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SEQUENCING, TIMING, RHYTHMIC AND EYE MOVEMENT PROBLEMS IN DYSLEXICS

CHARLES E. DODGEN and PROF. GEORGE Th. PAVLIDIS*
Fair Oaks Hospital, Summit, New Jersey, and
* The Reading Center, George Washington University,
Washington DC USA

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Overview

Dyslexia is a syndrome that manifests itself in a wide and varied symptom picture. Because of the diversity of symptoms associated with the syndrome (see Pavlidis, 1990 for a comprehensive list) and the intrinsic complexity of the processes involved, it has remained very difficult to accurately define dyslexia despite active multi-disciplinary investigation. The possible existence of subtypes (Rourke, this volume) complicates the picture further. Attempts to define dyslexia have evolved from unidimensional theoretical approaches (see Benton, 1980 and Sampson, 1975 for historical perspectives) to the more recent trend of neuropsychological definition (Hynd & Hynd, 1984). Interest in sequential, or serial order, processing has grown with the increasing interest in and sophistication of neuropsychological testing. Dyslexics have been found to be deficient in sequential processing across behaviors, sensory systems, and across research procedures as well (Andersen, Podwall, & Jaffe, 1987; Atterbury, 1983, 1985; Badian, 1977; Badian & Wolff, 1974; Bryden, 1972; Cohen & Netley, 1981; Corkin, 1974; Denckla & Rudel, 1976; Gaddes, 1978; Hatchette & Evans, 1983; Hooper & Hynd, 1985, 1986; Katz & Deutsch, 1964; Koppitz, 1973; Lindgren & Richman, 1984; Pavlidis, 1981, 1985, 1986, 1990; Richie & Aten, 1976; Sehy, 1984; Tallal, 1980; Vande Voort & Senf, 1973; Wolf, 1986; Wolff, Cohen, & Drake, 1984; Zurif & Carson, 1970). This convergence of results strongly implies brain dysfunction with respect to sequential processing ability.

Investigators agree that sequential processing is an integral part of the larger reading process (Aaron, 1982; Das, Kirby, & Jarman, 1979; Gaddes, 1978; Pavlidis, 1981, 1986, 1990; Tallal, 1980; Vernon, 1977). Deficits in performing visual- and verbal-sequential tasks are associated with deficits in reading ability (Bakker, 1972; Gaddes & Spellacy, 1977). Gaddes (1985) suggested that serial order processing is an ability with its own functional integrity. In this conceptualization, certain verbal tasks appear to place a load on sequential processing ability which the respondent may possess in varying degrees.

Since Orton's (1925) time, the relative activity of the cerebral hemispheres has been of interest. This interest gained a firm boost in the late 1960s with the work on split-brain individuals (Gazzaniga, 1970; Sperry, 1968). Normal hemispheric differences have been found on anatomical and neuropsychological levels. Dyslexics do not exhibit the typical left hemisphere advantage for verbal material across visual (Marcel, Katz, & Smith, 1974), auditory (Sommers & Taylor, 1972), and tactile modalities (Witelson, 1976). The results of these studies (Marcel, et al., 1974; Sommers & Taylor, 1972; Witelson, 1976) seem to indicate the disruption of left hemisphere functioning due to bilateral representation of spatial functions which are normally confined to the right hemisphere (Witelson, 1976).

Sequential processing demands of reading involve both temporal and spatial components. Studies have linked the left hemisphere with temporal ordering and the right hemisphere with spatial ordering (Bakker & Licht, 1986; Davis & Wada, 1977; Gaddes, 1985; Gaddes & Zaidel, 1978; Hammond, 1982). Visuo-spatial processing appears to be more important in early reading and less important in skilled reading (Gaddes & Spellacy, 1977; Solan & Mozlin, 1986; Vernon, 1977), which has etiologic, diagnostic, and remedial implications for dyslexia (Bakker & Licht, 1986; Pavlidis & Fisher, 1986). Early reading is heavily dependent upon perceptual skills as the decoding task is of primary importance in unskilled reading. In skilled reading basic perceptual abilities are automated and, hence, less taxing for the brain permitting it to concentrate on the meaning deriving process.

Definition

The dyslexics' symptom picture reflects disturbances in many areas: cognitive, (sequential) behavioral, attentional, linguistic, emotional, and perceptual. The delineation of the associated features and symptoms is one matter; the explanation of their presence is quite another. Herein lies the problem of definition.

Historically, dyslexia was defined from the etiological perspective of the particular researcher (Benton, 1980; Sampson, 1975). The problem that developed over many years of research was quite predictable: many new symptoms were described and with each researcher claiming to have found "the cause" of dyslexia, the number of definitions grew correspondingly.

Sampson (1975) noted that it was the confusing state of affairs resulting from the above definitional approach that led to the adoption of the use of exclusionary criteria by the Research Group on Developmental Dyslexia of the World Federation of Neurology in 1968. The rationale behind the use of exclusionary criteria can be summed up simply: rule out all external factors known to have a negative effect on reading ability and the unexplained reading failure is called dyslexia. One major advantage of this definitional approach is that it is independent of etiologic perspective and, this avoids the problem discussed above concerning etiologically based definition (Sampson, 1975). Also, use of strict, quantifiable exclusionary criteria result in "purer" (more homogeneous) research groups and a truer picture of the dyslexic can be drawn (Pavlidis, 1985a; 1990). There are problems, however, with the World Federation definition as well as with the employment of exclusionary criteria in general. The criteria do not discriminate between subtypes which may result in heterogeneous populations. A case can be made for the existence of subtypes of dyslexia. On logical grounds, because of the complexity of the reading process, it makes sense that a problem at any given stage would result in a given "type" of dyslexia. There have been many attempts to classify dyslexics into subgroups (see Rourke, this volume).

Partially as a result of the problems with the use of exclusionary criteria, and partially due to increasing knowledge, there has been a recent trend towards more positive definition of dyslexia as reflected by the National Joint Committee for Learning Disabilities, which states that learning disabilities (of which dyslexia is one type): "are intrinsic to the individual and presumed to be due to central nervous system dysfunction" (Hynd & Hynd, 1984, p. 484). The difference between this definition and those of the past is that the diagnosis must rest firmly on neuropsychological evidence and not inference and theory.

The future of accurate diagnosis and classification appears to lie within the realm of neuropsychology, neurophysiology, and electrophysiology in the forms of electroencephalogram (EEG), computerized tomography (CT), computerized eye movement analysis, and other neuropsychological procedures. The use of psychoeducational testing will still be necessary, but these traditional measures will be of secondary importance and devoid of etiological implications.

