Development of a Reading Speed Test for Potential-Vision Measurements

David B. Elliott, Bhavesh Patel, and David Whitaker

PURPOSE. Previous studies suggest that optimal reading speed is unaffected by cataract, yet is significantly reduced in age-related macular degeneration (ARMD). This raises the question of whether a reading speed test could be developed to assess potential vision after cataract surgery.

METHODS. Nineteen subjects with cataract, 15 with ARMD, and 13 control subjects with normal, healthy eyes read Bailey-Lovie word charts aloud, and subsequently, critical print size and optimal reading speed were calculated. Measurements were also taken with the charts in reversed-contrast polarity and after pupillary dilation.

RESULTS. Although the subjects with cataract had reduced word acuity and increased critical print size, optimal reading speed was similar to that of the control group at a mean of approximately 100 wpm. Optimal reading speed in the subjects with ARMD was substantially worse (mean of 39 wpm). Reversing the contrast polarity of the charts slightly increased the word acuity and optimal reading speed of the subjects with cataract.

CONCLUSIONS. The results suggest that optimal reading speed would be useful as a potential-vision test. The proposed test would use text size of at least 1.32° (1.2 log minimum angle of resolution [logMAR]), and pupil dilation would be unnecessary. A reading test with black letters on a white background would be adequate, because charts with reversed-contrast polarity made minimal difference in reading speed. (Invest Ophthal Vis Sci. 2001;42:1945-1949)

Cataract surgery has been shown to provide substantial gains in visual function, subjective and objective functional vision, and self-reported quality of life, and in a number of countries cataract surgery has become the most common elective surgical procedure.1-9 Assessments of visual acuity (VA), subjective functional vision, and self-reported satisfaction with vision have shown that the most common cause of relatively poor visual outcome after cataract surgery is ocular comorbidity and, particularly, age-related macular degeneration (ARMD).1-10 For example, the percentage of eyes achieving 6/12 VA after cataract surgery decreases to 89.7% (from 95.5%) and 77% (from 92%) if eyes of patients with coexisting eye disease are included. Because the mean age of the population is rapidly increasing, not only will the number of patients with cataract grow, but so will the number of patients with cataract and an ocular comorbidity (particularly ARMD).

Munoz et al.10 reported that approximately 35% of people with ARMD in the Salisbury Eye Evaluation study also had clinically significant cataract, yet only approximately 2% of people without ARMD had cataract.11 The reason for the much lower figure for those without ARMD is probably that some of these people had had cataract surgery, whereas people with ARMD and cataract were discouraged from surgery. This hypothesis is supported by the high prevalence of patients with both ARMD and cataract in low-vision clinic populations (~19%).12 Unsuccessful surgery has been shown to have adverse effects on some patients,6,8,9 and there is the possibility that cataract surgery may lead to the development of exudative macular degeneration in some patients with preoperative macular changes.13 However, there is growing evidence that some patients with both cataract and ARMD benefit considerably from cataract surgery,6,8,9,11,14 and many patients with an ocular comorbidity have the operation.1-9,14 Therefore, it is very important to estimate by how much, if at all, surgery is likely to benefit a patient with cataract and coexistent eye disease. This information is likely to have several potential uses. It could provide valuable prognostic advice to the patient about the likely outcome of surgery, help the ophthalmologist decide which eye to operate on first in a patient with bilateral cataract, and contribute to the decision of whether surgical intervention is appropriate.

At present, many clinicians estimate the predicted visual outcome after cataract surgery by examination of the eye and the use of various potential-vision tests.15 A survey by Steinberg et al.15 showed that 37% of 538 ophthalmologists in the United States frequently or always used potential-vision testing in patients under evaluation for cataract surgery who had no history of other eye disease. It seems likely that the use of potential-vision tests in patients with cataract and an ocular comorbidity is considerably higher. However, the usefulness of potential-vision tests available at present has been questioned by a recent major review.1 Indeed, there is little consensus regarding which technique, if any, provides the best means of assessing neural integrity behind a cataract,1 and potential-vision techniques are continuing to be developed and evaluated.15-17 In addition, Schein et al.4 reported that 63% of patients who were predicted to have VA of 6/12 or worse after surgery (the level at which cataract surgery is typically deemed unsuccessful14-17) by a presurgical ophthalmic examination actually attained a VA of 6/9 or better.

