

## Letter identification in normal and dyslexic readers: A verification

ANTHONY R. PERRY, WILLIAM N. DEMBER, JOEL S. WARM, and JOEL G. SACKS  
*University of Cincinnati, Cincinnati, Ohio*

In a recent study, Geiger and Lettvin (1987) have reported that the Aubert-Foerster function—a decline in the identifiability of letters with increments in angular distance from the axis of gaze—is flatter in dyslexic than in normal readers. This study has received considerable criticism on methodological grounds. The present investigation, using more appropriate procedures, confirms Geiger and Lettvin's findings. In two experiments, dyslexic and normal readers identified letters presented tachistoscopically at fixation or at 2.5°, 5.0°, and 7.5° to the right of fixation. In both experiments, normal readers' accuracy of identification declined sharply between 5.0° and 7.5°, while the accuracy of the dyslexics did not decline from that achieved at fixation over the range of eccentricities employed. The results are probably not attributable to the dyslexics' inability or unwillingness to follow fixation instructions.

The problem of dyslexia has fascinated educators and researchers for several decades, and there is neither a shortage of hypotheses about its etiology nor a lack of recommendations for remediation techniques (see Hynd & Cohen, 1983; Just & Carpenter, 1987; Pavlidis & Fisher, 1986). Given the multifaceted nature of the disorder, it would seem foolish to expect any single hypothesis to be broadly applicable or any single therapeutic approach to be of general utility. Nevertheless, the news media and the public seem to latch avidly onto every new study that purports to have identified the way in which dyslexic individuals differ from normal readers beyond the obvious difference in reading ability itself.

A recent case in point is an article published by Geiger and Lettvin (1987) in the prestigious *New England Journal of Medicine*. In that article, which received considerable media attention, the authors report both a difference in visual functioning between normal and dyslexic readers and a treatment strategy based on that difference.

As with any clinical entity, one would expect to find some deficit underlying dyslexics' poor reading performance, perhaps a structural abnormality or some lack in ability to process perceptual or linguistic material. Indeed, considerable effort has been devoted to uncovering perceptual deficits in dyslexics, but these efforts have not met with much success (Just & Carpenter, 1987; Vellutino, 1987). What may have lent special appeal to the Geiger and Lettvin (1987) article was their finding of a visual advantage for dyslexic readers in their ability to identify letters presented eccentrically from fixation.

In their experiment, Geiger and Lettvin (1987) presented pairs of letters to subjects, one at the point of fixation, the other at 2.5°, 5.0°, 7.5°, 10.0°, or 12.5° to the right of fixation. The subjects' task was to identify

both letters. Geiger and Lettvin found that the accuracy with which normal readers could identify peripheral letters declined steeply with increasing eccentricity. That aspect of their data conforms to what is known as the Aubert-Foerster law—that is, a decline in the identifiability of peripheral letters with increments in angular distance from the axis of gaze—and it is not at all surprising. What is surprising is that the accuracy of the dyslexic readers remained stable out to 10°, before declining precipitously at 12.5°. Moreover, their data suggest that the dyslexic subjects performed better than the normal readers when the peripheral letter was presented beyond 5° from fixation, despite what may have been superior performance by the normal readers when the peripheral letter fell close to fixation (the data at fixation were not reported).

Upon careful reading of the Geiger and Lettvin (1987) experiment, we were struck by some potential flaws in procedure and data analysis that might render suspect the purported difference between the two groups. Among them were (1) the small number of subjects in each group—five; (2) the use of multiple *t* tests without prior demonstration of an overall significant *F*; and (3) the seemingly casual manner in which the dyslexic subjects were recruited.

Two additional problems were somewhat more subtle. Geiger and Lettvin (1987) made use of a procedure in which trials within a given eccentricity value were blocked, but they made no objective attempt to control for fixation. Thus, if so inclined, the dyslexic subjects could have learned to anticipate where the peripheral stimulus would appear within a block of trials and maintain their gaze at that point, making assumptions about eccentricity invalid. Furthermore, exposure times were not uniform for the two groups of subjects. Instead, they were tailored to each subject's performance level, and they were longer, on the average, for the dyslexic than for the normal readers (J. Y. Lettvin, personal communication,

We are indebted to James Levy for technical assistance. Requests for reprints should be sent to William N. Dember, Department of Psychology, University of Cincinnati, Cincinnati, OH 45221-0376.