Etiological Theories

Several theories have been proposed in order to account for unexpected reading failure, or dyslexia. The major etiological perspectives may be characterized as those implicating mixed or incomplete dominance/laterality, impaired perceptual processes, problems with intersensory integration, linguistic problems, and difficulties in sequential or serial-order processing (Benton, 1980; Sampson, 1975). These approaches will be briefly described below.

As Downing and Leong (1982) note, early investigators (Dearborn, 1931, 1933; Monroe, 1932; Orton, 1925) observed an elevated incidence of poor-reading students demonstrating left, mixed, or no dominance. Orton (1925) being particularly impressed by the frequency of reversal errors made by dyslexics, developed a theory to account for reversal phenomena. He posited that dyslexia was caused by incomplete cerebral dominance leading to rivalry between the hemispheres in processing visual stimulation. While the relative importance given to reversals in the study of dyslexia has diminished somewhat since Orton's time, interest in dominance and laterality has continued. Extensive writings by some authors on the development and theoretical importance of laterality gives evidence of the continuation of interest in this area (Annett, 1976, 1981; Annett & Kilshaw, 1984; Bertelson, 1982; Geschwind, 1984; 1986; Kershner, 1975, 1977). This interest has persisted despite the fact that most studies reveal no significant association between left-handedness and reading disability (Belmont & Birch, 1965; Clark, 1970; Rutter, Tizard, & Whitmore, 1970; Satz & Soper, 1986). Interest has also taken the form of neuropsychological studies designed to investigate processing styles of dyslexics when compared to normal readers. Such studies have employed dichotic listening (Bryden, 1970; Kimura, 1961a, 1961b, 1964, 1967; Zurif & Carson, 1970), visual-half field (Bakker, 1979; Witelson, 1977), and dichotomous tactile stimulation (Witelson, 1976) procedures. Results of these studies give evidence of the existence of differences in (hemispheric) processing styles with dyslexics being inferior in the processing of information usually processed efficiently by the left hemisphere; that is, verbal/sequential information (Bakker & Licht, 1986).

Perceptual inefficiencies in reading failure have been investigated in the following areas: figure copying (Brenner & Gillman, 1966; Brenner, Gillman, Farrell, & Zangwill, 1967), directional confusion (Critchley, 1964, 1981; Orton, 1937), and spontaneous writing and spelling impairment (Zangwill, 1962). Benton (1980) noted that others have investigated basic visual- and auditory-perceptual processes (Benton, 1962; Fildes, 1922; Hincks, 1926; Nielsen & Ringe, 1969). As Downing and Leong (1982) observe, some investigators have posited that perceptual difficulties may represent a maturational lag rather than enduring deficits (Bender, 1958; Gesell, 1945; Ilg & Ames, 1964). Longitudinal studies, however, indicate that problems of the learning disabled typically last into adulthood (Cooper & Griffin, 1978; Critchley, 1973, 1981; Horn, O' Donnell, & Vitulano, 1983; Johnson, 1980; Johnson & Blalock, 1987; Kline & Kline, 1975; Rawson, 1968; Scarborough, 1984). These findings strongly argue against the maturational lag notion.

The intersensory integration model posits that dyslexics are inferior in the ability to integrate information from different sensory systems (Beery, 1967; Birch & Belmont, 1964; Senf, 1969). In the procedure popularized by Birch and Belmont (1964) subjects were required to match auditory patterns with their visual representation. The procedure was based on the theory that reading rests on the ability to transform temporally distributed auditory patterns into spatially distributed visual ones. Birch and Belmont's study has been criticized for sampling and control problems (Muehl & Kremenak, 1966; Sterritt & Rudnick, 1966). Subsequent studies designed to replicate Birch and Belmont's (1964) original results as well as to test all combinations of stimulus presentation (i.e., auditory-visual, visual-auditory, auditory-auditory, visual-visual) have challenged the conclusion that dyslexics are inferior specifically in auditory-visual integration (Badian, 1977; Bryden, 1972; Gaddes, 1978; Hatchette & Evans, 1983; Vande Voort & Senf, 1973; Zurif & Carson, 1970). With dyslexics performing at an inferior level on the inter-and intra-modal integration tasks it appears as though they have difficulty with the analysis of any stimulus pattern which is presented serially.

Proponents of the linguistic model contend that language-based problems underlie the dyslexic's difficulties (Smith, 1978; Vellutino, 1977, 1978, 1979). The crucial chore for the reader is to derive meaning from written words by using the various forms of available information. For example, the reader forms expectations of what is to occur and by using orthographic, semantic, and syntactic information he/she can have a good idea of the word(s) before referring to the graphemic aspects of the word(s) in question. Using orthographic, semantic, and syntactic information many alternatives are eliminated so that the use of grapheme- (letter or unit with own distinct sound) phoneme (sound associated with grapheme) cues should be the last and simplest step in reading a word. Vellutino (1977, 1979) has suggested that all observed difficulties of the dyslexic can be explained in terms of a deficit in verbal processing. More specifically, he states that difficulties in intersensory integration, serial order, and visual -perceptual processing can be explained via verbal-encoding deficiencies. This theory, however, fails to explain the findings of the majority of the dyslexia literature showing that dyslexics exhibit non-verbal problems in a variety of tasks and settings.

Temporal-order, sequential processing ability has been investigated with verbal and non-verbal stimuli. The main thesis of this approach is that sequential processes are important to reading at several levels. For example, sequencing is important in putting letters and words in order and moving the eyes in sequence from left to right (Pavlidis, 1981). In this conceptualization cognitive and linguistic processes involved in reading are seen to be dependent upon more basic sequential processes (Pavlidis, 1981; Tallal, 1980; Vernon, 1977). Sequential difficulties can account for verbal as well as non-verbal sequential behavioral problems of the dyslexic while the verbal-deficit hypothesis (Vellutino, 1977, 1979) can only account for the former (Pavlidis, 1981). The data that this theory rests on is presented below.

