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"Dyslexic Children Learn a New Visual Strategy for Reading: a Controlled Experiment"

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Dyslexic Children Learn a New Visual Strategy for Reading: a Controlled Experiment

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Recent studies by Geiger, Lettvin and Zegarra-Moran have proposed a new non-reading test for the diagnosis of dyslexia, and a new method for remediation. The latter involves the learning of a "visual strategy". On adult dyslexics the test was reliable and the remediation apparently effective. The purpose of this study is to confirm the usefulness of the remediation and test with children. Dyslexic children (3rd–6th grade) were divided into two groups. The experimental group (9) was given a new remedial regimen of practise. The control group (6) continued the remedial process given in their school. After 3 months of practising their separate regimens all the dyslexic children who were in the two groups were retested and compared. The "experimental" dyslexics improved in reading by 1.22 grade level on average while the "control" dyslexics improved by 0.17 grade on average. The form-resolving field (FRF) plots narrowed significantly for the experimental dyslexics while they changed little for the control dyslexics. At the end of the second testing the control dyslexics were also given the new regimen of practise. Five months later all the dyslexic children were tested for the third time. The initial control dyslexics who later practised the regimen (2) improved in reading by 2–2.5 grades and their FRF plot narrowed. The experimental dyslexics continued to improve yet further. All the dyslexic who practised the new regimen started at an average of 2.5 grades behind their expected grade/age level and after 8 months were at an average 0.75 grades behind their expected grade/age level. 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. The dyslexic children were compared with matched grade/age ordinary reading children for reference. The study confirms the usefulness of the test and the applicability of the remediation method for children. It also shows that improvement under that method is quite rapid.

Dyslexia Lateral masking Visual strategy Reading Peripheral vision Learning

INTRODUCTION

The many diverse causes correlated with dyslexia—genetic, anatomic, linguistic—will not be considered here. Our concern is with relief of dyslexia as a symptom not with changing the trait it expresses. Previous studies showed that dyslexics and ordinary readers differ in the relation of central to peripheral visual perception, specifically in the distribution of lateral masking. The various distributions of lateral masking can be regarded as task-directed visual strategies. Studies suggested that a dyslexic can learn a new visual strategy that enables reading (Geiger & Lettvin 1987, 1989, 1993, Geiger, Lettvin & Zegarra-Moran, 1992). Our aim in this paper is to compare the learning regimen proposed in those studies with existing remedial methods. It is useful to review the background first.

In the peripheral visual field of ordinary readers, there is a direct relation of the angular size of a just recognizable letter to its angular distance (eccentricity) from the center of gaze as was shown by Aubert and Foerster (1857) in tachistoscopic presentation. Accordingly, the recognition of letters of fixed size falls off sharply with eccentricity. A different distribution was found for dyslexic persons (Geiger & Lettvin, 1987, 1989, 1993; Geiger *et al.*, 1992; Perry, Dember, Warm & Sacks 1989). To measure central–peripheral field relations regarding letter recognition the studies above used the form-resolving field (FRF) test. In this test, pairs of letters of the same font and angular size were presented tachistoscopically one pair at a time. One letter of each pair was presented at the axis of gaze, and a different one at some angular distance (eccentricity) along the horizontal axis. The distance between the letters was varied between presentations, but one of the letters was always presented at the center of gaze. After presentation of many pairs the average correct identification of the letter pairs was taken for each peripheral letter position. The plot of probability of recognition of the peripheral letters as a function of their eccentricity is the form-resolving field (FRF) along the horizontal axis.

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The score of recognition of the letter at the center is given numerically but not shown on the plot.

An important aspect of the FRF test used by Geiger and Lettvin (1987, 1989, 1993) and Geiger *et al.* (1992) is the setting of the stimulus exposure duration for each subject individually. The duration was set to achieve just under 100% recognition at the eccentricity at which the peripheral letter was recognized best. That exposure duration was kept for the subject throughout the test and for all presentations. In this way relative recognition across the visual field was measured rather than absolute sensitivity. We will refer to this process as auto-scaling.

The FRF of ordinary readers is narrow and symmetric with best letter-recognition in and near the center of gaze. Recognition of the eccentric letter rapidly falls off with angular distance from the center of gaze (as implied by the Aubert–Foerster law, 1857). On the other hand, the FRF of dyslexics is wider in the direction of reading, i.e. wider in the right hemifield for English-native speakers, and wider in the left hemifield for Hebrew-native speakers. These asymmetric plots of the FRFs are mirror images of each other reflecting the opposite directions of reading (Geiger *et al.*, 1992). In addition, letter pair recognition for dyslexics is lower when the peripheral letter is in the near right hemifield than when it is further in the periphery (Geiger & Lettvin, 1987, 1989, 1993; Geiger *et al.*, 1992; Perry *et al.*, 1989). In general, recognition of aggregates of letters in and near the center of gaze is lower for dyslexics than for ordinary readers (Bouma & Legein, 1977).

Recent studies (Goolkasian & King, 1990; Klein, Berry, Briand, D'Entremont & Farmer, 1990; Slaghuis, Lovegrove & Freestun, 1992) were critical of the study by Geiger and Lettvin (1987). These studies used different methodologies, hence arrived at different conclusions. The most common difference was the use of CRT displays which biases dyslexics in the peripheral field as described by Zegarra-Moran and Geiger (1993). However, the study which replicated the tachistoscopic method of Geiger and Lettvin (1989), verified their findings (Perry *et al.*, 1989). Rayner, Murphy, Henderson and Pollatsek (1989) arrived at similar results by other methods. The initial study by Geiger and Lettvin (1987) reported results only in the right hemifield and was criticized for being so restricted. Their later studies dealt with both hemifields (Geiger & Lettvin, 1989, 1993; Geiger *et al.*, 1992) where the stimuli were presented randomly in the left or right hemifields. The differences in the FRF between ordinary readers and dyslexics were already found when measured on the right hemifield only (Geiger & Lettvin, 1987), the left–right asymmetry was confirmed only when bilateral presentations of the stimuli were made in adults (Geiger & Lettvin, 1989, 1993; Geiger *et al.*, 1992). However, the indication for the asymmetry was already available when single hemifield presentations were used. Dyslexic children measured with bilateral presentation had wider FRFs than adult dyslexics and showed less asymmetry (Geiger & Lettvin, Geiger, and Geiger & Zegarra-Moran, unpublished results).