March 1988). Accordingly, the dyslexic subjects could have had more time to extract peripheral information during an observation interval. Similar, as well as additional, criticisms have been raised by Dunn (1987) and Helveston (1987).

The Geiger and Lettvin (1987) study, by virtue of its theoretical and clinical importance, needed to be repeated with a more rigorous methodology. The present investigation was conducted for that purpose.

## EXPERIMENT 1

In Experiment 1, we sought to determine whether Geiger and Lettvin's (1987) results would again be observed if care was taken to avoid the criticisms described above. Toward that end, the sample size was doubled, exposure times were made uniform for both the normal and the dyslexic subjects, and the spatial position (eccentricity) of the peripheral stimuli was made unpredictable from trial to trial.

### Method

**Subjects.** Ten normal readers (5 males and 5 females) and 10 dyslexics (6 males and 4 females), ranging in age between 18 and 23 years (mean, 20.5 years), served as subjects. The age range of the subjects was similar to that in the Geiger and Lettvin (1987) study. The normal subjects were enrolled in upper-division psychology courses at the University of Cincinnati. They had no history of any reading disability. The dyslexics were recruited from the Department of Handicapped Services at the University; they had been diagnosed as dyslexic within the past year. All the subjects either had no history of refractive problems or wore corrective lenses. The subjects were paid \$10 for their participation.

**Apparatus and Procedure.** The stimuli were presented binocularly in a Scientific Prototype three-field tachistoscope. They consisted of pairs of boldfaced black capital letters (approximately 35' high and 30' wide) arrayed along a horizontal vector on a white background. The luminance of the letters was 1.7 cd/m<sup>2</sup>, while that of the background was 34.6 cd/m<sup>2</sup>. The letters used in this study were identical to those employed by Geiger and Lettvin (C, E, H, I, N, O, S, T, W, Y). One letter was always located at the fixation point, which was specified by four black dots arranged in a diamond-shaped configuration at the extreme left of the viewing field, while the other letter was placed to the right of fixation at eccentricities of 2.5°, 5.0°, or 7.5°. This range of eccentricities was narrower than that employed by Geiger and Lettvin (2.5° to 12.5°), because of constraints imposed by our equipment.

Ten combinations of letters were selected at random for each of the three eccentricity conditions and used for both groups of subjects. Each subject experienced 2 trials with each of the combinations at each eccentricity, in a random order as the subject progressed through the experimental session (a total of 20 trials within each eccentricity condition). The randomization procedure ensured that the subjects had no knowledge of the eccentricity value prior to each trial.

The subjects initiated each trial by pressing a button when they had achieved proper fixation. The target duration for both groups of subjects at all eccentricities was 10 msec. This value was selected on the basis of pilot testing with normal readers; it was quite a bit lower than the upper limit (40 msec) of the values used by Geiger and Lettvin. The subjects were instructed to report both the letters and their location on each trial. To be considered correct, a response had to match both the target identity and the locus. The subjects were given five practice trials prior to the formal collection of data, and they were permitted a brief rest midway through the experiment.

### Results

For each subject, the percentage of correct identifications was determined for each of the two elements (fix-

ated and peripheral) within each letter combination in the three eccentricity conditions. For both the normal and the dyslexic subjects, the preponderant type of error was an inability to name one or both of the target letters correctly; position reversals were rare. Mean percentages of correct identifications for the normal and the dyslexic subjects are plotted as a function of retinal position in Figure 1.

The most impressive aspect of the figure is the difference in the functional relation between identification accuracy and retinal eccentricity in the two groups of subjects. The curve for normal readers shows a considerable decline in accuracy beyond 5° of eccentricity. Among the dyslexics, however, the level of accuracy at all eccentricities never drops below that at fixation. An analysis of variance based upon an arcsin transformation of the data of Figure 1 revealed no significant difference in the overall frequency of correct identifications between the normal and dyslexic subjects ( $F < 1$ ). There was, however, a significant main effect for retinal position [ $F(3,54) = 13.69, p < .001$ ] and a significant groups × position interaction [ $F(3,54) = 4.79, p < .01$ ]. Newman-Keuls tests (with an alpha level of .05 for all comparisons) were used to probe the nature of the interaction by comparing the effects of retinal position within each group. Among the normals, the frequency of correct identifications at 7.5° was significantly poorer than that at all other retinal positions, which, in turn, did not differ significantly from each other. For the dyslexics, performance at 2.5° eccentricity was significantly higher than at the other retinal positions. All other comparisons in the dyslexic group lacked significance. Taken together, the analysis of variance and subsequent Newman-Keuls tests support the impression in Figure 1 that the function relating the accuracy