SEQUENTIAL BEHAVIOR and DYSLEXIA

A review of the literature reveals that many studies exist comparing normals and disabled readers on sequencing ability (Pavlidis, 1981). Several studies used verbal tasks (Andersen, et al., 1987; Cohen & Netley, 1981; Denckla & Rudel, 1976; Hooper & Hynd, 1985, 1986; Katz & Deutsch, 1964; Koppitz, 1973; Wolf, 1986), two employed spatial tasks (Corkin, 1974; Lindgren & Richman, 1984), six employed tasks that involved the reproduction of sequential patterns by the subjects (Atterbury, 1983, 1985; Badian & Wolff, 1974; Gaddes, 1978; Hooper & Hynd, 1985, 1986; Wolff, et al., 1984) and others required judgment of similarity or dissimilarity of sequentially presented stimuli (Badian, 1977; Birch & Belmont, 1964; Bryden, 1972; Gaddes, 1978; Hatchette & Evans, 1983; Richie & Aten, 1976; Sehy, 1984; Tallal, 1980; Vande Voort & Senf, 1973; Willette & Early, 1985; Zurif & Carson, 1970).

Verbal Sequencing

Denckla and Rudel (1976) found that dyslexics were differentiated from normals and other learning disabled subjects on the test of "rapid automatized naming" (RAN). Subjects were asked to perform on tests requiring rapid repetitive naming of pictured objects, colors, letters, and numbers. Dyslexics' performances were distinguishable from non-dyslexic learning disabled subjects and normal-reading subjects; that is, dyslexics had a slower naming speed than both other groups. The authors pointed out that this was not due to a generalized slowing of reaction time. Andersen, et al. (1987) and Wolf (1986) obtained similar results in more recent studies employing the RAN test procedure. Koppitz (1973) found that reading disabled subjects were inferior to normals on tasks involving the written and oral serial recall of digits presented either visually or aurally. Katz & Deutsch (1964) required subjects to recall serially presented word lists and drawings of common objects, and Cohen and Netley (1981) had subjects recall digits in order. Reading disabled subjects performed significantly poorer on these recall tasks. Hooper and Hynd (1985, 1986) had dyslexic and normal reading subjects perform two serial recall tests (Number Recall, Word Order) used on the Sequential Processing Scale of the Kaufman Assessment Battery for Children (K-ABC) (Kaufman & Kaufman, 1983). Dyslexics' performance was inferior to normals in both studies. The results of the above mentioned studies could be interpreted as partly demonstrating the existence of a verbal deficit of some kind, and not necessarily a serial processing problem because of the use of verbal stimuli or a combination of both. The studies discussed below clear this confusion up with the employment of non-verbal stimuli.

Serial-Spatial Ordering

Corkin (1974) compared normal and disabled readers on a visual serial-ordering task. Subjects had to tap a linear array of cubes in the same order as the examiner immediately following the examiner's performance and after a short delay. Disabled readers were found to be significantly inferior at this task in the delayed condition. Lindgren and Richman (1984) employed a similar procedure having reading disabled and normal children recall the order in which different colored chips were presented. They found that serial order errors occurred significantly more frequently for reading disabled than normal children.

Production/Reproduction of Temporal Patterns

Atterbury (1983, 1985), Badian and Wolff (1974), Gaddes (1978), Hooper and Hynd (1985, 1986), and Wolff, et al. (1984) employed procedures which required subjects to perform sequential behaviors. Badian and Wolff (1974) had normal and reading disabled subjects tap a key in time with a metronome in single-hand and alternating-hand conditions. They found significant differences between normal and disabled readers when alternating hands were used to respond to the metronome. These results were replicated in a later study (Wolff, et al., 1984). Atterbury (1983, 1985) found reading disabled subjects to be inferior in the ability to reproduce rhythmic auditory patterns by clapping their hands. Gaddes (1978) conducted a series of studies designed to investigate the developmental course of serial order abilities. In one study he compared normal-reading second- and fifth-grade students on a task where subjects had to reproduce visual-sequential patterns by tapping on a key which electronically converted taps into light patterns emitted from a lamp. The ability to perform on this task was found to correlate strongly with reading ability. That is, unskilled readers tended to perform more poorly on the serial-order task than skilled readers. Hooper and Hynd (1985, 1986) had dyslexic and normal reading subjects perform a motor test (Hand Movement) which is part of the Sequential Processing Scale of the K-ABC (Kaufman & Kaufman, 1983). Normal-reading subjects performed significantly better than dyslexics in both studies.

Perceptual-Discrimination Studies

Many of the studies of interest employed comparative procedures where auditory patterns were compared to visual-spatial patterns (Badian, 1977; Birch & Belmont, 1964; Bryden, 1972; Gaddes, 1978; Hatchette & Evans, 1983; Richie & Aten, 1976; Vande Voort & Senf, 1973; Willette & Early, 1985; Zurif & Carson, 1970), to auditory patterns (Badian, 1977; Bryden, 1972; Dodgen, 1987; Gaddes, 1978; Hatchette & Evans, 1983; Sehy, 1984; Tallal, 1980; Vande Voort & Senf, 1973; Willette & Early, 1985; Zurif & Carson, 1970); or, visual to visual comparisons were made (Bryden, 1972; Gaddes, 1978; Hatchette & Evans, 1983; Vande Voort & Senf, 1973; Willette & Early, 1985; Zurif & Carson, 1970). The basic procedure in all of these studies is to present the first stimulus followed by the second stimulus and have the subjects decide whether the two are the same or different; or, the subject has to pick a printed pattern which corresponds to the stimulus patterns. Significant differences were found in all of these studies with subjects with reading disabilities being consistently inferior.

Eye Movement and Sequence

There is a widespread agreement as to the existence of differences in eye movements between dyslexics and normals on reading tasks (Calvert & Cromes, 1966; Donders & Van der Vlugt, 1984; Elterman, Abel, Daroff, Dell' Osso, & Bornstein, 1980; Griffin, Walton, & Ives, 1974; Heiman & Ross, 1974; Pavlidis, 1978, 1981; 1986). In these studies dyslexics have been found to exhibit greater numbers of regressive eye movements, irregular fixations, and greater numbers of eye movements overall. Of course, because the experimental stimuli used were verbal in nature, these studies do little to help determine whether the observed differences reflect difficulties in comprehension, with sequential, or oculomotor functioning.

Pavlidis (1981) performed a series of studies designed to help answer this question. He conducted three separate studies the rationales for which were as follows. He reasoned that if dyslexics' erratic eye movements were solely a result of poor reading habits or difficulty with reading material then: 1) normals' eye movements should become erratic when reading more difficult material; 2) dyslexics' eye movements should become normalized when reading easier text; and 3) dyslexics' eye movements should be indistinguishable from other equally poor readers who are not dyslexic. None of these hypotheses was supported leading to the conclusion that text difficulty or poor reading habits could not account for dyslexics' erratic eye movements. Rather, brain malfunction was implicated.