Our purpose was to develop and subsequently evaluate a potential-vision test based on the measurement of optimal reading speed. To our knowledge, no previous reports have suggested using optimal reading speed in this capacity. Previous studies have used reading speed as an assessment of functional vision, rather than as a diagnostic test. However, these earlier studies have shown that optimal reading speed has many of the qualities required of a diagnostic test of potential vision. For example, optimal reading speed is relatively unaffected by simulated cataract,11,18 media opacity,19 and cataract,20 but is significantly reduced by ARMD and other macular disease.10,19,21,22 Although reading speed of small text such as newspaper-size text (1.0 M) is significantly reduced by cataract,20 when the text is enlarged enough, reading speed in
subjects with cataract is similar to that in age-matched normal subjects.20 Cataract surgery (specifically, first eye cataract surgery) returns reading speed of small text to normal levels but does not affect optimal reading speed.20 Reading speed has other useful attributes as a likely potential-vision test, including the fact that it is relatively cheap to produce a reading card, and patients and practitioners are very familiar with the test.23

In this study, we examined the usefulness of optimal reading speed as a diagnostic test to predict macular function behind a cataract. Our results confirmed that optimal reading speed was unaffected by cataract, but was severely reduced in subjects with ARMD, and showed that the test could discriminate very well between subjects with these two common age-related diseases. In addition, we found that pupillary dilation was not required for optimum performance of the test and we identified some of the ideal design features of a potential-vision test based on optimal reading speed.

**MATERIALS AND METHODS**

Thirty-four subjects were recruited from the low-vision clinic and preoperative cataract assessment clinic at the Bradford Royal Infirmary. The tenets of the Declaration of Helsinki were followed, and the study gained approval from the University and Hospital ethics committees. Informed consent was obtained after the nature of the study had been fully explained. Exclusion criteria included inability to read English, previous ocular surgery, presence of diabetes mellitus, and ocular disease or abnormality other than cataract and ARMD. Nineteen subjects (mean age, 76.5 ± 8.7 years) had age-related cataract with no significant coexistent eye disease, as determined by indirect ophthalmoscopy after pupil dilation.

Cataract was categorized and graded using the Lens Opacities Classification System (LOCS) III.24 The presence of cataract was defined as greater than grade 2 nuclear opalescence or color, greater than grade 1 cortical opacity, and any sign of subcapsular opacity. There were 6 subjects with nuclear cataract and 13 with mixed cataract. Of those with mixed cataract, eight had nuclear and cortical cataract, three had nuclear and posterior subcapsular cataract (PSC), and two had all three morphologic types of cataract. The mean (±SD) LOCS III grades for all 19 subjects were 3.6 ± 1.0 for nuclear opalescence, 4.2 ± 1.3 for nuclear color, 2.6 ± 1.0 for cortical spokes, and 2.4 ± 1.5 for PSC. Fifteen subjects (mean age, 77.9 ± 6.1 years) had ARMD with no significant media opacity, as defined in this study, or other ocular comorbidity.

ARMD grading was based on a simplified version of the international ARMD classification system.25 The central 1500 μm around the fovea (diameter, 3000 μm) was graded for hypo- and hyperpigmentation, hard and soft drusen, hemorrhaging, geographic atrophy, and disciform scarring on a 1 to 5 scale, without consideration of individual segments within the central ring. Grading was performed using fundus biomicroscopy and a graticule within the slit lamp eyepiece calculated to extend 3000 μm around the fovea of an emmetropic eye. Features were graded on a 1 to 5 scale; depending on the extent of the 3000-μm area covered. Grade 1 was 0% to 20%, grade 2 was 21% to 40%, grade 3 was 41% to 60%, grade 4 was 61% to 80%, and grade 5 was 81% to 100%. The individual number of drusen was not assessed.

Four subjects had grade 5 geographic atrophy and one patient, grade 4; two subjects had grade 5 disciform scarring; three had grade 5 hyperpigmentation; one had grade 5 hypopigmentation; one had grade 5 hard drusen with grade 3 hyperpigmentation; one had grade 2 hard drusen and grade 4 hypopigmentation; and one had grade 2 hemorrhage with grade 3 macular edema. To be able to compare results with age-related normal values, 13 subjects (mean age, 72.7 ± 8.1 years) were recruited who had normal, healthy eyes. They had no significant cataract or macular changes as defined earlier. There was no significant difference in age between the three groups (F2,14 = 1.6, P = 0.2).

