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Developmental Dyslexia: a Different Perceptual Strategy and How to Learn a New Strategy for Reading

Gadi Geiger
Center for Biological and Computational Learning, Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139 USA.

Jerome Y. Lettvin
Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139 USA.

Summary: *Processes involved in the physiology of ordinary reading are presented to discuss the way they differ from the physiology of the inability to read, as seen in developmental dyslexia. The ability to read ordinarily is marked by the ability to mask the text surrounding the word currently read. This process is named lateral masking. On the other hand, the dyslexics'inability to read is marked by the inability to mask the text surrounding the word currently read. We suggest that the distributions of lateral masking (the setting of the visual strategy) which either allow masking of the surrounding text or disallow it are learned by practice. On the basis of these observations we developed a regimen of practice for dyslexics. As we show the dyslexics who practiced the regimen learned a new visual strategy for reading in which they learned to mask the text surrounding the word currently read. This practice also resulted in a dramatic immediate improvment in reading wich was maintained for long periods.*

1. Introducing our Approach

Developmental dyslexia commonly signifies a marked deficit in learning to read. However, a generally agreed upon definition of dyslexia is not yet had. That makes it necessary to state our premises. Throughout the studies reported here we use a definition which does not imply the cause or an aberration of a specific sensory modality, but only describes the symptom. We regard developmental dyslexia as an unexplained retardation of reading skill in spite of adequate tutoring and the absence of any recognizable aberration in visual resolution or neurological state or intellectual status. From here on we will use the term "dyslexia" exclusively for developmental dyslexia. As the deficit in reading skill is a symptom common to all dyslexics, our approach to dyslexia is to address the symptom rather than the cause. That implies that we study the physiology of reading and how it differs from the physiology of the inability to learn to read.

For some time researchers have been searching for two things: a non-reading measure that reliably distinguishes between dyslexics and ordinary readers, and a method based on the rationale of this measure, by which dyslexics can better their reading skill to adequate levels. In this account we review our work which provides both: a non-reading perceptual measure that reliably distinguishes dyslexics from ordinary readers, and a regimen of practice by which dyslexics learn a new visual strategy for reading. As a result of the practice, their reading skill improves dramatically while their measure changes to resemble that of ordinary readers.

Our main thesis is that the difference between dyslexics and ordinary readers is

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in the pre-cognitive setting of foreground and background — whatever in the image needs attentive and distinct resolution versus that which can be taken as a less distinct surround. Conventionally it is supposed that an enhancing "spotlight of attention" renders more vivid what one wants to see. But the same effect is had by diminishing the cognitive resolution of what has lesser immediate importance. One such process is called "lateral masking", the de-emphasizing of image resolution in the background.[11] It is an active process[6] that is easily demonstrated, as we will show. The distribution of lateral masking depends on the perceptual task to be performed, and the strategy of seeing, represented by that distribution, can be modified by practice. Our main argument is that lateral masking is task-dependent — it is shaped by what one expects to see clearly. The dyslexic, especially in reading, lacks the ability to distinguish specific words from the surrounding text by the inability to mask the surrounding text. Recent findings show that language learning impaired (LLI) children have similar difficulty in telling sound signals in the presence of background noise.[22] Control of lateral masking is important and it can be learned.

The relevance of the argument to dyslexia rests on convincing demonstration and unambiguous measures. In the body of this paper we will demonstrate how the dyslexic differs from ordinary readers due to a mislearned use of lateral masking for text. We will show how this difference bears on the impaired ability to read, how that ineffective perceptual strategy can be supplanted by an effective one through a designed practice, and how that transition can be tracked by the non-reading test.

2. A Perceptual Measure: the Form-Resolving Field (FRF)

In order to measure the difference in visual perception between dyslexics and ordinary readers we devised a measure in visual perception which we call the form-resolving field (FRF). It measures visual recognition of letters along the horizontal axis. In the measurement two simultaneously presented letters appear briefly on a screen, one at the center of gaze and the other at some distance to the right or left along the horizontal axis. The subject's task is to report both letters seen. These presentations are repeated with different letters and with different distances between the letter at the center of gaze and the peripheral letter. (We express these distances as angular eccentricities.) At the end of 100 (or 200) such presentations the fraction of the correctly recognized letters at each eccentricity is calculated. The plot of the fractions of the correctly recognized letters at the various eccentricities is the form-resolving field (FRF) along the horizontal axis. The recording of the fraction of recognition of the letters in the center is usually given numerically. However, since in most of the cases reported here, the recognition of the center letter was at or above 85% whatever the eccentricities of the peripheral letters, we omit mentioning the value.

The average FRFs of 10 adult, English-native ordinary readers and of 10 adult English-native dyslexics are shown in figure 1. It shows that ordinary readers recognize the peripheral letters best when they are nearest to the center of gaze and the recognition falls off symmetrically and rapidly with growing eccentricities. On the other hand, the FRF of dyslexics is markedly different. The dyslexics recognize the letters which are presented further to the right significantly better than do ordinary readers. However, for the dyslexics best recognition on the