Studies have been conducted which have totally removed the comprehension factor present with verbal stimuli by employing tasks with non-verbal stimuli (Adler-Grinberg & Stark, 1978; Bogacz, Mendilaharsu, & Mendilaharsu, 1974; Black, Collins, & DeRoach, 1984; Elterman, et al., 1980; Griffin, Walton, & Ives, 1974; Pavlidis, 1981, 1983; Lefton, Lahey, & Stagg, 1978). Lefton, et al. (1978) recorded eye movements of dyslexics and normals on a match-to-sample task. On this task subjects were required to choose from one of four five-letter alternatives that matched a sample. On simpler items no differences were found. However, on items which called for sustained attention, dyslexics engaged in unsystematic search strategies as detected by erratic eye movements (Conners, 1990). Some of these investigators employed procedures which demanded sequential eye movements similar to those needed while reading (Elterman, et al., 1980; Griffin, et al., 1974; Pavlidis, 1981, 1983; Dodgen & Pavlidis, 1990). Elterman, et al. (1980) and Griffin et al. (1974) used horizontally arranged stationary stimuli and required subjects to move their eyes from point to point along the horizontal array. On these tasks dyslexics exhibited significantly greater numbers of regressions, longer fixations, and showed a tendency to skip and omit stimuli.

Pavlidis' (1981, 1985) studies have employed both stationary and moving stimuli. Subjects were required to move their eyes to accurately follow a stimulus dot moving horizontally from point to point (i.e., sequentially) across a screen. On this test dyslexics have consistently been found to exhibit significantly greater numbers of eye movements, greater numbers of regressions, and fixation difficulty. Adler-Grinberg and Stark (1978), Black, et al. (1984), and Bogacz, et al. (1974) investigated pursuit eye movements (i.e., movements necessary to follow a continuously moving stimulus). They found that dyslexics exhibited a significantly greater number of saccadic eye movements than normals on the pursuit tasks.

As previously discussed, dyslexics have been found to be deficient in sequential processing across behaviors and across procedures as well. Differences have been found with verbal tests, visual tests, tests requiring the reproduction of sequentially presented stimulus patterns and with tests requiring the judgment of similarity or dissimilarity of sequentially presented stimuli. From the long list of sequential processing studies, two variables appear to be of particular importance: the rapidity of presentation of the stimuli, and the variability of the rate of presentation. Many of the above studies presented stimuli with short, variable inter-stimulus intervals (ISIs). Therefore, it is unclear whether the difficulty for dyslexics stemmed from the rapidity or the changing nature of the stimulus pattern. Tallal (1980) and Gaddes (1978) investigated one of these factors. Tallal (1980) employed auditory stimuli and found reading-disabled subjects to perform more poorly on serially presented stimulus patterns only at fast speeds (with ISIs of approximately 100 ms or less). Similarly, Gaddes (1978) employed visual stimuli and found dyslexics to perform significantly more poorly only for those stimulus patterns presented with ISIs of 100 ms or less. There appears to be a clear trend: the faster the rate of stimulus presentation, the greater the discrimination between dyslexics and normals.

The other factor of concern is the variability of the ISIs. Tallal and Piercy (1974) found that language-delayed children were impaired in discrimination of speech sounds characterized by rapidly changing ISIs, but unimpaired in discriminating speech sounds that were steadily presented. On oculomotor (sequential performance) tasks Pavlidis (1981, 1983) has reliably discriminated between dyslexics and normals with relatively slow, but variable 7ISIs (of 1 sec. and 2 sec.).

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Dodgen and Pavlidis (1987) investigated these variables in a study in which they attempted to determine whether oculomotor sequential performance difficulties reflected general oculomotor control problems or were yet another manifestation of a general sequencing problem. They reasoned that if the dyslexics' eye movement problems were to be seen as reflecting a sequential performance deficit, and not a general oculomotor control problem, dyslexics should be inferior in temporal (left hemisphere, sequential), but not spatial (right hemisphere, holistic) accuracy when performing eye movements. In their study they also attempted to investigate the relationship between sequential eye movement difficulty and sequential difficulties as measured with more conventional manual performance procedures, and an auditory discrimination test. In order to accomplish this, Dodgen, (1986); Dodgen and Pavlidis (1987) required dyslexic and carefully matched normal readers to reproduce stimulus patterns of varying speeds and complexity, across two motor-effector systems (manual and oculomotor); also on the discrimination test subjects had to listen to two sets of rhythmically varied auditory patterns to decide whether the two patterns were the same or different.

Relationship of Sequential Processing to Reading

Given that a basic sequential deficit exists in the ability to process rapid and/or changing stimuli, how does this relate to reading and reading disability? Several authors have noted the association between temporal processing difficulties and reading disability (Aaron, 1982; Bakker, 1972, 1981; Das, et al., 1979; Gaddes & Spellacy, 1977; Tallal, 1980). Visual-sequential task performance has been found to correlate with academic ability (reading, writing, and arithmetic) (Gaddes & Spellacy, 1977) as has verbal-sequential task performance (Bakker, 1972; Gaddes & Spellacy, 1977). Tallal (1980) found the ability to process rapidly presented non-verbal auditory stimuli to strongly correlate with reading ability. Jost (1988) using two subtests of the Pavlidis Test, which have a strong sequential component, could predict future academic problems with the remarkable accuracy of 91.5% .

Theoretical explanations exist which attempt to explain the association between temporal processing and reading abilities (Ojemann, 1983; Pavlidis, 1983; Tallal, 1983; Vernon, 1977). Vernon (1977) describes four basic processes which she feels underlie reading deficiencies: 1) inability to analyze complex, sequential visual and/or auditory-linguistic structures; 2) difficulty in the linking of visual and auditory-linguistic structures; 3) inability to establish regularities in variable grapheme-phoneme correspondences; and, 4) difficulty grouping words into meaningful phrases. The first two, and most basic, processes appear strongly based on temporal processing abilities (Pavlidis, 1985a). Ojemann (1983) has concluded from his brain stimulation studies, and Tallal (1983) has confirmed with neuropsychological studies, that language skills are intimately related to sequencing skills. Ojemann (1983) speculates that this relationship between sequencing and language skills may be due to a more basic mechanism of the cortex of the left hemisphere, precise timing, which underlies both processes. Ojemann (in Tallal, 1983) has offered a developmental explanation for the proximity of brain cites as well as the functional relationship between language and sequencing skills: "during the course of human development, the initial role of this common cortex for language production and understanding may be in the decoding of sounds during language acquisition, identifying those significant to speech. The same cortical area later develops the patterns of motor output to generate these significant sounds" (p. 219). On a performance level, Pavlidis (1986) noted that the eyes must move in rapid sequence in order to pick up the visual information necessary to read efficiently. Therefore, a problem exists in obtaining the information and in processing the information. The importance of the oculomotor demands in reading were recently demonstrated (Pavlidis, 1987). A procedure was used whereby text was flashed on a computer screen on the same spot, one word at a time in sequence. This procedure eliminated or greatly reduced the need for eye movements. On this task dyslexics read at a much higher rate than usual while maintaining an almost 90% comprehension.