The differences in the FRF between adult ordinary readers and adult dyslexics were attributed by Geiger and Lettvin (1987) and Geiger *et al.* (1992) to different distributions of lateral masking over the visual field (cf. reviews on lateral masking: Bouma, 1970; Mackworth, 1965; Townsend, Taylor & Brown, 1971; Wolford & Chambers, 1983). Geiger and Lettvin first showed that lateral masking is modifiable and its distribution over the visual field might be learned (1986). In subsequent studies they demonstrated directly that lateral masking is differently distributed for adult ordinary readers and dyslexics (Geiger & Lettvin, 1987, 1989) and in addition demonstrated that the FRF is a good measure of the distributions of lateral masking over the visual field (Geiger & Lettvin, 1987, 1989, 1993; Geiger *et al.*, 1992). Due to reciprocal masking between parts of the letters the shape of the FRF also becomes a measure of the distribution of lateral masking similar to the direct measure (Geiger *et al.*, 1992). For ordinary readers lateral masking is least effective at and near the center of gaze, and increases with growing eccentricities, which implies best recognition of forms in the central field. Dyslexics, on the other hand, laterally mask in and near the center of gaze, when presented with an aggregate of letters, whereas lateral masking is reduced in the peripheral field in the direction of reading. This distribution of lateral masking implies a wider extent of letter recognition in the direction of reading and difficulty in recognition of aggregates of letters in and near the center. The distribution of lateral masking employed by ordinary readers enables them to mask most of the text surrounding a small area (of a words' size) and move ahead with their gaze to a following small area after recognition of the word. This is the way the process of ordinary reading is described. On the other hand, dyslexics mask the aggregate at which they gaze and at the same time perceive a large area of the text in the direction of reading, and are confused by the wealth of information, especially since they do not recognize words as distinct forms when embedded in text the way ordinary readers do. Results demonstrate superior performance by dyslexics on single word presentations compared with whole line presentations and the contrary by ordinary readers (Lovegrove & MacFarlane, 1990). These results are in line with the above claim.

The modifiability of the distribution of lateral masking, the process of demasking (Geiger & Lettvin, 1986) and the reversal of the asymmetry in the FRF of dyslexics, depending on the direction of reading (Hebrew vs English-native speakers), suggested to Geiger and Lettvin (1987, 1989, 1993) and Geiger *et al.* (1992) that particular distributions of lateral masking are learned. These authors also demonstrated that adult severe dyslexics were able to learn a new visual strategy by a regimen of practise which was comprised of novel hand-eye coordination tasks combined with the reading of single words through a window in a blank masking field viewed side long (the regimen will be explained in detail below). The results showed that the reading skills of the dyslexics improved dramatically, while at the same time their FRF narrowed and finally resembled that of ordinary readers. This finding is a strong indication for causal relations

between or at least a common cause for the distribution of lateral masking as measured by the FRF test and the task of reading. As noted by Geiger *et al.* (1992) the relation of change in FRF to change in reading was found empirically. These authors also pointed out that one change does not cause the other but rather that both are different measurable aspects of the same central process.

The ability to exhibit different distributions of lateral masking and the indication that these distributions are learned led them to view any particular distribution of lateral masking as a task-determined state. That is, each state is a visual strategy shaped for the task and for each class of tasks another task-determined visual strategy is learned as part of the gaining of expertise (Geiger & Lettvin, 1987, 1989, 1993; Geiger *et al.*, 1992).

However, the learning of a new visual strategy for the task of reading (Geiger & Lettvin, 1987, 1989, 1993) differs from previously described and practised "perceptual learning" (Frostig & Horne, 1964) in spite of a superficial resemblance. The latter method associated broad learning of visuo-motor skills with auditory perceptual skill and language skill and was based on the hypothesis of "developmental deficit". Geiger and Lettvin's hypothesis is that a dyslexic can learn a particular visual strategy for reading, a proper precognitive distribution of lateral masking in central and peripheral visual fields which enables the acquisition of the idea of a printed word so that reading would become an understandable task to the dyslexic—a concept that is task directed and less general.

The studies mentioned above showed only that adult dyslexics have the ability to learn a new visual strategy within a few months, and as a result can improve in reading skills. This was tested with children who were also able to learn such visual strategy and to improve their reading skills. However, no carefully designed experiment had been performed to demonstrate how the suggested regimen of practise compares with other remedial procedures for dyslexia. We decided to try such a comparative study on a limited scale in the grammar schools of Tübingen, Germany.

In designing this controlled experiment the question is the starting age of the group. Contrary to the opinion of many experts our experience is that so long as a child under the age of 8 has not yet established a personal strategy for reading, the child is best left alone since remedial procedures may even delay or hamper acquisition of such a strategy. This notion is supported by recent findings (Shaywitz, Escobar, Shaywitz, Fletcher & Makuch, 1992) that a large proportion of children evaluated as dyslexic or dyslexia-prone in first grade are not considered dyslexic in the third grade. Therefore we choose to start our program with children at third and higher grades.

METHODS

Apparatus and stimuli

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 1700 cd/m $\pm$ 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 electronically by a timer. It adjusted the openings and closings of the shutters to minimize transitional changes in luminance on the screen between presentations. Stimulus durations were adjustable over the range of 1.6–150 msec. 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 second 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. 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 for each position). They were presented in a random order. This procedure helped observers to maintain central fixation and reduced the bias of expectation of appearance (Geiger & Lettvin, 1989; Geiger *et al.*, 1992). The two letters on 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.

