Understanding Low Vision Reading

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Abstract: Reading difficulties usually accompany low vision. This article presents an overview of a series of psychophysical studies dealing with visual factors that influence normal and low vision reading. Despite fears that the heterogeneity of low vision conditions might be too great to yield general principles, this research has uncovered distinctions, such as the presence or absence of central vision, that predict reading performance. Moreover, the findings indicate that the visual requirements of reading are modest and within the capacity of most low vision subjects. This research establishes optimal stimulus conditions for low vision reading, the best reading performance that low vision individuals may hope to achieve, new methods of visual assessment, and principles for the design of new low vision reading devices.

Most people with low vision are handicapped in reading. Indeed, one definition of low vision is the inability to read the newspaper at a normal distance of 40cm with best optical correction. (The corresponding criterion for acuity is about 20/70.)

Despite its importance, low vision reading has received little attention from researchers. One reason for this neglect is the complexity of the problem. Low vision reading is limited by visual, motor, motivational, and cognitive factors and interactions among these factors. A major goal of our research has been to develop methods that isolate visual factors so their effects can be studied separately. This strategy has allowed us to identify sensory limitations on low vision reading.

Another reason for the neglect of low vision reading was the once-prevalent belief that reading and other prolonged visual tasks can aggravate and accelerate a disease process of the eyes. This notion was institutionalized at the Myope School in London, established in 1908. A sign above the door declared, "Reading and Writing Shall Not Enter Here" (Hathaway, 1943). Over the next 50 years, the philosophy of "sight conservation" was generalized from myopia to all forms of low vision. Many low vision children were discouraged from reading print and sent to schools for the blind to learn braille. Often, elderly people with impaired vision were discouraged from reading altogether. During this period, there was little incentive for researchers to be concerned with low vision reading.

In the past 20 years or so, the sight-conservation philosophy has been replaced by a sight-utilization view. In 1964, Barraga showed that instruction with suitable educational materials could markedly enhance the visual functioning of children with impaired vision. Sloan (1968) reported that the majority of 513 patients who had visited her low vision clinic in a three-year period were successfully using low vision reading devices. In the late 1960s, Genensky (1969) was instrumental in developing a closed-circuit television magnifier that enabled people with low acuity to read. By the mid-1970s, the National Eye Institute, a branch of the National Institutes of Health, was actively calling for low vision research (National Institutes of Health, 1978).

Research in our laboratory on low vision reading is guided by three interwoven themes. First, to understand reading in low vision, we must understand reading in normal vision. In recent years, a great deal has been learned about basic sensory mechanisms of pattern vision, but we still know next to nothing about the roles played by these mechanisms in important everyday tasks like reading. We need to discover what visual mechanisms participate in normal reading. Second, to understand low vision reading, we must ultimately understand low vision per se. To do so requires us to extend models of normal visual performance to encompass low vision. In the context of reading, a start can be made by carefully documenting normal performance and then trying to understand departures due to visual impairment. Several examples of this strategy will be discussed later. Third, practical applications were found from the research, including new tests for assessing low vision, new methods for prescribing reading devices, and the design of new types of reading devices.

In this article, we review some major findings from our research. For more details of the work, see Legge, Pelli, Rubin, and Schleske (1985); Legge and Rubin (1986); Legge, Rubin, and Luebker (1987); Legge, Rubin, Pelli, and Schleske (1985); Legge, Rubin, and Schleske (1987); and Pelli, Legge, and Schleske (1985).

Method

Figure 1 shows a subject looking at a television monitor. Ten characters are visible, representing part of a full line of text. Each character subtends 6° at the viewing distance shown. (Recall that the angular character size is measured as the angle subtended by a letter at the eye. For example, a 1cm letter viewed from a distance of 57cm subtends 1° of the arc.)

Figure 1. A subject viewing a stimulus display used in an experiment.

We vary the angular character size by changing the subject's viewing distance. The text on the monitor may be presented as black letters on a white background, as in Figure 1, or as white letters on a black background. We call this the *contrast polarity* of the text.

In a trial, an 80-character line of text drifts from left to right across the screen at constant speed. The subject is asked to read the text aloud as it drifts by. If no

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errors are made, the experimenter increases the speed on the next trial. This process continues until the speed is high enough so the subject consistently makes a small number of errors. We then compute the subject's reading rate in words per minute, having corrected for the proportion of errors made.