Distance high-contrast VA, contrast sensitivity, and reading speed measurements were made monocularly with the subject’s optimal refractive correction, including working-distance lenses, after a full objective and subjective refraction. Distance VA was determined using a high-contrast Early Treatment Diabetic Retinopathy (ETDRS) log minimum angle of resolution (logMAR) chart, and contrast sensitivity was determined using the Pelli-Robson letter chart. Both were measured at a test distance of 4 m, with letter-by-letter scoring and a chart luminance of 100 candelas (cd)/m2.

Reading speed was measured by asking subjects to read aloud Bailey-Lovie word charts viewed at 25 cm.26 These are noncontinuous text charts with print ranging in size from 1.6 to 0.0 logMAR in 0.1-log unit steps. Reading speeds were determined by recording the patient while he or she read the charts as fast as possible, and subsequently calculating reading speeds in words per minute (wpm) for each of the 14 print sizes from 1.3 to 0.0 logMAR on each chart. The first three lines (1.6–1.4 logMAR), which contain only two words each, were read by the subjects, but reading speeds were not calculated for these lines. Lines of text sized 1.3 to 1.1 logMAR contain three words, and the remaining eleven smaller text lines contain six words each. Any words that were miscalled were not included in the calculation of reading speed. Near word VA was determined as the smallest character size that could just be read. Scoring was per line, with a line judged to be successfully read if the majority of words on that line were read correctly.

A training session was not conducted, because previous studies have shown no learning effects for similar reading speed tasks.18,23 Reading speeds were measured using traditional contrast polarity (black letters on a white background) and with the contrast polarity reversed (white letters against a black background). Both were measured with an 800-lux illuminance on the chart. These measurements were repeated after pupillary dilation with 2 drops 0.5% tropicamide. For each condition, reading speeds for each line of text were calculated as the average of three measurements using different versions of the charts. Therefore, 12 measurements of reading speed were taken in total, with the order of measurements before and after dilation being randomized.

**RESULTS**

The mean distance logMAR visual acuities for the three groups were 0.39 ± 0.16 (cataract, Snellen equivalent 20/50; range, 20/28–20/110), 0.67 ± 0.32 (ARMD, ~20/100 Snellen; range, 20/32–20/200), and 0.02 ± 0.06 (control, 20/20 Snellen; range, 20/17–20/25). The mean near logMAR visual acuities for the three groups were 0.43 ± 0.15 (cataract, 0.67 M), 0.87 ± 0.46 (ARMD, 1.85 M), and 0.04 ± 0.05 (control, 0.28 M). There were no significant differences among the three groups regarding age at final year of education (P > 0.05). However, there was a significant difference among the groups in the reported number of hours spent reading per day (ANOVA, F2,44 = 4.2, P < 0.05). The cataract and control groups read for a similar number of hours per day (1.46 ± 1.09 and 1.42 ± 0.83, respectively), but the subjects with ARMD read much less (0.55 ± 0.98 hours per day).

Reading speed versus print size has been shown to have an inverted U-shaped function, in that it decreases from optimum speeds for both small and very large words.19,27 However, over the limited print sizes used in this study (~0.3 to 1.3 logMAR, text size of 0.04 to 1.66”) reading speed increases as a function of text size until it reaches a plateau.19,27 This plateau represents the optimal reading speed, and the word size at which this is reached represents the critical print size. For each condition, reading speeds for individual subjects were plotted against log print size (Fig. 1). The user-defined curve-fitting capabilities of graph-making software (KaleidaGraph ver. 3.08; Synergy Software, Reading, PA) were used to perform the following least-squares bilinear curve fit to the data.
If print size $> size_{critical}$, reading speed $= reading speed_{optimal}$

Else $reading speed = reading speed_{optimal} - [m \cdot (size_{critical} - print size)]$

where $size_{critical}$ is the critical print size above which reading speed is optimal at a level $reading speed_{optimal}$, and below which reading speed decreases linearly with a gradient $m$.

The print size at which no words could be read was assigned a reading speed of zero and included in the curve fit. Seven of the subjects with ARMD could read very few lines on the charts. In these cases, there were not enough points to provide a reliable fit using the least-squares method. Instead, critical print size and optimal reading speed were determined by eye. Often, critical print size was the largest print size used (1.3 logMAR), and optimal reading speed was therefore recorded as the reading speed for that line.

Means and SDs of optimal reading speed for the three subject groups are shown in Table 1. Optimal reading speed was unaffected by cataract, yet was significantly reduced by ARMD ($F_{2,44} = 44.9, P < 0.001$). Optimal reading speed was affected by contrast polarity ($F_{1,44} = 12.0, P < 0.002$), with subjects with cataract reading slightly faster with white-on-black text (102.7 compared with 99.1 wpm) and subjects with ARMD showing no difference. Pupillary dilation had no significant effect on optimal reading speed ($F_{1,44} = 0.03, P = 0.87$).