Subjects

The records and their analysis in the Results section are from three groups of volunteer subjects. Two groups consisted of dyslexic children, an "experimental" and a "control" group while the third group were ordinary reading children. Altogether 15 dyslexics (9 in the experimental group and 6 in the control group) and 6 ordinary readers were included in the experiment.

After receiving permission to recruit pupils in the local schools, we applied to three schools, two grammar schools and a high school accommodating all three German schooling types (Gymnasium, Realschule and Hauptschule). Teachers from these schools recommended pupils for testing who had weak reading skills or whom they thought might be dyslexics. "Dyslexia" (Legasthenie in German) is no longer used in the education system of Baden-Württemberg (although used outside that system) but is replaced by a broader concept of "reading and spelling weakness" (Lese-Rechtschreibschwäche). Accordingly testing in the educational system is made with respect to this weakness rather than dyslexia, i.e. the emphasis often lies on correct spelling. Therefore we asked the teachers to recommend mainly the pupils whom they thought to be

primarily weak in their reading skills. Teachers then transmitted a letter, written by us, to the parents of the recommended pupils. The letter explained the procedures, the risks and the experimental nature of the proposed investigation. A few additional subjects came to us by their own initiative from other schools.

Another group was similarly recruited by the teachers or also volunteered from other schools to be our ordinary reading subjects. (To be certain that all these subjects had no problems in reading, they were taken from the more advanced readers in their classes, yet they were not much above their grade level as can be seen from Table 1.)

Those pupils who had the consent of their parents and the willingness to participate in the experiment were called to the University Eye-Hospital in Tübingen to be tested and instructed.

Volunteering for the experiment were 6 ordinary reading pupils (4 females and 2 males) from the 3rd–6th grades and 21 pupils (8 females and 13 males) from the 3rd–7th grades who were recommended by their teachers as having reading difficulties. Those with reading difficulties were: 4 children from 3rd grade, 4 from 4th grade, 6 from 5th grade, 6 from 6th grade and 1 from 7th grade. After screening all subjects and excluding other learning disabilities (cf. Aaron & Simurdak, 1991) we ended with: 3 dyslexic subjects in 3rd grade, 4 dyslexics in 4th grade, 6 dyslexics in 5th grade, 4 dyslexics in 6th grade and 1 dyslexic in 7th grade, i.e. altogether 18 dyslexic children. The screening procedure will be described in the next section. These subjects were randomly divided into two groups. One group, the experimental group, was assigned to the new regimen suggested by Geiger and Lettvin (1987) and by Geiger *et al.* (1992) while the other group, the control group, was expected to continue the regular remedial practice offered by the schools. After the second testing (see Procedure section) 15 subjects remained for the comparison between the first and second testing. Two dyslexics could not participate in the second testing and one decided to drop out from the experiment. The final tally of dyslexic subjects to which we refer in the results were 9 subjects (4 females and 5 males) in the experimental group and 6 (5 males and 1 female) in the control group. As a result of this selection procedure we ended with an uneven gender distributions in the groups. However, we hope that the gender issue will be of low significance concerning the goals of this experiment. As will be seen later, this was confirmed by the results of the experimental group where gender distribution was about even. Two participants of the control group were originally assigned to the experimental group, but as they failed to practice the offered regimen they were moved to the control group prior to the second testing (the process by which this was decided will be explained in the procedure section).

Procedure

General. Each of the participating subjects was usually accompanied by one of the parents and was tested by one of us in the University Eye-Hospital. The first session consisted of an introductory interview, an ophthalmological test, questions on hand preference, a reading level assessment, the form-resolving field (FRF) test and a closing interview (see Table 1). The ordinary reading subjects did not have the closing interview and did not go further in the program. In the closing interview all the participants received general encouragement but only the experimental group received additional instructions for the regimen of practise they should follow.

After the initial session of testing each subject (and the accompanying persons) received only two phone calls from us, the first one week after the interview, the second a week later, to provide support and any needed additional guidance. That was the sole extent of our post-interview contact.

About three months later all the dyslexic subjects (from both groups) were called in for the second session of testing, again in the Eye-Clinic. This session started with an interview which was followed by a reading level assessment and the form-resolving field test and ended with the closing interview of the second session. In the closing interview our method of practise was offered to the subjects of the control group.

A third session of testing followed about five months after the second for both the experimental and control groups. This session was similar to the second one.

The procedure in detail

(a) The first session of testing started with the introductory interview which began with the explanation of the procedure and the purpose of the experiment. This part ended with the explanation and signing of the informed consent form. We then asked the child to write his or her name and age. This introduction was followed by:

(1) Questions on medical and educational history.

(2) The Briggs and Nebes (1975) questionnaire for gauging hand preference.

(3) An in-depth ophthalmological test.

(4) Detailed questions about academic achievements, preferences, performance and status at the school. The social and familial statuses were also discussed. At this point we were able to assess the approximate intelligence level by the child's understanding and ability to respond intelligibly as well as the scholastic performance. For the purpose of this study it was sufficient to estimate if the person had an intelligence below average or if it was average and above. This was possible by the inquiry described above. We had to resort to this method because it was stipulated in the school's permission to perform the study that no IQ or similar intelligence test would be performed.

(5) The reading level was assessed by asking the child to read the appropriate texts and word lists from the Züricher Lesetest (ZLT). This allowed us to assess the

level of reading of the child with respect to the scores normalized for grade and age level of reading given in the ZLT. The test consists of lists of single words and passages of continuous texts which are read aloud by the subjects. For different grade levels different lists and passages are given. The duration of reading and the number of errors made are noted separately for the lists of words and for the passages. The results are compared with norm-performance given in the tables in the test instructions. The comparisons are made separately for the reading of lists of words and passages, and are then combined to give the end results. The results can be expressed in grade-equivalence or as percentile range of performance level in the normal distribution listed in the tables. We chose to use the grade-equivalence since the table lists for grades 4 and 5 are coarse and because the ZLT does not extend beyond the 5th grade. The kind of errors made by a subject suggested the type of dyslexia as prescribed by the ZLT. We also inquired about comprehension but did not introduce it as a measure. At that point the interviewer was able to decide whether the subject was dyslexic, and marked it in the protocol.

