their own, and the timing of all page turns was recorded and used to calculate the reading speed for each individual page of text.

Calculation of Reading Parameters and Statistical Analyses

The MNRead acuity chart was used to determine reading acuity, maximum reading speed, and critical print size. Reading acuity (RA)

TABLE. Relationship between Reading Speeds Determined by the MNRead Card, IReST Passages, and the Sustained Silent Reading Test

Reading Speeds Compared	<i>r</i>	Δ Reading Speed, wpm		Coefficient of Repeatability, wpm	Limits of Agreement, wpm
		Mean	SD		
Sustained silent – sustained silent*	0.95	2	20	57	–
IReST – IReST†	0.78	1	13	37	–
MNRead – IReST‡	0.72	24§	19	–	–13 to +60
Sustained silent – IReST‡	0.68	53§	52	–	–48 to +154
Sustained silent – MNRead‡	0.59	29§	56	–	–81 to +139

Reading speed measured out loud using the IReST (International Reading Speed Text) passages and the maximum speed obtained on MNRead card. SD, standard deviation of the difference in reading speed.

* Determined in 49 normally-sighted controls reading the two sustained silent reading passages on separate days.

† Determined in 49 normally-sighted controls reading two distinct 77-word IReST excerpts on the same day.

‡ Determined in a group of glaucoma suspect control and glaucoma patients.

§ Value statistically different than 0 in one-sample *t*-test.

was calculated using the formula below in order to account for the fact that the 20/200 line was the first line read:

$$RA = 1.1 - (\text{sentences read} \times 0.1) + (\text{number of words read incorrectly} \times 0.01) \quad (1)$$

Maximum reading speed and critical print size were calculated in R version 2.14.2 (provided in the public domain by the R development team; www.r-project.org), using the nonlinear mixed-effects modeling methods described by Cheung et al.¹⁴

IReST reading speed was calculated in words per minute (wpm) by dividing the number of words read correctly over the time taken in minutes.

Sustained silent reading speed was calculated by dividing the total number of words read over the time required to read. A frequent clinical complaint among patients with vision loss is reading fatigue with sustained reading. To capture fatigue, changes in reading speed were calculated for each patient as the slope of reading speed over time. First, we estimated the reading speed at time points spaced 10 seconds apart for the duration of the test duration. Reading speed at each time point was taken as the reading speed for the page of text that was being read at that point in time, such that all time points occurring during a given page of reading would be assigned the same speed. Next, we plotted reading speed at each time point against test time for the entire period of silent reading. A regression coefficient was then calculated for each patient, reflecting the acceleration (or deceleration) of reading speed in units of words per minute/minute (wpm/min). To determine if shorter reading durations were sufficient to accurately determine sustained silent reading speed and change in reading speed, these same methods were reapplied to the data collected from pages that were fully read up through time durations shorter than 30 minutes.

Subjects were excluded from the analyses if they demonstrated poor comprehension (less than 50% correct answers) and anomalous silent reading speed. To identify anomalous silent reading speeds, a regression model was run with silent reading speed as the dependent variable, and IReST reading speed, age, race, sex, severity of VF loss, cognitive ability, years of education, and employment status as independent variables. Individuals with a studentized residual less than –2 or greater than +2 were considered to have anomalous silent reading speeds.

Group differences were evaluated using χ^2 analysis for categorical variables, and Student's *t*-test for continuous variables. Correlations between continuous variables were described using Pearson correlation coefficients. Variability of reading parameters (sustained reading speed, reading speed slope, and IReST reading speed) with repeated sustained silent reading testing or IReST testing was assessed using Bland-Altman analysis.^{15,16} Differences in measured parameters noted between repeated tests were plotted against intrasubject mean values for the parameter. One sample *t*-tests were used to assess if intrasubject differences were distinct from 0, while linear model regression

coefficients with a *P* value less than or equal to 0.05 were taken as evidence of variability in test–retest differences over the range of mean values. Coefficients of repeatability were calculated as

$$1.96 \times \sqrt{2} \times s_w \quad (2)$$

where s_w represents the mean intrasubject SD.¹⁵ Reading speeds obtained with distinct testing methods (sustained silent reading, MNRead, IReST) were also compared using Bland-Altman methods, and the mean and SD of differences were described. For these comparisons, limits of agreement were expressed as the mean of the difference ± 2 SD.¹⁶ Graphing and nonlinear mixed effects modeling was performed in R, while all other analyses were completed in STATA 12 (Stata, College Station, TX).