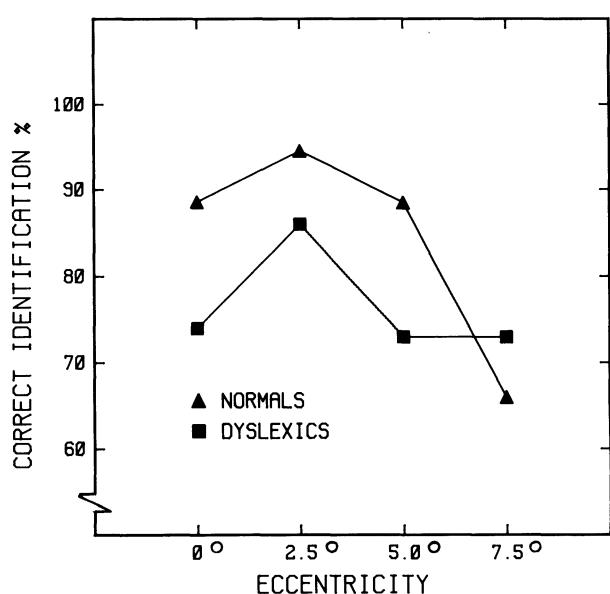


Figure 1. Percent correct identifications for normal and dyslexic readers of letters in the two-element display, as a function of retinal eccentricity.

of letter recognition to retinal eccentricity in normal readers is steeper than that in dyslexics. This result clearly substantiates Geiger and Lettvin's (1987) earlier finding.

## EXPERIMENT 2

An important feature of Experiment 1 was the use of a two-element display in testing the effects of retinal position on letter recognition, the procedure employed by Geiger and Lettvin (1987). Although we confirmed their finding of a flatter Aubert-Foerster function for dyslexic than for normal readers, the use of pairs of letters as target stimuli could cloud the interpretation of the findings. Recall that the  $0^\circ$  location (fixation) was a component in each of the three eccentricity conditions. Thus, the subjects in Experiment 1 had three times as much experience with fixation targets as with targets at any of the three peripheral locations. Perhaps this imbalance in target locations was in some way responsible for the differences in performance noted among the normal and the dyslexic subjects. Moreover, the finding that the dyslexics' peak performance was at an eccentricity of  $2.5^\circ$  rather than at fixation was curious, and we wondered about its reliability. Accordingly, a second experiment was conducted, in which we used only a single letter per trial located either at fixation or at eccentricity values of  $2.5^\circ$ ,  $5.0^\circ$ , or  $7.5^\circ$ .

### Method

**Subjects.** Five normal (3 male and 2 female) and 5 dyslexic (2 male and 3 female) readers ranging in age from 18 to 27 years (mean, 22 years) served as subjects. The dyslexics had participated in Experiment 1, about 6 weeks prior to serving in Experiment 2. They were the only dyslexic subjects available to us at the time—hence the reduction in sample size from that of Experiment 1. As in the earlier study, the normal subjects were enrolled in upper-division psychology classes at the University of Cincinnati; they had no history of any reading disability, and they had normal or corrected-to-normal vision. All the subjects received \$5 for their participation.

**Apparatus and Procedure.** The 10 letters used in Experiment 1 were also employed as stimuli in this study. Each subject received 2 trials with each letter at each of the four retinal positions (a total of 80 trials), in a random order as the subject progressed through the experimental session. The randomization procedure ensured that the subjects had no prior knowledge of the letter that appeared on any trial, nor of its retinal position. Except for the use of a single-element display, the conditions of this experiment were the same as those of Experiment 1.

### Results

The percentage of correct identifications at each retinal position was determined for each subject in the normal and dyslexic groups. Mean percentages of correct identifications for both groups of subjects are plotted in Figure 2, as a function of retinal position.

