



Temporal integration of visual form information in adult dyslexia
by Roberta Lee Winters

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Psychology
Montana State University
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Abstract:

Temporal integration of visual form information in dyslexic and nondyslexic adults was investigated to determine whether the dyslexics demonstrate problems in temporal integration similar to the problems that have been found in childhood dyslexia. Using procedures derived from signal detection theory, sensitivity to sequentially presented form information was determined for the two groups. The principle result of this study was that the sensitivity of the normals to sequencing was superior (i.e., better temporal acuity) to that of dyslexics when parts of a stimulus were presented contiguously in space. This result suggests that, under certain conditions, temporal processing of form information is slower within the visual systems of dyslexics. Based on this result, it is concluded that a temporal integration deficit exists in adult dyslexia which is similar to that found in childhood dyslexia.

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A thesis submitted in partial fulfillment
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Bozeman, Montana

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ABSTRACT

Temporal integration of visual form information in dyslexic and nondyslexic adults was investigated to determine whether the dyslexics demonstrate problems in temporal integration similar to the problems that have been found in childhood dyslexia. Using procedures derived from signal detection theory, sensitivity to sequentially presented form information was determined for the two groups. The principle result of this study was that the sensitivity of the normals to sequencing was superior (i.e., better temporal acuity) to that of dyslexics when parts of a stimulus were presented contiguously in space. This result suggests that, under certain conditions, temporal processing of form information is slower within the visual systems of dyslexics. Based on this result, it is concluded that a temporal integration deficit exists in adult dyslexia which is similar to that found in childhood dyslexia.

INTRODUCTION

Dyslexia is a specific learning disability that involves an inability to read, integrate, or interpret the written language (Pavlidis & Fisher, 1986). It has been estimated that 5 to 10 percent of the population are afflicted with the condition (Hynd & Hynd, 1984), and that it occurs in all parts of the world (Rawson, 1986). For those so afflicted, dyslexia can exact a severe cost in terms of retarding intellectual and social development, for the ability to read and understand the written language plays an important role in determining whether one succeeds both academically and socially. This is evidenced by the large number of dyslexics who are either unemployed or underemployed and by the disproportionately large number who are found in juvenile or adult correctional institutions (Johnson & Blalock, 1987; Scheiber & Talpers, 1985).

Because of the debilitating effects of dyslexia, it has attracted considerable research since its discovery by Orton (1925). This research has led to the development of two models of dyslexia, the linguistic deficit model and the sensory deficit model. As implied by their names, these two models differ in terms of the presumed location of the underlying impairment within the visual pathways involved in the reading process. A relatively peripheral impairment is assumed by the sensory deficit model whereas a relatively central impairment is assumed by the linguistic deficit

model. In order to discuss these models, it is necessary to briefly review the structure of the primate visual system. Following that review, the models of dyslexia will be discussed.

