

awards/honors

Glenn A. Fry Award Lecture 1990: Three Perspectives on Low Vision Reading

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There are about three million Americans with low vision.¹ One definition of low vision is a corrected acuity less than 6/18 (20/60) or a field less than 30°.² A performance-based definition is the inability to read the newspaper at a normal reading distance (40 cm) with best refractive correction. This definition emphasizes the functional consequences of low vision and the special importance of reading.

For the past decade, my colleagues and I have been studying the effects of visual impairment on reading. We hope that our research will enhance the ability of clinicians and rehabilitation specialists to assist low vision patients. The research should also contribute to the development of improved tests for assessing low vision and to the design of new low vision aids.

Three different perspectives provide insight into low vision reading. These viewpoints are associated with the three types of variables depicted in Fig. 1. In this paper, I will describe some of our research findings, placing them in the context of this tripartite view.

A vision scientist is likely to approach reading by studying the effects of important text variables. We have conducted several studies of this sort, examining the effects of character size and field size,^{3, 4} text contrast,⁵⁻⁷ luminance,⁸ and color.^{8, 9} The intent of these studies was to isolate the effects of stimulus properties from cognitive or other nonperceptual determinants of reading performance.

A clinical researcher's perspective on low vision reading might focus on the eye condition. There are enormous individual variations among low vision readers. It is important to ask how ocular variables like acuity, field status, or contrast sensitivity affect reading performance.^{4, 6-11} Research of this genre looks for patterns of performance that are correlated with ocular variables.

Rehabilitation specialists are particularly famil-

iar with a third perspective. Nonvisual factors have a major influence on reading performance. These include cognitive or linguistic capacity, motivation, and manual dexterity in the use of magnifiers. Age, another nonvisual variable, has only small effects on reading performance for people with normal vision,¹² but recent evidence shows that age plays a more important part in low vision reading¹¹ (see below). The research problem is made more difficult because it is hard to separate the effects of visual and nonvisual factors.

Reading is only one of many everyday visual tasks. Others include driving, orientation and mobility, object recognition, and face identification. Understanding the consequences of low vision for all these tasks will undoubtedly require insights from all three perspectives.

METHODS

Our primary measure of reading performance is reading speed in words per minute. We have developed two methods for measuring reading speed.

In the drifting-text method,³ subjects read aloud lines of text that drift smoothly across the face of a TV monitor. In Fig. 2 the subject sees 10 characters, representing part of a full line of text. Each character subtends 6° at the viewing distance shown. We vary angular character size by changing the subject's viewing distance, taking care to provide refractive correction where necessary. In a single trial, the subject reads aloud 1 line of text (80 characters) as it drifts by. If no errors are made, the experimenter increases the speed on the next trial. This process continues until the speed is high enough so that the subject consistently makes a small number of errors. We then compute reading rate in words per minute, having corrected for the proportion of errors made. The drifting-text method is similar to the way low vision people read when they scan text through the field of a high-power optical magnifier.

A second method for measuring reading speed uses stationary text.¹³ Test stimuli are sentences or

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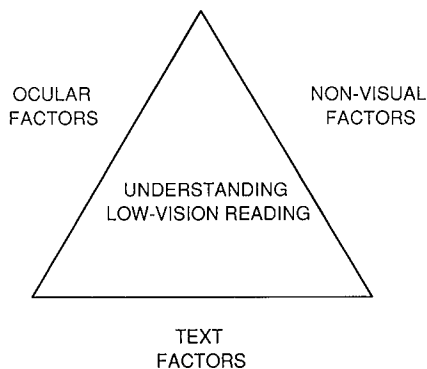


Figure 1. Three perspectives on low vision reading emphasize research on three types of variables.



Figure 2. Subject viewing the stimulus display used in the drifting-text procedure.

random words, displayed as white-on-black or black-on-white text (Fig. 3).

Testing is usually done for letters subtending 6° , a character size within the acuity limit of most low vision subjects. The text is displayed for a timed period. If the subject completes the text without missing any words, the period is shortened. When the period is too short for the subject to finish, reading speed is computed as the number of words read divided by the exposure time. The test is quick (5 min) and easy to administer. The results are highly reproducible ($r = 0.9$). The results are similar to those obtained with the drifting-text method. (On average, low vision reading rates are about 15% faster with drifting text.)