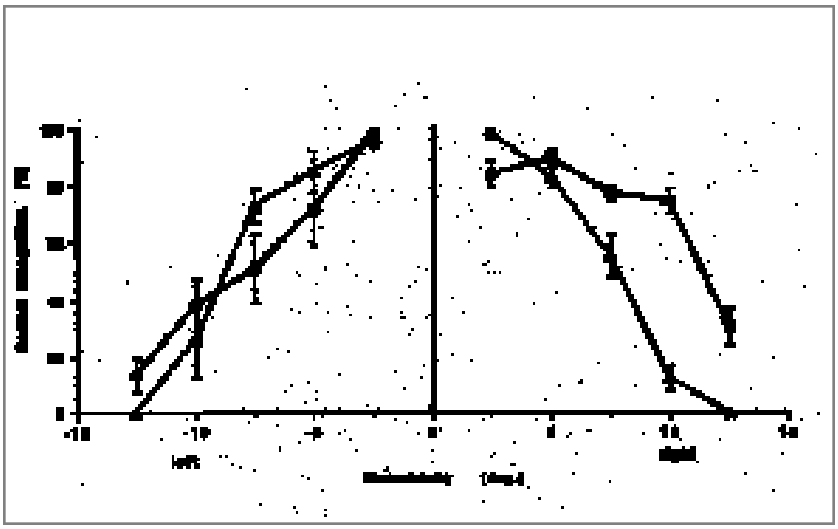

Fig. 1; The average form-resolving field (FRF) of 10 adult ordinary readers (dotted line) and of 10 adult severe-dyslexics (solid line). All are English-native. The differences between the FRFs at 7.5°, 10° and 12.5° to the right are statistically significant. For example, the recognition of letters by dyslexics at 10° to the right is 8 times better than that of ordinary readers. On the other hand, the recognition by the dyslexics near the center of gaze at 2.5° to the right is significantly lower than that of ordinary readers and is significantly lower than the recognition by the dyslexics further to the right at 5° On the left, recognition is similar between both groups. The vertical bars denote the standard deviation of the mean.

right is not nearest to the center of gaze as with ordinary readers but at some distance to the right. On the left side the FRF of dyslexics is narrow and similar to that of ordinary readers. Thus, the FRF of adult dyslexics is asymmetric with rapid fall-off of recognition on the left and an extended recognition far to the right.[9,11] These results are achieved exclusively with direct optical presentation devices (slide projectors or the like) and not with CRT displays. The reason for that will be explained in a later section.

2.1. Why is the FRF of the Adult Dyslexic Asymmetric?

As mentioned above, one of the differences between the two groups is that the FRF of ordinary readers is symmetric and that of dyslexics is asymmetric. The FRF of ordinary readers shows that recognition falls off with similar slopes away from the center of gaze to the right and left. But the FRF of adult English-native dyslexics is significantly asymmetric; recognition is extended in the right visual field and is narrow in the left. One is tempted to attribute this asymmetry to different hemispheric specialization in the dyslexic brain. However, we decided to look first into a simpler possibility. As all the subjects whose FRFs are depicted in figure 1 were English-natives with early training in reading exclusively in a language read from left to right, we thought that that might have an effect on the shape of the FRF of dyslexics. To test this notion we measured the FRF of adults whose early training was in a language read in the opposite direction, from right to left. As Hebrew is one such language, we measured 10 adult Hebrew-native subjects for their FRFs, five of whom were ordinary readers and five were dyslexics. All the subjects had been trained exclusively in Hebrew during the first four years at school. Figure 2 shows the average FRF of each of these groups. Most conspicuous is the extended recognition of letters by the adult Hebrew-native dyslexics farther in the left visual field rather than, as with the adult English-native dyslexics, to the right.[11] Other aspects of the FRF are similar for Hebrew and English native adults. We concluded from this experiment that the asymmetry in the FRF of adult dyslexics is the result of the way reading was trained, in particular the direction of reading. However, putting it

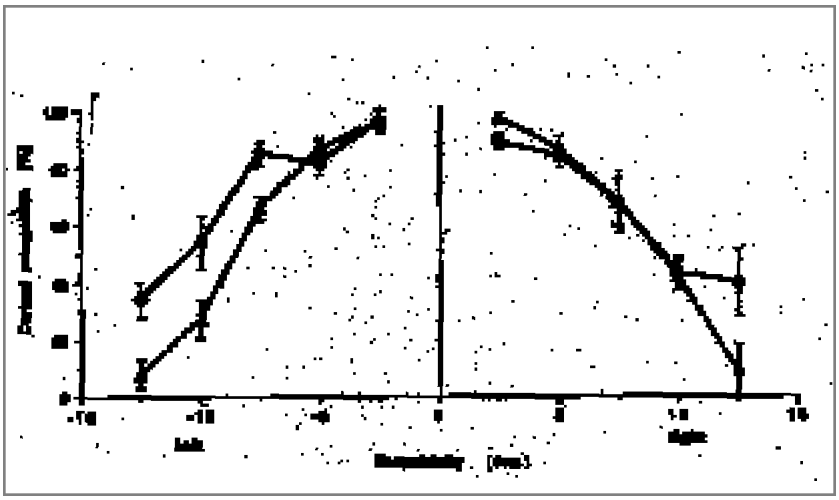

Fig. 2; The average FRFs of Hebrew-natives. For 5 adult ordinary readers (dotted line) and for 5 adult dyslexics (solid line). Recognition by the dyslexics at 7.5°, 10° and 12.5°. to the left is significantly better than that of ordinary readers. The asymmetry of recognition seen with Hebrew-native adult dyslexics is in the opposite direction of the asymmetry seen with English-native adult dyslexics, as shown in fig. 1.

this way also implies that if the shape of the FRF is related to the symptom of dyslexia, then the symptom is learned, as its asymmetry depends on the particular direction of sequential reading.

2.2. The Shape of the FRF and Reading

The crucial question is: how does the shape of the FRF relate to reading or the inability to learn to read. Although we relate here to the FRF as a measure of the distribution of recognition, we have shown that the recognition ability is dependent on lateral masking. Therefore, the FRF is also a measure of the distribution of lateral masking.[7,9,11] Lateral masking, which is also called crowding, is the adverse interaction of neighboring visual icons on each other. A demonstration of lateral masking is shown and explained in figure 3. By measuring directly the effect of lateral masking on recognition, with strings of letters, we have shown that the distribution of the effect of lateral masking along the horizontal axis is similar to the fall-off of recognition shown in the FRF measure, for the dyslexics and

