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SMR/302-2

COLLEGE ON NEUROPHYSICS:
"DEVELOPMENT AND ORGANIZATION OF THE BRAIN"
7 November - 2 December 1988

"Dyslexia and Reading as Examples of Alternative Visual Strategies"

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DYSLEXIA AND READING AS EXAMPLES OF ALTERNATIVE VISUAL STRATEGIES.

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Submitted to the Wenner-Gren International Symposium series, published by MacMillan in: "Brain and Reading".

17.June 1988

Running title: Visual Strategies in Dyslexics and Readers.

S.I.S.S.A. Ref. 97 Bio (July 88)

INTRODUCTION.

We offer evidence that ordinary readers and dyslexics differ systematically in the distribution of certain perceptual properties over the visual field. These differences are laid to alternative strategies of perception. Our supposition is that any ordinary person possesses a set of visual strategies and can switch between them, depending on the type of task to be performed. A strategy evolves as a result of practise that carries task performance from the novice to the expert level. Because our experiments and interpretations are influenced by this notion, it is proper to devote an introduction to it.

Consider expert performance of any sort, choosing it from the theatre stage, or playing field, or even from daily life. We will sketch the progress of novice to expert in a case o₁ two in order to remark some common features.

Regard a beginner who drives a car for the first time. He clutches the wheel in a firm grip and tries to guide the car as if perception and action are so concurrent that the car can be kept to a specific course in the immediate. But the mass of the car, the mechanics of the steering system, and the friction of the road impose a complex delay between the driver's intended trajectory and the actual one of the car. This delay makes itself brutally clear the first time the novice turns a corner at a moderate, rather than a slow, speed. Then his changing present perception is pitted against the delayed changing response of the car. Since there is a loop between the intended perception and the delayed action, the system goes into overshoot and oscillation above a critical low speed.

In becoming expert, the tyro learns the response of the car to sharp movements applied to the steering, and he begins to steer by a time series of steps applied to the steering wheel, as if predicting at intervals the current course for a short period into the future. Knowing where the car will go in this short period, if held to present course, and where the car is intended to be at the end of that period, the driver simply moves to correct the foreseen error. The point is that intention now has a different role. It is not concerned with optimizing the current course by almost instantaneous correction, but instead deals with expected course and intended course and proceeds to minimize the error between them. For this to be the case, the specious present of the driver's perception must extend from recorded past to expected future when referred to physical time, in order to compensate this delay between perception, purpose and action.

We have used the driving of a car only as an illustrative prelude. What is true for the lag between the driver's perception and the intended action of the car is also true, but with shorter lag, between anyone's perception and bodily action during performance. There is a process delay between physical events and their representations as offered to perception; another process delay between percept and instruction to the motor apparatus; yet another delay between that instruction and the muscular response (due to the mass of the body and the load against which the body action is pitted); and, finally, a delay in the response of that on which the action is exerted, the physical change that is visually perceived. This sequence of delays imposes a significant lag between the perception-informed intention and the consequent action. Whereupon, with respect to fast, efficient and accurate progressive movement through the world, expert performance with our own bodies, we are in much the same situation as the car driver.

A modern treatment of this problem in the biological realm was done by J. MacDonald (1964) in an unpublished thesis at MIT. He analyzed the writing of signatures, which is usually done more speedily than the handwriting of text. Graphologists had already pointed out that the detection of forgeries could be done by examining the distribution of transients along the line of ink, and showing where transitions had occurred in the direction of the pen movement as well as in pressure of pen on paper. MacDonald considered that such handwriting is ballistic. The hand is thrown in one direction at a velocity determined by the mass and visco-elastic properties of the hand, its friction against the paper, etc., and then is changed in direction by another throw, timed to occur at the proper position in the trajectory, and so on. The sequence of throw instructions is pulsatile and accurately timed, given the responses of the hand muscles to pulse inputs, and the mechanical impedance of the moving hand by which the trajectory is smoothed. Supposing this, he designed a surprisingly good signature forger, whose operations predicted the change of signature under varieties of different load (e g., signing a name under water).

Later, Bizzi and his collaborators (1973 and Bizzi,1974) showed that practised accurate intended movements of the eyes and head, are ballistically controlled, as if designed to get the intended trajectory by accounting the active (reflex-governed) mechanical characteristics of the expressive coupling, the body. The evolution from tyro performance to expert performance seems to be in the learning of how to shift from attempted continuous running control to adept predictive ballistic control.

Looking at the relation between perception and intention, it is clear that an intention is defined in terms of some future state or state sequence of perception. The process of changing perception by intention can be called appetition (Leibnitz). In the appetitive process, the prediction of the coming perceptual state from the current perceptual state is done on an internal world model and is compared with the intended perceptual state. The difference between predicted and intended perceptions, taken as error, is represented by instructions designed to reduce that error.

Let us define a task as a specific intended state sequence in perception. Tasks can be combined to form a more complex task. The perceptual sphere is enormous, and the world is a contrived chaos. It is absurd to contemplate the notion of a task in which the intended perception is global. (Classically that is the province only of God, who sees everything at once and and acts on everything at the same time.) Because we have only one point of view which is determined by the locus of the body in the world, we can address only such parochial tasks as the body can accommodate. The intended perceptual states are defined with respect to particular objects and relations – e. g., catching a ball, chasing an animal, escaping a threat, finding a path through traffic,– in short, an interaction with an active world. But there are also tasks in which the world can be taken as relatively passive, changing in perception only as our intentions change it. The intention may be to resolve the current stable world state in some detail–e.g. by reading, or by looking for an object in a quiet scene. Or it may be to change the perceived state, e.g. by playing piano, rearranging a room, painting a picture. But whatever the conditions, and whatever the intention, the delay between intention and the intended change in perception requires that the appetitive instruction be predictive, even for so simple an expert act as moving the eyes to change the visual percept. We will hold that all such expert performance, on however elementary a level, is attained by practise, at least in us humans. Precious little expert performance is built in, as with insects. And the function of practise is to provide, through learning, that world model which enables prediction whereby perception can optimize its own trajectory of intended change.

