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"How Dyslexics See and Relearn to Read"

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These are preliminary lecture notes, intended only for distribution to participants.

HOW DYSLEXICS SEE AND RELEARN TO READ.

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ABSTRACT

A new test designed by us, the form-resolving field (FRF), measures the recognition of letter pairs presented tachistoscopically in the visual field. It distinguishes reliably dyslexics from ordinary readers by significant and characteristic differences in the regions of best recognition. We show that these regions define distributions of lateral masking, and that each distribution represents a learned task-determined visual strategies. Then we show that dyslexics can learn a new visual strategy by a simple regimen of practise. Improvement in reading is rapid and is attended by change in the FRF to resemble that of ordinary readers.

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1. INTRODUCTION

Dyslexia is an unexplained retardation of reading skill in spite of dedicated tutoring. By all measures of intelligence and of clinical optics the dyslexic should be able to read, but doesn't, and somehow seems unable to learn how to read efficiently. Some organic pathologies have been correlated with dyslexia and a few have been proposed as causal (e.g. Denkla 1977, Galaburda and Kemper 1979, Galaburda et al. 1985, Geschwind and Behan 1982, Livingstone et al. 1991). But their diversity suggests that they are, at best, only contributory factors. Dyslexia as a symptom is uniquely expressed although it shows variations in detail. Therefore our approach to dyslexia considers different variants in the process of seeing such as are involved in reading. I.e. there should be some measure, independent of reading, that suggests an immediate basis for the symptom whatever the remote causes.

Although dyslexia is presently thought to be mainly a problem of language ability, especially phonemic awareness (e.g. Liberman 1971, 1982, Liberman et al. 1974, Lundberg 1982, 1989, Olson et al 1989,Zurif and Carson 1970), several studies in visual perception have shown consistent differences between dyslexics and ordinary readers (e.g. Di Lollo et al. 1983, Fowler et al. 1990, Lovegrove et al. 1980, 1986, Stein and Fowler 1981, Williams et al. 1990). The problem as we see it is not at a level of optical image formation or early visual processing but seems to be at the level where seen things are either coherently arranged into forms or perceived merely as collections of parts. There is every reason to believe dyslexics who say that the text and letters "are all over the place", thereby signifying the absence of coherent spatial ordering of the seen parts. We also suggest that what we find in vision may have its analogies in other perceptual modes and that distinction versus indistinction in perception is an issue in the temporal domain as well (e.g. Tallal and Katz, 1989).

Bouma and Legein (1977) have shown that dyslexics are worse at recognizing strings of letters than are ordinary readers when the strings are presented at or near the center of gaze. However both groups recognized equally well single letters presented at the same locations. That is, optical acuity and recognition of single letters at or near the center of gaze are similar for both groups. But when letters are presented as strings they interfere with the perception of one another, and this influence is more marked for dyslexics than for ordinary readers at these central locations in the visual field. Such lateral interactions are known in the literature as lateral masking (e.g. Bouma 1970, Mackworth 1965, Townsend 1971, Wolford and Chambers 1983) or "crowding" (e.g. Atkinson et al. 1988). Figure 1 gives a demonstration of lateral masking.

In a visually guided task, parts of the visual field which are important for doing the task, have distinct vision and forms are salient there. In the rest of the visual field forms are indistinct and seem to be reduced to textures. In earlier studies (Geiger and Lettvin 1989, 1993; Geiger et al. 1992) we suggested that lateral masking is the operation that reduces forms to texture, i.e. to a spatially indistinct perception of seen parts. We also suggested that for different tasks there are different complementary distributions of spatially distinct versus indistinct regions of vision. We called each such distribution a visual strategy, considered that there are many different task-determined visual strategies, and suggested that a visual strategy is learned by practise of the task.

What is meant by a strategy? A simple example will suffice. In driving a car you have the experience of either attending broadly to the traffic by peripheral vision in which case you are not aware of the details on which your gaze is fixed, or else attending to detailed structures at the center of gaze in which case you are not keenly aware of the traffic around you. In either instance what is attended has form, what is unattended has only texture - a collection of attributes without distinct form. Each strategy is defined by the distribution of lateral masking. The masking is in the periphery if you are concerned with details in the center of vision, and is in the center if you are concerned with what is happening in the periphery.

In order to describe the regional distribution of lateral masking in the task of reading we designed a test called the form-resolving field (FRF) (Geiger and Lettvin, 1987, 1989) which measures letter pair recognition under tachistoscopic presentation.

In Experiment I we first establish the perceptual differences between dyslexics and ordinary readers in terms of distributions of lateral masking as measured by the FRF test. We then show in Experiment II that the distribution of lateral masking for dyslexics is dependent on the direction of reading the language, an intentional factor which determines the strategy they use. In Experiment III we show a change of distributions (visual strategies) within one individual at different times. The subjects in this experiment are ordinary readers for part of the day and dyslexics otherwise, suggesting that dyslexia is not a fixed symptom. These experiments (I, II, and III) lay the ground for the hypothesis that the distribution of lateral masking is learned. We put this hypothesis to test in Experiment IV - where a few adult severe dyslexics learned a new visual strategy for reading - and in Experiment V - a controlled experiment on 15 dyslexic children who also learned a new visual strategy for reading. In both experiments the change of strategy was accompanied by change in distribution of lateral masking.

2. GENERAL METHODS

2.1. The apparatus and stimuli for the FRF test.

Three slide projectors, equipped with flat field lenses and electrically activated shutters (Vincent Associates), back-projected images of letters on a diffusing screen. The arrangement served as a wide-screen tachistoscope. Each of the projectors gave uniform luminance of 180 cd/m^2 (1700 cd/m^2 for experiment V) ±10% across the whole screen. The first projector carried a slide with a central fixation point. The second carried the stimulus slide. The third carried a blank "eraser" slide. The order of presentation of the slides on the screen and the duration of presentation was controlled by an electronic timer. It adjusted the openings and closing of the shutters to minimize transitional changes in luminance on the screen between presentations. Stimulus durations were adjustable over the range of 1.6 ms to 150 ms. The screen was 49 cm wide and 32 cm high corresponding to 39° of visual angle horizontally and 26° vertically from an observation distance of 69 cm.

Each stimulus slide carried two letters, one in the center at the location of the fixation point and the other in the periphery. The stimuli were divided into 5 groups. In each group the letters in the periphery were at a fixed angular horizontal distance from the fixation point at the center. The angles used were from 2.5° to 12.5° in 2.5° steps. Each group contained 20 slides, no two alike in the letter pairs used. In half of them the peripheral letter was to the left of the fixation point and in half to the right (i.e. there were 10 slides at each eccentricity). They were presented in a random order. This procedure helped observers to maintain central fixation and reduced the bias of expectation of appearance (Geiger and Lettvin, 1989, Geiger et al., 1992). The two letters in each stimulus presentation were different, and were chosen from a fixed set of 10 upper-case Helvetica-medium letters (I, S, C, O, V, M, N, E, T, H). The letter height subtended 35 min of visual arc, and letter contrast was 90%. Each letter appeared once at each of the eccentric visual field positions, and twice at the central position.

2.2. The procedure for the FRF test.

The subject was seated 69 cm away from the screen in a dimly lit room. A fixation point was projected on the screen. The subject was asked to look at the fixation point. Shortly after a verbal warning the stimulus slide was briefly projected (replacing the fixation point slide) and followed by a blank eraser slide which was projected for 2.5 s. The subject was asked to name the letters in the stimulus slide and their relative position. This cycle was repeated until all 100 stimulus slides had been presented. Then the average letter recognition for each eccentricity was calculated and plotted to give the FRF plot. The average recognition of the letter at the center was also taken and numerically recorded.

Prior to the test itself the effective stimulus duration, i.e. the time between the offset of the fixation point slide and the onset of the eraser slide, was determined for each subject separately. In this pre-test procedure, various stimulus durations were tested with samples of letter pairs which had the peripheral letters at different eccentricities, until a stimulus duration was found in which the correct letter identification reached just below 100% for that eccentricity of the peripheral letter where recognition was best. We refer to this procedure as auto-scaling. Once the appropriate stimulus duration was found it was kept constant during the test and for all subsequent FRF tests on the same subject.