SUBJECTS

All subjects were carefully selected based on exclusionary criteria established by Pavlidis (this volume).

Dyslexics. Subjects used in the present study were students at a private, residential school for individuals with severe reading difficulties. The Exclusionary Criteria are widely used in dyslexia research and have been established in an attempt to obtain standard, homogeneous research groups (Pavlidis, 1985).

39 male dyslexic students were used in this study. Their ages ranged from 12 years and 10 months to 18 years and 1 month, with an average of 16 years and 7 months.

Normal Readers. Subjects were students at a private high school.
35 normals passed the criteria and were included in the study. Their ages ranged from 16 years and 4 months to 17 years and 4 months, with an average of 16 years and 10 months.
The normal readers met the same criteria as the dyslexics with the exception of the criterion concerned with reading level (Pavlidis, this volume). That is, where dyslexics were required to be at least two years behind in reading, normals were required to be reading on grade level or above.

All testing was conducted in the respective schools. Testing took place in the Spring.

Screening. The screening tests consisted of auditory and visual acuity, lateral dominance questions, a word identification reading test (Woodcock, 1973), possible attention deficit disorder was assessed by the Conners Teacher Rating Scale (Conners, 1990). For normals only a group intelligence test was used (Ottis, 1967). These tests were performed individually in regular classrooms within the schools, except for the group intelligence test which was given to the group of normals in a regular classroom.

Apparatus Eye movements were measured via the photoelectric method. Subjects were required to wear spectacle frames on which were mounted an infra-red light source and photocells to record from each eye. The computer continuously recorded eye movement position as a function of time with an accuracy of 1 msec, and resolution of better than 10 minutes of arc.

Measurement of timing ability.

The timing tasks all required the subject to respond by pressing the space bar on the computer keyboard. The computer continuously recorded bar presses as a function of time.

Experimental Procedure

Those students passing the requirements of all of the screening tests were given the five experimental tests. These tests were given in one sitting and took approximately 19-22 minutes from start to finish. The order of the five tests was counter-balanced. Subjects were asked to make certain they understood the task, then were given a practice trial which was exactly the same as the test trial. Feedback was given on the practice trial to ensure that the subjects understood what was required of them. Upon completion of the first task, subjects received instructions for the second task.

Test 1 (Timing-Location). A small dot appeared in seven successive locations across the computer screen which the subjects were facing. The locations were 4 degrees apart on a horizontal line. Each time the dot appeared for one second before appearing at the next location. To the observer it appeared as though a single dot was "jumping" from left to right across the screen. One second after reaching the rightmost location, a beep-tone sounded and the dot disappeared. At this time the subject was to be looking at the screen at the locations where the dot would have been if it had appeared, at the time it would have appeared at each location. In synchrony with eye movements to successive locations subjects were also required to make a bar press. The computer recorded eye location and bar presses as a function of time. The computer allowed subjects approximately 70 seconds to perform the test which would ideally be performed in approximately 7 seconds. The dot locations were placed 4 degrees apart as eye movements of this size typically occur while reading (Pavlidis, 1983) and are thought to involve only cortical control processes.

Test 2 (Location). A small dot appeared in seven successive locations across the computer screen which the subjects were facing. The locations were 4 degrees apart on a horizontal line. Each time the dot appeared for 1.5 seconds before appearing at the next location. To the observer it appeared as though a single dot was "jumping" from left-to-right across the screen. One second after reaching the rightmost location, a beep-tone sounded and the dot disappeared. At this time the subject was to be looking at the screen at the locations where the dot would have been had it appeared. At 1.5 second intervals a beep-tone sounded, signalling to the subject when he should move his eyes to the next location. The tone sounded seven times (one to signal the subject to move his eyes to the first location, and one more for each successive position). The computer recorded eye location as a function of time.

Test 3 (Timing). A small dot appeared near the center of the computer screen that the subjects were facing. It remained in position for 2 seconds, then appeared 1.25 degrees to the right of where it was located. It remained in position for 2 seconds, then moved back to the original position. This pattern repeated itself for a total of five jumps. After the fifth jump a tone sounded and the dot disappeared. At this time the subject was to be pressing the space bar each time he thought the dot would have jumped to the other position. The computer recorded the first six bar presses as a function of time. The computer allowed approximately 70 seconds to perform the task which ideally would have been performed in 12 seconds.

Test 4 (Rhythm). Subjects were asked to listen to a set of beep-tones produced by the computer, then saw a dot appear on the computer screen. The dot appeared 2 seconds after the last beep of the set and signalled subjects to begin pressing the space bar. There were one practice and four test sets. The sets of tones consisted of either four or five beeps separated by some combination of short (.5 second), medium (1 second), or long (2 second) inter-stimulus intervals. For example, the practice trial consisted of four beeps separated by inter-stimulus intervals of 1 second, 1 second, and 2 seconds, respectively. The sets of tones used in this test are similar to those described in Bryden (1972) and Zurif and Carson

(1970). The computer recorded bar presses as a function of time. The computer allowed approximately 65 seconds for the completion of the tasks which ideally would have been performed in approximately 6 seconds.

Test 5 (Same-Different). Subjects were required to listen to two sets of beep-tones produced by the computer. Two seconds after hearing the first set of beeps the experimenter pointed to the subject to signal the beginning of the second set of beeps. Immediately after listening to both sets of beeps subjects were required to state whether the two sets of beeps were the same or different. There were one practice and five test trials. Sets of tones consisted of five or six beeps separated by some combination of medium (1 second) or very short (.25 second) inter-stimulus intervals. Two trials had same pairs and three trials had different pairs. All pairs had the same number of beeps; pairs that differed only did so in the pattern of inter-stimulus intervals. For example, a "different" trial had subjects compare two five-beep sets with the following patterns of inter-stimulus intervals: .25 second, .25 second, 1 second, .25 second; .25 second, .25 second, .25 second, 1 second. The experimenter recorded subjects' verbal responses of either "same" or "different". The sets of tones are similar to those described by Bryden (1972) and Zurif and Carson (1970).