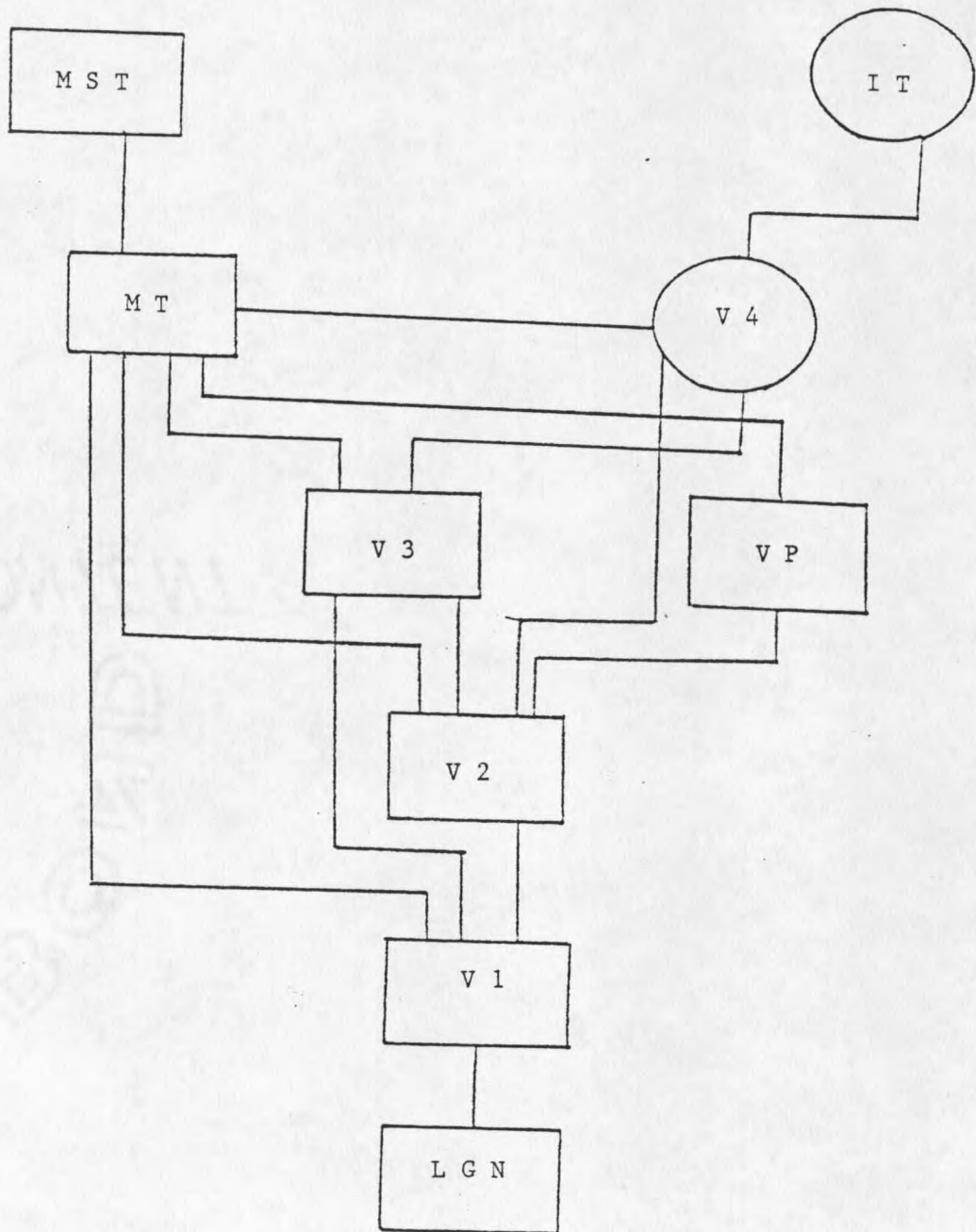
Since the early 1950's (e.g., Kuffler, 1953), it has been known that the firing rate of a given sensory neuron within the visual pathway can be influenced (i.e., increased or decreased) by stimulation of a limited area across the surface of the retina, an area referred to as the receptive field of that neuron. Receptive fields and their corresponding neural substrates have been conceptualized as "channels" that filter the visual scene along varying stimulus dimensions (e.g., Braddick, Campbell, & Atkinson, 1978; Maffei, 1978). For example, with respect to spatial vision, large receptive fields correspond to large spatial channels, which provide a coarse neural representation (i.e., global details) of the visual scene. Small receptive fields, however, correspond to small spatial channels, which provide a fine neural representation (i.e., fine or local details), of the visual scene. Depending upon their location within the visual system, the characteristics of receptive fields can vary along several other dimensions as well, such as preference for certain shapes (e.g., spots, lines, angles, even faces), colors, and motion.

For example, the receptive fields of neurons at the retinal and thalamic (LGN) stages of the primary visual pathway are circularly shaped. Based on this finding, it has been postulated that simple features of visual stimuli (e.g., spots of light) are extracted and encoded at this stage. Neurons at the cortical stages, such as areas

V1 (the striate cortex) and V2, have receptive fields that are elongated, which suggests that these neurons extract and encode such stimulus features as lines (e.g., Hubel & Wiesel, 1962; Hubel & Wiesel, 1965; Hubel & Wiesel, 1977). Finally, the receptive fields of neurons located at the highest visual centers, such as the inferotemporal (IT) cortex, are shaped like hands and faces, which suggests that these neurons perform complex tasks such as face recognition (e.g., Bruce, Desimone, & Gross, 1981; Gross, Rocha-Miranda, & Bender, 1972; Kendrick & Baldwin, 1987). These results have been interpreted (e.g., Hubel & Wiesel, 1977) as evidence for the idea that the processing of visual information along the primary pathway is hierarchical, such that the latter, more complex, stages are derived from and dependent upon the functioning of earlier stages.

In addition to being hierarchical in nature, the primary pathway is also organized in parallel: there are both transient and sustained pathways (see Lennie, 1980, for review and Figure 1). The transient pathway consists of neurons with relatively large receptive fields that require brisk stimulation for those neurons to be activated. This pathway originates in the magnocellular layers of the LGN, passes through V1, next the middle temporal area (MT), and terminates at the higher cortical centers (the medial superior temporal area) believed to be involved in the initiation of such responses as eye movements. It is hypothesized that this pathway detects motion and/or high temporal frequencies within the visual scene.