The plot of correct recognition of the peripheral letters as a function of their eccentricity is the form-resolving field (FRF) along the horizontal axis. The score of recognition of the letter at the center is given numerically but not shown on the plots.

2.3. Subjects

The subject group will be described for each experiment below.

3.1. EXPERIMENT I Perceptual differences between adult dyslexics and adult ordinary readers as measured by the FRF test.

The first systematic test we made was a comparison of adult residual dyslexics with adult ordinary readers (Geiger and Lettvin, 1987). But here we describe first the comparison between the FRF of adult severe dyslexics and that of adult ordinary readers.

3.1.1 Subjects

The subjects were all English-native adults. Ten of them were severe dyslexics (2 females and 8 males) 18 to 58 years of age, and ten were ordinary readers (3 females and 7 males) 18 to 45 years of age. The severe dyslexics came from the general population and did not belong to any specially targeted group. They had been diagnosed as dyslexics by their neurologists and/or psychologists, prior to calling on us. We designate these subjects as severe dyslexics because they received no special remediation for at least 3 years before they came to us, and their reading skills were much below the minimally expected level. None of the severe dyslexics had any known neurological impediments or any uncorrected refractive errors. All had normal comprehension of heard texts or conversations. The ordinary readers came from the general university-level student population. All had normal vision or had been corrected to normal visual acuity.

3.1.2. Results

After a short interview and assessments of reading skill the subjects were tested for their FRF's. The average results of the 10 adult ordinary readers and of that of the 10 adults severe dyslexics are shown in figure 2.

There are significant differences between the groups. The FRF of ordinary readers falls off monotonically, and is narrow and symmetric to the left and right of the center of gaze as is suggested by a correlate of the Aubert-Foerster law (1857). That is, the recognition of letter pairs for ordinary readers is best when the peripheral letter is near the center of gaze and diminishes rapidly with eccentricity. On the left side the FRF of the severe dyslexics is similar to that of ordinary readers but is not monotonic and is significantly wider (significance at $\leq 5\%$ level) on the right side, and therefore distinctly asymmetric. Best recognition of the letter pairs on the right occurs when the peripheral letter is at 5^{o}-7.5^{o} eccentricity. Thus the FRF of the severe dyslexics is significantly wider then that of ordinary readers. Near the center of gaze at 2.5^{o} eccentricity on the right, the recognition of the letter pairs is significantly lower than at 5^{o} eccentricity (Geiger and Lettvin 1989, Geiger et al. 1992).

These results suggest that ordinary readers recognize pairs of letters best in and near the center of gaze. On the other hand, English-native severe dyslexics recognize letters best away from the center of gaze to the right; the letters mask each other when they are in or near the center of gaze .

By the auto-scaling procedure stimulus-presentation duration on average was shorter for ordinary readers than for dyslexics (7.96 ms duration on average for dyslexics and 5.6 ms on average for ordinary readers) but not significantly shorter.

We also tested this procedure (the FRF) on a small group of subjects using in addition a computer-driven CRT for comparison. The results using the CRT were markedly different from those had with the projectors. The difference between dyslexics and ordinary readers were not reliably found with the CRT presentation (see Zeggara-Moran and Geiger, 1993).

3.1.3. Discussion

Such results show that distinction between dyslexics and ordinary readers can be reliably made by a non-reading test of visual perception, the FRF. We repeated the measurements of the FRF on an additional 67 dyslexics native to English, German or Italian. Their plots were similar to the plot of the severe dyslexics in figure 2. Similarly, an additional 56 ordinary readers native to English, German or Italian, were tested and their FRF's were similar to that of ordinary readers shown in the same figure. The differences in the FRF's between ordinary readers and dyslexics are significant consistent and easy to show, a property which makes the FRF test an easy, non-reading method for distinguishing dyslexics from non-dyslexics.

It is important to note that the FRF does not measure what is usually meant by visual acuity in the optical sense. Instead the difference lies at a later processing level as will be discussed presently.

After we introduced the FRF several attempts were made to repeat our findings or their correlates. In those studies where projective optical displays were used our findings were verified (Perry et al. 1989; Dautrich 1993). However where CRT displays were used (Bjaalid et al. 1993, Gulkasian and King 1990, Klein et al. 1990, Slaghuis et al. 1992), the differences between dyslexics and ordinary readers were mostly not found, as we had described earlier.

The FRF plots in our studies were obtained under auto-scaling of the stimulus duration. However, Perry et al. (1989) have shown that by choosing the presentation conditions carefully, so as to get below 100% recognition at all eccentricities, they got results similar to ours. This shows that the FRF does not depend on our auto-scaling providing only that all the measures have a maximum below 100% correct recognition.

We attribute the differences in the shape of the FRF's of dyslexics and ordinary readers to differences in the distribution of lateral masking. We have shown this more vividly by measuring recognition of tachistoscopically presented strings of letters: 3 letters in the right visual field and one letter at the center of gaze. The distance of the strings from the center was varied from 2.5° to 10° in 4 steps. The distribution of lateral masking for ordinary readers increased rapidly and monotonically with eccentricity, as suggested in the literature (e.g. Bouma, 1970). But the distribution for the dyslexics showed masking near the center and less of it in the periphery compared with ordinary readers, so that it was not monotonic (Geiger and Lettvin 1987 1989, Geiger et al. 1992). In addition we had shown in another set of experiments that letters mask themselves (except for I) (Geiger and Lettvin, 1986). We can conclude that the FRF test measures the distribution of lateral masking over the horizontal axis of the visual field.

The FRF of ordinary readers is narrow which indicates that letters are best recognized in and near the center of gaze and recognition is diminished with eccentricity. That implies that a word gazed at is recognized clearly while the surrounding text is rendered indistinct by lateral masking. That is, ordinary readers are able to perceive distinctly words in isolation by their forms with little interference from the surrounding text. Thus, while reading, an ordinary reader can progress from one word to the next perceiving each word separately. For dyslexics the situation is different. Letter strings at the center of gaze are masked (see also Bouma and Legein, 1977) while the letter strings farther in the right periphery at 5^{o}-10^{o} and beyond are less masked, thus keeping a large region of text salient. As a result dyslexics have great difficulty in perceiving words in isolation and therefore the process of reading is so difficult for them.

3.2. EXPERIMENT II. Does the direction of reading matter?

The FRF tests described above were performed with subjects whose native languages are read from right to left (English, Italian and German). The FRF's of dyslexics, native to these languages, were distinctly asymmetric with wide letter recognition to the right: the direction of reading these languages. Therefore we repeated the experiment with persons native to language read from right to left, in order to confirm the relation between the direction of reading the language and the asymmetry of the FRF.

3.2.1. Subjects

The subjects were all Hebrew-native adults who were exposed primarily to Hebrew through the first 10 years of their life and who had been taught to read only Hebrew during the first 3 years at school. All of them had learned to speak English from the 4th year at school. These subjects came from a background similar to that of the English-native subjects described in experiment I. From this group 5 subjects were dyslexic males 17-28 years of age. They did not receive remedial training at the time of testing but had received such training within less then 3 years prior to testing. Accordingly their reading levels were not as low as those of the severe dyslexics. They had been diagnosed as dyslexics by their respective neurologists and/or psychologists. Their reading was profoundly impaired but their comprehension of heard texts was normal. Another 5 subjects from the group (2 females and 3 males 20-31 years in age) were ordinary readers.

3.2.2. Results: The FRF of Hebrew-native dyslexics is differs from that of English-native dyslexics.

After an interview and reading assessments all the subjects were tested for their FRF's with Hebrew letters as stimuli. As seen from figure 3 the FRF of adult Hebrew-native ordinary readers is narrow and falls off monotonically with best recognition of letter pairs in and near the center visual field, similar to that of English-native ordinary readers. However, the FRF of adult Hebrew-native dyslexics is significantly different from that of ordinary readers. Recognition of Hebrew letters for Hebrew-native dyslexics extends further than for ordinary readers in the left visual field but not on the right. This is the mirror image of the FRF of English-native dyslexics. Similarly, the FRF of the Hebrew-native dyslexics is significantly wider then that of Hebrew ordinary readers. The masking near the center at 2.5^{o} eccentricity to the right is similar for both groups of dyslexics, Hebrew-native and English-native.