RESULTS

Comprehension Question Validation

Individuals who answered comprehension questions with and without reading the passage materials did not differ significantly with regards to age, race, or level of education ($P > 0.25$ for all). In the full group, mean age was 62 years, 87% of subjects had at least some college education, 97% had a full high school education, and 18% of subjects were not white. Among the 16 questions chosen to evaluate reading comprehension for the 7300 word passage, the median percentage of subjects answering each question correctly when not reading the material was 13% (range 0%–39%), as compared with 92% (range 65%–100%) for subjects who read the passage. Among the 22 questions chosen to evaluate reading comprehension for the 7600 word passage, the median percentage of subjects answering each question correctly when not reading the material was 16% (range 0%–34%), as compared with a median percentage of 90% (range 70%–100%) among subjects who read the material.

Test–Retest Evaluation

Forty-nine subjects read the two sustained reading passages on separate days, and also read two IReST passages on the same day. Subjects had an average age of 59 years. Fifty-five percent of subjects were female, 47% were African American, and 59% had at least some college education. Sustained reading speeds measured for the same individual were highly correlated ($r = 0.95$) (Table). The mean (SD) sustained reading speeds for the first and second passages were 183 (66) wpm and 182 (69) wpm, respectively. The mean (SD) difference in sustained reading speed was 2 (20) wpm ($P = 0.55$). A Bland-Altman plot showed no relationship between the difference in the reading

FIGURE 1. Bland-Altman analysis of reading parameters measured repeatedly. Repeated measures analyzed include sustained silent reading speed (A), out loud reading of IReST (B), and the slope of sustained silent reading speed (C). Sustained silent reading speeds and reading speed slopes were measured in a group of normally-sighted individuals reading the two sustained reading passages on several days.

FIGURE 2. Reading comprehension during the sustained reading test: distribution and relationship to the relative rate of silent and out loud reading. Reading comprehension is expressed as the percentage of comprehension questions answered correctly by a group of control and glaucoma subjects. The difference in sustained silent reading speed and out loud reading speed measured using an IReST was found to increase with the accuracy of reading comprehension.

speed for the 2 sustained reading passages and the average speed of reading ($P = 0.28$) (Fig. 1A). The coefficient of repeatability for sustained reading speed was 57 wpm. When analyses were limited to the 43 subjects with good ($>50\%$) comprehension on both reading passages, a similar correlation between reading speeds ($r = 0.96$) and coefficient of repeatability (56 wpm) was obtained.

IReST reading speeds were slightly less correlated ($r = 0.88$) than sustained reading speeds (Table). The mean (SD) IReST readings speeds for the first and second IReST passages were 151 (29) wpm and 150 (26) wpm. The mean (SD) difference in IReST reading speed was 1 (13) wpm ($P = 0.78$). A Bland-Altman plot showed no relationship between the difference in the reading speed for the two IReST passages and the average IReST reading speed ($P = 0.28$) (Fig. 1B). The coefficient of repeatability for IReST reading speed was 37 wpm.

Moderate correlations were observed between the reading slope calculated on separate days ($r = 0.55$). The mean (SD) reading speed slopes for the first and second passages were -0.62 (1.07) wpm/min and -0.57 (1.02) wpm/min. The mean (SD) difference in reading speed slope was 0.05 (1.00) wpm/min ($P = 0.71$). A Bland-Altman plot showed no relationship between the difference in reading speed slopes for the two sustained reading passages and the mean observed slope ($P = 0.70$) (Fig. 1C). The coefficient of repeatability for reading speed slope was 2.76 wpm/min.

IReST reading speeds were compared in the same group of subjects for two IReST passages read on the same day. For each analysis, the mean difference is shown with a *solid line*, while the upper and lower limits of agreement, representing two SDs above and below the mean, are shown with *dashed lines*.