There are proofs that in man-made, fed-back, goal- directed systems, with delays between the sensors and sense- informed control, as well as even more marked delays between control instructions and motor response, the easiest strategy for approaching optimum performance uses not only prediction to compensate the delays, but stepping or pulsatile instructions issued to the motors. Thus it is no surprise that in human expert performance instructions to the muscles have that quality.

The notion of a task entails that certain particulars in perception be more salient than others, weighted by relevance to the task. As remarked above, global tasks are implausible. Similarly, global detailed perception (as in Borges' "Funes, the Memorious") is paralyzingly useless. What is offered to perception is a detailed representation processed from the sense data. So long as perception simply weights some portions of the representation with respect to others, it does not alter the content which is determined solely by sense data. Such a weighting operation can be called "attention", a word that we will use loosely for the time being.

For efficiency in expert performance it seems reasonable to suppose that attentive weighting in perception can set what is useful to the task. That certainly accords with personal experience. Whereupon we assume, in an unargued leap, that expert performance involves a weighting strategy for perception itself. This would be a direct influence of appetition on perception. It does not use the loop through the external world, but weights perception to improve its intention-guided changes. We suppose that training for expert performance involves not only optimizing the strategy of instructing the body for some task, but also a strategy of shaping perception itself for what is relevant to the task.

Ordinarily, what is meant by "visual attention" is an intentional narrowing of the zone in which perception is clear and distinct. This can occur anywhere within about a 10 degree radius of the visual field. Practically, however, it usually means centering the axis of gaze on a part of the image in which detail of form and change in the detail is important. But, this view ignores the bulk of our use of vision.

Experience suggests that one can attend not only single things or small groups lying within a narrow visual angle of about 2 degrees but also arrangements of things in patterns that are spread more widely. In particular, if spatially separate things are moving quickly but as if somehow relationally connected by rules or patterns, the notion of sampling them separately by some sequence of foveation becomes untenable. Imagine driving through fast moving two- way traffic as an example in point. One cannot attend in detail to

a single car. The choice of a successful path through the traffic must depend on the changing pattern of relations of cars to each other under the assumption that their motions are not completely independent, e.g. that the drivers responsively see each other.

Alternatively, consider a sports broadcaster reporting a football scrimmage. Twenty-two men are engaged in a play that usually takes but a few seconds. Yet, the broadcaster not only tells who carried the ball, but who was blocked and by whom, who committed a penalizable move, and in general, provides far more important information than can be seen by a scholar-turned-football-buff viewing the same game from the stands. We must attribute to the reporter an attention in which the exact detail along the axis of gaze is not only mostly useless, but would distract from the more important patterns of action distributed over a fairly wide angle in the field of view. The reporter has learned the basic plays, and how they are embodied in configurations of the players prior to the action, and so reads, more easily than most of us, the actual events as departures from plan. In this way he uses prior knowledge to reduce how much information he needs to recount events in the scrimmage.

Without fussing about further refinement of this approach, we will now lay out two simple broad strategies of vision and call them the "scribe" mode and the "hunter" mode. In the scribe mode, attention is profoundly foveal, and objects rapidly become less clear and distinct as their angular distance from the fovea increases. In the hunter mode, attention is on the scene, and the gaze axis mainly sets a point in the scene as a kind of center of gravity around which events are occurring or expected. (Night vision below the photochromatic level – e. g., in bright moonlight – has this quality somewhat since the fovea is then a blind spot). In short, if the visual task calls for high local detail at a narrow region of a relatively stationary or slowly changing arrangement of objects in the field of vision, a scribe strategy is chosen. If the task calls for ruleful relations between more widely spaced moving things, the hunter strategy is chosen. This is an example of two task-determined strategies between which the observer can switch.

The notion that what is attended is clear and distinct, while what is not loses saliency, raises the issue, wherein lies the loss of saliency? The figure below provides the basis for the argument.

N   x   VHNEK

If you fix and hold your gaze on the x, the N on the left seems relatively clear. The N on the right, imbedded among other letters, is not clear at all.

(That this is not a function of left versus right in the visual field can be shown by turning the page upside down). The clarity of the solitary N on the left testifies that visual acuity is adequate at that angular distance from the fovea. Thus, the obscuring of the imbedded N has to be explained. The terminal letters of the group can be identified – the further one, surprisingly, is more definite than the nearer one. But it is as if the letters flanking the N prevent its being assigned a form. This property has been termed "lateral masking" in the literature (e.g. Bouma,1970; Mackworth,1965; Townsend et al.,1971). It increases in strength as the letters become more closely spaced or if the group is moved yet further out in the peripheral field. Another way of describing the impression of the letter string is that it has lost form and has become a texture, more or less in the sense of B. Julesz. One has the feeling that the perceived spatial order of the parts has been degraded while certain statistics of the image remain, so that there are distinct edges and corners, but where they lie with respect to each other and how they are connected is somehow obscured. That this is not a loss of information in early processing can be shown by "demasking" the interior N. If the letter string is flashed tachistoscopically with any figure except N flashed at the same time at the fixation point, the masking of the N is quite strong. But, if an N of the same font, size, contrast, and spatial orientation is flashed at the fixation point simultaneously with the string, the interior N stands out (Geiger and Lettvin,1986). The same is true in varying degrees for all other upper-case letters, save the plain vertical bar, "I". In the steadily shown image, steadily attended at the fixation point, a quick small vertical movement of an imbedded laterally masked letter demasks it.

What we suspected is that, among readers, the sharp increase of lateral masking with eccentricity of the letter string from the fixation point is a learned strategy. Even a single letter, if more complex than a simple vertical bar, shows lateral masking between its parts.