The FRF's of ordinary readers is similar for both the English-native and Hebrew-native groups. On the other hand, the FRF's of all dyslexics are systematically different from that of ordinary readers in that the FRF of Hebrew-native dyslexics is similar in shape to that of English-native dyslexics but opposite in direction of the asymmetry. That is, the wide part of the dyslexic FRF is in the direction of reading. That suggests that the distribution of lateral masking as measured by the FRF is learned by experience, and is not a fixed organic trait since it depends on the direction of reading. We therefore suggest that the symptom of dyslexia may be learned.

4. EXPERIMENT III. . Is a dyslexic person always dyslexic? Is there "conditional dyslexia"?

How varied dyslexia can be is shown by the following subject who is not an isolated case. We documented 3 more such cases and have found a few additional ones since.

The subject is an adult man whose profession is in the graphic arts. In the morning when he is "fresh", he reads easily and well but his artistic skill is not at its best. By afternoon he feels "tired" and cannot read easily at all . At the same time his graphic skill improves and he has no trouble at all in pursuing his artistic work. As shown in figure 4 the FRF is that of an ordinary reader in the morning but of a definite dyslexic in the afternoon. It is narrow in the morning and shallow and wide in the right visual field in the afternoon when reading is impaired. The stimulus presentation time was the same for both measurements. This effect was tested on 3 successive days with similar results. Such findings demonstrate two points. First, there is an immediate correlation between reading skill and the shape of the FRF, i.e the distribution of lateral masking. Second, dyslexia can be a plastic (changing) state rather than a "hard wired" constant state.

5. EXPERIMENT IV. Learning a new visual strategy for reading by dyslexic adults, a demonstration.

Until now we have described the systematic perceptual differences between dyslexics and ordinary readers, shown that these differences are dependent on the direction of reading, and shown that dyslexia can be a conditional state. Since we suggest that the symptom of dyslexia can be learned we will consider now the systematic changes that accompany learning a new visual strategy. That is the critical test for the validity of our approach.

We asked a 25 year old male severe dyslexic, who participated in experiment I and whose reading level was at about 3rd grade of school, to join in an experiment of learning a new visual strategy for reading. After reading assessment and the FRF test we suggested a regimen of practise which consisted of two complementary parts. One was to devote two hours a day to novel small scale hand-eye coordination activities like painting, drawing, clay modeling, etc. For the other part we asked the subject to use a specially designed mask to be laid on a text. The mask was a blank sheet with a rectangular window, cut to be some what larger than a long word in the text. Left of the window and at the optimal eccentricity determined by his FRF we put a fixation mark. The subject laid this mask on the text to be read, fixed his gaze on the mark, and was to read the word which appeared in the window on the right. He was to shift the mask along the text and read it word by word. In this way the text was masked except for the word in the window. This gave the subject the possibility to recognize words in isolation at that eccentricity where letter strings were best recognized. The subject did that regimen unsupervised but with occasional phone calls for encouragement.

Three weeks after he began he called to say that he now saw that words have forms. Four months after the start of practise we tested him again. His reading had improved markedly to the level equivalent to 10th grade of school and his FRF had changed as shown in figure 5. As seen from that figure the FRF had narrowed significantly and the lateral masking in and near the center was significantly diminished. Similarly, when we initially measured lateral masking at the center of gaze and near it with a string of 3 letters in the periphery and one letter at the center, we found strong lateral masking. The subject was unable to recognize even one letter when the string was at 2.5^o to the right, but recognition of the string was at 70% level at 7.5^o to the right. After practise of the regimen the subject recognized over 80% of the letters at 2.5^o and 7.5^o eccentricity, under identical conditions (Geiger and Lettvin, 1987, 1989).

We tested the same procedure on another 3 severe dyslexics with similar results. This report is telling but anecdotal. In the next section we describe a controlled experiment to demonstrate our point.

6. EXPERIMENT V. Dyslexic children can learn a new visual strategy for reading in a controlled experiment (Geiger et al. 1994).

6.1.1 Subjects.

The subjects were 15 children (3rd - 6th grade) who were diagnosed as dyslexics and 6 children who were ordinary readers. All came from the public school system in Tübingen, Germany. Table 1 shows the age, sex, handedness, grade, reading level, and reading retardation of every subject. The 15 dyslexics were later divided into 2 groups: the "experimental dyslexics" and the "control dyslexics". The children who were ordinary readers were tested for reference only.

6.1.2. Procedure.

The initial session of tests included for all subjects: an ophthalmological examination, a standardized reading test (Züricher Lesetest (ZLT)), a handedness preference test and an interview. The dyslexic subjects were confirmed as such on the basis of these tests together with the assessment of their intelligence. At the end of these tests the FRF test was given to every subject. Then the dyslexic children were divided into two groups. The experimental dyslexic group (9) was given a regimen of practise similar to the one described in experiment IV, and the control dyslexic group (6) continued the remedial process offered in their schools. At the end of the initial session all dyslexics were individually given an explanation of their problem and then encouraged.

After 3 months of practising their respective regimens all the dyslexic children (from the two groups) were retested for reading and given the FRF test. At the end of this session the regimen of practise was then given to the subjects in the control dyslexic group. At the end of 8 months from the initial testing (i.e. 5 months after the second session) all the dyslexic subjects were retested for reading and given the FRF test.

6.2.1 Results.

The results of the initial session of testing as given in Table 1 depict the dyslexics and establish the difference in reading skills between them and the ordinary readers.

Before testing the subjects with the FRF the dyslexics were identified as such. Then the FRF test was given and the results are shown in figure 6. The FRF of the dyslexics is significantly wider (on both sides) then that of the ordinary readers. At the end of this session the dyslexic children were divided into two groups, experimental dyslexics and control dyslexics. As seen in Table 2, the two dyslexic groups were matched for age, reading level and degree of reading retardation. Figure 7 shows the averaged FRF plots separately for the experimental dyslexics and control dyslexics. The FRF's of both groups are similar. At the end of the session the regimen of practise (described in detail below) was given to the experimental dyslexics while the control dyslexics continued their remedial practices at school.

6.2.2. The regimen of practise

The regimen of practise is similar to the one described for adults in the previous experiment and has two complementary parts. One part consists of novel, small-scale hand-eye coordination tasks like drawing, painting, modelling etc. It was important that the activity be novel to the child and preferably enjoyable. All kinds of art work and small scale mechanical constructions (and disassembly) were suggested to this end. Each dyslexic was asked to engage for about an hour daily in these activities which were to be performed in a private and unsupervised manner, not in a structured lesson. To motivate the children to perform this play, it was important that the child initiated and chose the activities and enjoyed doing them.

The second part of the regimen was to read (recognize) words in isolation. To this end we asked the children to use our specially designed mask sheet which they laid on the text to be read. The mask was a blank sheet (some times a colored transparent sheet) as described in the previous experiment.

6.2.3. Second and third session of testing

Three months after the initial testing was completed the second testing was conducted. It included reading assessment and the FRF test. In the interview during that session, we first had to establish whether the child had performed the practise long enough to be regarded as a subject in the experimental group. That is, the child and the accompanying person gave estimates of durations of practise. Every subject included in the experimental group practised for at least 1/2 hour per day, on average, hand-eye coordination tasks (mostly art-work) in addition to similar work given in school. They also did at least 1/2 h per day of reading with the mask sheet. The control dyslexics had continued their remedial procedure given by the school which included additional reading and writing assignments with syllable awareness training and the use of a finger as a pointer in reading.

The results of the second reading test is given in Table 2. The improvements in reading of every subject in each group and the average of each group are indicated in that table and are also shown in figure 8. In the 3 months period between testing, every child in the experimental group who practised the regimen had improved by at least 1 grade level. On average the experimental dyslexics improved by 1.22 grade level. At the same time the highest improvement rate reached by the control dyslexics was 0.5 grade level. The average improvement was 0.17 grade level for the group. The FRF's of the experimental dyslexics taken before practise and after 3 months practise are shown in figure 9. As can be seen the FRF of the experimental dyslexics narrowed significantly on the right side while remaining the same on the left side. It was now not significantly different from that of the ordinary readers on the right but it was significantly narrower on the right than the FRF of the control dyslexics, taken in the second testing session, as shown in figure 10.