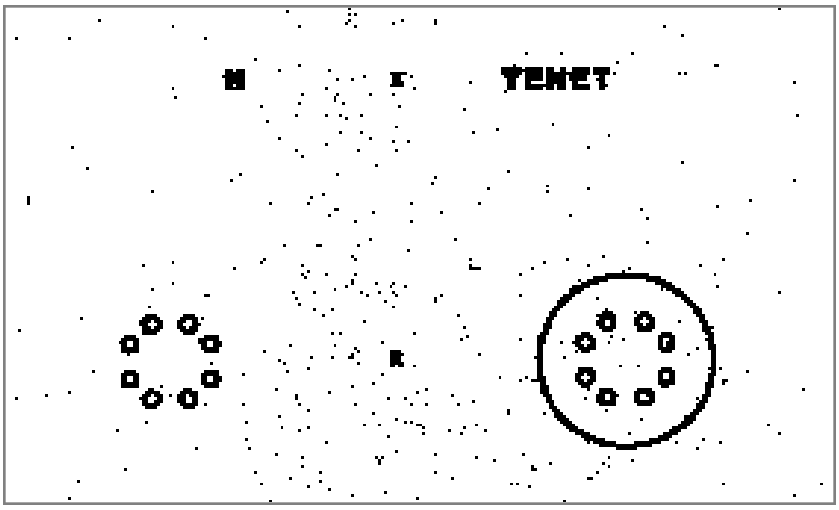

Fig. 3; a demonstration of lateral masking. Fix your gaze on the upper x. While keeping you gaze fixed on the x you will recognize the N on the left but most of you will not recognize the N on the right which is embedded in a string of letters. The N in the letter-string and the letters in the string are not blurred. The N is just not there or is confused to the point of not recognizing it. The distances of the N s to the x cannot explain the effect as they are the same. It is the interactions between the neighboring letters with the N that mask it. (Hence the term "lateral masking"). Turn the figure upside-down to see that the effect is symmetric. Now fix your gaze on the lower x and keep it fixed there. You see little circles on both sides. However, the little circles on the left form a spatial arrangement like a circle of circles or a diamond shape of little circles. While on the right the little circles are individually clear but have no distinct order. We suggest that lateral masking reduces a coherent figure to an aggregate of its components like

the ordinary readers.[7] In addition, although it is considered that in lateral masking the interactions are between neighboring visual icons, we have shown earlier that parts of letters interact with each other in a similar adverse way as do neighboring icons resulting in self masking of letters which are made of more than one part.[6] These considerations suggest that the FRF is a measure of the distribution of lateral masking along the horizontal axis. It measures recognizability, but the level of recognition depends on how strong lateral masking is at that particular location. Hence the shape of the FRF of ordinary readers implies little or no masking in and near the center of gaze (maximum recognition) and a steep increase of lateral masking with growing eccentricities from the center of gaze (similar to what has been described in previous publications on lateral masking, see Bouma[1]).

This shape of the masking allows the ordinary reader to gaze on a word without interference by the surrounding text which is laterally masked. After the word is deciphered, the reader moves (saccades) to the next word in the line, and so on. On the other hand, the dyslexic while gazing at a word also sees clearly a large portion of the text in the direction of reading as there is little lateral masking (high level of recognition, as seen from the FRF). That makes identification of single words almost impossible due to the clarity of the surrounding text which is as salient as the word to be read. That results in confusion and inability to read word by word, which is the way of ordinary reading. In addition, adult dyslexics mask the letters immediately to the right from the center of gaze, which in turn makes the central deciphering of single words even harder and adds to the confusion.

It also has been shown earlier that the FRF of children changes (over the time they learn to read) to be that of ordinary readers.[23] That suggests that the distribution of lateral masking is modified by the practice of reading. This observation together with the previous one on the dependency of direction of the asymmetry of the FRF on the direction of reading in adult dyslexics suggests that the particular form of the FRF is learned by practice. In other words, the appropriate distribution of lateral masking which enables ordinary reading is learned by practice. That implies that there is a learned perceptual visual strategy for reading, and it is learned by practice. When this particular strategy is not learned, ordinary reading is impaired.

Avisual strategy is the complex of many cooperative processes (like accommodation, vergence, color identification, motion identification, etc.) which are all set for optimizing task performance. The size of the spatial area of saliency is paramount. That is, selecting what is important for the task and what is to be ignored; what is in the region of saliency and what is outside it. The distribution of lateral masking is the setting of the spatial distribution of saliency.[11] We suggest that a particular visual strategy is task determined and is learned by practice for the accomplishment of the task.

By these observations we hold that dyslexics and ordinary readers differ in their strategies of visual perception.

2.3. Conditional Dyslexics: Examples of the Two Strategies

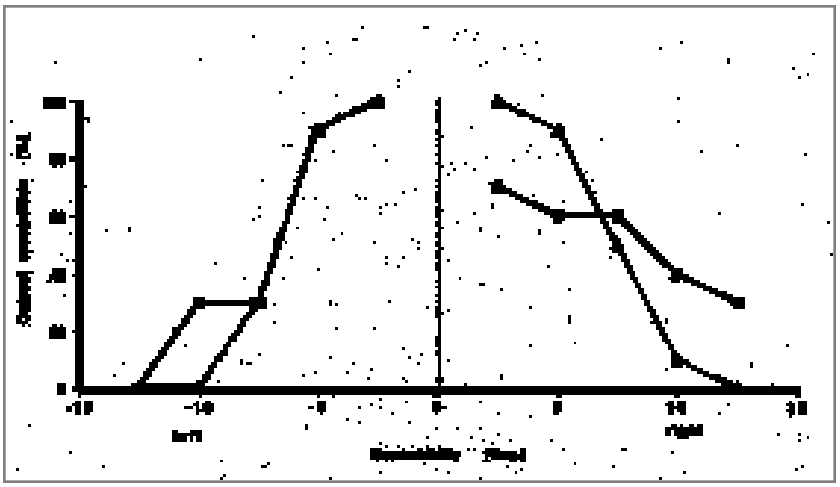

Fig. 4; The two FRFs of a conditional-dyslexic, when he is "fresh" and able to read at ease (dotted line) and when he is "tired" and his reading is impaired (solid line). This individual was fresh in the mornings and tired in the afternoons and the evenings. However his art work (as an architect) was better in the dyslexic phase rather during the phase when reading was easy.

in the Same Person

We found in "conditional" dyslexics additional support for the notion of the appropriate strategy in visual perception for reading. Aconditional dyslexic is able to read ordinarily some times, and at other times is dramatically impaired in reading. This happens within different parts of the day, or within an hour or two (not in different days or weeks). At the time the conditional dyslexics are able readers their FRF is narrow and symmetric, similar to that of ordinary readers. At the time when reading is impaired their FRF is like that of dyslexics.[11] A demonstration of the FRFs of one conditional dyslexic is shown in figure 4. The flips between the two states (strategies) are consistent and well correlated with the ability or inability to read. At first we regarded this as a rare occurrence. However, with time we encountered many conditional dyslexics. In fact it is more common than we anticipated.