FIGURE 3. Bland-Altman analysis of reading speeds obtained using different tests. (A) Out loud reading speeds measured using an IReST and the MNRead card were compared. (B, C) Sustained silent reading speed was compared with IReST and MNRead reading speeds, respectively. Subjects include glaucoma subject controls with normal vision and glaucoma subjects with bilateral VF loss. For each analysis,

Comparison of Sustained Silent Reading and Out Loud Reading Speeds

Sixty glaucoma suspects and 64 subjects with glaucoma completed tests of silent and out loud reading. One glaucoma suspect was excluded from the analysis on the basis of poor reading comprehension and significant deviation of their actual silent reading speed from their predicted silent reading speed, leaving 59 glaucoma suspects for analysis. A detailed description of the features of these subjects is described in the companion paper.¹³ Education level for the full group was well above the level of the reading text, with a mean of 15 ± 2 years, and at least 12 years of education for 97% of subjects. Out loud (IReST passage) reading speed was less than 80 wpm (the threshold for functional reading)¹⁷ in 2% of glaucoma subjects and no glaucoma suspects, and was less than 160 wpm (the threshold for functional reading)¹⁷ in 72% of glaucoma subjects and 47% of glaucoma subjects ($P = 0.006$).

In age and education-adjusted analyses, better reading comprehension was associated with higher sustained silent and out loud (IReST passage) reading speeds ($P < 0.05$ for all). Additionally, in linear regression models, the difference between sustained silent and IReST reading speeds increased with the accuracy of reading comprehension (Fig. 2).

Relationships between reading speeds obtained from IReST, MNRead, and sustained reading testing were compared for this group of glaucoma and suspect glaucoma subjects. The highest correlation coefficients, and narrowest limits of agreement, between reading speeds obtained from different tests were observed between the two tests of out loud reading (the IReST passage and the MNRead card, $r = 0.72$, limits of agreement = -13 to $+60$ wpm). Lower correlation coefficients and wider limits of agreement were observed in comparisons of sustained silent reading speed and IReST passage reading speed ($r = 0.68$, limits of agreement = -48 to $+154$ wpm) and in comparisons of sustained silent reading speed and MNRead reading speed ($r = 0.59$, limits of agreement = -81 to $+139$ wpm). Similar correlations and limits of agreement were obtained when glaucoma suspects and glaucoma subjects were analyzed separately.

Bland-Altman plots demonstrated greater MNRead reading speeds than IReST reading speeds ($P < 0.001$), and the magnitude of this difference varied with reading speed ($P < 0.001$) (Fig. 3A). Bland-Altman plots comparing sustained reading speed to out loud reading measures (MNRead and IReST) demonstrated higher sustained reading speeds ($P < 0.001$ for both) and systematic variation in reading speed difference over the observed range of reading speed ($P < 0.001$ for both) (Figs. 3A, 3B). Evidence of systematic error persisted in analyses plotting the mean difference between log-transformed sustained and log-transformed IReST reading speed against the mean log-transformed speed as previously recommended by Bland and Altman.¹⁸ Sustained silent reading speed was significantly more likely to differ from out loud reading speed by more than 50% in rapid silent readers (defined as having a sustained silent reading speed of 250 wpm or greater) as compared with silent readers with reading speed of 250 wpm or slower (odds ratio [OR] = 29, 95% CI = 10–87, $P < 0.001$). Limits of agreement were significantly broader in Bland-Altman analyses of sustained and out loud reading speed as compared with Bland-Altman analyses assessing the two measures of out loud reading speed (MNRead and IReST) (Table).

the mean difference is shown with a *solid line*, while the upper and lower limits of agreement representing two SDs above and below the mean are shown with *dashed lines*.

FIGURE 4. Difference between sustained silent reading speeds calculated for the full reading period and shorter durations. Differences were calculated as silent reading speed over the time duration shown minus the reading speed over the full reading period. Information was derived from older control and glaucoma subjects.

An additional feature of the sustained reading test is the ability to detect changes in reading speed over time. The median subject among the group of glaucoma patients and glaucoma suspect controls completing the sustained reading test had almost no change in reading speed over the 30 minute silent reading period (-0.05 wpm/min). In contrast, the subject at the 20th percentile had a significant downward slope in reading speed (-0.99 wpm/minute of reading), while a subject in the 80th percentile had a significant upward slope ($+1.14$ wpm/minute of reading).