At the end of this second session our regimen of practise was then given to the control dyslexics. Five months later, 8 month from the start, reading levels and the FRF were retested. The result of the reading tests are given in Table 2. All the dyslexics who practised the regimen improved further in reading skills especially the 2 control dyslexics who did practise (3 of the control dyslexics failed to take the 3rd session of testing and 1 did not practise).

For all the dyslexics who practised the regimen, their reading retardation was on average only 0.75 grade level below their expected grade levels, reduced from the initial deficit of 2.5 grade levels. This is on average 1.75 grade level improvement in reading within 8 months, a rate of improvement larger than that of ordinary reading subjects. At the end of 8 months, of the 11 dyslexics who practised the regimen 10 could no more be regarded as dyslexics (as they were 1.3 grade levels or less below their expected reading level) and only one was still dyslexic (at over 2 grade levels behind the expected level).

The FRF of the control dyslexics who practised had significantly narrowed on the right side while the FRF of the experimental dyslexics did not narrow further after the second session of testing.

6.3. Discussion

Comparing the average FRF's of adult dyslexics (Fig.2) and that of the dyslexic children (Fig. 6) indicates two differences: the masking at 2.5^{o} eccentricity which adults have is not present in the average of the FRF of children, and the FRF of dyslexic children is wider than that of ordinary readers on the left side as well as on the right. Although the asymmetry between right and left side is retained, it is not as pronounced as with adult dyslexics. These differences may be related to differences of age. But we found that the remedial procedure that had been given to these children at school (before our experiment) was to use a finger as marker while reading. We suspect on other observational grounds that this regimen is conducive to the particular visual strategy represented by the FRF.

7. GENERAL DISCUSSION.

7.1 The difference between dyslexics and ordinary readers.

Dyslexics and ordinary readers are systematically different under a specific visual perception test (the FRF) and the difference is in the hemifield corresponding to the direction of reading. Dyslexics who were first taught to read from left to right (English, German and Italian) have an FRF wider to the right while dyslexics who were first taught to read from right to left (Hebrew) have an FRF that is wider to the left.

The different shapes of the FRF's between ordinary readers and dyslexics and their associated distributions of lateral masking indicate how these two groups differ in visual perception. When ordinary readers gaze at a word, the letters comprising the word mask each other very little but the surrounding text away from the direction of gaze is strongly masked. On the other hand when dyslexics gaze at a word the letters in and near the center of gaze mask each other. At the same time this lateral masking is relieved in the near periphery in the direction of reading. As a result they perceive a large portion of the surrounding text, since it is poorly masked. Hence they do not perceive words in isolation as ordinary readers do. Consequently dyslexics do not recognize well the forms of words, cannot isolate words adequately; the text seems to be seen "all at once" as they say.

Our approach was to look at the symptom of dyslexia rather then its cause, and to describe a non-reading test by which dyslexics differ from ordinary readers. As we have shown in Experiments I, II and V all dyslexics, individually and on the average, significantly differ in the FRF plot from ordinary readers and vice versa. We have not chosen the dyslexics we measured and we had over 70 of them. Therefore we can suggest with confidence that the FRF reliably discriminates dyslexics from ordinary readers. Among the dyslexics we measured were different types of dyslexics (whether those of Boder (Boder, 1973) or those of Bakker (Bakker, 1972)). However they all had similar FRF's.

7.2. Learning a visual strategy for reading.

As shown in Experiments IV and V dyslexic adults and children are able to learn a new visual strategy which improves reading skills. This learning accompanies the practise of the regimen we suggested. Although the regimen resembles some earlier developmental type of motor skill training (Frostig and Horn 1964, Lewis 1968) it is task specific and based on the formation of a new visual strategy operationally defined by the task as suggested by Held and his colleagues (Held and Gotlieb, 1958, Held and Hein 1958) and by Kohler (1962).

The practise of the novel small scale hand-eye coordination tasks provides exercise for the making of new visual strategies through coordination of somatic sensory-motor control with visual control. At the same time the peripheral reading through the window provides blanking of the text surrounding the words and so enables the perception of isolated words as distinct forms in that region of the visual field where lateral masking for them is least. This ensures that the new practise does not clash with an entrenched existing strategy of masking in the center and permits the continuation of play to establish a new strategy for a novel task.

Such a regimen is simple and inexpensive. Its importance for children lies in its providing of a motivating drive to learn further. It is motivating because the regimen is unsupervised and involves non-reading work (art etc.) where success is easier to attain. The presentation of words where masking is least, allows their forms to be seen. Once the forms of words are known, the subject knows "what to look for" in the center of gaze. In cursive reading there must be the clear concept of a word as a visual form corresponding with a word in language.

This regimen resulted in a rapid improvement of reading skills, in many cases to competent reading at the expected level as dictated by age or grade. With children, once they learned the strategy it remained with them. However, adults have to practise to maintain reading level. With the learning of the new visual strategy by English-native and

German-native dyslexics the FRF on the right side narrowed significantly. When some of the adult dyslexics stopped the practise their reading skills deteriorated and the FRF widened again.

7.3 Conclusions.

-Dyslexic persons differ in their FRF's from ordinary readers in a systematic way.

-The difference indicates different distributions of lateral masking.

-There is a narrow unmasked region in the center of gaze for ordinary readers.

-There is a wide relatively unmasked region in the periphery (in the direction of reading) for dyslexics along with masking at the center of gaze.

-The different distribution of lateral masking in the dyslexic is the putative cause for reading difficulties.

-The distribution of lateral masking is learned.

-There is a way to teach dyslexics a new visual strategy for reading.

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FIGURE LEGENDS

1. A demonstration of lateral masking. Fix your gaze on the x of the upper row. Without shifting your gaze, the N on the left will appear clear and distinct while the N on the right will not be legible though segmented lines will be clear. Similarly, fix your gaze on the x of the lower row. You will see the small circles on both sides. However, on the left side there is a ring (or diamond shaped) arrangement of small circles, but on the right side the ring arrangement is lost although the small circles are clear. This holds for ordinary readers. Dyslexics may see both N's almost as clearly and also see both ring arrangements.

2. The FRF plots of adult English-native subjects; average of 10 ordinary readers (dashed line) and the average of 10 severe dyslexics (solid line). The measure is correct recognition (in %) of the peripheral letters of the letter pairs, at different eccentricities. The scores of the letters at the center was 95±5% for all peripheral letter eccentricities. The vertical bars denote the standard deviation. The FRF of the severe dyslexics is significantly wider then that of ordinary readers. Considering both sides together, at 20° width (-10° and +10° eccentricities) severe dyslexics recognize letters significantly better then ordinary readers, and similarly at 25°.

3. The plot of the FRF of adult Hebrew-native subjects; average of 5 ordinary readers (dashed line) and 5 dyslexics (solid lines). Correct recognition of the letter at the center for all peripheral letter eccentricities was 95±5%. The vertical bars denote the standard deviation. Considering both sides together, the FRF of dyslexics is significantly wider then that of ordinary readers; from 15° width (-7.5° and +7.5° eccentricity) and wider, dyslexic recognize letter significantly better.

4. The plot of the FRF of the same person at two different "phases": when alert (dashed line) and six hours later, when tired (solid line). Correct recognition of the letter at the center for all peripheral letter eccentricities was 90±10%.

5. The right side plot of the FRF of a severe dyslexic. The solid line is the plot of the initial test and the dashed line 4 months later after practising the regimen. Correct recognition of the letter at the center for all peripheral letter eccentricities, except for 2.5^{o} of the first plot, was 90±10%. The score of the center letter for 2.5^{o} eccentricity of the peripheral letter was 70%.

6. The plot of the FRF of German-native children: average for 6 ordinary readers (dashed line) and average for 15 dyslexics (solid line). Correct recognition of the letter at the center for all peripheral letter eccentricities was 94±6%. The FRF of the dyslexics is significantly wider.