Quantification of Data

Experimental tests 1 (Timing-Location) and 2 (Location). Of interest on both tests were locational and timing related characteristics of the eyes. The computer recorded eye location for both eyes, independently, over time. To evaluate locational accuracy the difference between where the eye was looking and position of the actual target location was determined for each of the seven locations across the screen. A subject's score on each test was the sum of the difference scores, in degrees.

To evaluate temporal accuracy the difference between when the eye moved to each successive location and when it should have moved was determined for each of the seven locations across the screen. A subject's score on each test was the sum of difference scores, in milliseconds.

Experimental tests 3 (Timing) and 4 (Rhythm). Timing ability on these two tests was measured by bar press behavior. The computer recorded when each bar press was made over time. The difference, in milliseconds, between when the bar was pressed and when it should have been pressed was computed. A subject's score on each test was the sum of difference scores.

Experimental test 5 (Same-Different). The number of correct judgments was recorded for each subject. A total of five correct decisions with a low of zero was possible.

RESULTS

Eye Movement Temporal-Spatial accuracy The effect of group membership (i.e., dyslexic, normal) upon performance on the eye movement tests (Location, Timing-Location) was analyzed by using a Multivariate Analysis of Variance (MANOVA) procedure. Eye movements were recorded on both eyes for both tests. The dependent variables of interest were dominant and non-dominant eye for each test; the independent variable under investigation was group membership.

The MANOVA was not significant $F(4, 52) = 2.3$. It was determined a priori to test the performance of the dominant eye for each test. The data were organized in this way so as to be comparable to the manual timing performance data for which the dominant hand was used. One-way ANOVAs yielded non-significant differences between groups on Timing-Location, $F(1, 57) = .03$, and on Location, $F(1, 64) = 2.75$. The means, SD, and univariate F statistics for each variable are presented in table 3.

INSERT TABLE 3 -HERE-

Since eye movement measurements were taken for both eyes, it was decided a posteriori to conduct one-way ANOVAs with the non-dominant data for both tests. In order to control the error rate for a posteriori tests, the Bonferroni correction method (Kirk, 1982) was employed. For each test a significance level of .025 was employed in order to achieve an overall significance level of .05. The one way ANOVAs yielded a non-significant difference for Timing-Location, $F(1, 57) = .43$, and a significant difference for Location, $F(1, 65) = 10.38$, $p<.005$. Dyslexics were inferior to normals. Since a significant difference was found between groups for non-dominant eye data but not dominant eye data, a multivariate profile analysis (MPA) was performed in order to test for differences between dominant and non-dominant eyes. The MPA was not significant $F(1, 55) = .52$, and neither was the interaction term $F(1, 55) = 2.7$. Improper calibration resulted in the loss of a few records.

Spatial Accuracy The effect of group membership on locational accuracy was analyzed by using a MANOVA procedure. The four dependent variables of interest were dominant and non-dominant eye for both tests; the independent variable of interest was group membership. The MANOVA was not significant $F(4, 32) = .97$. It was determined a priori to test the dominant eye for each test. One-way ANOVAs for Location, $F(1, 54) = .00$ and Timing-Location, $F(1, 47) = .19$ were not significant. Since the number of lost records was smaller for the non-dominant eye it was decided to use the data from the non-dominant eye. One-way ANOVAs for Location, $F(1, 61) = 2.35$, and Timing-Location, $F(1, 52) = .04$, were not significant indicating no difference in locational accuracy between groups (see teble 4).

INSERT TABLE 4 -HERE-

Timing Dyslexics performed significantly worse than normal subjects on the tests which measure timing ability, three of which involve manual performance, and the fourth of which involves only perception. The effect of group membership upon performance on the independent timing tests was analyzed by using one-way ANOVA procedures. Dyslexics were significantly inferior to normals on the test requiring the perception (Same-Different) $F(1, 70) = 4.9$, $p<.05$, and manual reproduction (Rhythm) of rhythmic stimulus patterns $F(1, 66) = 9.9$, $p<.01$. There were no group differences on the test requiring the manual reproduction of a relatively slow constant stimulus pattern (Timing), $F(1, 62) = 1.1$. On the test requiring the manual reproduction of a relatively fast constant stimulus pattern (Timing-Location) dyslexics performed worse than normals $F(1, 65) = 2.8$, although this difference was not significant. Dyslexics were on average inferior on all timing related tests, although the differences between groups only reached statistical significance for the tests with rapid, changing (i.e., rhythmic, non-constant) stimulus patterns (Rhythm, Same-Different). (SEE TABLE 5).

INSERT TABLE 5 -HERE-

DISCUSSION

Timing of Eye Movements

Dyslexics performed worse than normal readers with respect to the temporal characteristics of the eye movement tests.

An a priori ANOVA procedure, although not significant at conventional cut-off levels, yielded results in the predicted direction for Location. On Location the difference between groups approached significance with the dominant eye as the dependent variable. While no firm conclusions can be drawn on the basis of a non-significant trend in the data, it should be considered that a significant group difference was found when the non-dominant eye was used as the dependent variable. The organization of the eye movement data into dominant and non-dominant categories was done so as to be able to compare the oculomotor performance data to the manual performance data which was collected on the dominant hand. Aside from the implication that the eyes do not move in perfect synchrony, the significant difference found when non-dominant eyes were compared indicates that dyslexics had more difficulty than normals with the temporal characteristics of this test. Because a signal was used to tell subjects when to move their eyes, the memory factor was eliminated.

Spatial Accuracy of Eye Movements

With respect to the spatial/locational aspects of the eye movement tests the performance of dyslexic was similar to (not significantly different from) the performance of the normal subjects. That is, dyslexics were no less accurate than normals in visually locating points on the computer screen. Even though a group difference was noted in terms of timing accuracy of eye movements, this did not affect accuracy of location. Basic oculomotor control and good spatial judgment are requisite skills for such an achievement.

Timing

Dyslexics' performance was compared with that of normal readers on the tests which measure timing ability, three of which involve manual performance, and the fourth of which involve only perception. The tests involving stimuli with relatively slow, steady rates of presentation yielded virtually no group differences (Timing) or larger differences which did not reach significance (Timing-Location). The tests with non-constant, more rapid rates of presentation (Rhythm, Same-Different) yielded significant group differences with dyslexics performing at an inferior level. It appears by the pattern of results that the quicker rate of presentation is more difficult than the slower, and quick and variable stimuli are most difficult for the dyslexic.