FIGURE 1. A Summary of the Hierarchy of Many of the Visual Areas in the Macaque Monkey (after Van Essen & Maunsell, 1983)



The sustained pathway, on the other hand, consists of neurons with small receptive fields that require sustained stimulation for those neurons to be activated. This pathway originates in the parvocellular layers of the LGN, passes through areas V1, V4, and VP, and terminates at the higher cortical centers (e.g., the IT) believed to be instrumental in form and pattern recognition (e.g., Burbeck & Kelly, 1981; Tolhurst, 1973; Wilson, 1978).

The process of reading has been conceptualized as a series of visual information processing tasks. These tasks begin at the lower stages of the primary visual pathway and terminate at the higher cortical centers (e.g., Wernicke's area) devoted to processing the phonetic and semantic properties of linguistic stimuli (e.g., Arnett & DiLollo, 1979; Fisher, 1980; Gibson & Levin, 1975; Howell, Smith, & Stanley, 1981; Whyte, Curry, & Hale, 1985).

With respect to the models of dyslexia, the linguistic deficit model argues that dyslexia is the result of a failure of the higher linguistic centers to adequately recode the sensory characteristics of visual stimuli into the appropriate linguistic code (Bouma & Legein, 1980; Ellis, 1981; Ellis, 1984; Kinsbourne, 1986; McGuinness, 1985; Vellutino, 1977; Vellutino, 1987; Vellutino, Steger, Kaman, & DeSetto, 1975; Vellutino, Steger, Moyer, Harding, & Niles, 1977). Unfortunately, the results of experiments ostensibly supporting this model have been derived from studies whose validity is questionable (e.g., Fletcher & Satz, 1979). For example, in many cases threats to internal validity (e.g., ceiling effects) render the results of these studies uninterpretable. Thus, there has

been little valid support for this model.

There has been much support for the other model of dyslexia, the sensory deficit model. This model argues that dyslexia is the result of a failure of the peripheral stages of the visual system to process and integrate sequential visual information. Because the problem in dyslexia involves the perception of form information (e.g., letters of the alphabet) it is reasonable to speculate that the sensory deficit would reside within the sustained (form perception) pathway. The sensory deficit model is the one being investigated in the present study. Thus, an indepth review of the research investigating this model is given below.

Some of the earliest research investigating sensory deficits in dyslexia was performed by Stanley and Hall (1973). To assess how dyslexic and nondyslexic children process visual stimuli, these researchers compared the performance of the two groups on tasks assumed to index the early stages of visual information processing. The first task was a sequential threshold task in which two parts of a stimulus were exposed sequentially for 20 msec with the onset of each asynchronously presented (i.e., a specified time interval elapsed between the presentation of the first and the second form part). The second task was a masking task in which target stimuli (alphabetic characters) and masking stimuli (viz., a static rectangular array of dots) were sequentially presented at varying stimulus onset asynchronies.

Stanley and Hall found that dyslexic children required significantly longer temporal intervals than nondyslexic children

either to distinguish sequential presentations from simultaneous presentations (sequential threshold task) or to correctly identify the alphabetic character presented when the mask followed the character in time (masking task). Based on these findings, they concluded that there are significant differences in how dyslexics versus normals process visual information: visual information persists longer and is processed slower for the dyslexics.

Additional support for this conclusion has come from studies that have investigated the processing of visual information in dyslexics and normals employing a variety of stimulus parameters and experimental tasks. All studies found that dyslexics required significantly longer temporal intervals than did normals in order to perform the experimental tasks. This was true for: nonlinguistic stimuli (Badcock & Lovegrove, 1981; Lovegrove, Heddle, & Slaghuis, 1980; Stanley, 1975), linguistic stimuli (DiLollo, Hanson, & McIntyre, 1983; Lovegrove & Brown, 1978), stimuli of varying spatial locations and orientations (e.g., Lovegrove, Billing, & Slaghuis, 1978; O'Neill & Stanley, 1976), and for recognition, inspection, and identification tasks (e.g., Gross-Glenn & Rothenberg 1984; Lyle & Goyen, 1975; Whyte et al., 1985). Taken together, the results of these studies indicate that, relative to normals, dyslexic children have poorer temporal acuity, that is, longer durations of visual persistence (i.e., the representation of a stimulus remains within the visual system for an extended length of time) for both linguistic and nonlinguistic stimuli.

What are the theoretical implications of the finding that

dyslexics have longer than normal durations of visual persistence? DiLollo, Hanson, and McIntyre (1983) proposed an answer to this question. They believe that dyslexic individuals not only process visual information at a slower rate, but also that they require a longer period of time to recover from visual stimulation (i.e., a longer refractory period). And a lengthy refractory period would seem to be detrimental in those circumstances in which visual stimuli are sequential in nature (e.g., reading). This is because the existence of a refractory period during the processing of visual information would preclude the processing of any additional stimulation during that period, that is, any additional information which entered the visual system during the refractory period would be degraded.