This procedure has the advantage of permitting the easy control of stimulus parameters and provides highly reproducible measures of reading performance. It tends to isolate visual factors from cognitive and motor limitations. Moreover, the reading of drifting text is similar to the way low vision people read when they scan text through the field of a high-power optical magnifier. However, it differs from reading stationary text in the pattern of eye movements. Recordings in our laboratory and by Buettner, Krischer, and Meissen (1985) have shown that the eyes fixate on a drifting letter, pursue it across the screen through a distance of about five character spaces, then saccade back to pick up a new letter at the right of the screen. The resulting sequence of retinal images resembles the sequence that is found for stationary text: a series of fixations on letters separated by saccades spanning a few letter spaces. This finding suggests that there is a large measure of functional similarity in the reading of drifting and stationary text.

As was just described, our primary measure of performance is *reading speed.* An alternative measure is *reading comprehension.* We have chosen speed over comprehension because speed is easier to measure objectively and because comprehension is more dependent on cognitive factors. In a study in progress, we have found that low vision subjects comprehend drifting text at the same levels as do normal subjects as long as the drift rate is low enough so the subjects can read the text aloud without making errors.

Results

Character size

How does reading speed depend on the character size? This question has received surprisingly little attention. In connection with low vision, the requirements of the size of characters are critical because they determine magnification. Figure 2 shows reading data for normal subjects. The vertical axis is the reading rate in words per minute. The horizontal axis is the angular character size from .06° (which is smaller than 20/20 Snellen letters) to 24°. The three symbol shapes are for three subjects

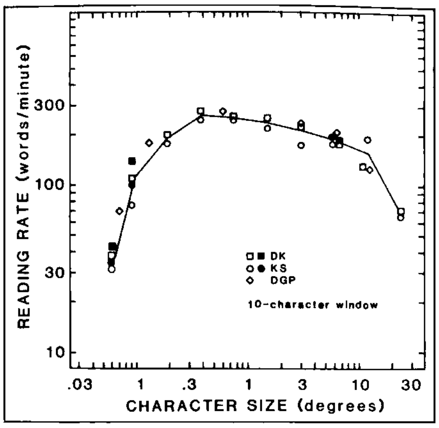

Figure 2. The reading rate is plotted as a function of the angular character size for subjects with normal vision.

and show only slight differences. The open and closed symbols are for the two contrast polarities, indicating that there is little effect of this variable for normal subjects. Notice that there is a broad peak at about 250 words per minute extending from about .4° to 2°—the range of character sizes for which reading is optimal. To the left of the peak, there is a rapid decline as the character size approaches the acuity limit. To the right of the peak, there is a more gradual decline for large letters, possibly related to failures in smooth-pursuit eye tracking. However, the reading rate is still about 70 words per minute for 24° letters. This finding is encouraging for low vision because it indicates that it may be possible to read highly magnified text rapidly.

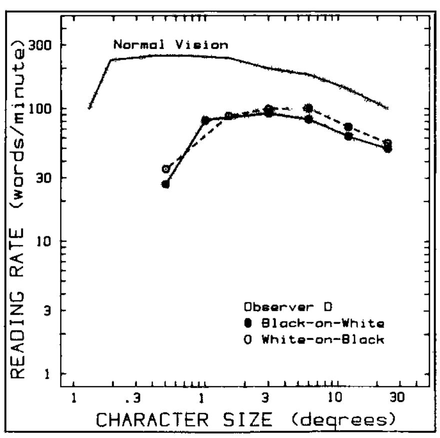

Figure 3. The reading rate is plotted as a function of angular character size for a low-vision subject with optic-nerve atrophy. The subject has central vision and has clear ocular media. The solid curve represents average results for normal subjects.

We conducted similar measurements on a diverse group of low vision subjects. Their results can be best understood if two major distinctions among these subjects are kept in mind—intact central fields versus central-field loss and cloudy versus clear ocular media.

Figure 3 shows data for a subject with optic nerve atrophy. The subject has intact central fields and clear media. Once again, the graph shows the reading rate versus the character size. As before, open and closed symbols refer to the two contrast polarities. The solid curve represents the average results for the normal subjects. The results are typical of subjects with residual central vision. The peaked nature of the curve indicates that there is a limited range of character sizes for which reading is optimal. In this case, the range is between 3° and 6° and the subject's peak reading rate is about 100 words per minute, which is potentially of great benefit to him. Since characters that are encountered in everyday reading are usually much smaller (the characters you are now reading subtend about .2° at a viewing distance of 40 cm), this subject certainly requires magnification. But notice that excessive magnification will result in suboptimal performance; the reading speed drops for characters that are larger than 6°.

