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EARLY VISUAL INFORMATION PROCESSING IN DYSLEXIA

BY

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ABSTRACT

This research was a beginning attempt to resolve the contradictions that are apparent in some six research studies on the topic of dyslexia and early visual information processing. Several investigations, e.g., Stanley (1976), Stanley and Hall (1973), and O'Neill and Stanley (1976) have found significant differences between dyslexics and normals in early visual information processing. Other researchers, e.g., Stanley and Hall (1973), Arnett and DiLollo (1979), and Fisher and Frankfurter (1977) have noted no differences in visual persistence or processing. Each of the above studies used somewhat different stimuli and tasks. Some have serious methodological weaknesses. Both of these facts have prevented the drawing of even tentative conclusions.

In this study the 20 male dyslexic subjects (ages 8-14) were chosen from a remedial learning center. Academic retardation in other subject areas was measured and noted. They were assessed on the WISC, the Schonell Reading, Spelling, and Arithmetic, and the Metropolitan Achievement Test (Reading Comprehension), and matched on age, and IQ to normal controls. Both dyslexics and controls were presented with four different tasks. Two of these were visual persistence tasks which estimated the duration of visual persistence of each subject. Two paradigms have been used to study the duration of visual
persistence: i) dark interval threshold and ii) temporal integration. Past research has resulted in contradictory outcomes for the two types of persistence tasks. The dark interval threshold studies have shown that the threshold increases with age and that dyslexics have a higher threshold value than normal controls. On the other hand, temporal integration studies suggest that there are neither dyslexic-normal differences on this aspect of processing. Since it is possible that the two methods measure two separate functions within the visual system, this study attempted to compare the results obtained from these two paradigms using the same subjects.

The first visual persistence task was that used by O'Neil and Stanley (1976). Each subject was presented with two spatially overlapping, identically oriented, straight lines at varying inter stimulus intervals (ISIs) and was required to determine if one or two lines were presented (dark interval threshold). Unlike O'Neil and Stanley (1976) a forced choice design was introduced to eliminate the possibility of conservative response bias on the part of the dyslexics. Additionally, luminance was adjusted appropriately so that extraneous cues were eliminated. The second visual persistence task was the same one used by Arnett and DiLollo (1979). Each subject was presented with two spatially adjacent, temporally successive dot matrices, one of which was missing a dot. The subject's task was to correctly determine which matrix was missing.
the dot, (temporal integration). Arnett and DiLollo's task was designed such that conservative response bias and brightness cues were effectively eliminated. However, intelligence was not adequately controlled, thus a replication with subjects matched for age and intelligence seemed necessary.

The other two perceptual tasks were backward masking tasks which have traditionally been used to measure rate of processing. The previous research was equivocal in determining whether differences exist between dyslexics and normals in the rate of transferring information to other stages of processing in order to result in a given level of stimulus identification. One task used in the present study was a verbally oriented task and the other a more structurally oriented task. Both were administered to the same subjects in the event that the normals and dyslexics might be differentially affected.

The first backward masking task was again one first used by Arnett and DiLollo (1979). It involved the simultaneous presentation of two adjacent dot matrices, one of which was missing a dot in the centre location. At varying ISIs, a random dot masking stimulus was presented to limit processing time. Once again the subject's task was to determine which matrix was missing the dot. The second backward masking task involved alphabetic characters. Following a brief presentation, a randomly chosen alphabetic character was covered up by a mask of letter fragments
at varying ISIs. The subjects' task was to identify the letter presented.

While testing the subjects, it became apparent that some younger subjects had greater difficulty on some of the tasks. As a result, the dyslexic and normal groups were divided arbitrarily (by a median split) into young and old subgroups. A multivariate analysis was performed on the data.

The results of this study indicated that while no differences could be observed between the dyslexics and normals in the duration of visual persistence using the temporal integration task, there were differences with the dark interval threshold task. The dyslexics required significantly longer times to report the gap between the two successively presented lines. Most of this difference appeared to lie with the young dyslexics. The duration of visual persistence times for the older dyslexics was more like that for the older normal controls.

The results obtained from the backward masking tasks used to measure rate of processing indicated that the dyslexics required longer ISIs than the normals on both the structurally oriented and the verbally oriented tasks. In other words, the dyslexics slower rate of processing is not exclusive to verbal tasks.