The specific stimulus attributes that would be degraded depend on the particular processing stage in question. Since the degradation probably occurs at an early stage of processing, the physical attributes of the stimuli would be affected. This, in turn, should limit the performance of the system at the higher stages where such properties as the structural and/or cognitive components of stimuli are processed. Within the present context, a child who is unable to adequately process sequential presentations of visual stimuli would not be able to read well.

It is important to note that a developmental trend toward normal visual processing in dyslexics is apparent in the results of some studies (e.g., Badcock & Lovegrove, 1981; DiLollo, Hanson, & McIntyre, 1983; Lovegrove & Brown, 1978; Lyle & Goyen, 1975; O'Neill

& Stanley, 1976). Specifically, in separation threshold paradigms, the temporal separation required by dyslexic children to perform certain experimental tasks decreased significantly as their ages increased from 8 to 14 years. This finding has been interpreted as evidence that the development of the visual system in dyslexics is delayed relative to normals.

This has led some researchers to propose that the sensory deficits exhibited by young dyslexics will, in all likelihood, disappear by the time these children reach adulthood. This proposal seems to be counterintuitive, however, as research that has investigated the literacy skills of adult dyslexics has found that neither adolescent nor adult dyslexics outgrow their problems, although significant gains are made by some individuals (Critchley, 1970; Finucci, 1985; Miles, 1986; Perreira, 1984; Rawson, 1968; Scarborough, 1984; Stone, 1980). Thus, it seems very likely that dyslexia does persist beyond the childhood years. It is not known, however, whether the same sensory deficits assumed to underlie childhood dyslexia are responsible for dyslexia in adulthood since temporal processing in adult dyslexics has not been investigated.

To perform that investigation, this study examined whether adult dyslexics demonstrate problems in the temporal integration of form information similar to the problems demonstrated in child dyslexics. To do so, this study employed an experimental paradigm that placed demands on the adult subject's ability to integrate visual form information over time. This paradigm was originally developed by McFarland (1965) and refined by Shontz (1968). In brief, it involved

presenting side or angle parts of a visual form either sequentially (i.e., a specified temporal interval elapsed between the presentation of each form part) or simultaneously (i.e., all of the form parts appeared at the same time) to each subject. The subject's task was to judge if the form parts were simultaneous, overlapping, or successive in time. Because the stimuli were presented foveally and because the subject's response was based on perception of form, it is likely that these procedures tapped the response properties of the sustained pathway.

Shontz (1968) expanded upon this paradigm by investigating, in addition to form-part configuration, the affect that contiguity, (i.e., the order of sequencing of form parts) has on temporal integration. His findings revealed that form-part configuration was the only factor significantly affecting temporal integration.

Employing a paradigm similar to the one described above, the present experiment compared dyslexic adults' ability to integrate visual form information over time to that of normals. Sensitivity to sequencing was investigated. Poorer sensitivity of adult dyslexics to sequential form information, relative to normals, was the expected result.

METHOD

Subjects

Eight adults (6 males and 2 females) who were diagnosed as dyslexic by the Resource Center of Montana State University were paid to participate in the study. In addition, eight nondyslexic adults (6 males and 2 females) were also paid to participate. The ages of the subjects ranged from 18 to 37 years.

In addition to being enrolled at Montana State University, all volunteers had to meet the following criteria in order to be accepted as subjects: (a) native speakers of English; (b) normal or corrected-to-normal vision; and (c) free of any physical, mental, or emotional disabilities. During the training period, one dyslexic male was excluded from the study because he did not have corrected to normal vision.

Apparatus and Stimuli

A Z-80 microcomputer breadboard, designed and built using conventional electronics, generated and displayed the visual stimulus on a Tektronix 2213A oscilloscope (P31 phosphor). The stimulus was a luminous outline square subtending a visual angle of 1 arc deg at the eye.

Procedure

Two levels of form-part configuration (sides vs. angles) were factorially combined with two levels of contiguity (contiguous vs.

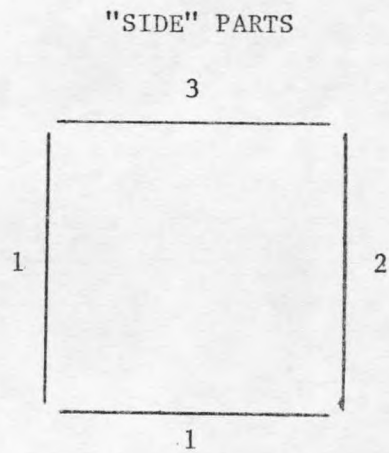
noncontiguous) which resulted in the following four experimental conditions (see Figure 2): sides-contiguous, sides-noncontiguous, angles-contiguous, and angles-noncontiguous. All four conditions were randomly presented to the dyslexic and normal subjects.