2.4. How Well Does the FRF Tell Dyslexics from Ordinary Readers

The significant differences of the FRF plots in figure 1 is not confined to the 20

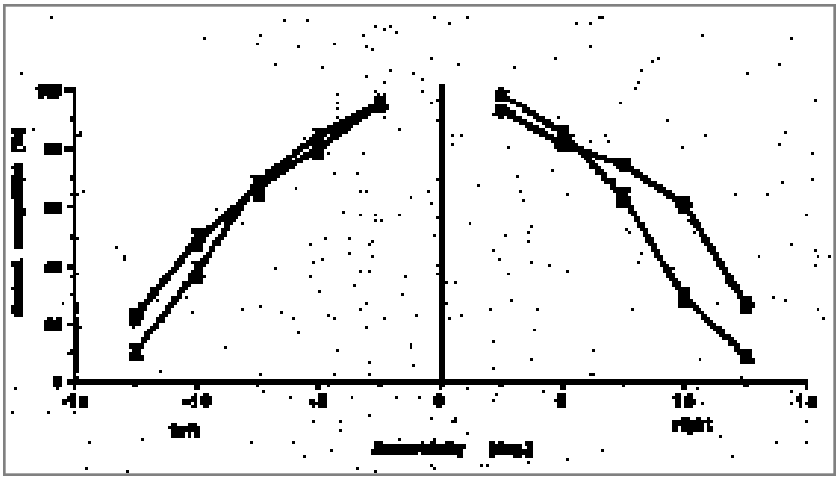

Fig. 5; The average FRF of 119 dyslexics (adults and children) and that of 65 ordinary readers (dotted line), all natives to languages read from left to right. The differences between the groups at 7.5°, 10° and 12.5° to the right are statistically significant.

subjects measured there, but, as seen in figure 5, the difference remains significant also for 184 subjects (119 dyslexics and 65 ordinary readers both adults and children) who were measured in the various studies we made. This difference was used by us to develop a reliable tool to distinguish, individually, between ordinary readers and dyslexics. For each individual FRF we calculated the ratio between near center recognition and the recognition in the periphery. When this number was larger than a cut-off value (which we set empirically) the person was considered to be an ordinary reader; when the number was equal or below that value the person was considered dyslexic. When we correlated these attributes, had from the FRF, with the classification based on reading test scores and other cognitive non-perceptual testing for dyslexia, we got above 91% agreement between the two methods for children between 7 and 16 years old and above 83% agreement for adults above 18 years old. We therefore suggest the FRF measure to be a reliable diagnostic tool for dyslexia. We are now in the process of testing this method on a large number of children at the La Nostra Famiglia hospital in Bosisio Parini, Italy.

2.5. Why not Use a CRT Display for Measuring the FRF

We mentioned earlier that the FRF (or measurements which are its correlates) should be performed only with direct optical displays like slide projectors[4,18] but not with CRT displays or the like. That because the significant difference in the FRFs between dyslexics and ordinary readers, seen in figure 1, becomes insignificant at best when measured with CRT displays (our own measurement 1988, Bjaalid,[2] Goolkasian and King,[12] Klein et al.,[15] Slaghuis et al.[19]). The reason for the disparate results obtained with different type of displays lies in the jagged appearance of the edges of the letters displayed on the CRT, in contrast to those displayed with slide projectors which appear smooth (to the resolution of our visual system). Recently one of us (GG) has shown that the FRF of ordinary readers is significantly wider when measured with jagged letters than when measured with smooth letters (using the same subjects) although, the letter sizes, fonts contrast and stroke width were the same. However, the FRFs of dyslexics were similar when measured with either jagged or smooth letters. He also has shown that for ordinary readers the effect of lateral masking on recognition is reduced when strings of jagged letters are displayed in the periphery compared with the effect on recognition when the letters are smooth. For dyslexics lateral masking remains the same for smooth and jagged letters. In short, the difference in the FRFs of dyslexics and ordinary readers is diminished when the presented letters appear jagged, but the difference is significant when the letters displayed appear smooth.

2.6. Summary of the FRF Measurements

We have shown that dyslexics and ordinary readers differ significantly in their perception as measured with the FRF. The FRF of ordinary readers is narrow and symmetric, while that of dyslexics is wide (in the direction of reading) and asymmetric. The shapes of the FRFs signify the distributions of lateral masking. Strong lateral masking surrounds the center of gaze in ordinary readers, as compared with little lateral masking in the direction of reading in dyslexics. The former enables word by word reading and the latter makes ordinary reading diffi-

cult and causes confusion. We suggested that these differences between ordinary readers and dyslexics are differences in learned task-determined perceptual strategies. In addition, we suggested a procedure by which the FRF measure could serve as a diagnostic tool for dyslexia. We explained why the FRF measured with a CRT display does not show the same significant difference between dyslexics and ordinary readers as is shown with a direct optical display.

3. Learning a New Perceptual Strategy - Learning Ordinary Reading

Once the particular perceptual strategy of the dyslexic was established by the FRF measure, it remained for us to demonstrate that a new perceptual strategy can be learned by the dyslexic and that this strategy will be characterized by both efficient reading and by a narrow FRF resembling that of ordinary readers. Here is the design of the regimen of practice.

1) The dyslexic learns to ignore, or mask, the text surrounding a word which is gazed on for reading. As expressed colloquially, the dyslexic learns to "direct attention" on the word to be read (while masking the surrounding text).
2) Practice reading word by word.
3) Practice the recognition of the forms of single words.

We were also guided by the notion that the learning of a new perceptual strategy cannot be achieved by just modifying an existing strategy but instead must be learned as a new and separate strategy. That is because existing established strategies, even though inadequate, take over during the attempt to perform the task.