One of the most important features of this study is that four separate perceptual tasks were given to the same subjects. Two of the tasks were visual persistence tasks.
designed to measure the duration of visual persistence, while the other two were backward masking tasks, used to compare rate of processing. No other study, to date, has been so comprehensive. The pattern of differences between dyslexics and normals allowed for the following tentative conclusions: Major differences were found in tasks that may be represented as engaging higher centers of processing, such as would be involved in extracting details from a geometrical configuration (i.e., a missing dot from a matrix) or in identifying an alphabetic character. Does this mean that lower stages of information processing are not differentially involved in dyslexic and normal populations? The answer would seem to be "no". The results in the young vs. old dyslexics on the dark interval threshold task suggest that there may be early differences which may give rise to faulty strategies at higher levels. Once established, these faulty strategies may persist (as reflected in the rate of processing tasks) even when the initial cause has been outgrown.
INTRODUCTION

As our twentieth century world becomes increasingly more complex our children have more and more to learn. In spite of our many technological advances in presenting new material we still rely heavily on reading as the way of acquiring new information. Therefore, any degree of reading retardation today has grave consequences not only for the poor or non-reader but for society as a whole.

A child is considered reading retarded when he or she is not able to score at the reading achievement level proper to his/her age and years of instruction. Often reading retardation can be traced to one or more of: chronic absenteeism, emotional illness, poor teaching, and family problems. In these instances, once the primary cause has been determined and the appropriate treatment accepted, significant reading gains can usually be made. There is, however, one group of reading retarded children, known as "dyslexics", whose problem defies determination of both etiology and treatment, and often even definition.

The volume of literature that has appeared in the last thirty years on the topic of "dyslexia" is overwhelming. An entire journal has been devoted to the topic of dyslexia and related learning problems. How so little is
known about a topic that has received so much attention is at first puzzling. While there are notable attempts (Spache, 1976; Cruikshank, 1975) to organize this wealth of research, much confusion still remains. The following two sections of this paper, the first concerning semantics, and the second etiology and treatment, will give the reader some understanding of the complexity of "dyslexia" and of why so few facts are known today.

The Semantics Issue: Historical Perspectives

In 1896, Morgan published the first description of "congenital word blindness". Nine years later, Thomas (1905) and Fisher (1905) noted multiple cases in individual families. Eventually, Hinshelwood (1917) brought this group of reading retarded children to public attention through a monograph, reporting in detail their symptomatology. He noted therein the similarity of his subjects' symptoms to others with known brain damage.

Orton (1925, 1937) emphasized the extent to which children who suffered from "word blindness" tended to reverse the order of letters and syllables in words, or of words in sentences. He observed the instability in recognizing and recalling the orientation of letters and the order of letters in words, which he named "strephosymbolia" (twisted symbols). Orton (1943) was impressed by the frequency with which he found his patients to be
ambidextrous or left-handed or to show conflicting laterality of eye and hand. He postulated an intermixture of control in the two hemispheres of the brain that serve the visual or reading part of the language function (which in normal children are active in only the dominant hemisphere). Moreover, he noted in the childhood histories of children with reading and spelling problems indications of developmental deviations in their acquisition of speech and motor problems. Consequently, the term "developmental dyslexia" was spawned in order to reflect the belief that retardation in acquiring reading was caused by some interference with the natural process of growth and development.

In a series of studies, Hermann and his colleagues (1946, 1958, 1959) reported on the deficient writing ability and abnormal spelling of children with "specific dyslexia". He defined his subject group of specific dyslexics as those having a "defective capacity for acquiring at the normal time a proficiency in reading and writing corresponding to average performance; the deficiency is dependent upon constitutional factors (heredity), is often accompanied by difficulties with other symbols (numbers, musical notation, etc.) ..." (p.41). Thus another term, although not appreciably different from "developmental dyslexia", appeared in the literature.

About the same time, Werner and Strauss (1941) introduced the concept of "minimal brain damage" in order to account for the many deviations in mental development
noted in these "dyslexic" children. The fact that "brain
damage" was found to be undemonstrable by clinical observa-
tion led to its loss of favor as an etiological assumption.
(The term "minimal brain dysfunction" survived, however,
and reflects the continuing belief that some neurological
problem may underlie the reading retardation.)