Each subject was greeted by the experimenter who explained the general purpose of the study and obtained informed consent. Once consent was given, the subject was seated in the dimly lit vision laboratory at a distance of 65 cm away from the oscilloscope screen. As the subject dark adapted, the experimenter read the instructions which detailed the experimental procedures and tasks (see Appendix).

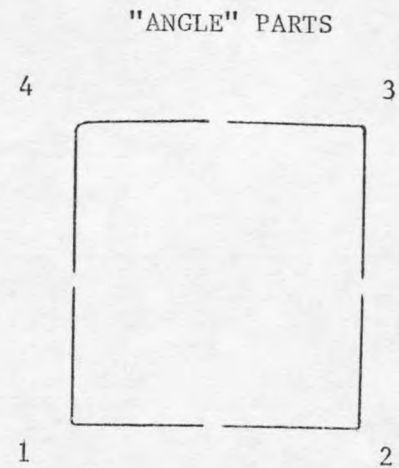
Although the occurrence of eye movements was unlikely since the durations of exposure used in the study (e.g., 41 msec) fell well within the latency required for the execution of saccadic or vergence eye movements (e.g., 160 msec), each subject was trained on the effects of eye movement and told to refrain from initiating eye movements during any of the experimental trials. All subjects complied with this request.

Next, the subject performed a brightness matching task in which the perceived brightness of squares presented under each of the four conditions were equated. The stimulus-on-time was 2 msec, the IPI was 12 msec, and the presentation mode alternated between sequential and simultaneous. The subject stated whether the squares appeared to be brighter, dimmer, or equal over trials. The purpose of this task was to insure that performance during formal data collection was based on temporal cues only and not on variation in brightness that

FIGURE 2. Illustration of Experimental Conditions



Order of Sequencing:
1,2,3,4 (Sides-Contiguous)
1,3,2,4 (Sides-Noncontiguous)



Order of Sequencing:
1,2,3,4 (Angles-Contiguous)
1,3,2,4 (Angles-Noncontiguous)

might covary with the experimental manipulations. All subjects judged the stimuli to be equally bright, indicating that no apparent brightness cues were present for the stimuli used.

Upon completion of the brightness matching task, the experimental procedures were explained to each subject. The subject was told that s/he would be shown parts of a square presented either simultaneously, in which the form parts of the square were presented at the same time, or sequentially, in which each form part was asynchronously presented. In the latter case, a specified time interval, known as the interpart interval (IPI), elapsed between the offset and the onset of the various form parts. The presentation order was randomly determined over trials (both types of presentation occurred equally). The subject was told that the task was to decide whether the form parts of the square were presented sequentially or simultaneously on each trial. In order to obtain a measure of sensitivity to sequencing free of response or criterion bias, each subject was asked to rate the confidence of that decision, using a six category rating scale: "1", sequential, very sure; "2", sequential, fairly sure; "3", sequential, guess; "4", simultaneous, guess; "5", simultaneous, fairly sure; and "6", simultaneous, very sure. Finally, each subject was instructed to develop a set of perceptual criteria for differentiating between sequential and simultaneous presentations of the square and to use these criteria throughout data collection.

Formal training of the subjects on the experimental task occurred during the first two sessions. The purpose of training was

twofold: (1) to stabilize each subject's performance and (2) to determine the IPI value at which each subject accurately discriminated sequential from simultaneous presentation of the form 70% of the time for the sides-contiguous condition. This will be referred to as the IPI threshold.

Training consisted of presenting the sides-contiguous experimental condition to each subject for six blocks of 50 trials each per training session. Each trial began with a simultaneous warning "beep" and plotting of a fixation point. One second later, the square was displayed and the subject gave his/her response. Four seconds later, the beep sounded again and the fixation point was once again plotted, indicating the beginning of another trial. Feedback was given throughout training.

Three sessions of formal data collection followed the training sessions. For these sessions, the IPI threshold established for the sides-contiguous condition during practice was used during presentation of the four experimental conditions. By holding IPI constant, across conditions, recognition performance was allowed to vary. All four experimental conditions were presented in two consecutive blocks, with a two-minute rest period provided after the first block and a five-minute rest period provided after the second block. Thus, data collection involved eight blocks of 50 trials each for a total of 400 trials per session (100 trials per condition). The order of presentation of each condition was determined randomly. No feedback was given during the sessions.

Finally, each subject was questioned, debriefed, and paid by the

experimenter when all five sessions had been completed.