3.1. The Regimen of Practice for Learning a new Perceptual Strategy for Reading

After we assessed the reading levels of 5 adult severe dyslexics and measured their FRFs we gave them our regimen of practice. It is comprised of two complementary parts: Practice of unfamiliar, small-scale hand-eye coordination tasks like drawing, painting, clay modeling and the like, for 1-2 hours daily, followed by reading practice with a specially designed mask (the window).

The purpose of the hand-eye coordination practice is to learn to mask and ignore form perceived for the accomplishment of the task. This has to be learned directly by practice and not by volition, as has been demonstrated in earlier works on adaptation (e.g. Kohler,[16,17] Held and Gottlieb,[13] Held and Hein[14]). These authors have shown that the most efficient way for adaptation to a new condition dictated by deformation of the visual space (by the use of special goggles) is the active practice of a task incorporating two sensory modalities. This led us to believe that the practice of novel small scale hand-eye coordination activities should facilitate a new adapting state.

In the second part of the practice we asked the dyslexics to use a specially designed mask which they laid on the text to be read. The mask was a blank sheet with a rectangular window, cut to be somewhat larger than a long word in the text. The dyslexics laid 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. This part was practiced for 1 hour a day on average, and concurrent with the first part. The reading with the window made it possible to read (recognize) words in isolation, learn to recognize the form of the words and read them one by one in a sequential manner. For those dyslexics whose FRF shows best recognition farther away to the right from the center, we marked a fixation point left of the window reflecting that individual measure. We then asked the dyslexic to gaze at the fixation point and read the words appearing in the window to the right.

The five adult severe dyslexics practiced that regimen for 4-6 months. (Within the first month we got calls stating "so that what a word looks like.") At the end of that period we assessed their reading and measured their FRFs. In all cases the reading improved dramatically (e.g. from 3rd to 11th grade level) and the FRF on the right side narrowed markedly. Four of the five subjects were artists who felt that learning this new visual strategy for reading compromised their artistic abilities. We then asked them to stop the practice of that regimen. Afew months later, their reading level dropped and their FRFs widened. They were again happy with their art work.

3.2. Four Studies to Show the Efficiency of the Regimen of Practice

The results above were encouraging but anecdotal. Subsequently, we performed four additional studies. Two of the studies were "controlled studies" with school age children where we compared the results of the practice of the regimen described above with other methods of remediation. The third study was - (and still is) - an ongoing study also with school age children. The fourth is a study with college age dyslexics and other adults. In all the studies we primarily measured the efficiency and the details of the learning process of a new perceptual strategy for reading. Some years later we conducted long term (2 - 5 years) follow-up on most of the original participants. Three of the studies were performed in the USA and one of the controlled studies was performed in Tübingen, Germany, which we reported on previously.[10]

In all the studies the following considerations were addressed:

1) the rate of reading improvement as a result of practice of the regimen, as measured with standardized reading tests;
2) correlation between the "conventional reading deficit based determination" of dyslexics with the FRF measure;
3) determining whether the learning of a new perceptual strategy for reading with that regimen was accompanied by a change in the FRF measure;
4) comparing the reading improvement results achieved by the regimen of practice suggested here with other remedial procedures (only in the controlled studies);
5) long term consequences of the practice of that regimen.

3.3. Methods

Each participant had first an interview to inquire about the nature of the problem, followed by an inquiry about the general medical status. We also established the handedness (Brigg and Nebes),[3] the intelligence level and addressed

other particular individual problems. After the initial interview a standardized reading test was administered. The Züricher-Lesetest (ZLT) was used for the children in Tübingen and the Letter-Word Identification, Passage-Comprehension and Word-Attack (reading nonsense words) tests from the standardized Woodcock-Johnson Psycho-Educational Battery-Revised[21] were used for these in the USA. The children in Tübingen were given an additional thorough ophthalmologic exam. After these tests were made we determined and recorded whether the participant was a dyslexic or an ordinary reader. Subsequently the FRF was measured. Following the FRF measurement a concluding interview was made. It included explanation of the condition and the particular regimen of practice which was given. In these studies the participants' ages were 7 to 39 years. Those who were between 7 and 16 years old were considered children and those between 18 to 39 years old were considered adults (which included the college students). Along with each study a group of matched ordinary readers were measured for reference. In all, there were 41 dyslexics (27 children and 14 adults) and 55 ordinary readers (16 children and 43 adults) in the learning studies.

All the dyslexics who practiced the offered regimen practiced it at home on their own. The children were asked to practice on average 0.5 to 1 hour daily of hand-eye coordination activities and 0.5 hour daily reading with the window. The adults were asked to practice 1 to 2 hours daily hand-eye coordination activities and 1 hour daily of reading with the window.

Each dyslexic was contacted periodically every 3-4 weeks by phone for encouragement and additional guidance. There was no direct supervision. After a period of 3-10 months the dyslexics were retested.