Among readers, there is also a sharp fall-off in recognition as single letters or figures are displaced increasingly peripherally from the axis of gaze. The shape of this decline in recognition with eccentricity – the Aubert-Foerster law (1857)– has been taken as a sturdy and primitive observation for over a century. No one seems to have noticed that the subjects were predominantly readers. Students and colleagues are cheap and cooperative.

When severe dyslexics are so tested for decay in recognition of a letter or figure as a function of its eccentricity from axis of gaze and its imbedding among other letters and figures, they show three remarkable features. First, lateral masking seems less marked than for ordinary readers, between 5 and 10 degrees in eccentricity to the gaze axis. And recognition of eccentric single

letters is best there for dyslexics. Second, lateral masking becomes relatively more marked as the eccentricity drops below 5 degrees and the recognizability of single letters or figures does not improve, or may even drop. Third, the loss in recognizability of single letters or figures as they are moved further eccentrically is a much less steep function of eccentricity than among ordinary readers. (These tests were performed originally with displacement of the letters and letter strings to the right of the fixation point, i.e. in the right field. When the left field was tested, there was little difference between ordinary readers and severe dyslexics. However, with Hebrew readers and dyslexics, there is reason to believe that the asymmetry is reversed, though we have too few observations to say this firmly).

In lateral masking, the reduction of form to texture has this quality: there are "features",by which we mean those primitives used to characterize forms. Let us suppose, for the moment, that they are the "textons" which Julesz and Bergen (1983) use in their description of texture elements. In perceiving a form, we see these component elements connected in a particular arrangement and spatial sequence. The form has handedness, orientation, and is clear and distinct. In perceiving the same arrangement texturized, we see the same component elements, but cannot assign them that connecting order which determines a form. If this transition between an aggregate, described statistically, and an arrangement, described geometrically, can be simply governed, i.e. if it is possible to shift between texture vision and form vision, then, one of the controls that appetition exerts on perception can be accounted for. It controls form-texture conversions. This would not introduce content into perception, but only weight the content that the perceptual process provides from the sense-data.

The notion of task-determined control of perception can be realized by such a scheme. Returning to the scribe/hunter paradigm, the scribe, whose action is confined to a narrow angle in the field of vision, practicing to become expert, introduces as a result of practice a degenerative lateral masking outside that angle. He uses the fovea, which is engineered for highest acuity. The hunter, whose action depends on a distribution of possible events over a wide angle in the field of vision, introduces, under practice, lateral masking in the fovea to suppress the excess of form resolution there. Instead he uses the fovea to set a barycenter around which he attends patterns of related change.

The common experience of driving in traffic testifies to the alternation between scribe and hunter states – instants when one glances at a road sign versus stretches when one is concerned with the ambient flow of cars. But this is anecdotal. A more careful experiment was done several years ago. It was shown that foveal vision is suppressed during a saccade. If a strobe light is made the sole illuminant in a dark room, and made to flash only in the middle of a large saccade, a reader finds it impossible to read even a newspaper headline when its image falls on the fovea during a saccade. (The subject quickly learns how to center the text on the fovea at the instant of the flash). The headline is there, but has the same textural quality that is observed in an eccentric letter strings (like in the previous demonstration) .What is interesting, however, is that after the subject tries to read for about a quarter-hour under this abnormal lighting, quite suddenly the reading ability returns as if the foveal "suppression" had been switched off.

Many sources provide impressive testimony for the proposition that practiced performance involves not only a change in the course of action, but also a change in the perceptions guiding that course. These changes can be attributed to practised task-determined strategies, and such strategies are mutually exclusive. We will cite only two references in support of this notion.

Ivo Kohler (1962) outfitted active subjects with spectacles that inverted the field of vision. After a few days of continuously wearing them, the subjects could negotiate well through their environment. By the end of the month, they could fence, ride bicycles through traffic, and indulge in active sports. They reported that the seen world seemed "right side up". When the spectacles were first removed after the month of wearing them, the seen world appeared "upside-down" at first. What is important here is that for over another month after the spectacles were removed, the seen world switched between right side up and upside-down – two mutually exclusive states – with the upside-down states becoming more infrequent until they vanished.

Richard Held and Alan Hein (1958) set a grid on a table top, and attached a sheet of paper underneath the table. Their subjects sat with arms hidden beneath the table and marked under the table where the intersections were on the upper surface. They did quite well. Then, while their arms stayed hidden, they were outfitted with prismatic spectacles that displaced the seen world laterally. Accordingly, the marks were displaced with respect to the intersections. Held and Hein then brought out the marking arm of the subject and moved it around as a passive object in the visual field about a hundred times. The subject saw the arm as displaced over where the position sense affirmed it to be. But, when the arm was replaced under the table, the error in marking intersection positions was not much affected. Then, the subject brought out the marking arm actively and moved it about, rather than having it moved passively. Now the error in marking the intersection positions was corrected. The point here is that abstract knowledge of error is not enough; coordinated

hand-eye motor practise is needed to correct error.

Such experiments testify that visual perceptions are molded by practise in a variety of ways that do not alter the content of visual perception, but provide it with a frame in which the other senses determine the nature of the space in which intention can be realized. What our experiments may contribute is that the content of visual perception can be differentially weighted within the visual field, without altering the content, so as to facilitate task-performance.

These notions, cursively and indirectly presented, and admixed here with indirect observations, lay at the basis of designing the experimental work to be reported, and enter strongly in the interpretation of that work.

We now report the studies.

EXPERIMENTS.

In order to show the differences in visual strategy between ordinary readers and dyslexics, we designed two tests. In one, we measured how recognition of single letters falls off in the visual field with increase of angular distance from the axis of gaze. In the other we used strings of letters rather than singlets to note differences in lateral masking as eccentricity increases away from the axis of gaze.