The curves in Figure 2 closely resemble those obtained in Experiment 1. Once again, the normal readers had a sharp decline in accuracy beyond  $5^\circ$  of eccentricity, while the accuracy of the dyslexics never dropped below that of fixation at any eccentricity. As in the first experiment, the curve for the dyslexics showed a rise at  $2.5^\circ$ , but this time there was also a rise at  $5.0^\circ$ . An analysis of variance based upon an arcsin transformation of the identifi-

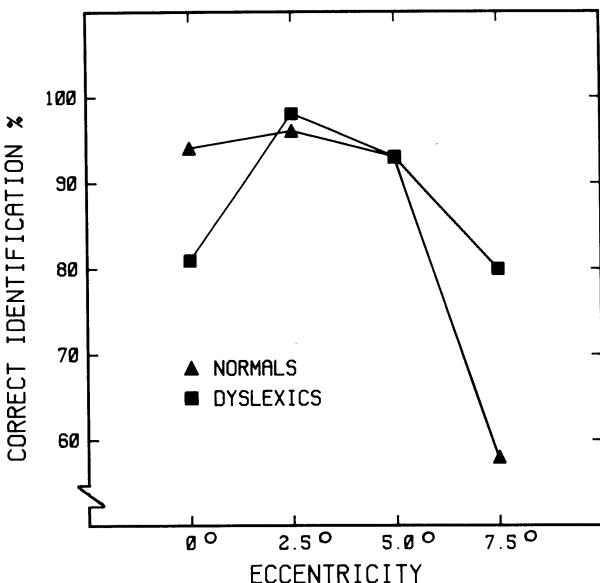


Figure 2. Percent correct identifications for normal and dyslexic readers of letters in the single-element display, as a function of retinal eccentricity.

cation scores revealed no overall difference in accuracy between the two groups ( $F < 1$ ). There was, however, a significant main effect for retinal position [ $F(3,24) = 19.19, p < .001$ ] and a significant interaction between groups and position [ $F(3,24) = 3.09, p < .05$ ]. Newman-Keuls tests of the differences between retinal positions within each group (with an alpha level of .05 for all comparisons) revealed that among normal readers, the accuracy of identification for letters presented at  $7.5^\circ$  eccentricity was significantly lower than that at all of the other retinal positions, which, in turn, did not differ significantly from each other. Among the dyslexics, accuracy at  $7.5^\circ$  did not differ significantly from that at fixation. Performance at  $2.5^\circ$ , however, was significantly higher than that at either end of the range of retinal positions employed. Accuracy at  $5.0^\circ$ , while not significantly different from that at  $2.5^\circ$ , significantly exceeded only that at the far right of the visual field ( $7.5^\circ$ ). The results of this study provide further confirmation of Geiger and Lettvin's (1987) finding that the Aubert-Foerster function is flatter in dyslexic than in normal readers. They also indicate the reliability of the unexpected finding in Experiment 1 of enhanced ability on the part of dyslexics to identify letters presented in the near periphery as compared to the central fovea.

### GENERAL DISCUSSION

The results of both experiments reinforce Geiger and Lettvin's (1987) conclusion that the Aubert-Foerster function is flatter for dyslexic than for normal readers. Moreover, the changes that these experiments introduced into the Geiger and Lettvin procedure add generality to that conclusion. Our results were obtained with a uniform target duration for all subjects, ruling out speculation that Geiger and Lettvin's findings might be attributable to the fact that their dyslexic subjects were run on average at longer target durations than the normal readers were.

Our results were also obtained under conditions in which the location of eccentric targets was more difficult to predict than it was in the earlier investigation. In Experiment 1, we made use of the dual-element display employed by Geiger and Lettvin, whereas in Experiment 2, using a single-element display, we ruled out the possibility that the Geiger and Lettvin finding is specific to the presentation of two letters at a time. Finally, the interaction between groups and retinal position was obtained with a considerably less extreme value of eccentricity than that used by Geiger and Lettvin—that is, 7.5° rather than 12.5°.

The one puzzling feature of our results was the elevated performance of the dyslexic subjects at 2.5° in both experiments and also at 5.0° in Experiment 2. Unfortunately, it is not possible at present to determine whether these findings are unique to our investigation, because of the absence of fixation data in the Geiger and Lettvin (1987) report. However, since these findings apply only to the dyslexic subjects, they are probably not attributable to some general procedural anomaly.