(6) The form-resolving field (FRF) test: The subject sat 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 sec. The subject was asked to name the letters in the stimulus slide and their relative position. This cycle continued until all 100 stimuli slides had been presented. The effective stimulus duration, the time between the offset of the fixation point slide and the onset of the eraser slide, was determined for each subject separately prior to the test itself. Various stimulus durations were tested (with samples of the letter pairs) in this pre-test until a stimulus duration was found in which the correct letter identification reached just 100% at one eccentricity of the peripheral letter in the display (this was at 2.5° for most subjects). Once the appropriate stimulus duration was found it was kept constant during the test and for the subsequent FRF tests. After all stimulus slides were presented the average letter recognition at each eccentricity was calculated and plotted to give the FRF plot.

(7) The closing interview included the disclosure of the findings. For all those who were found to be dyslexic the condition was explained and general recommendations given to reduce time pressure for performance in tests or studies. We also indicated that it may be possible "to do something about the condition". In addition to these general remarks the dyslexics who were assigned to the experimental group received explanations of the regimen of practise and the schedule for continuation was made clear.

The regimen of practise is described in full in the Results section as it is germane to the content of the results. During the three months between the two sessions of testing, the experimental group actively followed the regimen of practise. Meanwhile, the subjects in the control group continued the remedial practise offered by the schools. For some of the subjects the school's remediation included 2–3 hr per week of additional instructed classroom reading and writing. Others were given personal instructions in reading and writing for 3–4 hr per week. The subjects of both groups received phone calls 1 week and 2 weeks after the interview for encouragement and guidance (if it was needed). There was no further contact until the second session. We informed a subject to which group he or she belonged and were careful to hide this information about other subjects. The experimenters were the ones to know who belonged where and therefore this study cannot be regarded as a double blind study.

(b) Three months later the second session of testing started with a welcome interview in which the child was first asked to tell about the experiences of the last three months: how he or she felt at school and at home. The subjects from the experimental group were asked in addition to estimate how long (hours per day) they practised each of the two parts of the regimen separately. They were also asked for their subjective feelings about reading and writing. After the subject answered these questions the responses were checked against the account of the accompanying persons. At that point the interviewer (G.G.) decided if the daily duration of practise was long enough for the subject to be considered to be part of the experimental group or had to be considered as part of the control group. The decision was marked on the interview document and was checked against the test results later on. Only two subjects were moved to the control group as they practised the regimen less than $\frac{1}{4}$ hr per day. The data were analyzed in two different ways: in the first case, these two subjects were regarded as controls and in the second case their results were discarded altogether.

The ZLT reading assessment and the FRF test were performed after the welcome interview. The effective stimulus duration for the FRF test was the same as in the first FRF test. The session closed with another interview in which the results of the past three months were discussed. Some additional remarks were made to the subjects of the experimental group. Now our regimen of practise was offered to the control group.

(c) Five months later a testing session, similar to the second one, was performed.

RESULTS

The first session of testing

Table 1 shows the individual data for all the subjects and their assignment to the three groups. The groups were matched in age (no significant difference between the average age of the groups). Most of the subjects were right handed. They ranged from 3rd to 6th grade in school. All had normal or corrected to normal vision (a few had slight phoria) and they all had average or above

TABLE 1. Presentation of specific data on the subjects and the respective scores of the ZLT (reading test)

	General data					Reading assessments (ZLT) First test		Second test			Third test		Overall		
Name	Sex	Handedness	Age	Grade	Age/grade difference	Grade equivalence	Grades behind	Grade equivalence	Grades behind	Improvement grades	Grade equivalence	Improvement in grades	Perform practise	Improvement in grade	Grades behind
Experimental dyslexics															
E1	F	L	8.50	3	0	< 2	2	2	1	1	2.5	0.5	+	1.5	0.5
E2	M	R	9.58	3	0	< 2	2	2	1	1	2	0.25	0	1.25	0.75
E3	M	R	10.42	4	0	< 2	3	2	2	1	2.75	0.75	+	1.75	1.25
E4	F	R	11.20	5	0	2	3	3	2	1	4	1	+	2	1
E5	M	R	12.67	5	1	2	4	3	3	1	3.5	0.5	+	1.5	2.5
E6	M	R	12.50	6	0	4	2	5.5	0.5	1.5	Above 5	Yes	+	> 1.5	0
E7	F	A	11.50	6	0	4	2	5.5	0.5	1.5	Above 5	Yes	+	> 1.5	0
E8	M	R	12.25	6	0	4	2	5	1	1	5.5	0.5	0	1.5	0.5
E9	F	R	12.42	6	0	2	4	4	2	2	5	1	+	3	1
Average			11.23				2.67		1.44	1.22					0.83
SD			1.46				0.87		0.85	0.36					0.76
Control dyslexics															
C1	M	L	10.10	4	0	2	2	2	2	0	4	2	+	2	0
C2	F	R	10.20	4	0	2	2	2.5	1.5	0.5					
C3	M	R	9.90	4	0	2	2	2.5	1.5	0.5					
C4	M	R	12.42	5	1	4	2	4	2	0	4.5	0.5	0	0.5	1.5
C5	M	R	10.67	5	0	2.5	2.5	2.5	2.5	0	5	2.5	+	2.5	0
C6	M	L	11.42	5	0	2	3	2	3	0					
Average			10.79				2.25		2.08	0.17					
SD			0.97				0.42		0.58	0.26					
All dyslexics															
Average			11.05				2.50								0.75
SD			1.27				0.73								0.76
							Grades in advance								
Ordinary readers															
O1	M	R	9.25	3	0	3	0								
O2	F	R	10.50	4	0	5	1								
O3	F	R	10.42	4	0	4	0								
O4	F	R	10.42	4	0	5	1								
O5	M	R	10.58	4	0	4	0								
O6	F	R	11.50	6	0	6	0								
Average			10.45				0.33								
SD			0.72				0.52								