To determine the duration required to accurately capture sustained silent reading speed, the relationship of reading speeds measured over durations less than 30 minutes were compared with reading speed measured over the full testing duration. Variability of reading measured over shorter durations of time, using the full reading period as the standard, are shown in Figure 4. Larger changes were observed for reading times below 15 minutes. The variability in observed slopes decreased as reading duration increased, with the least variability among durations longer than 15 minutes (Fig. 5).

DISCUSSION

Here, we describe the construction of a test to formally evaluate sustained silent reading. We demonstrate that the sustained reading test has good test-retest reliability, particularly with regards to reading speed. Our data, from subjects with normal vision and VF loss from glaucoma, also demonstrate that out loud tests of reading do not accurately reflect sustained silent reading test ability for a number of reasons. First, the correlations between sustained silent and out loud reading speeds are lower than the correlation observed between two measures of out loud reading speed. Second, differences between sustained silent and out loud reading speeds vary proportionally with the magnitude of reading speed, demonstrate broad limits of agreement, and show extreme variability among rapid silent readers. Finally, measurement of sustained silent reading demonstrates the ability to capture novel aspects of reading not captured by out loud reading measures, such as changes in reading speed over time that may reflect reading fatigue. Many reading tasks

FIGURE 5. Comparison of changes in silent reading speed as assessed over various durations of time. Information was derived from older subjects with and without glaucoma. All subjects read for 30 minutes or until all 7300 words were read. Information regarding shorter reading periods was taken from the first portion of their reading period. For example, the slope for 10' of reading was taken from data corresponding to the first 10 minutes of each subject's sustained silent reading trial.

involve sustained silent reading, and this novel test offers a new and useful tool for relating vision to the ability to effectively perform reading tasks.

The distinction between out loud and silent reading has been discussed previously, with Carver describing silent reading done for the purpose of comprehension as “reading.”^{17,19–21} In a group of patients with AMD, Lovie-Kitchen demonstrated a high correlation between silent and oral reading rates ($r=0.90$), though silent reading was considerably faster.¹⁹ This work lies in contrast to the current findings, which demonstrated a considerably poorer correlation between out loud and silent reading ($r=0.59$ – 0.68). Differences in our findings may have arisen from the fact that our subjects had normal or near-normal visual acuities as opposed to poor vision, read much faster than the Lovie-Kitchen cohort,¹⁹ and much more frequently demonstrated silently read at rates at which they were likely incapable or willing to speak. Additionally, correlation coefficients have significant limitations as a measure of agreement,¹⁶ and our Bland-Altman comparisons of sustained silent and out loud reading measures demonstrated evidence of proportional error (Fig. 3), and extremely broad limits of agreement (Table). This proportional error could not be resolved by simply log-transforming both reading speeds,¹⁸ likely because linear increases in out loud reading speed correspond to exponential increases in sustained silent reading speed. These findings suggest that short duration out loud reading speed does not adequately capture sustained silent reading speed in patients with normal visual acuity, and that directly testing silent reading is important, particularly when evaluating reading in individuals with normal sight and/or visual limitation not defined by decreased visual acuity. Further work is necessary to determine whether the observed discordance is solely due to the mode of reading (silent versus out loud), or is also a function of other test differences such as duration of testing, type of reading material, or presentation style of reading material.

Another feature of the sustained silent reading test presented here is that it is able to measure changes in reading speed over time (illustrated in Fig. 4). Complaints detailing an inability to sustain reading over long periods of time are common in a clinical setting, and changes in reading speed may reflect such complaints. Indeed, as demonstrated in our companion paper, glaucoma was associated with a greater likelihood of decreasing reading speed over time than glaucoma suspects, which may at least partially explain the frequent clinical complaints of “fatigue” while reading in this population.¹³ While the magnitude of reading speed declines were small, it is possible that they reflect significant fatigue that may lead patients to “put down the book” earlier than they would like.