7. The FRF plots of the experimental dyslexic group (solid line), the control dyslexic group (dashed line) and the ordinary readers group (dotted line). The FRF's of the two dyslexic groups are similar.

8. Improvements in reading for all the dyslexic individuals and the averages for each group: E-experimental dyslexics, C- control dyslexics.

9. The average FRF plots of the experimental dyslexics group before practising the regimen (dashed line) and after practise (solid line). The FRF narrowed significantly on the right side after practise. The FRF of the ordinary readers (dotted line) are from figure 6 and given for reference.

10. The average FRF plots of the experimental dyslexic group after practise (solid line) and that of the control dyslexics group (dashed line) which was measured at the same time, in the 2nd session. The FRF of the ordinary readers are from figure 6 and given for reference.

Figure 1 (Geiger & Lettvin)

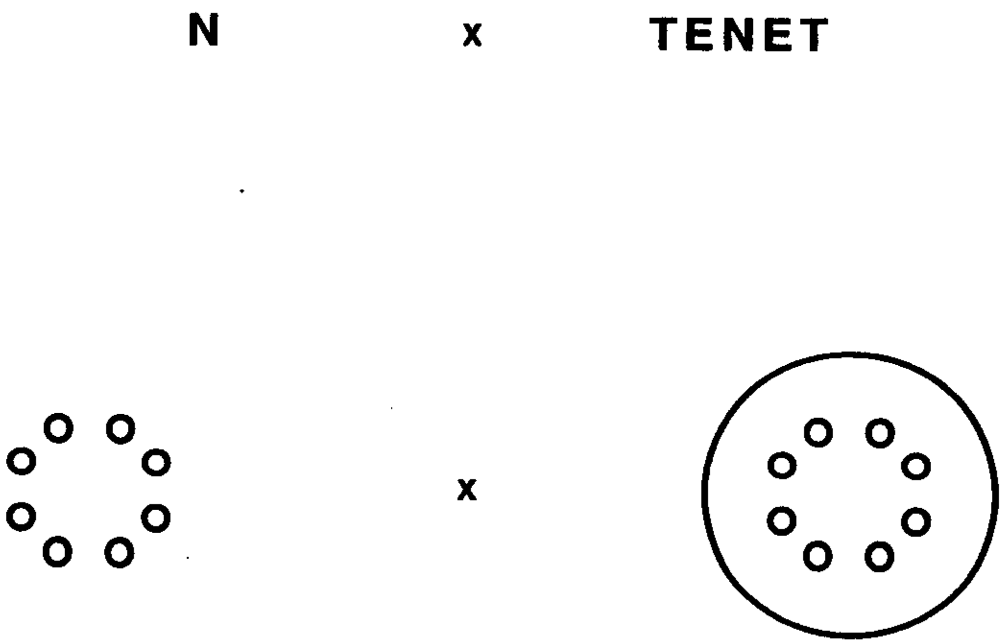

Figure 2 (Geiger & Lettvin)

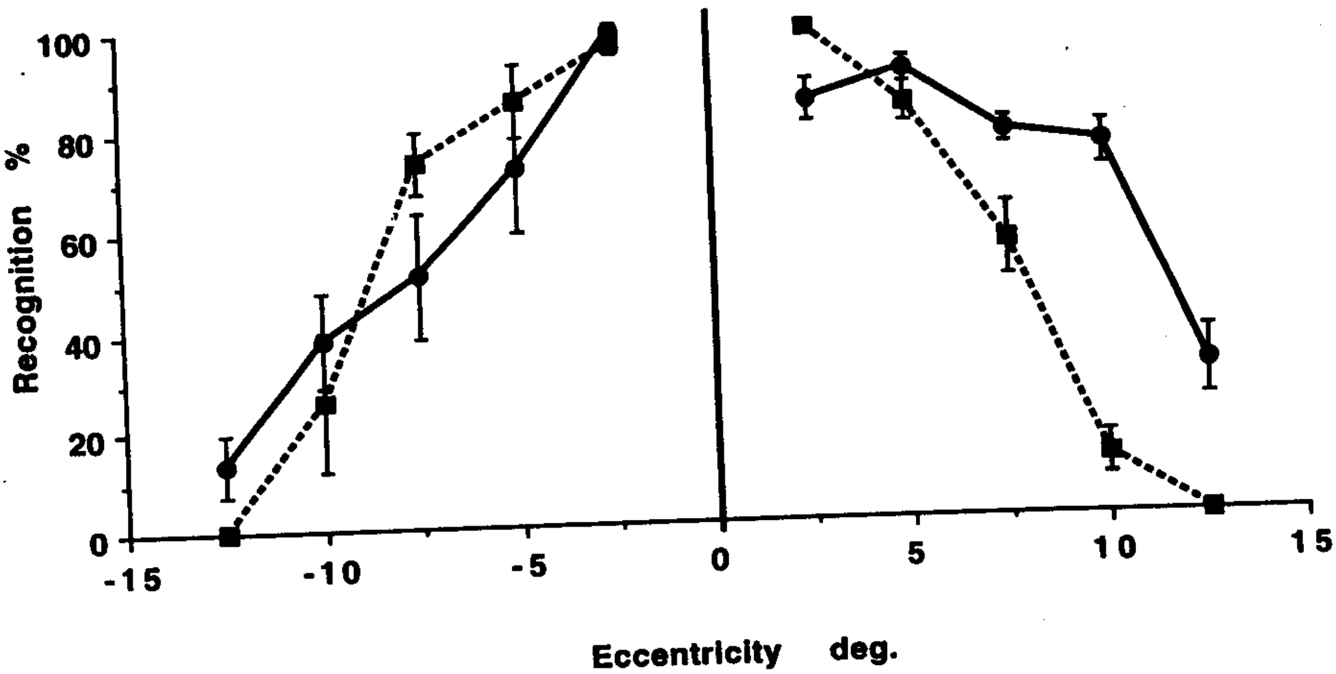

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Figure 3 (Geiger & Lettvin)

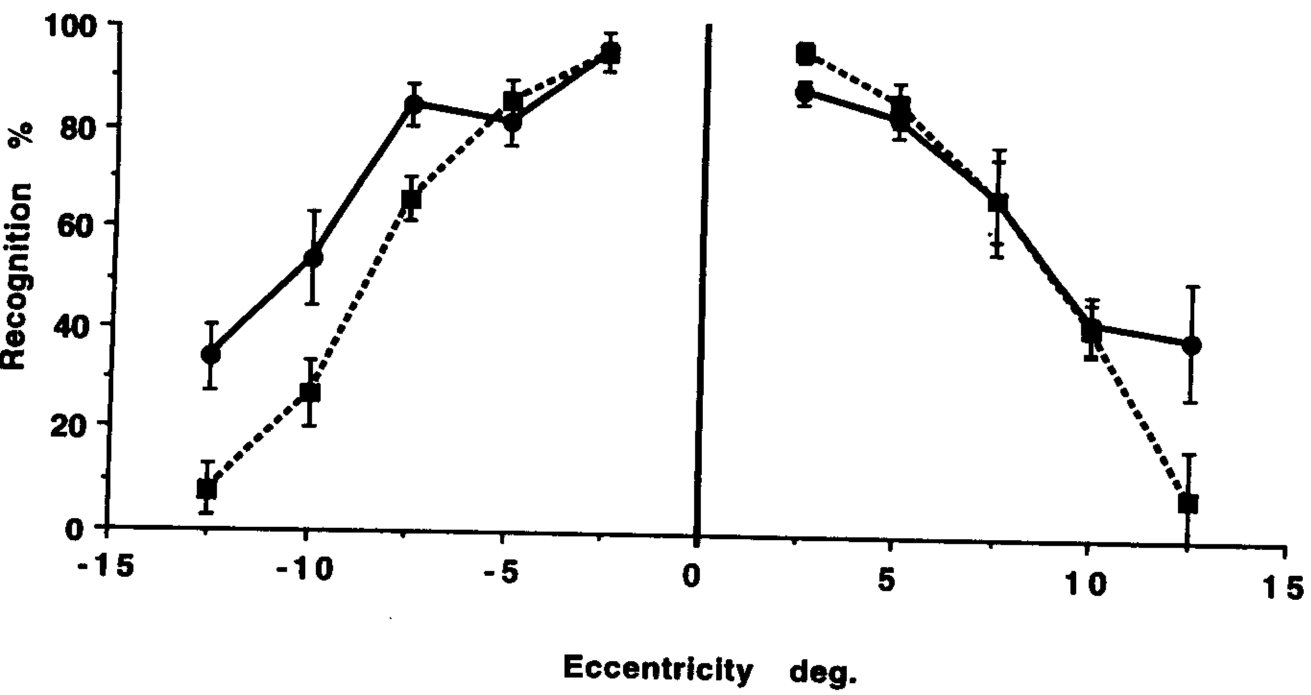

Figure 4 (Geiger & Lettvin)