Brain and Dyslexia

What is needed to support the empirical evidence for the existence of a deficiency in temporal processing is evidence that shows that dyslexics are impaired in left hemisphere functioning (the side of the brain considered to be more efficient, and preferred in processing time-related information). Ample research exists which places fine temporal discrimination within the domain of the left hemisphere. Hammond (1982) reviewed studies conducted on brain-injured as well as normal subjects from which he concluded that the language dominant hemisphere shows finer acuity (greater temporal resolution). Gaddes' (1985) review yielded a similar conclusion. Gaddes speculates that the left hemisphere may be language dominant because of its superiority in processing serially presented information.

Neuropsychological studies designed to tap the functioning of the cerebral hemispheres have revealed differences in functioning between dyslexics and normals. For example, contrary to normals, dyslexics do not show the usual right visual half-field (Marcel, et al., 1974), ear (Sommers & Taylor, 1972), or hand (Witelson, 1976) advantage with verbal material. The results of these studies seem to indicate the disruption of left hemisphere functioning due to bilateral representation of spatial functions which are normally confined to the right hemisphere (Witelson, 1977). Also, dyslexics have been shown to exhibit superior visual-spatial scores (and inferior verbal-sequential scores) on standardized intelligence scales (Badian & Wolff, 1974; Bannatyne, 1971). Similarly, Dodgen, (1986);Dodgen and Pavlidis (1987) found temporal performance difficulties but unimpaired spatial performance for dyslexics when compared to normal readers on oculomotor tasks. Spatial accuracy would be in the domain of right hemisphere functioning for most subjects (Davis & Wada, 1977; Gazzaniga, 1970; Sperry, 1968; Springer & Deutsch, 1981). The pattern of results obtained by Dodgen, (1986); Dodgen and Pavlidis (1987) resemble those obtained in brain-injury studies (Bakker & Licht, 1986) and brain stimulation studies (Ojemann, 1983). Bakker and Licht (1986) cite the fact that right-hemiplegics are accurate and slow in reading, while left-hemiplegics are fast and inaccurate (skipping letters and whole words). In other words, with the left hemisphere intact, time-related performance is not affected, but spatial-locational performance is affected. The reverse is true when the right hemisphere is intact and the left hemisphere is disabled. Ojemann (1983) has demonstrated that electrical stimulation of the brain can be used to selectively disrupt functioning for a given area of the brain, acting as a temporary lesion. Through this stimulation-mapping procedure Ojemann (1983) has shown that the brain is organized for language in discretely localized areas within the cortex. Stimulation of cortical areas of the left hemisphere selectively disrupts language functions, while stimulation of right hemisphere cortical areas selectively disrupts spatial functions. Within the left hemisphere adjacent areas are related but appear to be specialized in specific language functions (e.g., naming, short term verbal memory, sequencing, etc.). One area of particular relevance for the present discussion, the peri-Sylvian area of the left hemisphere, shows selective disruption of the ability to make orofacial gestures in sequence when electrically stimulated, demonstrating anatomical and functional links between non-verbal sequencing and language functioning.

It has been claimed by some researchers (Dodgen, 1986; Dodgen & Pavlidis, 1987; Pavlidis, 1986) that the timing difficulty of dyslexics obtained by eye movement measurement reflects difficulty at the level of the left hemisphere. This has not simply been assumed. Evidence for this claim comes from brain stimulation and brain-injury research. While many areas of the brain are involved with the control of eye movements, there are certain oculomotor difficulties which result from disturbances in certain levels of the system. Studies show that amongs others three areas are mainly involved in the control of horizontal eye movements are the frontal lobes, the cerebellum, and the parapontine reticular formation (Fox, Fox, Raichle, & Burde, 1985; Henriksson, Pykko, Schalen, Magnusson, & Wennmo, 1984; Shakhnovich, 1977). Dysfunctional brain stem activity results in decreased velocity of saccades, whereas cerebellar disturbances result in gaze nystagmus, saccadic and pursuit abnormalities (Henriksson, et al., 1984; Zee and Leigh, 1983). Frontal lobe disease or injury results in disruption of the initiation of saccades. In eye movement studies of dyslexia the presence of nystagmus is reason for exclusion from the study. Also, abnormal performance characteristics such as reduced velocity of saccades are not reported (Adler-Grinberg & Stark, 1978; Leisman, et al., 1978; Leisman & Schwartz, 1978). Rather, what are usually found are differences in the number of movements, both forward and backward (Elterman, et al., 1980; Griffin, et al., 1974; Pavlidis, 1981b, 1985b). The differences reported in the research more closely resemble those characteristic of disturbances at the level of the cerebral areas rather than at lower brain centers. For example, a study by Pykko, Dahlen, Schalen, and Hindfelt (1984) comparing subjects with left frontal lobe lesions and normals found that brain-damaged subjects had difficulty performing saccades on time command. This finding is similar to the results obtained by Pavlidis (1981b; 1985b), and also by the authors of this chapter in a task where subjects were required to move their eyes when a tone was sounded.

Diagnostic Implications

The typical diagnostic course is a multi-level process which usually begins with an informal observation made by the classroom teacher. Once a child is designated as being a poor reader, a more formal assessment process is set into motion. Formal assessment usually involves: various standardized reading tests; physical assessment; and, comparison of IQ to reading level (Bond, Tinker, & Wasson, 1979). Such an assessment necessitates multi-disciplinary involvement, and more importantly, time. As Hawkins (1985) notes, often times children are not referred for help until the end of the primary grades because there is a reluctance to label children and to hope that the children are going through a passing phase. Therefore, there is a tendency to under-identify potential dyslexic readers.

The unfortunate implications of the above typical scenario are highlighted by results reported by Strag (1972) and Muehl and Forell (1973). Strag (1972) reported that the percentage of poor reading children reaching normal reading levels dropped dramatically the later the diagnosis was made. For example, when the diagnosis was made by grade 2, 82% of the children were brought up to normal classroom work. This percentage is to be compared to only 46% of those identified by the third grade. Similarly, Muehl and Forell (1973) found that early diagnosis, regardless of the amount of subsequent remediation, was associated with better reading performance at a five-year follow-up.