We have chosen reading speed as our primary index of performance because it is straightforward to measure, highly reproducible, and sensitive to stimulus and ocular variables. Comprehension is an alternative measure. In one study, we explored the relation between comprehension and reading speed.¹⁴ We found that low vision subjects comprehended drifting text as well as normal subjects provided the drift rate was low enough so that the subjects could read the text aloud without making errors.

Comprehension measures are more dependent on cognitive factors than reading speed. Although reading speed is effective in isolating visual influ-

ences on reading, comprehension may be useful in revealing interactions between cognitive capacities and visual deficits.

RESULTS

Text Variables

To illustrate the study of text variables, I will describe experiments on field size and magnification. These two variables are of particular importance in low vision because they trade-off against one another in the design of optical magnifiers. As magnification gets larger, the number of letters in the field tends to get smaller.

How does the number of letters in the field affect reading speed? We used the drifting-text method to examine performance for display windows ranging in size from 20 characters to less than 1 character.^{3,4} Fig. 4 shows examples of 8-, 4-, 2-, and 1-character windows.

Fig. 5 gives results. The vertical axis shows reading rate, normalized by the rate for 10-character windows. The horizontal axis shows the number of characters visible. The solid curve shows average results for normal subjects and the letter symbols are data for low vision subjects. For all subjects, reading rate increased up to a critical window width of 4 or 5 characters. Reading was no faster with wider fields. This result appears to be quite general, applying to both normal and low vision subjects, and across a range of character sizes.

The field-size requirement of only about 5 characters is surprisingly small. It was measured with text drifting smoothly and automatically across the screen. Does this result generalize to the use of low vision magnifiers? Magnifiers require manual scanning and line finding. Perhaps their use necessitates a much wider field for maximum speed. In a recent study, we measured reading speed as a function of window size for subjects who read story passages with a closed-circuit TV (CCTV) magnifier.¹⁵ Subjects read several lines at a time. They controlled text presentation manually and found the start of new lines by moving the printed page through the video camera's field of view on a sliding X-Y platform. The results were similar to those shown in Fig. 5, except that the corner was less sharp. Accordingly, we defined the smallest window yielding 75% of maximum reading speed as the critical window size. The mean critical window size for low vision subjects was 4.92 characters (SD = 1.9). The mean critical window size for normal subjects performing the same CCTV reading task was 5.08 characters. This CCTV study suggests that low vision magnifiers require a field size of at least 5 characters to achieve near-maximum reading speed.

How large do characters have to be for rapid reading? Fig. 6 shows results of an experiment in which we measured reading rate as a function of angular character size. In each of the four panels, the upper dashed curve shows average results for two normal subjects. This curve has a broad peak,