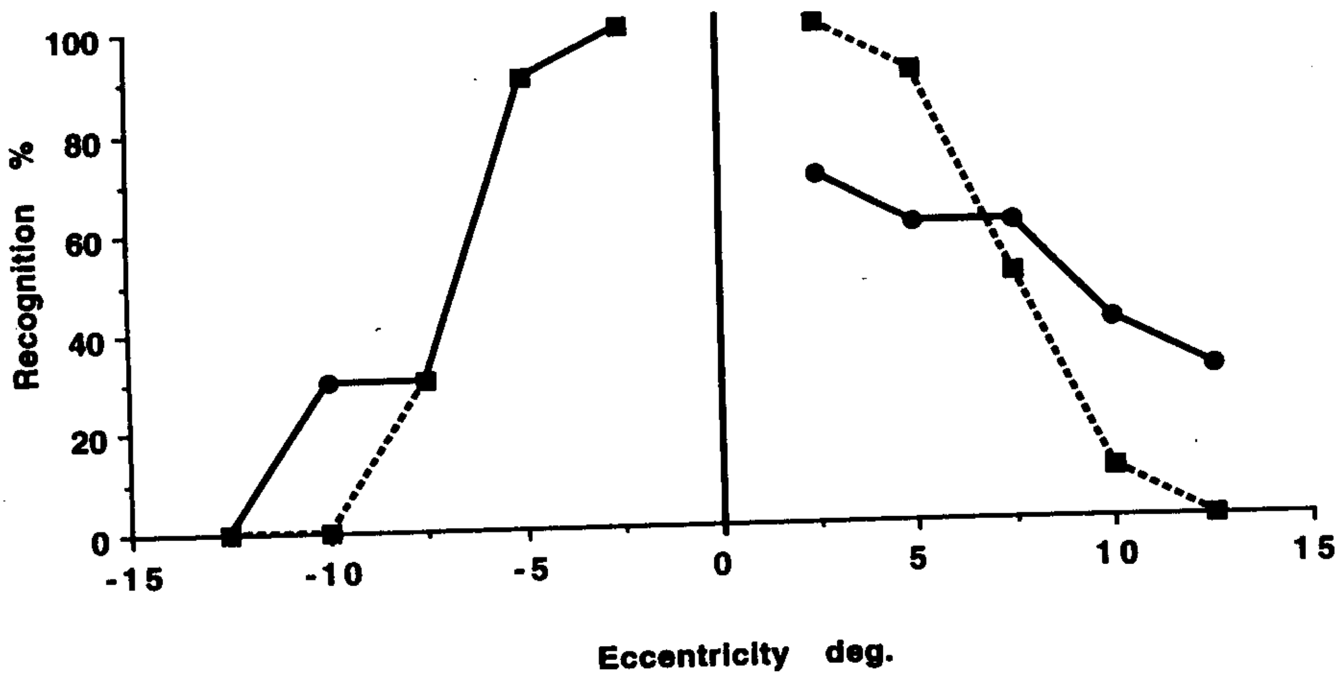

Figure 5 (Geiger & Lettvin)

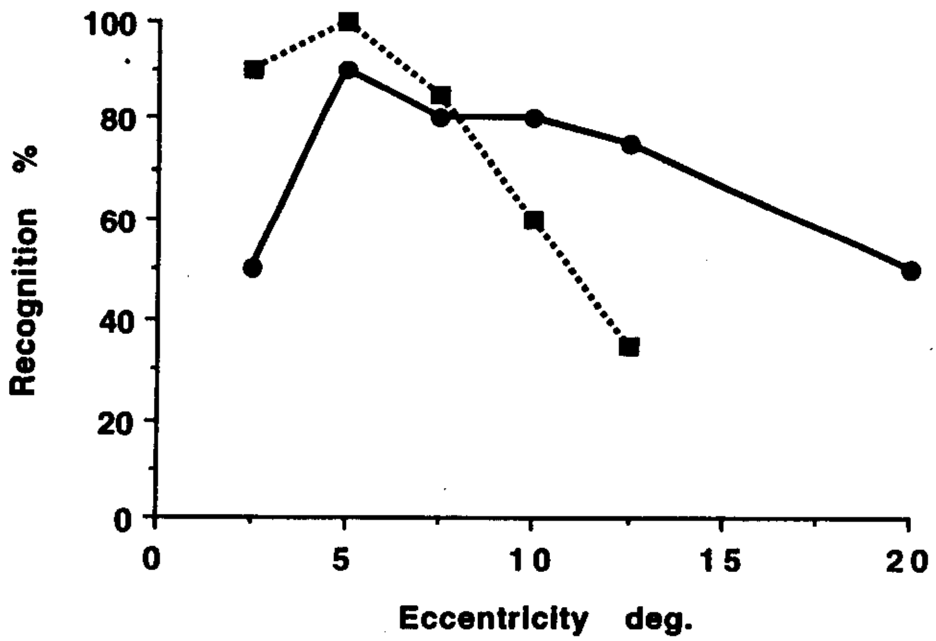

Figure 6 (Geiger & Lettvin)

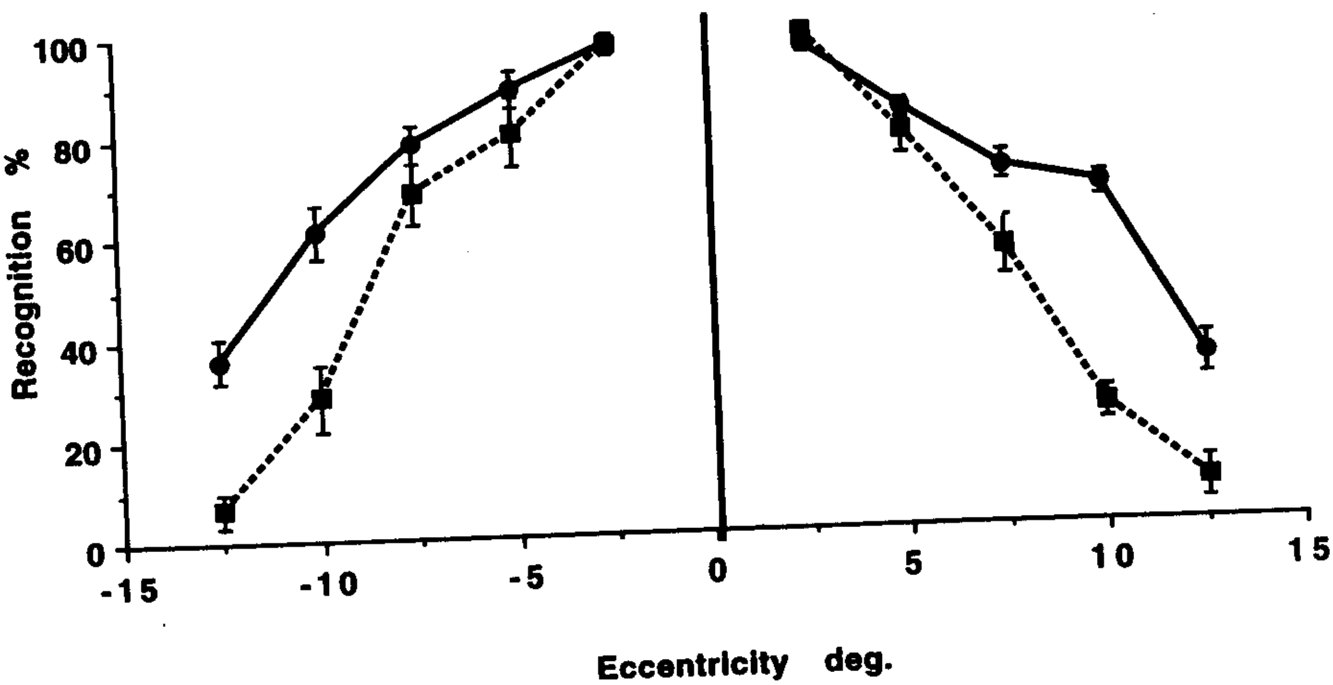

Figure 7 (Geiger & Lettvin)