RESULTS

Before the data were statistically analyzed for reliability, the percent discrimination data obtained for each subject under each of the experimental conditions were transformed into hit and false alarm rates and then plotted against one another on receiver-operating-characteristic (ROC) curves using double probability axes (Green & Swets, 1966). This was done in order to determine whether the assumptions necessary for the use of parametric sensitivity measures (e.g., d') were met. Inspection of the ROC curves revealed that the assumptions were not met. Therefore, an unbiased nonparametric measure of sensitivity, the area under the ROC curve $P(A)$, was calculated and an arc sin transformation performed (McNicol, 1972). Four area values, one for each condition, were calculated for each subject for a total of 60 area values.

A 2 x 2 x 2 three-way Analysis of Variance (ANOVA) for split plot designs was calculated on the sensitivity data (see Table 1). This analysis revealed that sensitivity to sequencing was not significantly affected by disability ($F < 1.0$). The sensitivity of dyslexics and normals was equivalent. However, sensitivity was significantly affected by configuration, $F(1, 13) = 17.080$, $p < .005$. All subjects, regardless of classification, were more sensitive to sequencing with angle parts than with side parts. Sensitivity was reliably affected by contiguity, $F(1, 13) = 15.000$, $p < .005$.

Sensitivity was greater with contiguous presentations than with noncontiguous presentations. Most important for this study, analysis revealed a significant interaction between contiguity and disability, $F(1, 13) = 70.000$, $p < .001$. Here, normals were more sensitive to sequencing with contiguous presentations relative to noncontiguous presentations, whereas dyslexics did not differ between the two conditions. And finally, the analysis also revealed a significant interaction between configuration and contiguity, $F(1, 13) = 105.930$, $p < .001$. Sensitivity was greater under the noncontiguous condition when angles were used, however, it was greater under the contiguous condition when sides were used.

Table 1. Analysis of Variance Computed on the Area Under the ROC Curve as a Measure of Sensitivity to Sequencing.

Source	SS	df	MS	F
Between	3.660	14	-	-
Disability (D)	0.260	1	0.260	0.992
error	3.400	13	0.262	-
Within	2.611	35	-	-
Configuration (C)	1.230	1	1.230	17.080*
D x C	0.002	1	0.002	0.028
error	0.938	13	0.072	-
Contiguity (CO)	0.030	1	0.030	15.000*
D x CO	0.140	1	0.140	70.000**
error	0.020	13	0.002	-
C x CO	0.220	1	0.220	105.930**
D x C x CO	0.004	1	0.004	1.930
error	0.027	13	0.002	-

* $p < .005$

** $p < .001$

By averaging the cumulative P(A) data of the normal subjects (see Figure 3) and the dyslexic subjects (see Figure 4) within

conditions, the overall effects of the experimental conditions on sensitivity to sequencing are summarized in pictorial form.

FIGURE 3. Average Receiver-Operating-Characteristic (ROC) Curves of Nondyslexics for the Experimental Conditions