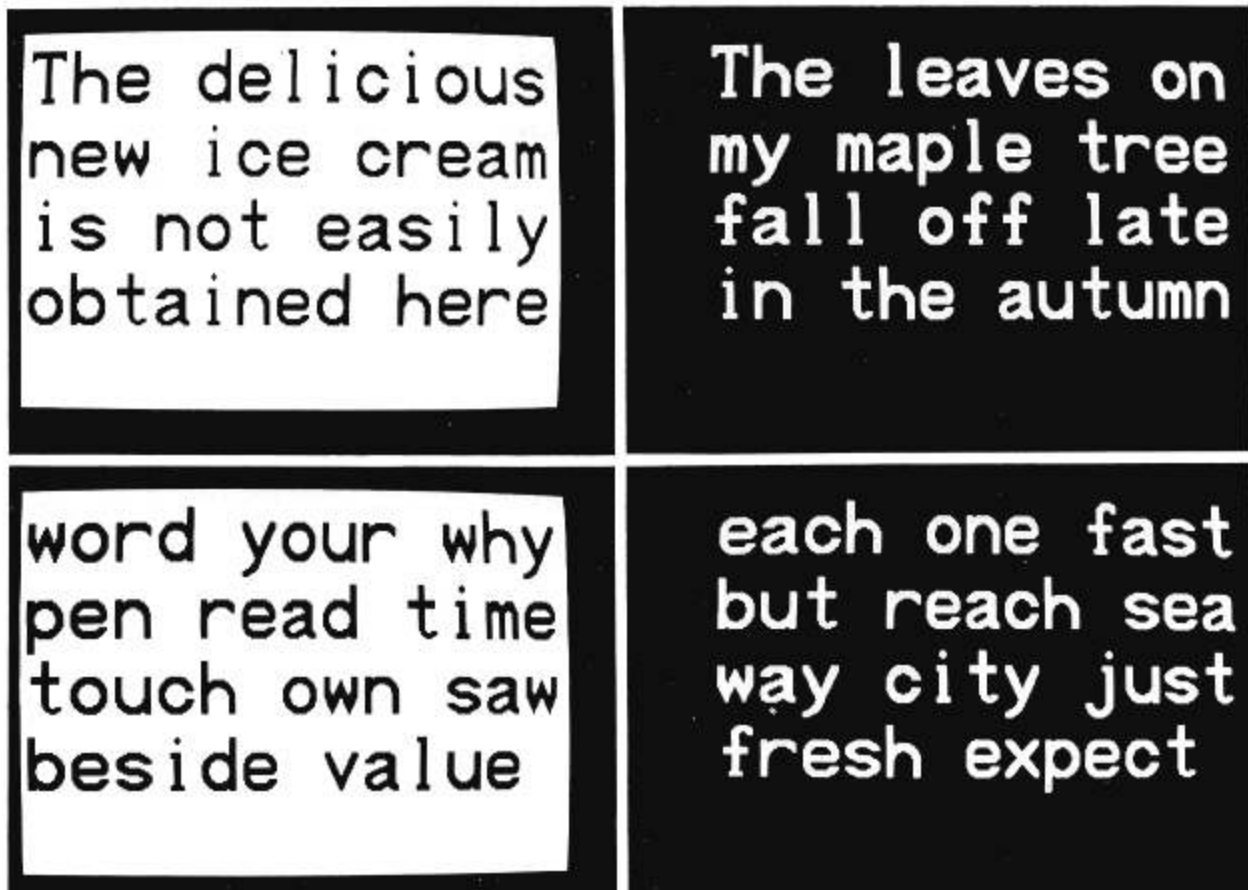


Figure 3. Illustration of the four types of text displays that can be used in the stationary-text procedure.

extending from approximately 0.3 to 3°. This is the range of character sizes for which normal readers achieve maximum speed. To the left of the peak, performance drops rapidly as character size approaches the acuity limit. Letters need to be three or four times the acuity limit before maximum reading speed can be achieved. To the right of the peak, there is a gradual decline in speed for very large letters.

The filled symbols (and solid lines) in each panel of Fig. 6 show results for low vision subjects measured with the drifting-text procedure. For comparison, the \times shows the rate obtained with the stationary-text method. At what character sizes do these subjects achieve their best performance? Subject D has central field loss resulting from Stargardt's disease. His curve shows a common pattern for subjects with central loss: monotonic growth of reading rate with character size. Subject O is an 83-year-old woman with age-related maculopathy (ARM) and cataracts. Despite rather high acuity, she needs large letters to achieve maximum reading rate. Subject T has cloudy media due to cataract but no known retinal involvement. We have found that subjects who retain central vision often have peaked curves, i.e., read fastest for some intermediate range of character sizes. There is evidence for such a peak in T's data but the peak is not very pronounced. Subject AA, who suffers from optic

nerve hypoplasia, has a more distinct peak occurring at about 4.5°. Curves like these can be used to identify the character size yielding fastest reading.

We measured character-size curves for a diverse group of low vision subjects⁴ and identified optimal character size (i.e., the character size yielding maximum speed). Regression analysis revealed a nearly linear relation between acuity and optimal character size. (There was a tighter link between optimal character size and Sloan M acuity¹⁶ than between optimal character size and Snellen acuity.) Low vision subjects required characters about five times larger than their acuity limits to read at their maximum rates. In recent work,¹⁵ we have found that this result also generalizes from controlled methods of text presentation to free reading with a CCTV magnifier.

Fig. 7 summarizes our field-size and character-size findings with the 5-by-5 rule. Suppose the size of acuity letters is known for a low vision subject. Letters for reading should be at least five times that size for maximum speed. The field size should be at least 5 characters in width. Therefore, the minimal field size for low vision reading should be at least 25 times the size of the acuity letters. For example, suppose a patient has 6/60 (20/200) vision. The acuity letters subtend 50 min arc. The field size for reading should be at least 25 times 50 = 1250 min arc (about 21°). Practical limitations