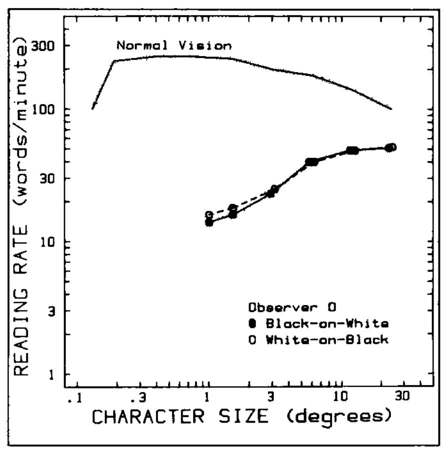

Figure 4. The reading rate is plotted as a function of the angular character size for a subject with ocular histoplasmosis. This subject has central-field loss.

Figure 4 shows a different pattern of results, but one that is typical of subjects with central-field loss. This subject suffers from ocular histoplasmosis. The graph shows no well-defined peak, but a steady rise to the largest character size used. The subject's best reading speed is only 50 words per minute.

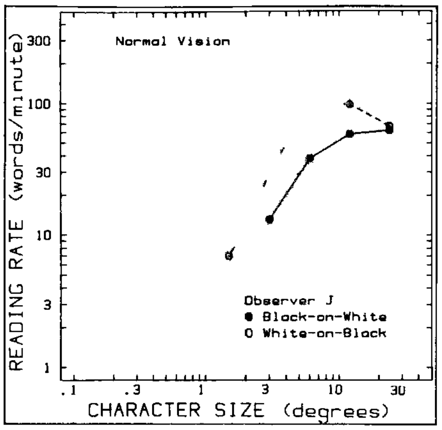

Figure 5. The reading rate is plotted as a function of the angular character size for a subject with corneal vascularization. This subject has central vision but his ocular media are cloudy.

Figure 5 shows data for a subject with severe corneal vascularization. His fields are intact but, unlike the previous subjects, his media are cloudy. Typical of subjects with cloudy media, he shows a contrast polarity effect—reading better for white characters on black than vice versa. This difference probably can be traced to light scatter within the ocular media. The identification of individuals who benefit from contrast reversal is important in the prescription of reading devices.

Outside the laboratory, it is impractical to measure entire curves like those shown in Figures 2–5, but it might be possible to design tests that give the optimal character size and peak reading rate for any given subject. Figure 6 shows predictions for the peak reading rate, based on multiple-regression analysis, using just the two clinically available variables, intact versus lost central vision, and clear versus cloudy media. The numbers in the cells give the predicted peak reading rates for the four types of subjects. It is evident that the presence or absence of central vision is critical, while the state of the ocular media plays a lesser, yet still important, role. This simple four-way prediction accounts for 64 percent of the variance in our data A second analysis showed that another clinical measure, Sloan M acuity (Sloan & Brown, 1963), accounted for 72 percent of the variance in the measurement of the optimal character size. These findings suggest that commonly available clinical measures can provide substantial information about optimal magnification and the best reading performance of low vision subjects.

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

Figure 6. A four-way classification of low vision subjects. The numbers in the cells are estimates of peak reading rates in words per minute based on a multiple-regression analysis.

Results like these reaffirm a general point. Visual variables, such as the presence or absence of central fields, are better predictors of low vision performance than are diagnostic categories.

Contrast

Contrast is another variable that is known to affect low vision reading. It is measured on a scale from 0 to 1. Figure 7 shows words at four contrast levels—.96, .30, 10, and .03. Imagine the difficulty even a normally sighted reader would have in reading text with one of the two lower contrasts.

In Figure 8, the reading rate is plotted against the character size for a normal subject. The four sets of data are for text displayed with the four contrast levels illustrated in Figure 7. Near the peak, the three upper curves nearly coincide; contrast has little effect on reading until it drops below .10. Remarkably, normal vision has a tolerance of about a factor of 10 in both the character size and contrast in the neighborhood of the peak. But now consider large character sizes, at the right of the graph, which are most pertinent to people with low vision. For these, the reading rate is more dependent on contrast, as illustrated by the divergence of the four curves. This indicates, *a priori*, that a reduction in contrast will have more deleterious effects for low vision readers.