Descriptive terms less burdened with etiological
assumptions, such as hyperkinesis, perceptual-motor handi-
caps, and dyslexia partially replaced the concept of the
"minimal brain damage syndrome", each formulated to empha-
size a particular clinical feature of the overall entity.
"Hyperkinesis" referred to the disruptive motor restlessness observed in many of the children (Werry, 1968);
"perceptual-motor handicaps" accounted for children who had
particular difficulty in co-ordinating both gross and fine
motor actions (Frostig, 1964); "dyslexia" became the term
of choice when the fact was noted that many of these
children were not receiving an adequate education in our
public school system (Boshes, 1964).

Due to the lack of operational criteria that defined
the borders of any one entity or differentiated among
the various designations in all of the other categories, it
became impossible to determine how the diagnosis of minimal
brain dysfunction differed from hyperkinesis, perceptual-
motor handicaps, or dyslexia.

In 1971, Wender repopularized the term "minimal
brain dysfunction" by proposing a theory which would once
again encompass all of the confusing and overlapping diagnoses. His theory assumes that these heterogeneous childhood disorders are simply individual deviations of a common defect in bioamine metabolism which can be treated by a specific drug (dextroamphetamine). His theory remains, however, largely unsupported.

Global theories, such as Wender's, probably represent a step backward in the advancement of knowledge in this area. Given our present neurological technology, further specification of each of these populations in terms of behavioral, physiological, and neurological characteristics, eventually determining how each of these groups responds to various treatment programs, is at present the most appropriate way in which to proceed. In the final analysis we may find that each diagnosis refers to functionally and etiologically distinct entities.

The term "dyslexia" has survived in spite of many attempts by minimal brain dysfunction theorists to subsume it. Although there remains general agreement that such an entity as "dyslexia" indeed exists (the many hundreds of books and articles on dyslexia attest to that fact), we are not, even at this late date, much wiser in terms of specification of population characteristics and determination of etiology and treatment. Cruikshank (1975) has noted that since 1963 the term "dyslexia" was changed by some to the term "learning disability" in recognition of the fact that many dyslexics have learning difficulties in more than
reading. Unfortunately, this term has been extended by many educators to include emotionally disturbed children as well. The term "dyslexia" will be retained in this paper because its historical origins reflect a possible physiological (probably neurological) deficit - as opposed to social/emotional deficits - which underlie the problem.

**Etiology and Treatment**

Etiology and treatment have been discussed together since they are often inextricably related. Many etiological and treatment theories of dyslexia abound in the literature. The major ones are mentioned here. Most theories hold that some minor neurological deviation is at the root of the dyslexia problem. However, one theory of dyslexia based on faulty learning, and a theory attributing dyslexia to a psychoneurotic reaction to anxiety caused by parentally induced stress are also included.

**Learning Theory and Dyslexia**

Behavior modification approaches to dyslexia have become relatively widespread in the last ten years. This approach has been mainly derived from the work of Staats (1963, 1968, 1971). One aspect of Staats' theory is that reading involves cumulative hierarchical learning. That is, the acquisition of certain skills provides the basis for acquisition of more complex skills. Reading begins with the learning of attention and discrimination skills.
These basic behavioral skills form the basis of learning the alphabet discrimination; these form the basis for learning the elementary reading units (grapheme-phoneme correspondences); these form the basis for acquiring a large repertoire of work reading responses; and so on (Staats, Brewer and Gross, 1970, p. 76).

He felt that one must analyze precisely the skills in this hierarchy which the child has acquired and teach those behaviors in which the child is deficient. This is true regardless of age or biological development. He believed that learning is not due to a "biological unfolding" or readiness, but rather that cognitive skills are acquired through specific training. Staats said one should not wait for a biological readiness to occur since "it is the learning that makes the child ready" (Staats, 1973, p. 213).