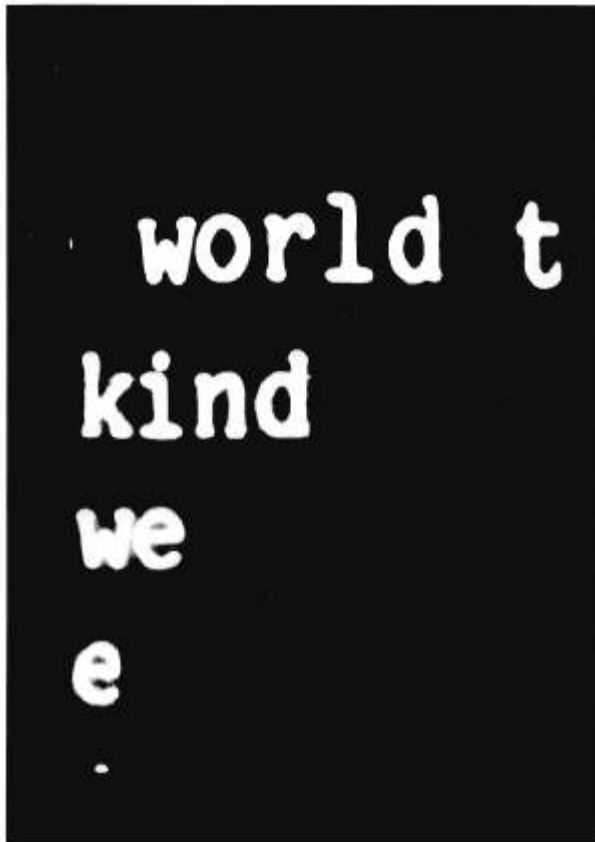


Figure 4. In the window experiments, portions of the display screen were occluded with black paper to vary the number of characters visible at any time. Examples of 1-, 2-, 4-, and 8-character windows are shown here.

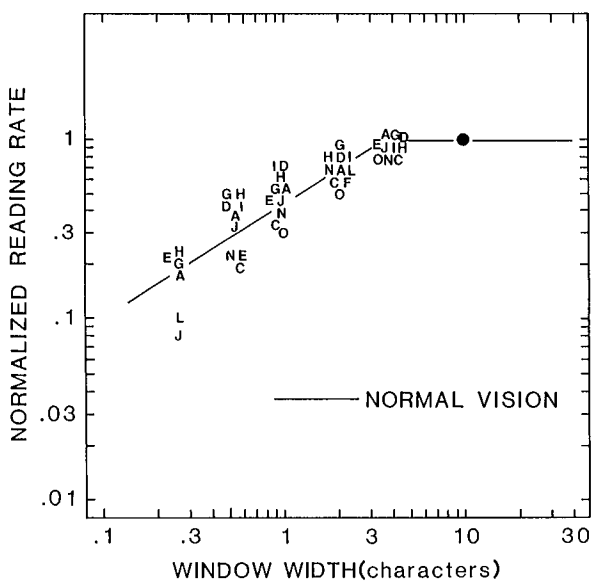


Figure 5. Reading rate is plotted as a function of window width. Each subject's reading rates were normalized with respect to their rate for a 10-character window. The solid lines represent average data for four subjects with normal vision. The letter symbols are data for low vision subjects.

of instrument design may compel violation of this rule. For cases in which a patient has a highly restricted field (e.g., some instances of retinitis pigmentosa), the patient's eye condition makes it impossible to abide by the 5-by-5 rule.

Ocular Variables

What is the impact of reduced acuity, field loss, or other ocular factors on reading speed? Fig. 8 summarizes an important result from one of our early laboratory studies.⁴ We showed that a simple 2-by-2 classification of low vision subjects provides substantial information about likely reading speed. We classified subjects by the status of the central field—intact or loss (scotomas covering all or part of the central 5°) and status of the ocular media—clear or cloudy (corneal opacities, cataract, vitreous debris). This simple four-way classification accounted for 64% of the variance in reading speeds in our sample. Fig. 8 shows the estimated mean reading speeds for the four groups, based on a multiple-regression model. It is evident that the status of central vision is very important, whereas the status of the ocular media plays an important but lesser role. (Media status by itself is a good predictor of individuals who benefit from contrast reversal. People with cloudy media often read substantially faster with white-on-black text.)