Means and SDs for critical print size are shown in Table 1. Critical print size was affected by patient group ($F_{2,44} = 31.6, P < 0.001$), but was unaffected by contrast polarity ($F_{1,44} = 3.1, P = 0.088$) or pupillary dilation ($F_{1,44} = 0.21, P > 0.1$).

### DISCUSSION

With the traditional chart, reading speed in the normal control group reached a plateau of approximately 106 wpm when the

![Figure 1](image1.png)

**Figure 1.** An example of a plot of reading speed against print size for an individual subject. Optimal reading speed and critical print size were determined for each subject, by using a bilinear fit to the data.

<table>
<thead>
<tr>
<th>Table 1. Optimal Reading Speeds and Critical Print Sizes for 13 Control Subjects with Healthy Eyes, 19 Patients with Cataract, and 15 Patients with ARMD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Black-on-White Print</strong></td>
</tr>
<tr>
<td><strong>Optimal Reading Speed (wpm)</strong></td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>Control</td>
</tr>
<tr>
<td>Cataract</td>
</tr>
<tr>
<td>ARMD</td>
</tr>
</tbody>
</table>

Data (mean ± SD) are shown from measurements with undilated pupils.
print size was larger than 0.40 ± 0.08 logMAR (equivalent to approximately 0.65 M at 25 cm). Although the letters had to be much larger for subjects with cataract to obtain optimal reading speed (mean, 0.87 ± 0.23 logMAR; equivalent to approximately 2.0 M at 25 cm), the optimal reading speed (99 wpm) was similar to that found in the control group. Similar oral optimal reading speed for subjects with normal, healthy eyes (approximately 100 wpm) has been found previously with the Bailey-Lovie word chart.18,20 Higher optimal reading speeds tend to be found with tests that use sentences rather than unconnected words21 and silent rather than oral reading.22 A similar absence of effect on optimal reading speed for subjects with simulated cataract,11,18 young subjects with low vision who have media opacity,19 and subjects with early cataract20 have been reported. The mean distance VA of the cataract group was 20/50, which is similar to levels of preoperative VA in recent cataract studies (~20/60).4 This suggests that optimal reading speed should be at normal control levels before surgery in the typical patient with cataract who has no coexisting ARM. Two subjects had relatively poor VA and dense cataract (logMAR VAs of 0.74 and 0.70, Snellen ~20/110; LOCs III mixed cataract of nuclear 3.1/PSC 4.2 and a nuclear cataract of grade 5.2) but retained good optimal reading speeds of 91 and 120 wpm. Further investigation is required to determine whether optimal reading speeds remain at normal levels in more dense cataract.

The reversal of contrast polarity slightly increased the optimal reading speed of the cataract group from 99.1 ± 13.4 to 102.7 ± 13.2 wpm, which confirms previous findings.19 The reversal of polarity has two major effects: It reduces the luminance of the chart, and it reduces the amount of unnecessary light that could lead to light scatter from the cataract or within the eye. Cataracts principally reduce vision by causing intraocular light scatter, which produces a veiling luminance on the retina and reduces the contrast of the retinal image. The slight reduction in light scatter with the white-on-black chart presumably led to a reduction in contrast loss caused by veiling glare. Pupil dilation had no effect on optimal reading speed or critical print size, indicating that the test could be performed with or without pupillary dilation. This is an advantage over potential-vision tests such as the potential-acuity meter (PAM) or interferometers that require pupil dilation. The hierarchical stepwise multiple regression results were similar to those found by Legge et al.,19 in a group of subjects with low vision. By far the best predictor of optimal reading speed was macular function, which accounted for 67% of the variance in the reading speed data.

There were large differences in critical print size among the three groups. Mean critical print sizes for the control, cataract, and ARM groups were 0.40, 0.87, and 1.07 logMAR (equivalent to 0.65 M, 2.0 M, and 3.0 M at 25 cm), respectively. These and the optimal reading speed data indicate that cataract reduced the reading speed of small text only, and, provided that the text was enlarged enough, it could be read at normal speeds (at least up to the density of cataract assessed in this study). Previous studies have shown that reading speed of small text, such as newspaper print (1 M) and medicine bottle text (0.4 M), is returned to normal levels after cataract surgery.20 Cataract surgery therefore has the effect of decreasing the critical print size and extending the plateau of optimal reading speed to smaller print sizes.