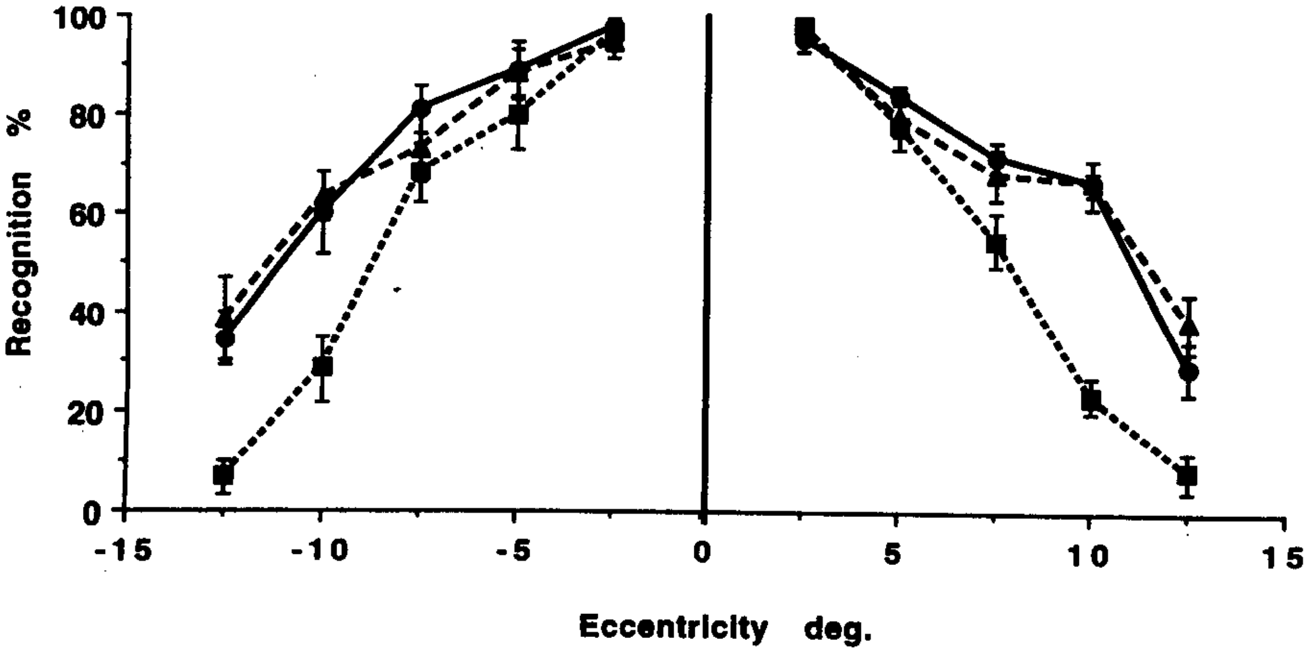

Figure 8 (Geiger & Lettvin)

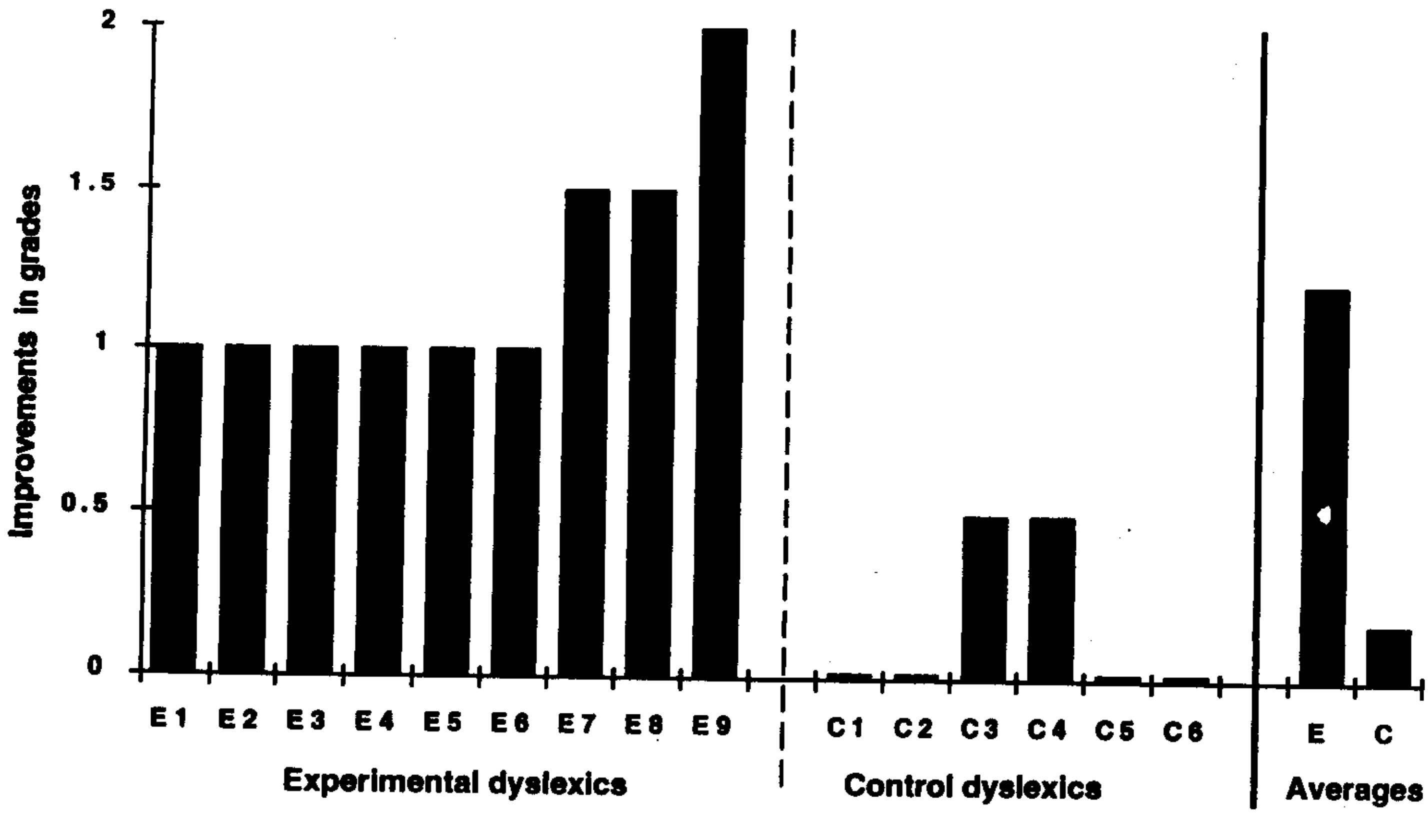

Figure 9 (Geiger & Lettvin)