Can ocular variables be used in a clinical setting to predict reading performance? In clinical assessment, it is important to have a realistic estimate of the performance level a patient can hope to achieve. Rehabilitation strategies will be different for 2 patients, one who can hope to read no faster than 15 words/min and another who should achieve 150 words/min. If performance could be predicted accurately from ocular variables, clinicians could make recommendations to their low vision patients without the need for labor-intensive special testing and a large inventory of visual aids.

To address this question, we measured the reading speeds of 141 clients entering the Low Vision Program of the Minneapolis Society for the Blind, and a group of 17 normals.¹¹ We used the stationary-text method, which is well suited for clinical testing. The character size was large (6°), well within the acuity limit of most of the subjects. Our intent was to determine whether common clinical measures could predict reading performance. The clinical variables were Snellen acuity, status of the central fields (scotomas present or absent), status of the ocular media (clear or cloudy), diagnosis, and age. Values were obtained from a thorough eye examination immediately preceding the reading test.

The link between Snellen acuity and maximum reading speed was very weak, replicating earlier findings.^{4, 17} There was a low but statistically significant correlation of 0.31 which accounted for only 9.53% of the variance in low vision reading speeds. The central-loss subjects differed from those with intact central vision in showing a slightly

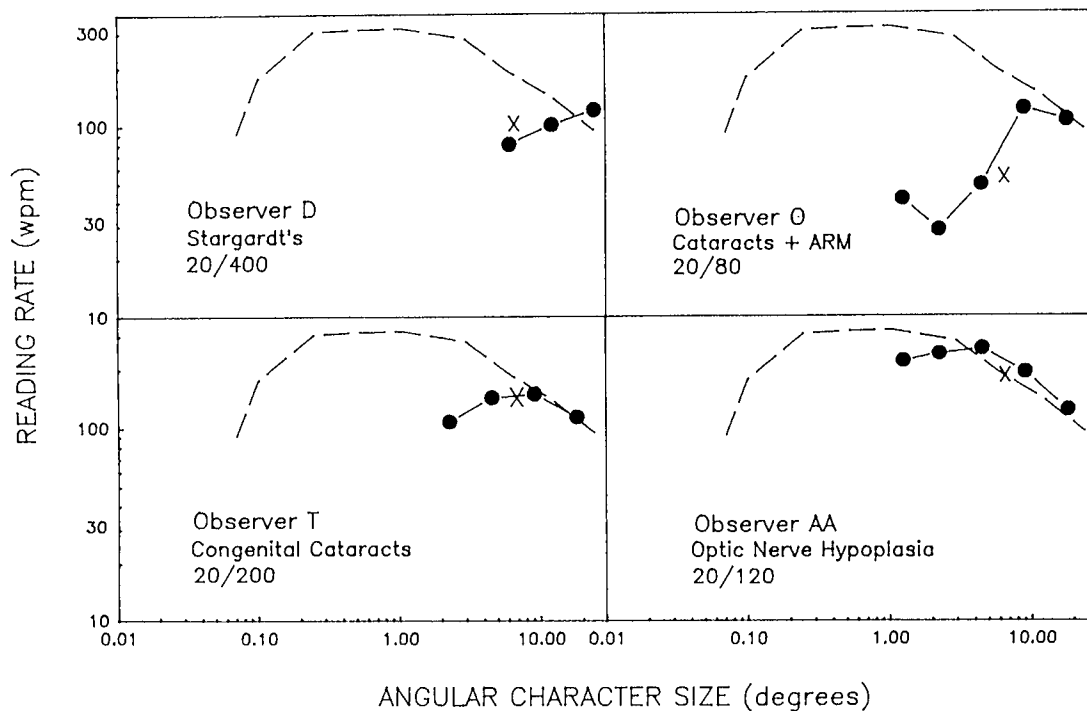


Figure 6. Illustrative data showing the effect of character size on reading for four low vision subjects. The upper dashed curve represents average data for two normally sighted subjects. The filled symbols show drifting-text reading rates for the low vision subjects. The X in each panel shows the stationary-text reading rate for 6° characters.

stronger dependence on acuity, and having lower reading rates at medium and low acuities. Status of the ocular media had no predictive power.

In this study, our largest diagnostic category was age-related maculopathy (ARM), $N = 41$. We asked whether a diagnosis of ARM, distinct from other causes of central-field loss, is predictive of reading performance. A comparison of ARM subjects with other central-loss subjects indicated that the answer is yes. ARM subjects read only about one-half as fast as acuity-matched subjects with other forms of central loss.