What is needed is the early application of short, easy to administer, objective, and accurate diagnostic tools. To the extent that temporal/successive processing ability is thought to be involved with reading at all stages, tests which measure this ability may be useful in the early, objective diagnosis of dyslexia. For example, Jost (1988) conducted a study in which eye movement performance on the Pavlidis test given during the first semester of schooling, was used to predict reading ability in the second and third grades. Using the Pavlidis eye movement test, Jost was able to correctly predict with an accuracy of 91.51% who of his 6 year old would develop academic problems by the end of the second grade. Jost also noted that eye movement efficiency was more highly correlated with reading ability than the more conventional measures of socioeconomic status and (Wechsler) IQ. The youngest age at which the group differences can be reliably measured needs to be further investigated. Jost's (1988) study is a good starting point but its applicability for early diagnosis needs to be replicated and expanded.

Remedial Implications

Many remedial approaches are discussed in the literature. Zigmond (1978) classified them into three categories: those which focus on requisite skills; blanket approaches applied to all dyslexics; and those identifying strengths and weaknesses and matching the appropriate treatment. Those in the first category (e.g., Frostig & Horne, 1964) typically involve visual and motor perceptual training. Those in the second category (e.g., Orton-Gillingham approach) usually involve sensory training, multi-sensory training, and phonics instruction. Those in Zigmond's third category work on the assumption that a match can be made between deficiencies of a given child and a given type of instruction (e.g., Naidoo, 1981).

Remedial efforts with dyslexics have yielded equivocal results at best. Spache (1981) reviewed over 30 remedial studies and concluded that "remedial treatment apparently does not affect school progress appreciably over time." (p. 397). He noted that most studies found significant gains during the treatment period which were dissipated over time. This observation suggests that the obtained skills were not generalizable and reading did not advance any further once the programs stopped. However, Dumont (1990) reaches a different conclusion, claiming that remediation of dyslexia can be successful.

Given that temporal processing difficulties have been shown to reliably discriminate dyslexics from normals, some remedial implications follow. From the literature review two areas of difficulty have been identified: in the picking up of the written information (due to the oculomotor-attentional problem) and in the processing of serially presented information (left hemisphere processing). Interventions have been proposed to increase dyslexics' abilities to employ successive (left-hemisphere) processing strategies. For example, Gunnison, Kaufman, and Kaufman (1982) have suggested exercises which involve the rehearsal of strategies designed to improve successive processing abilities. McCarthy (1985) has proposed a novel approach which involves employment of time-based components of music (i.e., rhythm). For example, he suggests that reading words to music may be helpful to dyslexics.

Another approach involves the stabilization of the eyes or remove the need to move the eyes during reading. Larger scale, well controlled studies need to be conducted before firm conclusions can be drawn, although the Pavlidis (1987) results are encouraging.

Pavlidis (1987) eliminated the need for eye movements during reading. He presented words on a computer screen, one after another, at the same central spot. Dyslexics were able to read at a much faster rate than normally while retaining near 90% comprehension. This method produced very promising results and deserves further investigation.

Direct implications for remedial training: whatever the source of the dyslexics' erratic eye movements, they disturb the reading process. If eye movements are found to be temporally or spatially inaccurate, or both, this will provide appropriate information for specific remediation. The more clearly eye movement characteristics are understood, the clearer are the remedial implications. Procedures to train the eyes in timed movement, or accurate distance estimation could be implemented as needed. Dodgen and Pavlidis' results suggest that dyslexics have problems in timing. However, the effectiveness of such a training will depend on whether any gains in eye movement efficiency transfer to reading performance as well.

3 disc2

Several studies have actually applied successive processing strategies discussed above (Kaufman & Kaufman, 1979; Kirby & Robinson, 1987; Klein & Schwartz, 1979). All three studies reported academic improvement which was particularly encouraging because the subjects were not specifically trained in reading. Therefore the potential to generalize and apply these skills after the training period is increased. This is important as the previously noted review by Spache (1981) revealed that progress in reading usually dissipated after treatment stopped. Of course, long-term well designed studies are needed to empirically substantiate the long range effectiveness of this type of training.

Conclusions

1. The manifestation of temporal/serial order difficulties across procedures and modalities in the research literature strongly implies central nervous system (i.e., brain) dysfunction. The Dodgen and Pavlidis finding of oculomotor difficulty in timing, but not locational accuracy, is in agreement with other neuropsychological studies implicating left-hemisphere dysfunction (Marcel, et al., 1974; Sommers & Taylor, 1972; Witelson, 1976). Brain stimulation (Calvin & Ojemann, 1980; Ojemann & Mateer, 1979) and cytoarchitectonic analysis of the brain of the dyslexic (Galaburda & Kemper, 1979; Galaburda, 1986) also locate dysfunction in the left hemisphere. Temporal order processing difficulties appear to be related to verbal and non-verbal difficulties of the dyslexic due to the proximity of location of brain areas responsible for these respective processes (Ojemann, 1983; Pavlidis, 1986).
2. Oculomotor measurement appears to be more sensitive than manual performance methods in detecting differences in time-related behavior.
3. Eye movement analysis holds promise for the early objective

diagnosis of dyslexia.

4. Deficiencies of the dyslexic can be remediated in a number of ways, some of which are currently being applied. Reduction of the need for reading eye movements (Pavlidis, 1987), and training in successive processing strategies (Kaufman & Kaufman, 1979; Kirby & Robinson, 1987; Klein & Schwartz, 1979) have yielded encouraging results.

In order to achieve maximum discrimination between dyslexic and non-dyslexic readers (for maximum diagnostic accuracy) certain parameters need to be more systematically investigated. The rate of stimulus presentation which yields maximum discrimination needs to be found as well as the optimal variability of the inter-stimulus intervals. The modality of presentation (i.e., visual, auditory) which best exploits timing differences as well as the most sensitive measurement procedure need to be further explored. In order to achieve the important goal of early diagnosis, studies should be conducted with younger children. The predictive value of these tests can then be tested empirically.

The investigation of intervention strategies should be undertaken in long-term studies. While a few studies have reported positive results (Kaufman & Kaufman, 1979; Kirby & Robinson, 1987; Klein & Schwartz, 1979; Pavlidis, 1987; Punnett & Steinhaur, 1984; Solan, 1985), the meaningfulness of these results can only be evaluated in terms of their long range effectiveness.

Computerized, automatically analysed, eye movements will play a vital role both for the early diagnosis / prognosis of dyslexia and also in the leading to and the objective evaluation of various methods of treatment.

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