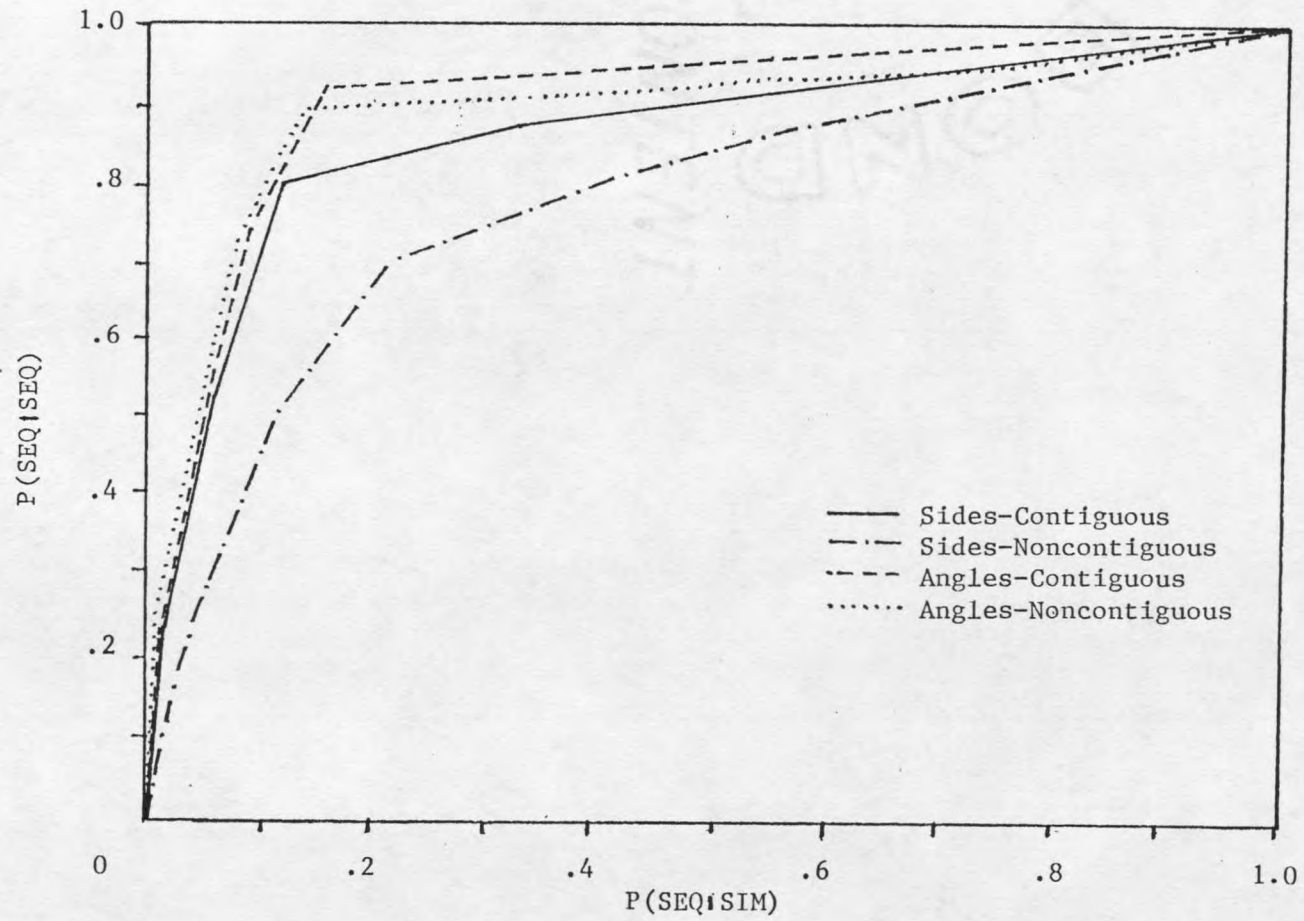
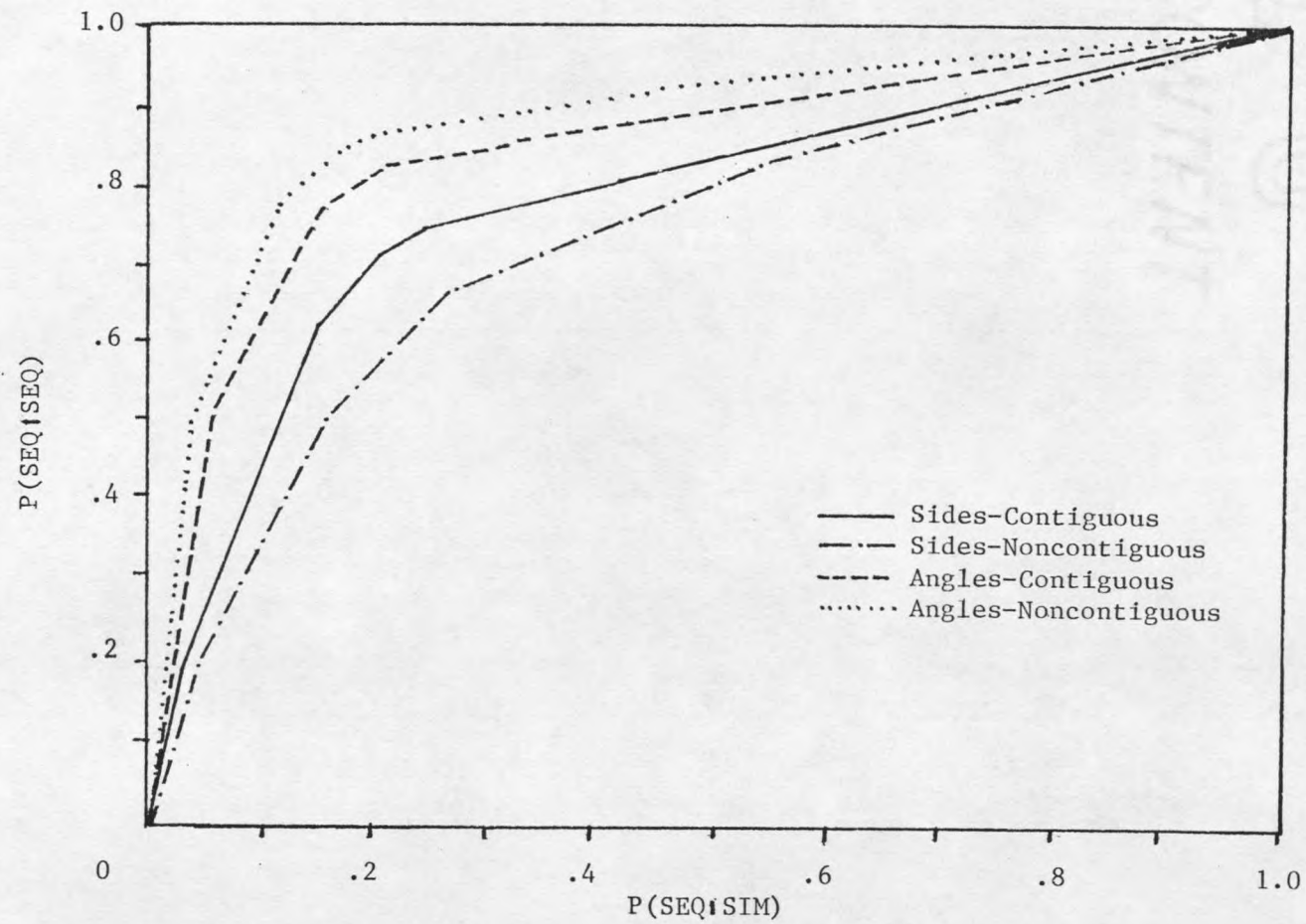