3.4. Dyslexic Children Improve Reading by Learning

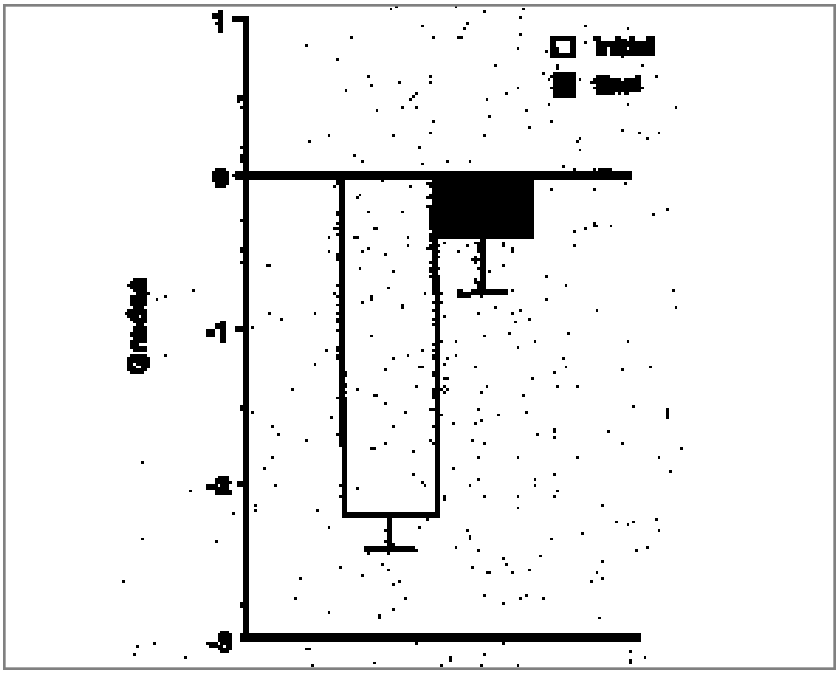

Fig. 6; The initial and final reading deficits of 27 dyslexic children expressed in terms of Broad Reading which is the combined results of the scores of the Word Identification and Passage Comprehension tests. This measure is similar to the German ZLT though it lacks the timing element the ZLT has. The final results were taken after an average of about 7.5 months of practicing the regimen.

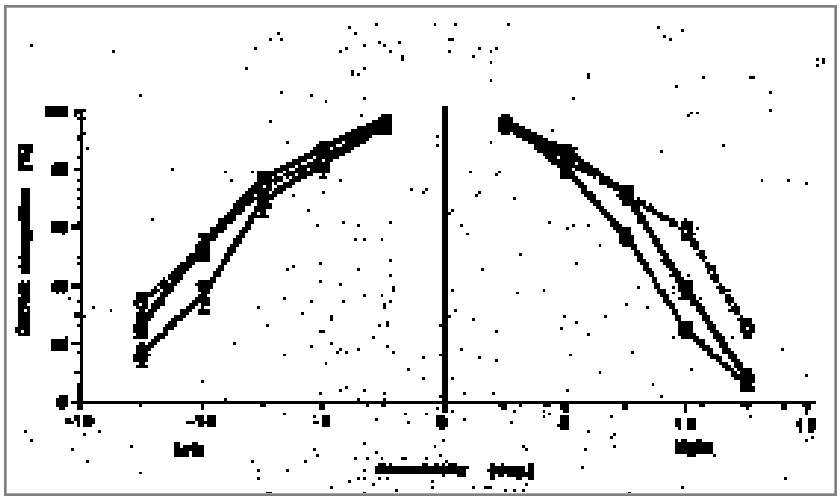

Fig. 7; The average FRFs of 27 dyslexic children when first measured (dashed line) and that of 12 children who are ordinary readers (dotted line). The solid line is the average FRF of the 27 dyslexic children after practicing for about 7.5 months the regimen we offered.

a New Perceptual Strategy

In this section we give the main results from the three studies which were performed on children. The initial average reading deficit (i.e. the average of the individual reading scores below the expected level, expressed in grades), and the final reading deficit of all the dyslexic children are shown in figure 6. The average initial reading deficit of all the dyslexic children was 2.2 grade levels with a deficit of at least 1.8 grade levels for each individual. The average FRF measure of all the dyslexic children is shown in figure 7. As seen, the FRF measured at the end of the initial session of testing is significantly wider than the FRF of children who are ordinary readers.

After 5-10 months of practice of the regimen all the dyslexic children had the final session of testing. Their reading was tested, their FRF measured and the length of the period of practice was noted as well as the daily duration of practice of the regimen. The average period of practice of the regimen we offered was 33 weeks (~7.5 months) with an average of 0.8 hours daily hand-eye coordination activities and an average of 0.35 hours daily reading with the window. The final reading deficit was then measured with respect to what grade the child was in at the time of the final testing session. The score of the average final reading deficit was 0.4 grade levels (figure 6), implying an average improvement in reading of 2.1 grade levels during just 7.5 months of practice. The improvement in reading was measured with respect to the time of the initial testing. This rate of improvement is more than twice that of ordinary reading children.

The FRF, which was measured again at the end of the practice period is also shown in figure 7. It had narrowed dramatically in the right visual hemifield, to resemble that of ordinary readers. That is, the average FRF measure after practice is significantly narrower than the FRF of the same children measured before starting their practice, and it is no longer significantly different from the FRF of ordinary readers (though still different). The dramatic improvement in reading (which was accompanied by a significant narrowing of the FRF on the right) suggests the learning of a new perceptual strategy for reading by the dyslexic

child. It is a real turning point in reading performance as becomes evident in the long term follow-up.

3.5. Results of the Controlled Experiments with Dyslexic Children

In the two controlled studies with dyslexic children we made comparisons between the regimen of practice - as suggested above - and other existing methods of remediation for dyslexia. As mentioned, one of the controlled experiments was made in Tübingen, Germany and the other in Brookline, Massachusetts, USA.

There were 15 dyslexic children in the Tübingen study and 12 dyslexic children in the Brookline study. In addition, in each study 6 children who are ordinary readers were added for base-line. All the participants were from the 3rd to 6th grade of school and their average age was 10.9 years. Every dyslexic child went through the tests and measurements described above.

The initial average reading deficit of the Tübingen dyslexics was 2.5 grade levels, and an average of 2.1 grade levels (in Broad Reading) below the expected level for the Brookline dyslexics. The average initial FRF measure was significantly wider than that of the ordinary readers (the data is incorporated in figure 7). At the end of the initial testing and the concluding interview the dyslexic children were divided, in each study, into two groups, matched for age and reading: The "experimental dyslexic" group who were given our regimen of practice (described above) and the "reference dyslexic" group who practiced the remedial method given to them at their schools.