Subjects with ARM showed reduced reading speed for all text, no matter how much it was enlarged. It is likely that the optimal reading speed of some of the subjects with ARM could have been increased if larger text than the maximum used in this study (1.3 logMAR, 1.66’’ letters) had been used.19 This needs further investigation. It could be argued that the differences in optimal reading speed between the subjects with cataract and those with ARM were solely due to the differences in their VAs. Unfortunately, we were unable to find subjects with ARMD with better VA to be able to match that of our subjects with cataract. However, the ROC curve for optimal reading speed and VA in Figure 2 indicates that optimal reading speed discriminated between the cataract and ARM groups much better than did VA. This figure indicates that if a subject in the study had a reading speed above 80 wpm, they had a normal macula behind a cataract, and if they had a reading speed below 75 wpm they had ARMD. Similarly, Legge et al.19 found that a reading speed of 90 wpm indicated that a patient had an intact central field, whereas a rate below 70 wpm indicated a patient with central field loss.

The measurements used here (reading up to 17 lines of text and measuring reading speed for each line to determine optimal reading speed) would be too prolonged and complicated to use clinically. Ideally, critical print size could be predicted from a standard clinical test, so that reading speed of text larger than the critical print size could be measured in one simple, quick measurement. Similar to the findings of Legge et al.,19 the multiple regression analysis suggested that distance and near VA were good predictors of critical print size (r² = 0.76 and 0.69, respectively). However, these regression analyses included data from all subjects, and the association between the measurements in the 19 subjects with cataract was weaker (distance VA versus critical print size, r² = 0.19; near VA versus critical print size, r² = 0.30). Near word VA is a better predictor of critical print size in the subjects with cataract than distance VA. The regression equation was as follows:

\[
\text{critical print size} = 0.82 (\text{near VA}) + 0.52. 
\]

For the near VAs of subjects with cataract in the study, the equation indicates that critical print size was on average 0.44 logMAR (4.5 lines) above near VA. However, as indicated by the relatively low r² of 0.30, near VA is an inaccurate predictor of critical print size.22 A better option appears to be the use of 1.2 logMAR as a standard text size that is larger than the critical print size for all the subjects with cataract used in the study. As expected, the reading speed of 1.2 logMAR print predicted optimal reading speed very well (r² = 0.96). Discrimination between the cataract and ARMD subject groups remained excellent for the 1.2 logMAR reading speeds, with an AUC score of 0.97, calculated from the area under the ROC curve (see Fig. 2 for comparison).

Because reading speed versus print size has been shown to have an inverted U-shaped function in subjects with normal27 and low vision,19 it is important that the text be both larger than the critical print size but also smaller than the point at which reading speed starts to decrease with large print sizes. The 1.32’’ print size (1.2 logMAR) is within the range of print sizes that have been found to provide maximum reading speeds for normal subjects (0.3–2’’).27 and well below the range for low vision subjects with either intact visual fields (3–6’) or central-field loss (12–24’).19 It may be that for more dense cataract (worse than 0.8 logMAR) a larger text should be used to ensure the text is larger than the critical print size. This needs further investigation.

These results confirm the hypothesis that optimal reading speed could be a useful potential-vision test before cataract surgery and is worthy of clinical evaluation. Optimal reading speed is unaffected by cataract, but is severely reduced by ARMD. We show that such a measurement can discriminate very well between subjects with these two common age-related diseases. The proposed test would use text size of at least 1.32’’ (1.2 logMAR), and pupil dilation would be unnecessary. A reading test with traditional contrast polarity (black letters
on a white background) would be adequate; charts with reversed-contrast polarity made minimal difference to optimal reading speed in subjects with cataract. It is likely that a variety of available reading speed tests, such as the Bailey-Lovie\textsuperscript{26} or Minnesota Low-Vision Reading charts\textsuperscript{23} could be used to measure optimal reading speed.

Potential disadvantages of optimal reading speed potential-vision tests include an inability to use the test with illiterate patients and an inability to differentiate poor reading rates due to neural disease or subtle cognitive deficits. In addition, the test would be unlikely to give an indication of the quality of other important functional abilities that rely on vision, such as mobility and orientation. Clinical evaluation, particularly using subjects with dense cataract and both cataract and ARM in a pre- and postcataract surgery study, is needed. The effect of various types of macular disease on reading speed, such as geographical atrophy with macular sparing, also should be investigated.

References