The First Test: Form-Resolving Field (FRF)

The form-resolving field (FRF) is that portion of the visual field in which forms, presented tachistoscopically, are recognized to one degree or another. We operationally defined the FRF in the following way: In a test flash (as described below under "methods") the displayed letters are presented at some fixed angular size and contrast against a background of fixed luminance. Once the flash duration is chosen for a subject it is held constant for the run of measurements. The displayed letters are changed with every flash, and their angular distance from the gaze axis can be varied. Two letters are exposed in each flash, one at the fixation point (the center of gaze), the other at some angular distance in the peripheral field. The two letters are never the same. Both are to be identified by the subject immediately after the presentation. When about twenty such exposures of different letter pairs have been delivered at one eccentricity, the eccentricity is changed and a new series of twenty is presented.

After the tests in all eccentricities are finished we plot the percentage of correct identification of the peripheral letters as a function of eccentricity. This plot is the FRF. It is not a measure of acuity, as will be evident later. What is at issue is the recognition of form rather than the resolving power.

<u>Aparatus and Stimuli:</u> Three slide projectors were focussed from behind on a framed translucent diffusing screen 35 cm. long and 23 cm. high. Each projector was set to give a uniform illumination across the screen at 180 cd/sq.m. as measured at the front of the screen. The projectors were operated in the time sequence shown by figure 1.

One projector used a blank white slide with only a small black dot on it to give a fixation point on the screen. The second projected the stimulus slides. The third projected the "eraser" slide, which in this case was completely blank. Each projector was occluded with an electrically driven shutter that opened or closed within 5.5 ms. The opening and closing of the shutters were electronically timed to give smoothest transition between the projections of the fixation point slide and the stimulus so that the transition transient was minimized. On each stimulus slide there were two letters. One at the fixation point and another eccentric to the left or right along the horisontal axis. Several eccentricities were used, with twenty stimulus slides at each eccentricity.

No two letters on any slide were the same, and no two slides were the same. All eccentricities are given in terms of visual angle away from the fixation point.

<u>Procedure:</u> In the stimulus sequence as shown in figure 1, the effective stimulus duration (from onset of the stimulus until the onset of the eraser) was adjustable. It always has been less than 10 ms. long. The eraser was on for 2.5 seconds. After the eraser went off the sequence started from the beginning. The fixation point stayed on while the subject reported.

The stimulus exposure duration was adjusted in such a way that the best score of identification (at whatever eccentricity of the peripheral letter that gave the best score for the subject) lay just below 100%. This normalization procedure is best suited for form resolution since this normalizes sensitivity in form identification and not the sensitivity to contrast or lightness[1].

The stimulus exposure duration was set prior to the test itself. Once the best duration was determined for a subject it was fixed for that subject

[1] In another study we measured correct identification when stimuli exposure durations were equal for all subjects. The results were similar to the ones obtained with this normalization, but were less distinct.

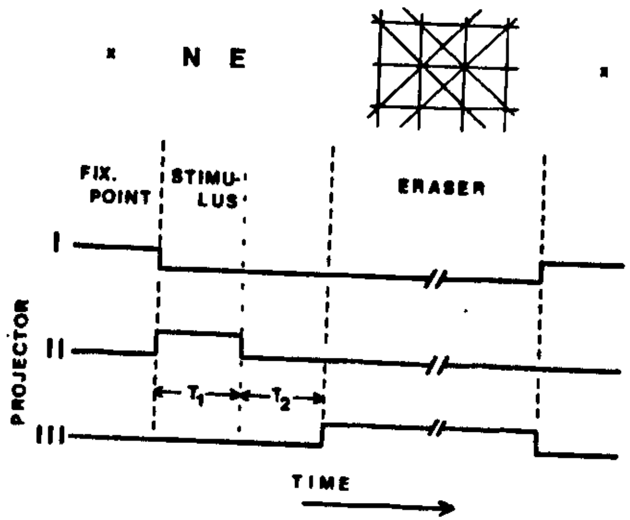

Figure 1. This is a schematic drawing of the sequence of events for a single stimulus. Top part of the figure show the events on the screen. Reading from left to right, at first a fixation point is presented (by projector I). Except during a test this slide is constantly on. In a test the shutter in front of projector I shuts as that in front of projector II opens for short interval, T_1, to present the stimulus image. T_1 is followed by a second interval, T_2, when no projection plays on the screen. The stimulus duration is counted as the sum of T_1 and T_2. This sum is adjustable but never was longer than 10 ms. In the first test,(single letters to show the FRF), and it was 61 ms in the second test,(letter strings to show the effects of lateral masking). Folk..ing the interval T_2 the eraser goes on (projector III) for 2.5 seconds. In these tests the eraser consists of a blank lit screen. Following the eraser a new cycle starts after the subject reports.

throughout the test at all eccentricities. After each stimulus presentation, the subjects reported what letters they had seen and which was at the fixation point, which in the periphery. The report was recorded and the next stimulus was given. Once all slides for all eccentricities had been presented, the percentage of correctlly identified letters at each eccentricity was determined.

The centering of the subject's gaze on the fixation point was visually monitored by the experimenter. This crude monitoring was sufficient, as some later instrumental verification has shown.

Subjects: All subjects were above 18 years old. All but two of them were completely unaware of the purpose of the tests until the testing was finished. Three groups were tested: ORDINARY READERS: This is a group of 10 ordinary readers (3 females and 7 males), all between 18 and 25 years of age with one exception. The subjects came from the general university-level student population. RESIDUAL DYSLEXICS: This is a group of 9 students (3 females and 6 males) who are dyslexics. All came from a college where they were enrolled in a special program for those with reading and learning difficulties. Each had received special tutoring for at least 3 years prior to the testing. All had improved reading skills due to the tutoring. All were between 18 and 23 years of age. DYSLEXICS: This is a group of 10 dyslexics (2 females and 8 males) who did not have special tutoring within the last 3 years. They were between 20 and 58 years of age. All the dyslexics were diagnosed as such by their respective neurologists, psychologists and teachers. They all showed a normal level of comprehension of heard texts, but all had serious difficulties in reading. The group of residual dyslexics showed significantly better reading skills than did the dyslexics.

Results of the Test: At the end of testing all the subjects, the scores of correct identification were gathered and averaged at each eccentricity for each separate group . These avereges are plotted in figure 2 to show the FRF's of the groups.