Figure 9 shows the effect of contrast on reading rate for a fixed character size of 6°. The upper curve shows the average results for three normal subjects. Notice

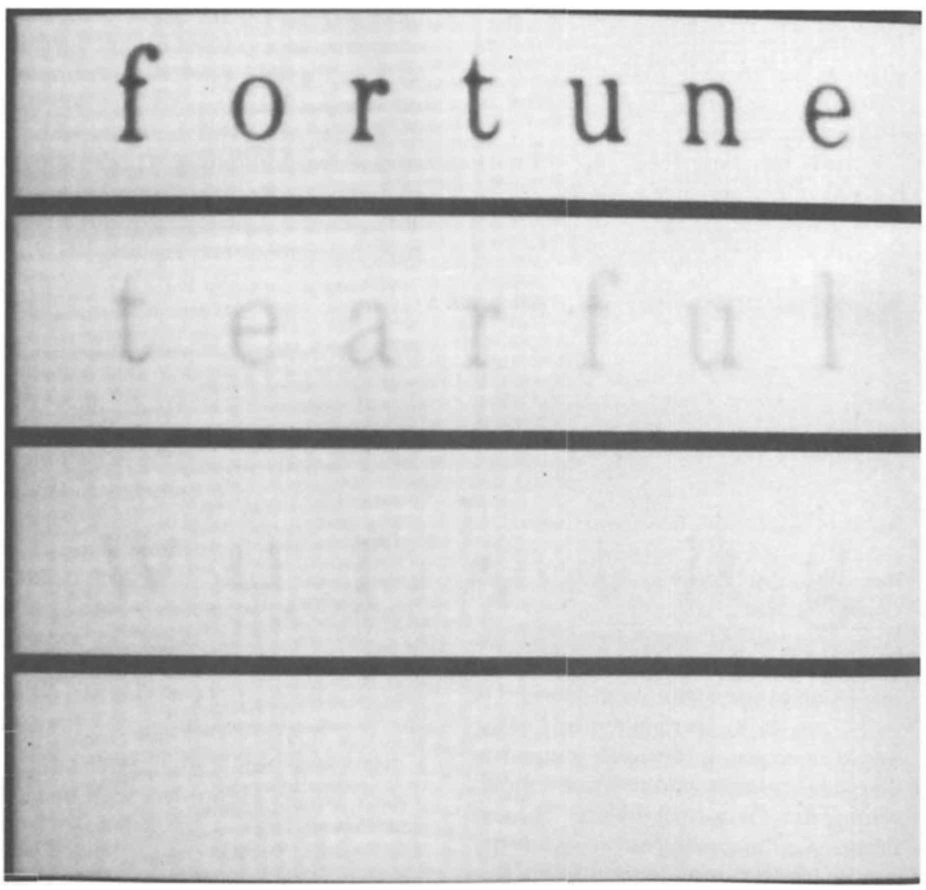

Figure 7. The words are printed at four contrast levels: "fortune" at .96, "tearful" at .30, "working" at .10, and "visible" at .03.

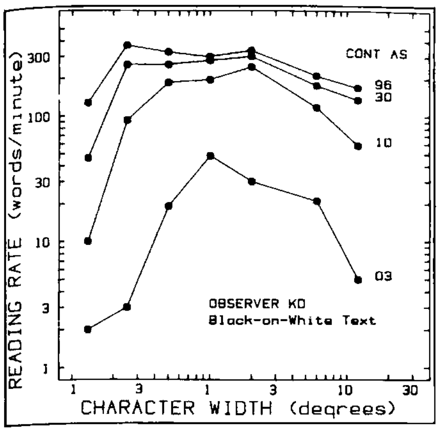

Figure 8. The reading rate is plotted as a function of the angular character size at four contrasts for one normal observer.

that the curve rolls over and becomes nearly flat, reflecting the tolerance to changes in high contrast. The data points show the results for a low vision subject with cloudy media from congenital cataracts. The different symbols are for the two contrast polarities. Again, the subject's performance was better for white-on-black text. Unlike normal readers, this subject's performance dropped sharply with any reduction from