FIGURE 4. Average Receiver-Operating-Characterisitic (ROC) Curves of Dyslexics for the Experimental Conditions



DISCUSSION

The principle result of this study is that the sensitivity of the normals to sequential form information is superior to that of dyslexics when parts of a stimulus are presented contiguously. The normals are able to discriminate sequential from simultaneous presentations at briefer durations than can the dyslexics. This result implies that, under these conditions, temporal processing of form information is slower within the visual systems of dyslexics, or in other words, for dyslexics, form information persists longer (i.e., poorer temporal acuity).

What is the explanation for these results? It may be argued, for example, that the differences between dyslexics and normals under these conditions could be the result of sampling, response, or criterion biases. The possibility of sampling bias is ruled out, however, because the same subjects were used under all four experimental conditions. The possibility that these differences are due to response or criterion biases is also ruled out since the average miss and false alarm rates were compared using the Mann-Whitney U Test and no significant differences were found.

The most likely explanation is that a temporal integration deficit exists within the visual pathway of the adult dyslexics. In this view, slower processing of form information would mean that the neural representation of successive stimuli should perceptually

overlap in time. In the present study, the representation of sequential form parts overlapped in the visual systems of the dyslexics, and consequently, these representations were more often perceived as simultaneous rather than sequential.

One consequence of having temporal overlap of representations is that the characteristics of those representations (i.e., size, shape, etc.) would be degraded: in other words, each representation of a given stimulus would interfere with one another. This idea is similar to the explanation proposed for such phenomena as visual masking (e.g., Fox, 1978; Kahnman, 1968). In masking, the presence of one stimulus, the mask, impairs the visibility of a second stimulus, the target, when both occur closely coupled in time. The impairment is presumably due to interference between the neural representations of target and mask.

In terms of dyslexia, this tendency for perceptual overlap and interference would apply to the processing of alphabetic and linguistic stimuli, such as letters. Such degradation of the physical attributes of alphabetic stimuli would result in the loss of important contour information. This loss of information should cause difficulty in differentiating between letters of similar configuration. It seems that this is, in fact, what happens since dyslexics frequently see letters incorrectly and confuse letters that look alike.

Now turning to the other results, it was found that all subjects, regardless of classification, were more sensitive to sequencing with angle parts than with side parts. Although this

result does not bear directly on the issues addressed in this study, it does support the conclusion of McFarland (1965) and Shontz (1968) that angles and sides are integrated differentially within the visual system. And finally, it was found that subjects were more sensitive under the noncontiguous condition when angles were used, whereas they were more sensitive under the contiguous presentation when sides were used. This interaction between configuration and contiguity, while reliable, was unexpected and, to date, remains unexplained.

Based on the principle results of this study, it is concluded that a temporal integration deficit, similar to that found in childhood dyslexia, exists within the visual pathway of adult dyslexics. It seems, therefore, that the integration deficits underlying childhood dyslexia are not transient; rather these deficits seem to persist into adulthood. Such a conclusion is in direct contradiction with the belief held by many theorists (e.g., Badcock & Lovegrove, 1981; DiLollo, Hanson, & McIntyre, 1983; Lovegrove & Brown, 1978; Lyle & Goyen, 1975; O'Neill & Stanley, 1976) that the sensory deficits of childhood dyslexia diminish with maturity. An important direction for future research is to compare directly temporal integration of form information in adult and child dyslexics.

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