In general the FRF falls off with eccentricity from the center of gaze. However, there are obvious differences in the shape and the grading of the fall-off.

In the right hand side of figure 2 three curves are plotted; one for ordinary readers, one for the dyslexics and one for a severe dyslexic. From these curves we see that ordinary readers and dyslexics are significantly different at all eccentricities except at 5 deg. (we have performed the ANOVA and t-tests). Therefore it is safe to say that these are two distinct groups under this test. The scores for the residual dyslexics and for the dyslexics were very similar except very near the center, therefore we do not show them. (Very near the center the score for the residual dyslexics lies in the middle between the scores of the ordinary readers and the dyslexics.)

The differences between the dyslexics and the ordinary readers are twofold. Dyslexics identify letters further in the periphery than ordinary readers do. Also, dyslexics identify letters better at 5 deg. eccentricity than they do nearer to the center under the conditions of this test (i.e. a letter at the center

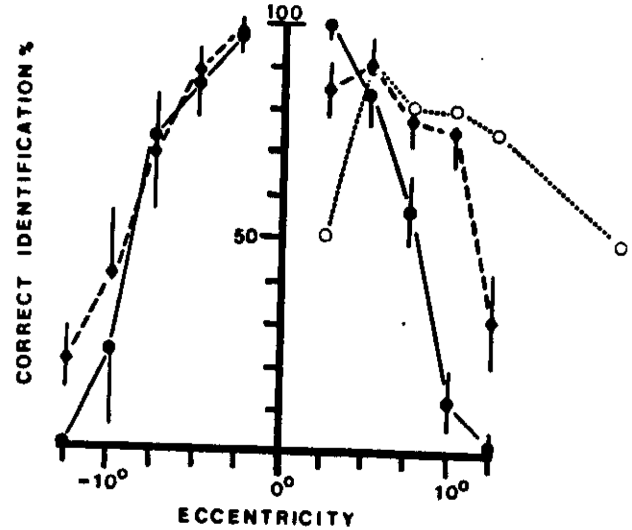

Figure 2.This figure displays the Form-Resolving Field (FRF) of ordinary readers ● , of dyslexics ◆ and of a severe dyslexic ○ . The measures are of % correct identifications of the letters at different eccentricities in the periphery. Vertical bars show the standard deviations. The scores for the letters presented at the same time at the fixation point are constant for all eccentricities (95%+or-4%) and are not given here. On the right side of the figure, the measures for the ordinary readers and the dyslexics are significantly different, except at 5 degrees eccentricity. Near the center (2.5 deg.), the two letters presented simultaneously are laterally masking each other for dyslexics whereas they do not laterally mask for ordinary readers. The best score for readers is nearest to the center of gaze. But the best score for the dyslexics is at 5 deg. to the right of the center of gaze. The dyslexics have better recognition than do ordinary readers for letters further in the periphery. No such marked differences in FRF appear on the left side of the figure, corresponding to the left visual field. That is because the subjects had English as their native language. (cf. later in text).

and the second one in the periphery). This is in contrast with ordinary readers who identify letters best at the center and have an FRF that falls off monotonically to the periphery.

The differences between ordinary readers and dyslexics in the center of vision was reported by Bouma and Legein (1977). They showed that dyslexics have worse recognition of aggregates of letters than do readers in the fovea and parafovea (2 deg. eccentricity), although both groups recognize single letters equally well. The presence of the letter at the fixation point alters the recognizability of the nearby eccentric letter.

As this test is a measure of the form-resolving field we are able to say that ordinary readers have a narrower FRF than do dyslexics. The shape of the FRF in dyslexics shows a peripherally displaced peak. That is, lateral masking occurs near the center of gaze, a peak of "best vision" shows up in the near periphery, and the FRF falls off shallowly with further eccentricity. In contrast, among ordinary readers the FRF falls off steeply, smoothly and monotonically with eccentricity from the center of gaze. The implications are that ordinary readers are able to discern forms (single or aggregates) best at the center of gaze (fovea), whereas dyslexics discern aggregates of forms best in near periphery but have lateral masking at the fovea.

The left side of figure 2 shows no significant difference between ordinary readers and dyslexics. The shape of the fall-off of identification on the left is monotonic and steep for both groups. But the fall-off is steeper on the right for ordinary readers than on the left, and for dyslexics is clearly much shallower on the right than on the left. We attribute the differences between left and right in ordinary readers to the conventions of reading. (The basis for this guess is that two readers, for whom Hebrew is the native language, have shown the opposite asymmetry.)

These measures of the form-resolving field (FRF) are well correlated with ability to read. The reader has a narrow FRF and a most clear vision around the center of gaze, as is needed for usual reading (we do not talk here about speed reading). On the other hand, not having that kind of FRF seems connected with difficulties in reading, as manifest in the dyslexics.

As also can be seen, what the FRF measures is certainly not what is ordinarily meant by "acuity". We do not hold that there is a difference in peripheral acuity between ordinary readers and dyslexics. Instead the difference lies in the perception of forms and not in the resolving power, as is suggested by the figure used in the introduction.We suspect that the differences are accountable by different strategies in the distribution of lateral masking. With single letters (not "I") the parts of a letter exert masking effects on each other. We can call this self-masking. If ordinary readers and dyslexics differ in FRF we propose to explain the difference in terms of distributions of lateral masking and self-masking.

Experiments on demasking (Geiger and Lettvin, 1986) have shown that only "complex" letters are demasked (non-annular letters comprised of more than a single bar). Single bars can not be demasked, while annuli are not easily masked Thus it is reasonable to think of parts of a letter masking one another in much the same way as one letter laterallly masks another.

We have been mentioning that the lateral masking at the center of gaze, such as occurs in dyslexics, looks similar to the lateral masking in the peripheral field had by ordinary readers. It remains for us to show how ordinary readers and dyslexics differ in lateral masking.

The Second Test: Lateral Masking Between Letters in a String.