After 3-4 months all the dyslexic children had their reading tested again, their FRF measured and the actual practice period noted as well as the average daily practice of the two parts of the regimen. The dyslexic children practiced for an

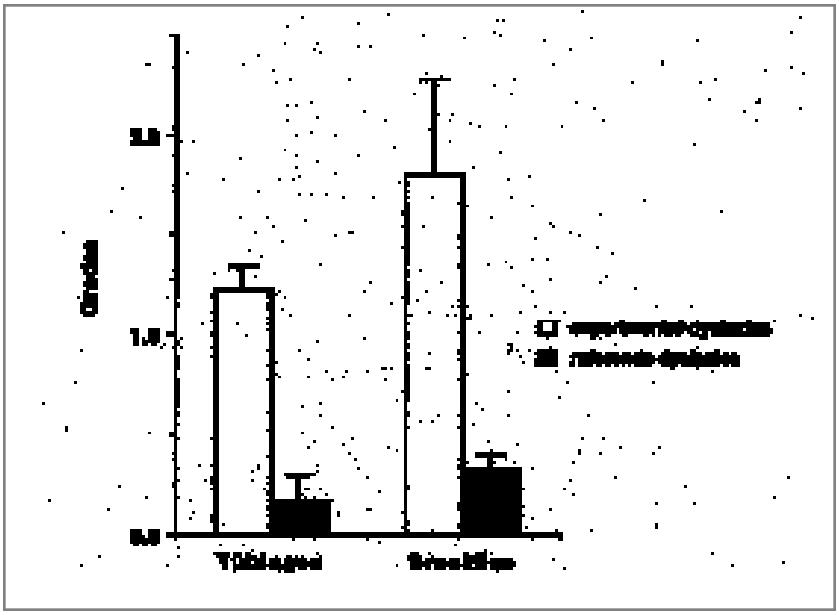

Fig. 8; The average reading improvements for each study separately measured after 3.3 months of practice. The experimental-dyslexics practiced the regimen given by us and the reference-dyslexics practiced their remedial methods given by their schools for the same period.

average of 3.3 months their respective regimens. The dyslexics who followed our regimen practiced for an average of 0.8 hours daily the hand-eye coordination activities and 0.33 hours daily reading with the mask.

Figure 8 shows the average reading improvements of the experimental-dyslexics and reference-dyslexics for each of the two studies separately. In both studies the average improvement in reading by the experimental-dyslexics was significantly larger than that of the reference-dyslexics. It was 1.2 grade levels improvement for the experimental-dyslexics compared with 0.2 for the reference-dyslexics in Tübingen and 1.8 grade levels improvement compared with 0.3 in the Brookline study. All the experimental dyslexics (except 2 from the 7) in Brookline improved at least one grade level or more.[9] On the other hand, the largest individual improvement among the reference-dyslexics was 0.5 grade levels. These differences also were reflected in the FRF measure. The FRF of the experimental-dyslexics narrowed significantly from the initial measure, while the FRF of the reference-dyslexics remained wide, similar to the initial measure.[10] These finding show that the practice of our regimen resulted in significantly larger reading improvements compared with the practice of the other methods. It also resulted in the narrowing of the FRF.

Accordingly, our regimen of practice was then given also to the reference-dyslexics. A few months of practice improved their reading to the level of the experimental-dyslexics.

The final results of the tests and measurements which took place about 5 months later are incorporated in the final results shown in the preceding section. In the second period of practice, the experimental-dyslexics continued to improve their reading. They practiced an additional period of 4.9 months on average and they improved another 1.1 grade levels on Broad Reading.

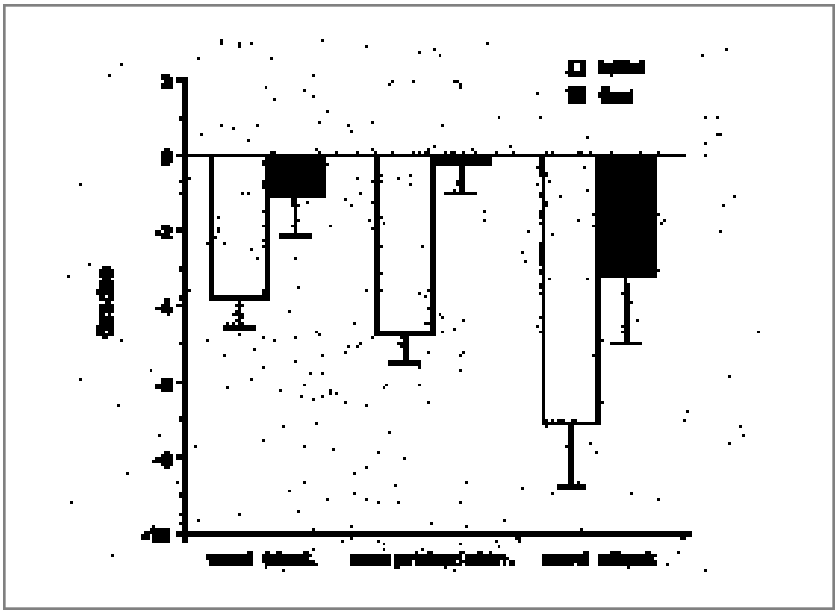

Fig. 9; Initial and final reading deficits of 14 adult dyslexics shown for each test separately

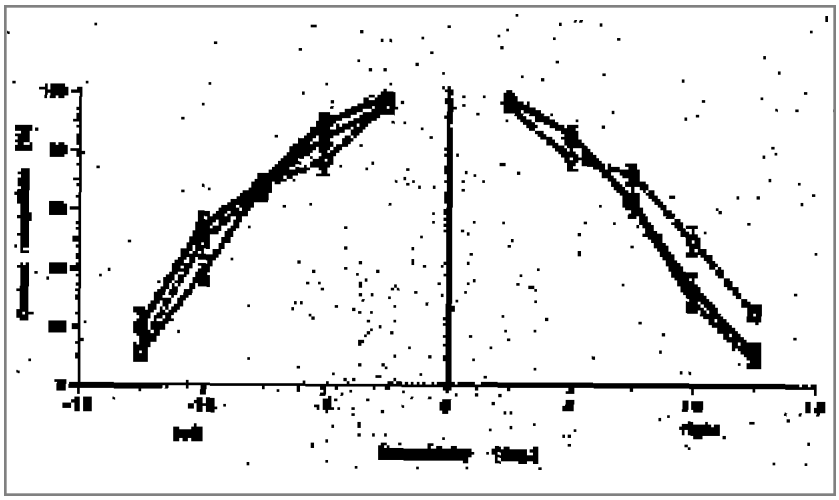

Fig. 10 The average FRF of 14 adult dyslexics at the initial session of testing (dashed line) and for the same dyslexics after practice of our regimen for about 6.5 months (solid line). The average FRF of 43 adult ordinary readers (dotted line), is shown for comparison.