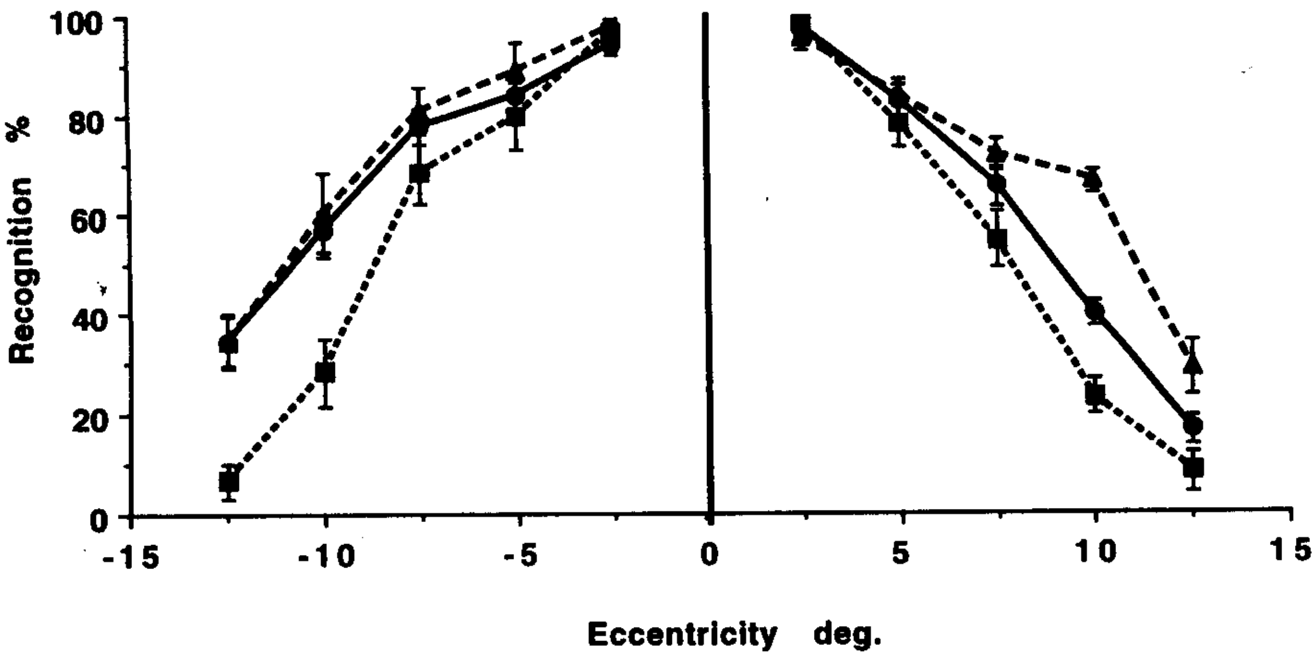

Figure 10 (Geiger & Lettvin)

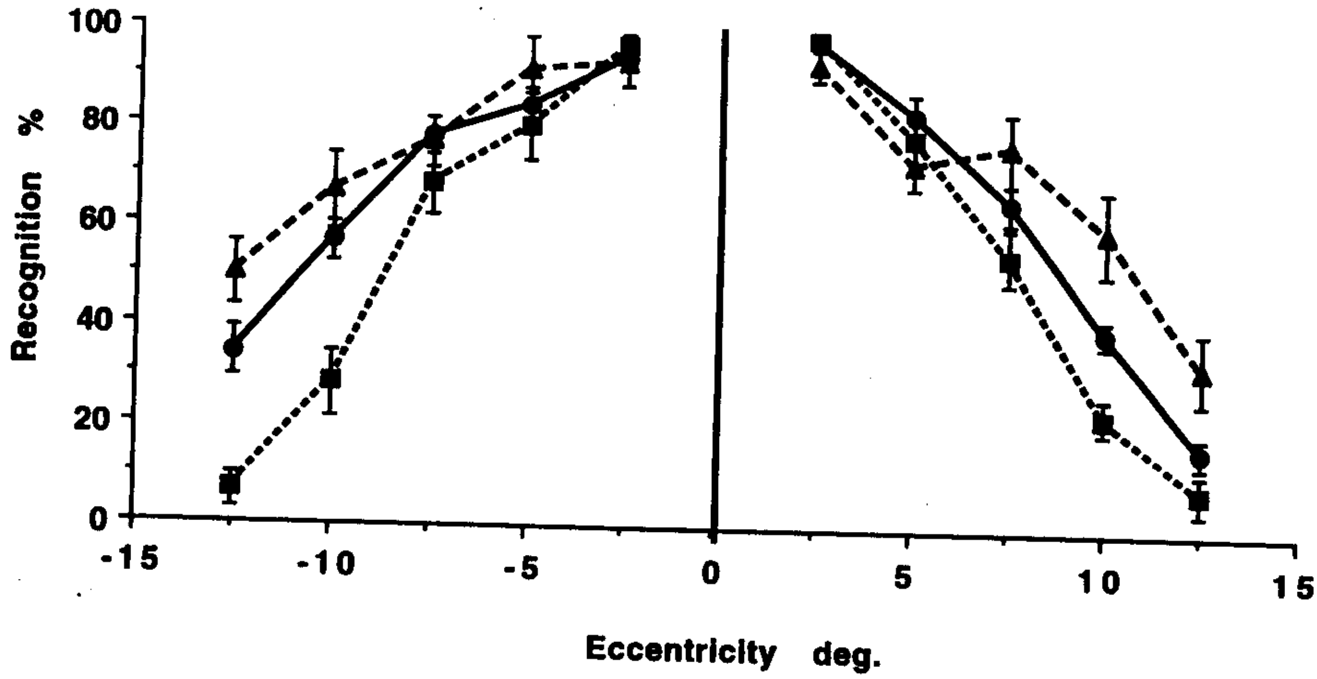

Table 1

Name	sex	handednes	age	grade	Reading assessments (ZLT) initial test: grade equivalent	grades behind
Dyslexics						
ED1	F	L	8.5	3	<2	2
ED2	M	R	9.58	3	<2	2
ED3	M	R	10.42	4	<2	3
ED4	F	R	11.2	5	2	3
ED5	M	R	12.67	5	<2	4
ED6	M	R	12.5	6	4	2
ED7	F	A	11.5	6	4	2
ED8	M	R	12.25	6	4	2
ED9	F	R	12.42	6	2	4
CD1	M	L	10.1	4	2	2
CD2	F	R	10.2	4	2	2
CD3	M	R	9.9	4	2	2
CD4	M	R	12.42	5	4	2
CD5	M	R	10.67	5	2.5	2.5
CD6	M	L	11.42	5	2	3
average			**11.05**			**2.50**
SD			**1.27**			**0.73**
Ordinary readers						Grades in advance
OR1	M	R	9.25	3	3	0
OR2	F	R	10.5	4	5	1
OR3	F	R	10.42	4	4	0
OR4	F	R	10.42	4	5	1
OR5	M	R	10.58	4	4	0
OR6	F	R	11.5	6	6	0
average			**10.45**			**0.33**
SD			**0.72**			**0.52**

Table 2

			Reading assessments (ZLT)								
			initial test		second test			third test		Overall	
Name	age	grade	grade equivalence	grades behind	grade equiv.	grades behind	improv. grades	grade equiv.	improv. grades	improv. grade	grades behind
Experimental dyslexics											
ED1	8.5	3	<2	2	2	1	1	2.5	0.5	1.5	0.5
ED2	9.58	3	<2	2	2	1	1	2	0.25	1.25	0.75
ED3	10.42	4	<2	3	2	2	1	2.75	0.75	1.75	1.25
ED4	11.2	5	2	3	3	2	1	4	1	2	1
ED5	12.67	5	<2	4	2	3	1	3.5	0.5	1.5	2.5
ED6	12.5	6	4	2	5.5	0.5	1.5	abve 5,5	yes	>1.5	0
ED7	11.5	6	4	2	5.5	0.5	1.5	abve 5.5	yes	>1.5	0
ED8	12.25	6	4	2	5	1	1	5.5	0.5	1.5	0.5
ED9	12.42	6	2	4	4	2	2	5	1	3	1
average	**11.23**			**2.67**		**1.44**	**1.22**				
SD	**1.46**			**0.87**		**0.85**	**0.36**				
Control dyslexics											
CD1	10.1	4	2	2	2	2	0	4	2	2	0
CD2	10.2	4	2	2	2.5	1.5	0.5				
CD3	9.9	4	2	2	2.5	1.5	0.5				
CD4	12.42	5	4	2	4	2	0	5	0.5	0.5	1.5
CD5	10.67	5	2.5	2.5	2.5	2.5	0	5	2.5	2.5	0
CD6	11.42	5	2	3	2	3	0				
Average	**10.79**			**2.25**		**2.08**	**0.17**				
SD	**0.97**			**0.42**		**0.58**	**0.26**				
Both groups											
average	**11.05**			**2.50**							**0.75**
SD	**1.27**			**0.73**							**0.76**