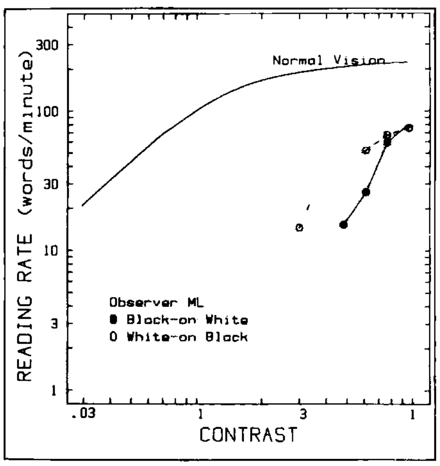

Figure 9. The reading rate is plotted as a function of contrast for 6° characters. The upper curve is average data from three normal subjects. Data points are for a low vision subject with cloudy media due to congenital cataracts.

the maximum contrast. In fact, his data resemble the steep, low-contrast portion of the normal curve. It is as if the high-contrast text forms a low-contrast image on the retina, which is consistent with the view that light scatter dilutes image contrast in an eye with a cataract.

Figure 10 shows comparable data for a subject with central-field loss caused by age-related macular degeneration. Although his reading rates are low overall, the dependence on contrast is not different from normal (unlike that of the cataract patient who may have been contrast-limited).

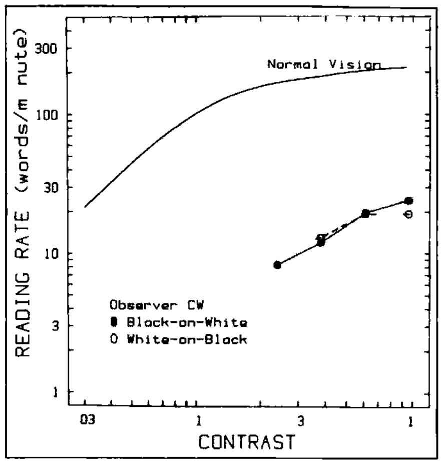

Figure 10. This figure is the same as Figure 9 except that the data are for a subject with central-field loss from age-related macular degeneration.

Sampling density and window size

Low vision reduces the amount of stimulus information that is received. This prompts us to ask: What is the minimum information required for reading?

People with advanced glaucoma or retinitis pigmentosa may have only small regions of remaining visual field. How many letters must fit within the restricted field of view to enable them to read fast?

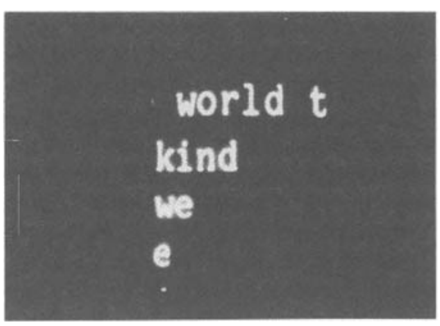

Figure 11. In the window experiments, portions of the display monitor were occluded with black paper to permit a fixed number of characters to be visible at any time. Examples of 1-, 2-, 4- and 8-character windows are shown here.

Figure 11 shows a television monitor masked to windows containing 8, 4, 2 and 1 characters. We measured the reading rate as a function of the window size for windows ranging in width from one-quarter of a character to 20 characters. Figure 12 shows the normalized reading rate (having a maximum value of 1.0) as a function of the window width. The solid curve summarizes results for normal subjects, and the letters are data for low vision subjects. For all subjects, the reading rate rose with the window size to a critical width of 4 or 5 characters. Having more than 5 characters in the field does not increase reading speed. This low number means that many people with severe field loss may be able to read rapidly. It tells us that the field of view for a high-magnification reading device should be at least 4 characters wide.

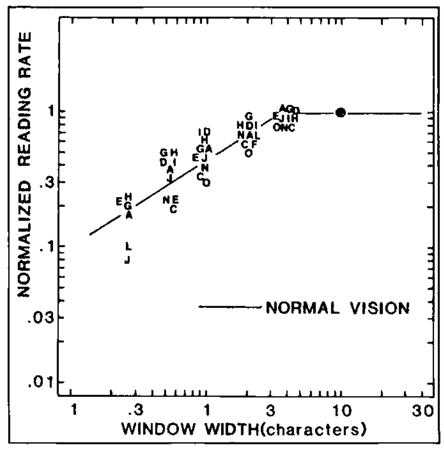

Figure 12. The normalized reading rate (having a maximum value of 1.0) is plotted as a function of the width of windows measured in character spaces. The solid curve summarizes the results for normal subjects. The letter symbols are data for low vision subjects.