Two groups of dyslexics (experimental and control) and a group of ordinary readers. The general data include sex, handedness, age, the current grade affiliation and the age-grade difference (a positive number indicates higher age than grade equivalence). Three tests of the ZLT for the dyslexics include the grade equivalence of performance and the grades behind. Impovement (from first to second test or from second to third test) is indicated by positive numbers.

average intelligence as assessed indirectly (i.e. not by a formal test). The ordinary readers were average or good readers as measured by the ZLT (Züricher Lesetest). The dyslexics were diagnosed as such by all the tests given and by the exclusion rules of opportunity. However, each individual who was found to be dyslexic in the tests, excluding the FRF test, was also dyslexic by the FRF test. Each dyslexic individual was at least two grade-levels or age levels below his or her expected grade. Both dyslexic groups were on average at similar reading levels below their expected grade or age level [$F(1,13) = 2.59$, $P < 0.3$].

All the dyslexics had a good comprehension of text that was read to them. They were a mixed group of dyslexics from the three sub-types—the visual, auditory and mixed (similar to Boder's classification 1973), as indicated by the results of the ZLT.

The FRF of the first testing (Fig. 1) shows that there is a significant difference between ordinary readers and both groups of dyslexics combined. The average FRF of ordinary readers is narrow and the fall-off of letter recognition with eccentricity is steep in both hemifields. The average FRF of the dyslexics is significantly wider in the right visual hemifield than that of ordinary readers [$F(1,103) = 63.61$, $P < 0.001$]. At eccentricities farther away from the center of gaze, the difference is significant for each eccentricity [at 7.5° $F(1,19) = 7.56$, $P < 0.02$; at 10° $F(1,19) = 104.3$, $P < 0.001$; at 12.5° $F(1,19) = 12.12$, $P < 0.01$]. In the left visual hemifield the FRF is wider for dyslexics and significantly wider only at the far eccentricities [$-10°$ $F(1,19) = 12.57$, $P < 0.01$; at $-12.5°$ $F(1,19) = 11.87$, $P < 0.01$]. The FRF on the left and right hemifields are not significantly asymmertic for the dyslexics as was the case in adults (Geiger *et al.*, 1992).

Due to the normalization procedure the stimulus presentation times differed between subjects. The average exposure time for the ordinary readers was 6.5 ± 1.1 msec and for the dyslexics 8.97 ± 2.9 msec (a difference which is statistically not significant). This might thought to be the reason for the differences in the FRFs. However, it will be seen later that the FRF of the

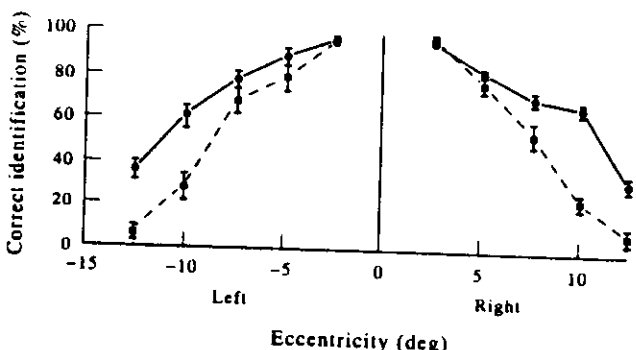

FIGURE 1. The FRFs measured in the first session for 6 ordinary readers (squares, dashed lines) and 15 dyslexics (circles, solid lines). In this presentation both dyslexic groups (experimental and control) were lumped together. Correct identification of the letters in the center (for all peripheral letter eccentricities) was 97% ± 3% for ordinary readers and 94% ± 6% for dyslexics. The vertical bars denote the standard error.

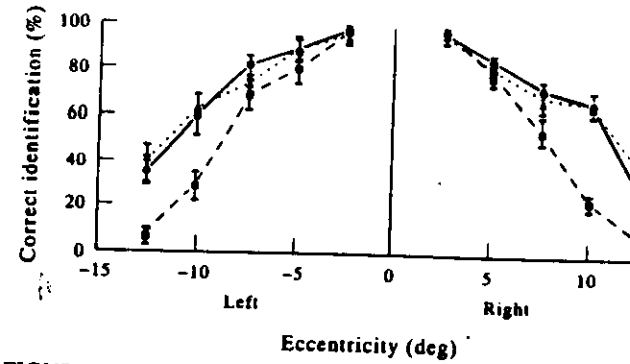

FIGURE 2. The FRFs of the same 6 ordinary readers (squares, dashed lines) and the dyslexics by groups, measured in the first session. Nine experimental dyslexics (circles, solid lines) and 6 control dyslexics (triangles, dotted lines). Correct identification of the letters in the center (for all peripheral letter eccentricities) was 97% ± 3% for ordinary readers, 93% ± 7% for the experimental dyslexics and 95% ± 5% for the control dyslexics. The vertical bars denote the standard error.

experimental dyslexics became narrower although measured with the same stimulus durations as in this session. As the FRF measures only relative form recognition across the visual field and not absolute sensitivity for contrast or luminance, the only concern is that for each subject an eccentricity of maximum recognition is achieved at which the stimulus duration is that which yields just 100% recognition. By this all subjects have comparable ranges of recognition.

Figure 2 depicts the FRF of each dyslexic group separately (after the first testing) and that of the ordinary readers for reference. The FRF of the dyslexic-experimental groups and the FRF of the dyslexic-control group are similar on both sides. Each of these groups separately has a significantly different FRF from that of ordinary readers.