Considerable effort was devoted to developing and validating comprehension questions corresponding to the silent reading passage. Comprehension questions were introduced to avoid having subjects simply skim the reading material in order to complete the passage faster, though the apparent value added from our testing of comprehension was not clear. We observed that faster readers tended to perform better on comprehension questions, suggesting that greater intelligence/cognitive ability allows both faster reading and better comprehension, even though for the same individual speed is likely to decrease as accuracy increases. This finding suggests that poor concordance between silent and out loud reading was not a result of fast silent readers paying less attention, thus, reflecting a speed-accuracy tradeoff previously described by Carver and others.^{17,21} More likely, administration of comprehension questions minimized the variation in attention given to the reading material; thus, minimizing this source of reading speed variability. As comprehension could be calculated

as a continuous variable, analytic models in the companion paper also incorporated this factor as a covariate.¹³ The threat of comprehension questions may also have lead some individuals to read slower than what they were capable of, which may (along with reading fatigue) explain why several individuals demonstrated slower silent reading speeds than out loud reading speeds.

A significant obstacle to measuring silent reading is the time required for test administration. We administered our test for 30 minutes, the longest duration we felt was realistic without giving the subject a break. However, our findings suggest that accurate estimates for sustained silent reading speed and reading speed slope can also be obtained in nearly all patients with shorter testing durations (15–20 minutes). The accuracy of data obtained over these shorter durations also mitigates concerns that our data may be inaccurate in the few individuals who read so quickly that they completed the reading material well before the full 30 minute reading period had elapsed.

There are limitations to our sustained silent reading test, which may limit its utility. The text presented was only one size, and was relatively small print. Therefore, the test as constructed would not be useful in evaluating individuals with significant visual acuity loss from AMD or other conditions, nor was the test validated in such a low vision population. Additionally, there is a limited amount of reading material available, which limits the number of conditions under which reading may be tested. Testing is also time consuming and may not be feasible in a clinical setting or even in a research setting where time is limited. Reading speed is also determined by several nonvisual factors such as language development, producing a variability that we did not account for.^{17,22,23} Finally, the text was written at the sixth grade level, and may not be appropriate for individuals who do not have at least some high school education.

Despite these limitations, to our knowledge, there are no standardized tests available to evaluate silent reading speed and change in reading speed over long durations of time. Given that sustained silent reading is a central feature of many types of employment and is also a requisite for many leisure activities, evaluating reading under such conditions may provide new insights into the degree of disability experienced among patients with vision loss and/or the extent to which visual rehabilitation is successful. In particular, our sustained reading test would be useful in evaluating how reading is impacted when visual acuity is normal or nearly normal, and in conditions where the inability to sustain reading is a frequent complaint, such as dry eye, computer vision syndrome, and glaucoma.

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APPENDIX

Excerpt of Text from First Sustained Reading Passage

Moving to Texas. Nancy lived in Kentucky for several more years before she moved to another state again. This time it was Texas. But by now Nancy was older and moving around was getting unpleasant. She did not want to leave her friends in Kentucky.

She had a best friend named Misti whom she played with every day. One summer they even built a room out of a refrigerator box and slept on the front porch. When they moved to Texas, Misti sat on their steps and cried while they were driving away. Nancy remembers sitting in the back seat of the station wagon and waving goodbye to her friend. She was crying too and she found out years later that Misti had come and sat on the steps of their empty house for many weeks after they had moved.

It was June when they moved so, of course, it was very hot when they got to Texas. Her dad had gone ahead of the rest of the family and had already found a place to live. It was a very small, hot apartment. Nancy recalls that there were huge cockroaches in Texas. She also remembers that there were not very many people outside on the streets. Everyone was inside enjoying their air conditioning. She spent most of the summer reading books and waiting for school to start so she could make some new friends. Her family also had a German exchange student who lived with them in the small apartment. She read books to Nancy but she read them in German because that was the only language that she spoke. It was great because Nancy picked up a lot of the German language just by listening to her.

The family lived in Texas for two years and while they were there the father worked in the emergency room which was very busy. They ended up leaving that small apartment and renting other places to live. The first one was a small yellow house with a playground in the back yard. Nancy recalls seeing Halley's Comet from the top of that playground with her father. The second house was a bigger house closer to school. The best thing about Texas was that their father built a balance beam for the girls to use. They kept it in the living room behind the couch which made it fun to be inside.

Comprehension Question Corresponding to This Excerpt

What was something fun Nancy remembers about living in Texas?

- a. that her best friend was from Australia
- b. that her neighbors all had swimming pools
- c. **that her father built the girls a balance beam in the living room**
- d. that her mother was always making cookies