How much detail is required in each letter? Common experience with inexpensive dot-matrix printers illustrates that reading can be sustained with letters constructed from relatively few dots (samples). The number of samples per character is a measure of the resolution of the text. We have studied how reading speed depends on the number of samples per character. Figure 13 shows the same words four times with resolutions ranging from 2.8×2.8 samples per character to 22×22 samples per character. In Figure 14, the reading rate is plotted as a function of sample density for one normal and three low vision subjects. All the subjects found reading to be impossible when the sample density was low, but their performance rose rapidly to a plateau at a critical density. Beyond this critical point, the

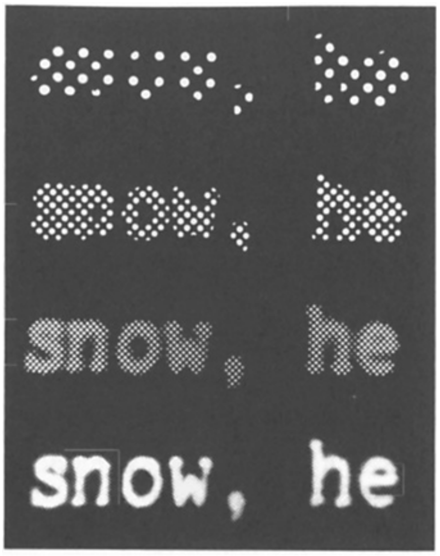

Figure 13. The same words are printed with densities of 2.8x2.8, 5.6x5.6, 11x11 and 22x22 samples per character.

increased sample density (more dots per letter) conferred no further benefit on their reading speed. The critical sample density for the normal subject was 11×11 samples per character, the same as for one low vision subject. The other two low vision subjects had lower critical densities, that is, they required fewer samples per character to achieve their best reading performance. We have found that the critical sample density is weakly dependent on the character size being higher for larger letters. Values measured for

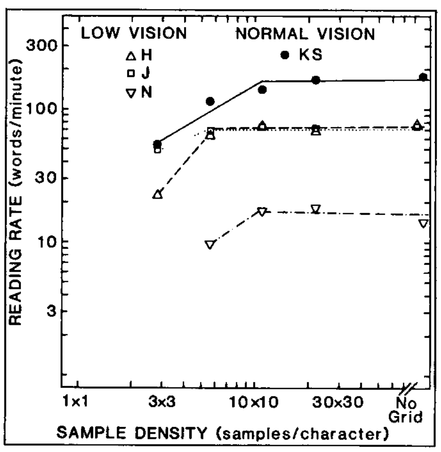

Figure 14. The reading rate is plotted as a function of the density of samples for one normal subject and three low vision subjects. The critical sample density is the horizontal coordinate at which the curve reaches its plateau. The curves for the different subjects plateau at different points on the vertical scale, indicating different maximum reading rates. "No grid" refers to measurements taken with a continuous (rather than a sampled) display.

normal subjects set upper bounds that were never exceeded by low vision subjects. Overall, the critical sample density is never more than 20×20 samples per character and, often, a much lower resolution is sufficient.

Results from the window and sample-density experiments indicate that the visual information required for reading is modest—just 4 characters in the field and no more than 20×20 samples per character. One implication is that reading is possible even with narrow visual fields or low resolution.

The fiberscope

Our findings provide guidelines for the design of low vision reading aids. One example is the fiberscope magnifier described by Pelli, Legge, & Schleske (1985).

Figure 15 shows a reader using the fiberscope. The reader is moving an objective lens, located at one end of the fiberscope, along a line of text. This lens places an image of a few letters of text on the end of a flexible bundle of optic fibers. The

Figure 15. The fiberscope in use. The user scans the objective end over the page while looking through the eyepiece. A built-in battery-powered lamp illuminates the page.

120×120 array of plastic fibers carries the image up to the eye. A microscope eyepiece enlarges the image for viewing. Figure 16 shows text photographed through the fiberscope. The individual samples, visible in the image, correspond to light transmitted by individual fibers. The power of the objective lens is chosen so there are about five characters across the field. The eyepiece is chosen to meet the magnification requirements of the low vision reader.

In a brief evaluation of the fiberscope (Pelli, Legge, & Schleske, 1985), a heterogeneous group of low vision subjects read at rates of 17–95 words per minute with a median of 59 words per minute. Normal subjects read with the fiberscope at an average rate of 73 words per minute. As is consistent with our other findings, the subjects with residual central vision read faster with the fiberscope than did the subjects with central-field loss.