The apparatus and methods are the same as for the FRF test. The differences lie in the nature of the stimuli and the duration of the stimulus-exposures. In this test four letters are presented in each stimulus (instead of two as in the previous test). One letter is at the fixation point and a string of three letters is in the periphery. All letters in each stimulus display are unlike each other. As in the previous experiment no two slides are alike. The strings in the periphery are displayed at various eccentricities in the various slides. Duration of the stimulus exposure was 61 ms. for all subjects.

Figure 3 presents the data by which to compare nine dyslexics with five ordinary readers. At each eccentricity of the string we give identification scores for each locus along the string (first, middle and terminal letters).

Some general properties of lateral masking are seen in the plots for ordinary readers: Masking increases with eccentricity; it is least effective for the terminal letter of the 3-letter strings and strongest for the middle letter. These properties are generally preserved for the dyslexics. However, there are some differences. a. Near the center the masking of the first, middle and last letters are about the same for dyslexics and for readers; but at 10 deg. eccentricity the middle letter is significantly less masked for dyslexics than for readers. b. The variance of the masking of the middle letter at string eccentricity of 10 deg. is larger for the dyslexics.

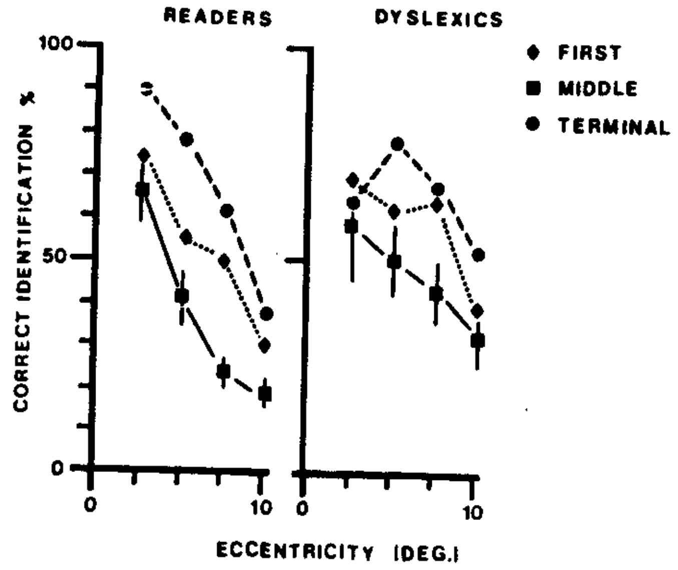

Figure 3. The graphs show the strength of lateral masking as it varies with eccentricity. Ordinary readers are compared with dyslexics for correct identification of each letter in 3-letter strings that are presented at various eccentricities. The % of correct identification at each locus along the string is given separately. The loci are marked first ◆ : second ■ : and last ● . Masking generally increases with growing eccentricity. However, the increase with eccentricity in the lateral masking of the middle letter is signifcantly shallower for dyslexics than for ordinary readers. That is, the lateral masking of the middle letter when the string is near the center is about equal for both groups with that for dyslexics being somewhat stronger. But at 10 deg. eccentricity the lateral masking of the middle letter is significantly stronger for readers than for dyslexics. The vertical bars (given only for the middle letter) denote the standard deviation. The variation of lateral masking is larger among dyslexics.

Learning Visual Strategies.

The results of the two kinds of test, as described above, suggest differences between readers and dyslexics in the distribution of certain perceptual

processes over the visual field. The differences become magnified when severe dyslexics are examined. In the case of the severe dyslexic, whose FRF is shown in figures 4 and 2 (dotted line) and the test for lateral masking gave the plots graphed in figure 5a.

In figure 5a we show, for this severe dyslexic, the initial results of measuring lateral masking as a function of eccentricity. At 2.5 deg. eccentricity his score for all the letters in the string was almost zero. At the same time his score for the fixation letter also went to zero, as if the mutual lateral masking was extremely intense in the region around the center of gaze. With respect to this test he acts as if he had little or no form vision of aggragates in the fovea and parafovea. However at 7.5 deg. and 10 deg. he performed as if there were little lateral masking and little loss of letter recognition (as evident also from the FRF in figure 4). In this respect he was superior to readers in his peripheral vision. Such a case might raise the suspicion of some organic deficit in retinal function at the fovea were it not for the fact that so long as the background was blanked up to 5 deg. away from the center of gaze, he had normal vision for single letters presented in the foveal field.

At this point, using the line of thought sketched in the introduction, we asked if it would be possible for this severe dyslexic to learn a new visual strategy that would permit him to read. Whatever set of visual strategies he possessed, if there were indeed such a set, excluded reading at and around the center of gaze. Thus no use of his existing set of strategies could be made in teaching him to read, because no reinforcement could occur in the foveal region. Since his FRF as well as his performance with the tests on lateral masking showed that his near peripheral vision had acuity adequate to reading, we decided to probe whether he could acquire a strategy for reading in the peripheral field of vision. If he could, and our tests measured something that correlated with visual strategy, then a retest after acquisition of the new strategy would show the change. Our hopes were based on the well-known phenomenon of speed-reading which implied that peripheral vision might be adequate to the task.

He was the first subject on which we tried the learning of a new strategy. The program we tried on him is described below in the protocols for training four dyslexics. It must be emphasized here that we were not and are not proposing a therapy. We are only testing the hypothesis that a new visual strategy can be learned if it does not compete in the domain of other firmly set strategies, i.e. it would not be advisable to train for foveal reading if the consequences of his existing strategies are that he masks in the fovea. He would than have no success by which to reinforce a new strategy by practise.