As was the case in the Geiger and Lettvin (1987) experiment, objective control over the subjects' angle of gaze was not maintained in the experiments reported here. Hence, it might be argued that the enhanced performance of the dyslexic readers with letters presented in the near periphery could be the result of a failure to follow fixation instructions. Instead of directing their gaze to the far left of the viewing field, the dyslexics may have fixated at points in the area of 2.5° to 5.0° to the right of the "assumed" fixation point. In addition to accounting for enhanced identification in what would no longer be the near periphery, an argument of this sort would also imply that the flattened Aubert-Foerster function for the dyslexics is merely an artifact of their moving their angle of gaze rightward, thereby reducing the range of retinal eccentricity to which they were exposed. The possible failure of dyslexic readers to follow instructions could result from an inability to maintain the indicated direction of gaze or from a fixation strategy designed to increase their likelihood of making correct identifications.

While these possibilities represent extensions of criticisms leveled against the original Geiger and Lettvin study (see Dunn, 1987), the oculomotor-deficiency hypothesis is not likely in either investigation, since gross oculomotor deficits are not characteristic of dyslexia (Olsen, Kliegl, & Davidson, 1983). Moreover, the fixation-strategy hypothesis can be indicted in the present case, if one considers the performance of the normal subjects. Recall that the accuracy of these individuals was constant from the "assumed" fixation point (0°) out to an eccentricity of 5.0°. If the differences in peripheral letter identification noted between the normal and dyslexic readers were only artifacts of the fixation position adopted by the dyslexics, we should also expect uniformity in performance over a 5° range of eccentricity with the dyslexic subjects. However, significant changes in accuracy were found with the dyslexics when targets were located only 2.5° to either side of the effective angle of gaze suggested by the fixation-strategy hypothesis in

Experiment 1 (2.5° to the right of the instructed fixation point). Similarly, significant changes in the dyslexics' performances were also found in Experiment 2 when targets were located less than 5° from what would be the expected angle of gaze according to the fixation-strategy hypothesis (between 2.5° and 5.0° to the right of the instructed fixation point). Rather than attribute the elevated performance of dyslexics with letters presented in the near periphery to an inability or an unwillingness to maintain fixation as instructed, it might be worthwhile to consider these results as reflecting something basic about dyslexic subjects' retinal organization. That possibility merits further examination.

In broad outline, the present investigation has confirmed Geiger and Lettvin's (1987) results as they pertain to the interaction between reading status and the ability to identify briefly presented letters. In their original report, Geiger and Lettvin speculate about how the dyslexics' flattened Aubert-Foerster function might prove a liability rather than an asset. They argue, in essence, that the dyslexics' heightened sensitivity to peripheral stimuli makes them vulnerable, in the course of reading, to the lateral masking effects (see Wolford & Chambers, 1983) of such peripheral stimuli on more centrally fixated targets. They also provide data to support their argument. Our results, of course, do not speak directly to that intriguing hypothesis, but they do allow us to endorse the original, highly controversial finding that led to it.

## REFERENCES

- DUNN, P. M. (1987). Peripheral vision in dyslexia (Letter to the editor). *New England Journal of Medicine*, **317**, 1737.
- GEIGER, G., & LETTVIN, J. Y. (1987). Peripheral vision in persons with dyslexia. *New England Journal of Medicine*, **316**, 1238-1243.
- HELVESTON, E. M. (1987). Peripheral vision in dyslexia (Letter to the editor). *New England Journal of Medicine*, **317**, 1737-1738.
- HYND, G., & COHEN, M. (1983). *Dyslexia: Neuropsychological theory, research and clinical differentiation*. Orlando, FL: Grune & Stratton.
- JUST, M., & CARPENTER, P. (1987). *The psychology of reading and language comprehension*. New York: Allyn & Bacon.
- OLSON, R. K., KLEGL, R., & DAVIDSON, B. J. (1983). Dyslexic and normal readers' eye movements. *Journal of Experimental Psychology: Human Perception & Performance*, **9**, 816-825.
- PAVLIDIS, G. TH., & FISHER, D. F. (1986). *Dyslexia: Its neuropsychology and treatment*. Chichester, England: Wiley.
- VELLUTINO, F. R. (1987). Dyslexia. *Scientific American*, **256**, 34-41.
- WOLFORD, G., & CHAMBERS, L. (1983). Lateral masking as a function of spacing. *Perception & Psychophysics*, **33**, 129-138.

(Manuscript received February 15, 1989.)