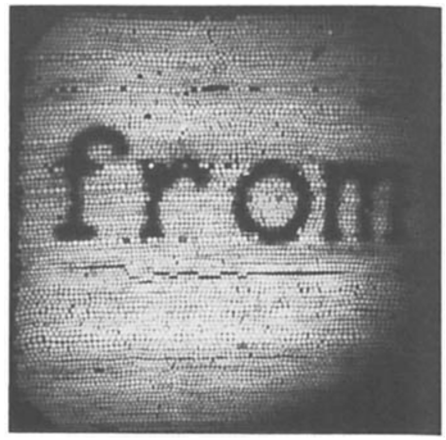

Figure 16. A view through the fiberscope. The honeycomb appearance is due to the individual optical fibers.

The fiberscope has several attractive features. It can provide high magnification (up to $40\times$), a large field (up to 60°), and good resolution of individual characters. It is portable and allows the reader to sit comfortably with a book on the table while reading.

Conclusion

In conclusion, we return to the three themes mentioned in the introduction to this article. First, we have described how laboratory methods can be used to study the role of vision in reading. Although not discussed in this article, we have been able to interpret sensory limitations on normal reading in terms of principles of contrast coding, processing by spatial-frequency channels, spatiotemporal contrast sensitivities, retinal inhomogeneity, and eye-movement control.

Second, we have presented several examples of how low vision reading deviates from normal reading. At the heart of understanding the results for low vision subjects are distinctions between the presence or absence of central vision and clear or cloudy ocular media.

Finally, we have shown some ways in which these results may have practical implications: for example, in estimating optimal magnification, in setting maximum performance goals, and in the design of new low vision reading devices.

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The Parent and Toddler Training Project for Visually Impaired and Blind Multihandicapped Children

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Abstract: Numerous clinical reports have shown that many families with visually impaired or blind multihandicapped children have problems of social and emotional adjustment and that the development of seriously handicapped children is enhanced by early intervention. This article describes the Parent and Toddler Training (PATT) Project—research-based early intervention program—that serves visually impaired and blind multihandicapped infants and toddlers and their families. The purpose of this project is to 1) increase the social responsiveness of handicapped infants, 2) implement a psychoeducational intervention program to develop adequate parenting skills, 3) initiate specific treatment approaches with parents to reduce psychological distress and improve the quality of family life, and 4) collect quantifiable data that permit the assessment of the progress of all participants.

In recent years, special educators, psychologists, and child development specialists have directed increased attention to social functioning in young children (see reviews by Gresham, 1981; Strain & Kerr, 1981; Van Hasselt, Hersen, Whitehill, & Bellack, 1979). The heightened activity in this area is attributable, in part, to research that has found that problems in social adaptation may be associated with the quality of interpersonal relationships formed as early as infancy. A major developmental task for the first two years of life is to establish effective social interactions with others. This process is facilitated by the formation of a strong attachment (reciprocal relationship) between infants and their caregivers, usually their mothers (see the review by Campos, et al., 1983). The social interactions of handicapped infants, however, may be severely impaired (Odom, 1983). As Walker (1982) posited, "the handicapped infant may have qualities that affect his [or her] abilities as initiator, elicitor, responder, and maintainer of synchrony in the interactive bout. He or she may be less reinforcing, less interesting, and more difficult as a social partner."

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The potential for the disruption of the social relationships of handicapped infants and their caretakers is perhaps more clearly illustrated by the behavior of blind children. For example, smiling is regarded as potent behavior for promoting infant-adult interactions (Odom, 1983) and is considered an "indicator of the infant's participation in a social relationship. . . and of the strength of the developing attachment bond" (Warren, 1977). However, blind infants, in comparison to their sighted counterparts, have a low rate of smiling and the quality of their smiles is different (Fraiberg, 1970, 1977). Another elicitor of infant-adult interactions is the ability of infants to establish eye contact and then a gaze. The role of eye contact as a "releaser of appropriate and personal maternal responses" has been discussed in the developmental literature for many years (Bakeman & Brown, 1977; Robson, 1967). Although empirical data regarding the amount of eye contact established by blind infants is limited (see Als, 1985; Als, Tronick, & Brazelton, 1980a; 1980b). Warren (1977)