An explanation for slower reading in ARM subjects brings us to the third class of variables affecting low vision reading, the nonvisual variables.

Nonvisual Variables

The subjects in this large sample study had a wide age range with a mean of 51 years. We asked whether age, a nonvisual variable, would be a useful predictor of low vision reading performance.

Even in the absence of pathology, normal aging is accompanied by subtle changes in vision.¹⁸ In an earlier study¹² we found that there are only slight deficits in reading speed associated with normal aging. We therefore anticipated only small effects of aging on low vision reading.

To our surprise, age was a better predictor of low vision reading rate than was acuity, accounting for 20% of the variance, compared with only 9.5% for acuity. Age is a more potent variable in low vision reading than in normal reading. Although young and old subjects with normal vision differ by no

more than about 30% in reading rates, acuity-matched low vision subjects with similar conditions can have reading rates differing 2- or 3-fold depending on age.

The age effect explains the differences between ARM subjects and other central-loss subjects. On average, the ARM subjects are older. Regression analysis showed that when age, acuity, and ARM diagnosis were considered jointly, ARM diagnosis was no longer a useful predictor. Although it is true that people with ARM tend to read more slowly than others with central loss, it is not because of the unique pathology associated with this disease. It is because ARM subjects are older, and older people with low vision read more slowly.

The age effect on low vision reading is puzzling. There appears to be an interaction of unknown origin between age and presence of low vision that depresses reading speed. One possibility is that extra attentional capacity is required to read in the face of visual impairment, and that less attentional capacity is available in old age.

The results of this clinical study showed that a set of common ocular variables plus age accounted for only 30% of the variance in low vision reading speeds. The clinician's dream of predicting reading performance accurately from a set of simple clinical variables does not seem to be within grasp. It is possible, of course, that additional visual tests (e.g., contrast sensitivity) might capture some of the remaining variability. More refined specification of field loss or ocular media status might also help, but appropriate indices are not yet a part of com-

THE 5-BY-5 RULE

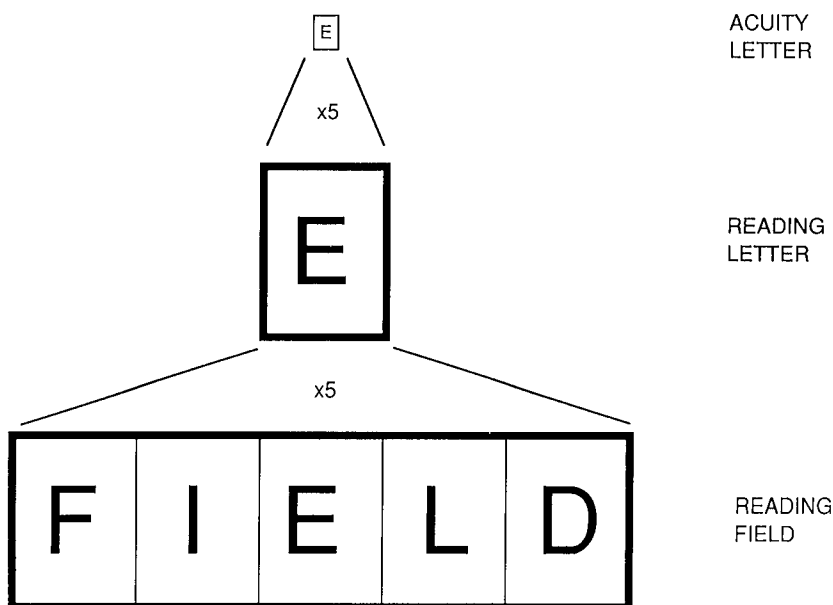


Figure 7. The 5-by-5 rule describes minimum character-size and field-size requirements for optimal reading performance.

		OCULAR MEDIA	
		Clear	Cloudy
CENTRAL FIELD	Intact	131	95
	Loss	39	29

Figure 8. A four-way classification of low vision subjects. The numbers in the cells are estimates of maximum reading rates (words/minute) based on a multiple-regression analysis.

mon clinical practice. It is likely that nonvisual factors in addition to age interact with low vision to play a role in determining reading performance.