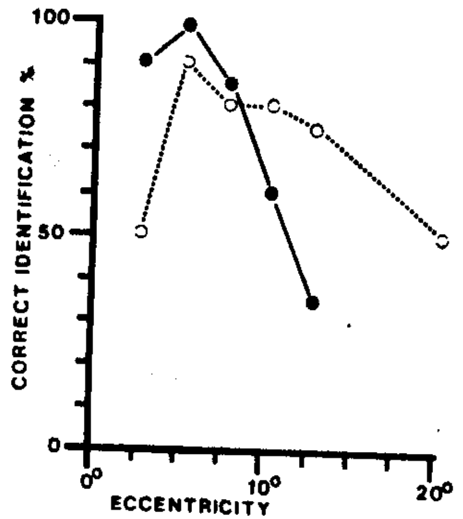

Figure 4: The initial plot of the FRF on a severe dyslexic is compared to the plot of FRF taken four months later (solid line), after the practise described in the text.

If, as we felt, the two tests, given above, measure some properties related to visual strategy, retesting after successful training, should it occur, would reflect the introduction of the new strategy.

He responded to the procedure, and, within four months went from what might be called a third grade reading level to about a tenth grade level. In practical terms he was able to take a job in which he had to read memos, bills of lading, and the like. When tested at the end of four months he showed the change in FRF graphed in figure 4, and the change in lateral masking shown in figure 5b. Note that in figure 5b he can now make out letters in strings presented at 2.5 degrees eccentricity. His performance at that eccentricity is not as good as that of an ordinary reader or residual dyslexic, but is far better than in the initial test. Curiously, in now reporting the letters at that eccentricity, he stuttered.

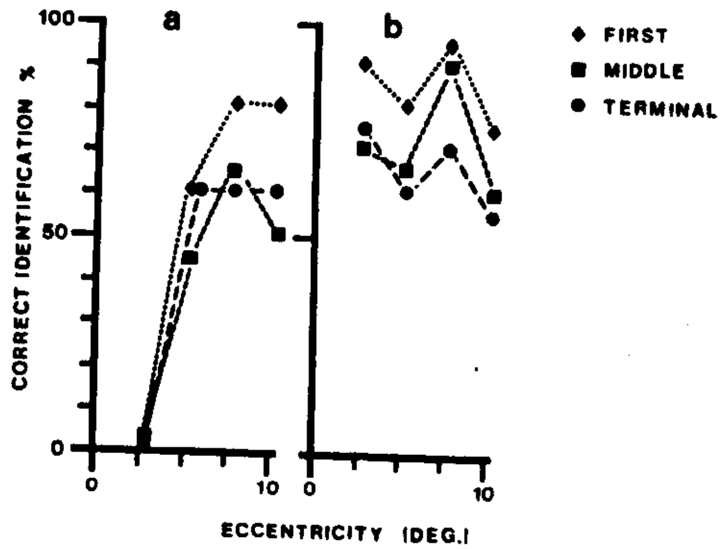

Figure 5: a.) This graph of lateral masking against string eccentricity (done as in figure 3) plots the initial performance of the same severe dyslexic as in figure 4. b.) This graph shows the performance of the same subject four months later after the practise described in the text.

There is no point in describing further what the picture makes clear, and so we will go on to lay out the general method for testing the hypothesis.

We asked four of the dyslexics (part of the group of 10 and including the severe dyslexic just described) to participate in a program aimed at their learning a new strategy. After we characterized each of the 4 subjects with the two tests, we advised them to devote two hours every day to the performance of novel, direct, small-scale, hand-eye coordination tasks such as drawing, painting, clay-molding, model-building, etc.. The rationale for this practise comes from experiments performed by Held and Gotlieb (1957), Held and Hein (1957) and remarks by Helmholtz (1867) on how a person shifts spatial localization after viewing his hand through a prism. These and related observations are given at the end of the introduction to this paper. The general idea was to provide visual perception with a new space of operation as defined by the new tasks.

Alongside this practise the subjects were to try reading through a window in the peripheral field. A sheet lay over the text to be read. It could be transparent and colored, or translucent, or opaque. On it lay a fixation point or mark. At the right of that mark a window was neatly cut to a size somewhat larger than the length and height of a long word in the text. The distance from the fixation point to the center of the window was set individually for each subject by using the eccentricity of the peak of the FRF and the eccentricity at which there was a drop in lateral masking of the middle letter in a string.

When the subjects intended to read they were to lay the window over the desired word or words in the text while gazing at the fixation point and try to read what lay in the window. Keeping gaze on the fixation point they then shifted the sheet so that the window lay over the next word, and so on. In this way the words in the window might be seen as form rather than texture, without interference from the ambience.

After a few months (2.5–4) with this combined practice we again measured the FRF curves for each of the four subjects. We measured the lateral masking curves afterwards on only the severe dyslexic described above. We also inquired about, but did not measure, their reading skills. Figure 6 shows the averaged FRF for the four subjects before and after the practice term. For comparison, the curve for ordinary readers (from figure 2) is also displayed.

We should remark that the four subjects were not chosen by us. They were the only candidates among the 10 original subjects who could afford the time to practise daily. We did not instruct or guide the subjects more then by occasional telephone conversation.

As seen in figure 6 there is a significant shift of the FRF from before practice to after practice. The shift is toward the FRF of ordinary readers. Ordinary readers do not vary significantly in FRF over time although we measured some over periods of 2 years and longer.

In general the reading performance of all the four improved much. The reading score of one went from 3rd grade before practice to 10th grade after practice. Another subject went from hardly reading at all (about 2nd grade) to reading fluently for half an hour at a time (difficult to estimate grade level). Another went from spells of slow reading for five minutes at a time to spells of reading fluently for hours at a time.(So he reported). The fourth initially could only skim fast (like speed reading) with many errors. He had no ability to read slowly and with care. After the course of practise he was able to read "word by word" as well as by skimming.