It should be noted that the FRF of the dyslexics is generally similar to the FRFs measured previously with English (and Italian)-native dyslexics (Geiger *et al.*, 1992) but differs in some details. Most dyslexics in this study did not show the depressed letter recognition nearest to the center on the right which was seen with most dyslexics from the previous studies. In addition, the FRF of the dyslexics in this study is also wider than that of ordinary readers on the left side. In the previous studies the FRFs on the left side were similar for dyslexics and ordinary readers.

Remedial process

The regimen of practise was given first to the experimental group only. It had two complementary parts. One part consisted 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 disassemble) were suggested to this end. The dyslexic child was to engage for about 1 hr daily in these activities. These activities were performed by the children in a private and unsupervised manner, not in a structured lesson. To motivate the children to perform these activities, it was

important that the child initiated and chose the activities and had fun in doing them.

The second and complementary part of the regimen was to read (recognize) words in isolation. To this end we asked the children to use a specially designed mask which they laid on the text to be read. The mask was a blank sheet (some times a colored transparent sheet) with a rectangular window, cut to be somewhat larger than a long word in the text. The children lay this mask on the text and read the word which appeared in the window. They shifted the mask along the lines of the text and read it word by word. For the few children who had their best peripheral letter recognition (in the FRF test) farther in the periphery and not at 2.5°, we marked a fixation point on the blank sheet to the left of the window. These children fixed their gaze on the fixation point and read the word appearing in the window. The distance of the fixation point from the window depended on the individual FRFs of the dyslexics. The children performed this regimen of practise on their own (with an occasional reminder by their parents).

In the interview during the second session, we had to establish whether the child had performed the practise long enough to be regarded as a subject in the experimental group. As described in the Procedure section, the child and the accompanying person gave estimates of durations of practise. All the subjects finally included in the experimental group practised at least $\frac{1}{2}$ hr per day, on average, hand–eye coordination tasks (mostly art-work) in addition to similar work given in school. They also did at least $\frac{1}{2}$ hr per day of reading with the window (one subject used the window only in the early course of the regimen period and then felt uncomfortable with it and dropped it). Two subjects who performed less than $\frac{1}{4}$ hr per day of (combined) practise were excluded from the experimental group and were added to the control group (see above). Gauging the daily practise duration was based on the report by the accompanying person.

The subjects of the control group continued their remedial procedure given by the school in small groups or for individuals. It included additional reading and writing assignments with syllable awareness training and the use of a finger as a pointer in reading.

In the assignment to the experimental and control groups we paid attention to the separation between the groups, i.e. siblings or classmates were assigned to the same group to insure that information from an individual in the experimental group would not pass to another in the control group.

Second session of testing

Three months after the first session, reading levels and the FRF were retested in all the dyslexic subjects; the experimental group who practised the regimen and the control group who did not practise this regimen but continued the remedial program of the school. The reading scores of the second testing of the ZLT are shown in Table 1. Both groups of dyslexics had improved their reading to a certain degree. However, the reading skills of the experimental group had improved on average by 1.22 grade-levels while the improvement of the control group was minimal (0.17 grade levels). The improvement rate for each individual of the experimental group is significant and similarly, the difference in the improvement rates between the experimental and the control group is significant [$F(1,16) = 19.67$, $P < 0.001$]. As mentioned before, the ZLT measures accuracy and speed of reading lists of single words and of passages of continuous text separately. After practise the experimental group improved on both parts of the test almost equally. Improvements in reading lists of words was on average 1.32 grade level (SD = 0.66) and improvements on passages of texts 1.14 grade levels (SD = 0.28). The difference is not significant ($P < 0.6$). Subjects also gave the clear impression of higher level of comprehension for the passages read, although comprehension was not measured systematically. The FRF of the experimental group which was measured after the practise (the second testing) is compared to the FRF of the same group before the practise (first testing) and also compared to the FRF of ordinary readers in Fig. 3. The FRF of the experimental dyslexic group has narrowed significantly on the right [$F(1,88) = 20.95$, $P < 0.05$] but not on the left side [$F(1,88) = 1.0$]. The narrower FRF of the experimental group is still wider than that of ordinary readers but this difference is not significant on the right side [except at 10° eccentricity, $F(1.13) = 17.73$, $P < 0.01$]. It remains significantly wider in the left visual field.

On the other hand there is no significant difference between the initial and second FRF tests of the control group (Fig. 4). At the same time the FRFs of the second testing of the control group and the experimental group (after practise) do not have an overall significant difference. However, the FRF of the experimental group is significantly narrower on the right at the eccentricities farthest from the center than that of the control group as seen in Fig. 5.

Relations of results and significance did not change when evaluation was made excluding the two subjects

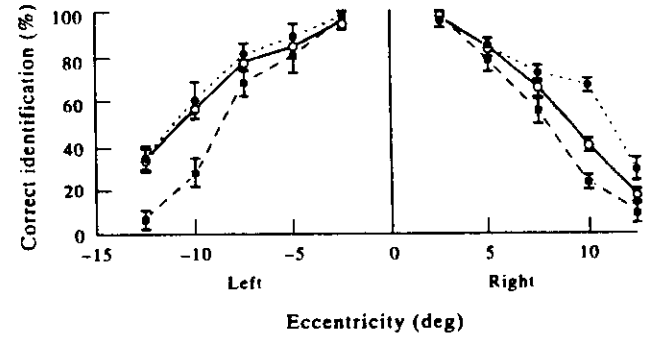

FIGURE 3. The FRFs of the experimental dyslexics measured in the first session (from Fig. 2, solid circles) and for the same group after practise which was measured in the second session (open circles). The FRF of the ordinary readers from above is shown for reference (squares). Correct identification of the letters in the center (for all peripheral letter eccentricities) was 97% ± 3% for the experimental dyslexics in the second testing session. The vertical bars denote the standard error.