Because low vision reading performance depends on both visual and nonvisual variables, assessment is accomplished best with a direct test of reading. The Pepper test is a recent example.¹⁹ Although acuity and other clinical variables appear to be inadequate predictors of real-world reading ability, work in progress in our laboratory has shown that a standardized test of reading is predictive of real-world performance. We measured how quickly low vision subjects read through standard passages printed on cards with their preferred magnifier. Each subject read in his or her accustomed manner. We then measured each subject's reading speed in

a controlled manner using the stationary-text method. Preliminary results from 27 subjects reveal a high correlation between standardized test speed and preferred magnifier speed ($r = 0.89$, accounting for 77% of the variance). The conclusion is an obvious one: the best way to assess low vision reading performance is to measure it.

CONCLUSION

Understanding the functional deficits experienced by people with low vision is a challenging problem. There are three distinct perspectives that focus research on different aspects of the problem. Vision scientists take a special interest in the role of stimulus variables, clinical researchers in the role of ocular variables, and rehabilitation specialists in the role of nonvisual variables. It is likely that critical issues in the understanding of low vision will require interdisciplinary analysis from two or more of these perspectives.

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REFERENCES

1. Tielsch JM, Sommer A, Witt K, Katz J, Royall RM. Blindness and visual impairment in an American urban population: the Baltimore eye survey. *Arch Ophthalmol* 1990;108:286-90.
2. Genensky SM. Functional classification system of visually impaired to replace the legal definition of blindness. *Ann Ophthalmol* 1971;3:150-4.

3. Legge GE, Pelli DG, Rubin GS, Schleske MM. Psychophysics of reading. I. Normal vision. *Vision Res* 1985;25:239–52.
4. Legge GE, Rubin GS, Pelli DG, Schleske MM. Psychophysics of reading. II. Low vision. *Vision Res* 1985;25:253–66.
5. Legge GE, Rubin GS, Luebker A. Psychophysics of reading. V. The role of contrast in normal vision. *Vision Res* 1987;27:1165–71.
6. Rubin GS, Legge GE. Psychophysics of reading. VI. The role of contrast in low vision. *Vision Res* 1989;29:79–91.
7. Legge GE, Rubin GS, Schleske MM. Contrast-polarity effects in low-vision reading. In: Woo GC, ed. *Low Vision: Principles and Applications*. New York: Springer-Verlag, 1987:288–307.
8. Legge GE, Rubin GS. Psychophysics of reading. IV. Wavelength effects in normal and low vision. *J Opt Soc Am* 1986;A3:40–51.
9. Legge GE, Parish DH, Luebker A, Wurm LH. Psychophysics of reading. XI. Comparing color contrast and luminance contrast. *J Opt Soc Am* 1990;A7:2002–10.
10. Pelli DG, Legge GE, Schleske MM. Psychophysics of reading. III. A fiberscope low-vision reading aid. *Invest Ophthalmol Vis Sci* 1985;26:751–63.
11. Legge GE, Ross JA, Isenberg LM, LaMay JM. Psychophysics of reading. XII. Clinical predictors of low-vision reading speed. *Invest Ophthalmol Vis Sci* (under review).
12. Akutsu H, Legge GE, Ross JA, Schuebel K. Psychophysics of reading. X. Effects of age related changes in vision. *J Gerontol*, in press, 1991.
13. Legge GE, Ross JA, Luebker A, LaMay JM. Psychophysics of reading. VIII. The Minnesota low-vision reading test. *Optom Vis Sci* 1989;66:843–53.
14. Legge GE, Ross JA, Maxwell KT, Luebker A. Psychophysics of reading. VII. Comprehension in normal and low vision. *Clin Vis Sci* 1989;4:51–60.
15. Beckmann PJ, Legge GE. Field-size and character-size requirements of low-vision magnifiers. *Invest Ophthalmol Vis Sci* 1991;32 (Suppl):818.
16. Sloan LL. *Reading Aids for the Partially Sighted: A Systematic Procedure for Prescribing Reading Aids*. Baltimore: Williams & Wilkins, 1977.
17. Goodrich GL, Mehr EB, Quillman RD, Shaw HK, Wiley JK. Training and practice effects in performance with low vision aids: a preliminary study. *Am J Optom Physiol Opt* 1977;54:312–8.
18. Owsley C, Sloane M. Vision and aging. In: *Handbook of Neuropsychology*, vol 4. Amsterdam: Elsevier, 1990:229–49.
19. Baldasare J, Watson GR, Whittaker SG, Miller-Shaffer H. The development and evaluation of a reading test for low vision individuals with macular loss. *J Vis Impairment Blind* 1986;80:785–9.

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