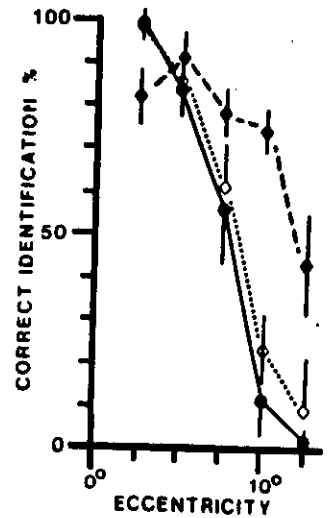

Figure 6. Graphed here is the effect of learning and practicing a new strategy. Plots of the FRF are averaged for a.) ordinary readers ● (taken from figure 2) ; b.) four dyslexics ◆ prior to the practise described in the text; c.)the same four dyslexics after that practise ◇ . The bars measure standard deviation.

Three of the four stopped practising after they had achieved some skill, and fairly quickly regressed in their ability ro read. This change was also reflected in their FRF's.

<u>An Unusual Case.</u> As a final note we want to describe an unusual case in some detail. This subject is a male 30 years of age. He has the peculiar complaint that while he can read facilely when he is "alert", he is unable to read or reads with great difficulty when he is "tired". When he is extremely tired he is able to "speed read" or skim a newspaper with good comprehension of the text, but he is unable to read in a "usual" way.

We interviewed him and tested him in two of his "phases", the alert one (mostly occurring in the mornings) and the tired one (in the same afternoons). We did not test him in the extremely tired phase.

When he was in the tired phase he appeared to be markedly dyslexic. He had high level of comprehension and intelligence. He seemed generally alert in his tired phase and without optical defects, but could hardly read. In the alert phase his reading was good for long spells of time (over an hour), with the usual speed of reading and with only an occasional stumble over an unfamiliar long word every now and then.

The measures of his FRF in these two phases are shown in figure 7. On the right side of the figure, one of the plots matches nicely the FRF of ordinary readers. These data were taken when he was in the alert phase. The other plot was taken when he was in his tired phase. It falls off shallowly with eccentricity and so extends further into the peripheral field. It resembles that of the dyslexics. On the left side of figure 7 the differences in the plots are small although a slight extension of the FRF into the periphery is evident for the tired phase.

Figure 7 shows a clear relation between measures of the FRF and the task-competence reported by the subject. In the light of his subjectively distinct states we can suppose him to be a conditional dyslexic whose states can be told by objective testing. He switches between these states for some not very obvious reason. In the tired state he is not fatigued—he uses the term to describe only his inability to read; otherwise he is alert and competent. That this is not a problem of acuity is driven home by the fact that these states are in the same individual. If his acuity is improved for peripheral vision, can the same change in optics worsen his foveal acuity, if one supposes that his physical optics have somehow altered? Alternatively, can one suppose that his retina has changed its connectivity somehow? Has he changed his linguistic ability? If so, what tests could be used to distinguish his clearly reported states? Has he altered the anatomical connections in his brain?

After we had made our measurements on this subject and explained to him our notion of task determined strategies, he succeeded in teaching himself to use the wide field (dyslexics') strategy when he was alert (in the morning). He was doing it because he knew that creative art work is easier for him when he was tired, but, when he needed to do creative work when he was alert he had switched to the tired mode by his own will. The reverse shift, from tired strategy (wide FRF) to alert strategy (narrow FRF), he is unable to do.

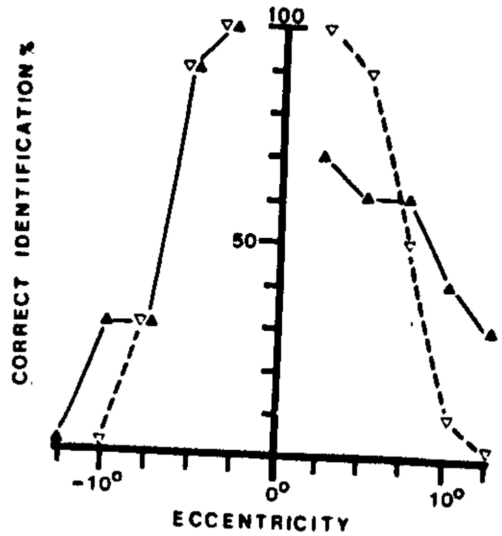

Figure 7. Two strategies in one subject are measured within a few hours interval. One FRF was taken when he was in an alert phase (mostly in the morning) ▽ . The other FRF was taken 6 hours later when he was in a tired phase ▲ . In the alert phase this person was an able reader and in his tired phase he was unable to read. On the right hand side the alert FRF falls off steeply with eccentricity as with ordinary readers. In the tired phase the FRF falls off more shallowly with eccentricity and resembles that of the dyslexic.

CONCLUSIONS.

We have presented evidence for the existence of alternative states or strategies in visual perception. These strategies can be tested by measuring recognition of figures or letters as a function of eccentricity from the gaze axis. They are also tested by measuring the strength of lateral masking as a function of the same eccentricity. By both these sorts of tests there are marked differences between ordinary readers and dyslexics in the peripheral field of vision. These differences cannot be laid to changes in visual acuity between subjects for two reasons: first, they can be altered by certain kinds of practise; second, they can be demonstrated in the same subject (one case) at different times of the same day.

In the strategy of the ordinary reader, best vision is around the axis of gaze. Lateral masking increases steeply with eccentricity from the gaze axis as does loss of letter recognition. In the visual strategy of the dyslexic there is masking around the center of gaze and best vision occurs a few degrees to the right of the gaze axis (if the language is English). Loss of letter recognition beyond that peak increases less steeply than for ordinary readers.

A dyslexic can be trained to read in the peripheral field of vision. This training does not challenge a prior strategy which masks letter strings in the foveal region. (Such masking does not allow that reinforcement needed to practise the foveal seeing of letter strings). When he is practised in reading by peripheral vision, the test signs of his visual strategy, when plotted, approach the plots found for ordinary readers.

The training of reading in the peripheral field is not to be construed as a therapy. It was done to probe the hypothesis that task-determined visual strategies can be learned, and that the presence of a new strategy can be detected by testing. While a therapy may possibly be based on this demonstration and the reasoning that led to it, we emphasize again that the demonstration was meant only to test a notion, not to cure a disorder.

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