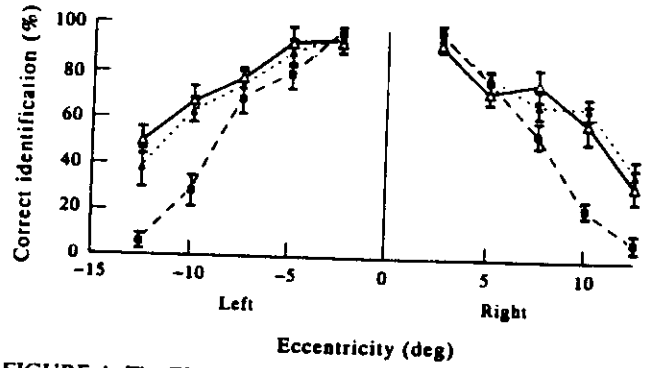

FIGURE 4. The FRFs of the control dyslexics measured in the first session (from Fig. 2, solid triangles) and for the same group in the second session (open triangles). The FRF of ordinary readers from above is shown for reference (squares). Correct identification of the letters in the center (for all peripheral letter eccentricities) was 97% ± 3% for the control dyslexics measured in the second session. The vertical bars denote the standard error.

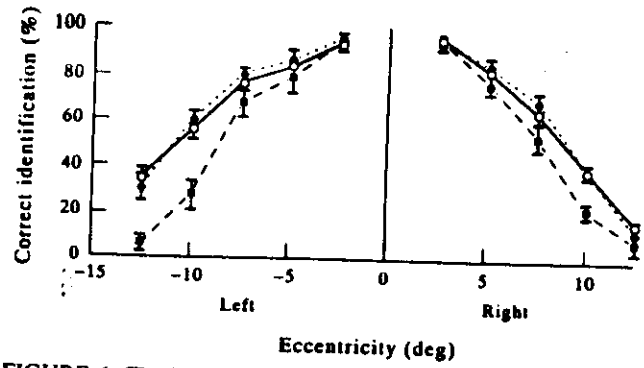

FIGURE 6. The FRF of the experimental group measured after 3 months of practise (from Fig. 3, open circles) and 5 months later diamonds. The FRF of ordinary readers is shown for reference (squares). Correct identification of the letters in the center (for all peripheral letter eccentricities) was 96% ± 4% for the experimental dyslexics measured the third time. The vertical bars denote the standard error.

who were moved from the experimental group to the control because they did not practice.

The third session

Five months after the second session of testing, reading levels and the FRF test were given to all dyslexic participants. At the end of the second session the regimen of practise was also offered to the control group.

The reading scores of each subject of the experimental group had improved further (Table 1). The average cannot be given numerically as the ZLT is scored only up to 5th grade. However, the average value of the lag in reading skills is given and at the end of 8 months of practise it is 0.83 grades behind the expected grade level compared with 2.67 grades behind at the beginning of testing and 1.44 grades behind the expected level after 3 months.

It was unfortunate that only 3 subjects from the control group came to the last session (one did not want to continue and 2 were ill). From the 3 control subjects who were measured, 2 practised the regimen and improved their skills dramatically (2 and 2.5 grades improvements since they began to practise after the second session). One subject of the control group did not practise and improved only by 0.5 grades.

Two subjects from the experimental group did not continue in their practise of the regimen but still improved in reading further.

The FRF of the experimental group is shown in Fig. 6 which shows not much change compared with the previous testing, indicating that the strategy was learned earlier and what was accomplished further is the expertise in using the strategy.

The FRFs of the two subjects in the control group who practised also narrowed but that of the subject who did not practise remained unchanged.

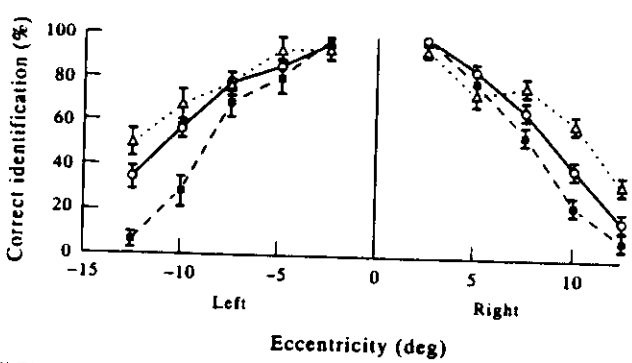

FIGURE 5. The FRF of the experimental group measured after 3 months of practise (from Fig. 3, open circles) and that of the control group measured at that time (from Fig. 4, open triangles). The FRF of the ordinary readers is shown for reference (squares). Correct identification of the letters in the center is given in the previous figures. The vertical bars denote the standard error.

DISCUSSION

Improvements in reading

After 3 months of unsupervised practising the regimen (for at least 0.5 hr/day on average of hand-eye coordination and 0.5 hr/day on average of reading with the mask and window) each individual improved in reading skill by at least one grade level. The average improvement for the experimental group was 1.22 grade levels, while the highest improvement score for the individuals from the control group who continued with the remedial procedure at school was 0.5 grade levels. The average improvement of the control group was 0.17 grade levels, significantly lower than that of the experimental group. After the subjects of the control group were offered the regimen of practise, two subjects who practised the regimen improved by 2 and 2.5 grade levels after 5 months practise. The one control subject who did not practise improved in that period by only 0.5 grade level. All the dyslexic children who practised the regimen during these 8 months had started on average at 2.5 grade levels behind their expected grade/age level; at the end of 8 months they were on average at 0.75 behind their expected grade level. An average improvement of 1.75 grade levels in reading skills within 8 months is a pace faster than that of ordinary readers. These improvements in speed and accuracy were equally significant for

the reading of lists of words and of passages of continuous text. Our impression as well as the reports by the subjects also indicated that comprehension had improved although this was not measured systematically.