3.6. Adult Dyslexics Practice the Regimen

Asimilar procedure was used with the adult dyslexics: an initial session of testing, a period of practice of the regimen and a final session of testing. The results of the initial reading test of the 14 adult dyslexics are shown in figure 9. The initial deficits in reading are given for each of the 3 reading tests from the Woodcock-Johnson battery. These were on average 3.8 grade levels deficit in Word Identification, 4.7 for Passage Comprehension and 7.1 grade levels deficit for Word Attack. The deficits in adults are larger than those of children when expressed in grade levels, but are similar when expressed in SD (standard deviation) units. After the reading test the FRF of each dyslexic was measured. Their initial average FRF is significantly wider on the right than that of adult ordinary readers as seen in figure 10. Subsequently the regimen of practice, described above, was given. We recommended 1-2 hours daily of novel small scale hand-eye coordination activities and 1 hour daily of reading with the mask.

About 7 months later the adult dyslexics who practiced the regimen were retested and their activities noted. They practiced for an average period of 29 weeks (~6.5 months) with a daily average practice for 0.9 hours of the hand-eye coordination activities and for 0.5 hours daily of reading with the mask. The final average reading deficits as seen in figure 9 were: 1.1 grade level average deficit for Word Identification, (an improvement of 3.4 grade levels), average of 0.2 grade level deficit for Passage Comprehension, (an improvement of 5 grade levels) and 3.2 grade levels average deficit for Word Attack, (also an improvement of 4.5 grade levels) during those 6.5 months. These improvements in reading were accompanied with the significant narrowing of the FRF to resemble that of ordinary readers, as seen in figure 10. These results also show a dramatic improvement in reading which is accompanied with the change of strategy in visual perception.

3.7. Long-term Observations

About five years after we first started the study in Tübingen we interviewed by phone 13 of the 15 original participants (the other 2 moved away). Probably

most striking is that 9 of the participants said that they like to read for "fun", and they do so for about 1-3 hours daily. From their account, they read and write “very good”, “good” or “medium”, only one participant thinks he reads “not so well” and writes “badly”. He also thinks he might be still a dyslexic, all the others said they are not dyslexic any more. Their grades given at school reflect these achievements. Their grades in German were at the level or higher than their average grades in all subjects learned. The average grade in German for all the participants was 2.53 and the average of the averages on all the subjects was 2.88, when 1 is the highest grade and 6 the lowest. They did not get any special interventions for reading after learning the new perceptual strategy for reading by practice of our regimen. As they were approaching the end of high school they gave their future plans as follows: 11 of them plan to go for higher studies, 5 to university to study science economies and psychology, 6 were planning to go to a technical higher college, one planned to be a watchmaker and one determined not to study further. Most of them like to do art work and they do a lot of it. Some of them reported that when they are very tired they use the window to make reading easier. All of them have noted that the practice of the regimen has "opened" them up to easier reading.

The follow-up with the Brookline children was made 2-3 years after beginning the study and the follow-up with the adults, between 1-3 years after the start. They show similar tendencies as with the Tübingen study.

This suggests that there was a definitive turn in reading abilities after the practice of the regimen we suggested.

3.8. Remarks on Learning the new Strategy

In this chapter we have shown that the practice of the regimen we offered resulted in a dramatic improvement in reading skill. Similar results were reported in a study by Fahle and Luberichs[5] which was conducted on a heterogeneous group of 49 children with reading and/or spelling problems (including dyslexics, poor readers and ordinary readers with only spelling deficit). After only 2 months of practice of a regimen similar to the one we offered here (for 23 minute per day on average), 30 of the children improved reading by 0.72 grade levels and 19 did not improve in reading. And all improved in spelling by an average of 0.63 grade levels. This suggests a general applicability of that regimen.

The improvement in reading we report here was not a singular jump but it laid the ground for continual improvement in reading as demanded by the process of learning at school or college. As we showed, the practice of the regimen did result not only in an improvement in reading but also in the narrowing of the FRF measure, which means that a new perceptual strategy was learned, a strategy for laterally masking the region around the word to be read.

Another issue which these results raise is the following: The regimen we offered here promotes only practice of hand-eye coordination and visual recognition of the forms of words, and it does not address phoneme awareness directly. As could be seen from figure 9, the improvements of the adult dyslexics on the three reading tests (including Word Attack) were about equal. Similar results were seen with dyslexic children who were tested with these three tests. However, the Word Attack test, in which a person is reading nonsense words, is regard-

ed to be a test of phoneme awareness (e.g. Witton et al., 1998). What is it then in the practice of hand-eye coordination and visual recognition of words that leads to improvement in phoneme awareness? We suggest two possible answers. Either, there is a general perceptual strategy which governs perception, i.e. once a strategy is learned in one sensory modality it is learned for all sensory modalities. Or, there is no such general perceptual strategy but learning a strategy is modality specific. Once it is learned in that modality there is a "spill-over" from one modality to another. In the future we plan to address this question.

4. Concluding Remarks

At first we described the physiology of the symptom common to most dyslexics, the inability or the great difficulty in reading. We characterized the physiology of the symptom with a perceptual measure, the FRF. The ability or inability to read was marked by the ability or inability to mask the text surrounding the word read. Ordinary readers while reading a word are able to laterally-mask its surrounding text. However, the dyslexics while gazing at a word see a lot of the text in the direction of reading and therefore are unable to isolate the words and by that get confused. On the ground of this description we suggested a regimen of practice. The practice of that regimen by the dyslexics resulted in a dramatic and long lasting improvement in reading while the perceptual measures changed to resemble those of ordinary readers. That suggests the learning of a new perceptual strategy. This new strategy is to change the pre-cognitive setting of the information for later cognitive processing.

We characterized the symptom common to most dyslexics and showed that the symptom is learned. That led us to devise a method of learning a new perceptual strategy which helped many dyslexics.

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