The difference in improvement in reading skills between the experimental and control groups and the subsequent improvement of subjects from the control group who practised the regimen suggests a causal relation between the regimen of practise and the improvement in reading skills. (If one suspects this might be some form of "placebo", effect, we would like to stress that our treatment seems to improve reading skills while others are less successful.) Moreover, this practise indicates a rapid improvement in reading skills in the first 3 months of practise (1.22 grade levels for the experimental group) and a more modest one in the next five months (0.62 grade level).

A note of caution will be adequate. We do not think that we have "solved" the whole problem of dyslexia and found a complete "cure" for it. This paper presents only the results of a pilot study on a limited number of dyslexic children.

Though we compared results of an experimental and a control group, and found a significant difference between the two groups, one has to keep in mind that the number of children involved was small. Another point is that though the experimental group improved their reading skills much faster than the control group did, the experimental group still lagged behind their expected age level at the end of the experiment while their FRFs were almost like those of ordinary readers. This might be due to the fact that additional factors such as language problems contribute to the reading problems of our group of dyslexics. Clearly this is a modest first demonstration of the possible value of the method of treatment, but application of both the test and the treatment on much larger groups of dyslexic children is necessary before any general conclusions can be drawn.

The practise

We strongly emphasize that the regimen of practise was placed at the initiative of the child with least possible intervention of adults and with no structured school practise at class. One part of this practise involved small-scale novel hand–eye coordination tasks (comprised mostly of artwork) which should be considered "fun". This motivated the children and gave them a sense of accomplishment and success. We suggest that this procedure is of importance as it feeds back by success to encourage and drive the child. Concurrently, the children were reading through a window in a blank field which enabled them to perceive the forms of words in isolation. They were observing words in isolation at a location where lateral masking was least, as identified by the FRF test.

The rationale for this regimen of practise was given earlier (Geiger & Lettvin, 1989, 1993; Geiger *et al.*, 1992) and rests in part on the "adaptation" to new visual spaces by active control of at least two sensory modalities as suggested by Held and Hein (1958), Held and Gottlieb (1958) and Kohler (1962). However, hand–eye coordination tasks are not sufficient for the establishment of a new visual strategy for reading as can be seen from one of the subjects in this study. She was a good artist before she came to us but was a poor reader. Only after practising artwork novel to her concurrently with reading through the window did she improve in her reading skill. That suggests that consensual interactions between the creation of a new visual space associated with perception of words in isolation gives the ability to recognize what to look for in the text, i.e. words.

This description perhaps is the best argument for keeping both parts of the regimen of practise as a unit and not segregating it into its components.

The FRF

The number of subjects is not large but sufficient to make the case for the FRF as a significant test and the regimen as a new and important remediation of dyslexia. The speed of response to the regimen is notable given the common view that remediation of dyslexia is a slow process.

From a broad selection of subjects suggested by the schools, a group of dyslexics was selected by two tests, the estimate of reading retardation from evaluating reading skills and the FRF test. The FRF was well correlated with dyslexia: we found a wide FRF for dyslexics and a narrower one for ordinary readers. That is, the FRF measures whether the subject has mastered the visual strategy of reading without measuring the reading capabilities. It used only recognition of single letters.

The average FRF of the dyslexic children did not have a "dip" in peripheral letter recognition near the center. However, the individual FRF shapes varied: 2 subjects had a dip at 2.5° to the right, another 4 subjects had a dip at 5° to the right, another 3 subject had a dip at 7.5° to the right and the remaining 6 subjects did not have a dip. This is different from the findings previously obtained in adults (Geiger & Lettvin, 1987, 1989; Geiger *et al.*, 1992; Petty *et al.*, 1989). Moreover, the FRF of the dyslexics in this study is significantly wider on the left side than that of the ordinary readers. One possible reason could be the age of the subjects. The method of measuring the FRF was similar in this study to the previous studies (excluding the Geiger & Lettvin, 1987 study) where letter presentation was bilateral. In this study only children were measured, not adults as in the previous studies. However, measurement of 6 children in the U.S.A. have shown similarities of the FRFs between adults and children including the dip near the center of gaze (Geiger & Lettvin, unpublished results). Similarly, measurement of 8 dyslexic children in Italy (Zegarra-Moran & Geiger, unpublished results) and 3 dyslexic children in Israel (Geiger, unpublished results) have shown that similarity. One feature of the remedial procedure in the schools in Tübingen is different from elsewhere. That is the extensive use of the finger as a reading marker for early readers, and, in later grades the

use of the "imaginary" finger. This practice by itself would generate a distinct visual strategy.

Equal conditions

In a controlled experiment of this kind it is important to equalize conditions between the compared groups as much as possible to eliminate or reduce biases. That is the reason why, in the closing interview at the end of the first session, we told all the dyslexics to reduce time pressure in dictations and other tests involving reading and writing at school. We also made all the dyslexics aware of their condition and explained it. This was especially important as the school system did not recognize the term dyslexia (Legasthenie). In addition we encouraged the dyslexics by mentioning that their achievements in school were great in face of their condition, and that "we will do something about it together".

The psychological effect of these suggestions were evident for all the dyslexics independent of group affiliation. They felt self-assured and encouraged. However, although this psychological effect was evident in their school performance (as told by the parent and teachers) it did not show in reading performance (Table 1) or FRFs (Fig. 5) of the control group. We believe that the psychological reinforcement is of great importance in our remediation of dyslexia and, in particular, our using the explanation of the condition and the notion of visual strategies as a prerequisite for the regimen of practise.

Conclusion

The suggested regimen of practise is an effective process of learning the visual strategy of reading. It is short and enjoyable. However, this regimen of practise is not going to succeed with a person who is not motivated to learn to read. This is a modest demonstration of the method and should be tested again on a larger sample of dyslexics.

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