One of Staats' observations was that children typically are presented with many learning trials in the acquisition of oral language, but that in the acquisition of reading behavior the child is given far fewer and more poorly arranged opportunities to respond. Consequently, Staats developed simple procedures and an apparatus for presenting many explicit learning trials and providing reinforcement for correct responses. His token reinforcer system in which the child was given plastic discs as tokens (which could be exchanged for a wide variety of toys or other items) for correct responses, was the first use of such procedures in educational behavior modification.
His learning materials were designed to be simple to administer and to facilitate the recording of the child's progress. Typically, a child learned new words to be presented later in a story. The child was told the name of each word singly and was reinforced for looking at it and saying its name. When the child could spontaneously read all of the words, they were presented in the paragraphs of the story, and then in the whole story. Better performance was reinforced with a higher value plastic disc (there were three values).

Included in the studies of Staats and his colleagues were children with severe learning problems who learned well with the teaching methods employed. Unfortunately, Staats did not define his children with "severe learning problems" very precisely. Consequently, although his techniques are being widely used in educational systems everywhere, their efficiency with an actual dyslexic population is still in question.

**Neurosis and Dyslexia**

Anna Freud (1943) stated that learning problems originated in impaired parent-child relationships. Her logic was that this resulted in a faulty capacity to sublimate infantile erotic and aggressive instincts, and that the necessity for utilizing psychic energy for repression leaves little for learning. Many clinicians (e.g., Houde, 1968; and Boudin, 1968) believe psychotherapeutic methods
with learning disabled children are the treatment of choice. It is entirely possible, though, that their subjects have emotional disturbance rather than dyslexia as the primary clinical feature.

More recently, Manzo (1977) has attempted to illustrate that dyslexia may be a conversion reaction syndrome. This syndrome is defined as an unconscious process by which deep intra-psychic conflicts, which would otherwise give rise to considerable anxiety, are converted into a symbolic external expression. Manzo described two forms of conversion: somatic and physiologic. The latter variety delimits or incapacitates sensory awareness and results in seeming losses or distortions of vision, hearing, and speech. With the premise that a reading dysfunction could be a symbolic representation of a deeper conflict, Manzo concluded that a substitute for reading, i.e., something not having the same emotional associations (though highly analogous in its requirements) might be learned more readily by his subjects. Employing an alternate orthography (squiggles) he claimed to have taught two 12-year old "hardcore" dyslexic children to read in 15 hours of instruction. He promised more supportive evidence for his claims soon.

Until such time as convincing evidence appears and the research populations are more carefully defined, psychoneurotic theories of dyslexia will remain as unpopular as they are vague.
Neurology and Dyslexia

One view of dyslexia is based on a theory of neurological disorganization. Delacato (1963) offered this interesting view of dyslexia which he based on observations of the ontogeny of neurological organization. He noted that the evolution of neurological organization has developed from the simple presence of a medulla and spinal cord in basic life forms, through pons, midbrain, cortex, and finally, cortical cerebral dominance in man. He felt that dyslexics may be neurologically disorganized and not injured. Like many theoreticians, Delacato offered a treatment regimen - the goal of which is neurological organization.

Building largely on Orton's observations on dyslexia, three clinicians, Doman, Doman, and Delacato (1959, 1963) employed concepts of the hierarchical organization of the brain and emphasized evaluation and recognition of each level of ontogeny. The most critical to reading was considered to be the establishment of dominance of the eye, hand, foot, and speech, in one cerebral hemisphere. Remedial methods for establishing cerebral dominance included creeping and emphasis on the use of one hand and homolateral eye as dominant. Delacato, to whom most of the treatment procedures are attributed, placed special emphasis on "cross-patterned" creeping or advancing the contralateral leg and arm simultaneously. While positive effects on visual perception and language development from
procedures given according to the Delacato rationale were reported by Lavin (1972), a number of other experiments (Robbins, 1966; McLees, 1970) failed to show that the Delacato procedures increased reading scores.

Frostig (1970, 1975) believed that the problems of children with learning disabilities have resulted from neurological disturbances which have affected the integration of verbal and non-verbal functions. She offers an approach that is predominantly remedial. She and her colleagues developed a program of sensorimotor skill development, emphasizing both gross and fine motor activity, as well as direct visual-perceptual development. Several studies (Gamsky and Lloyd, 1971; Bishop et al., 1972) have supported hypotheses that the Frostig program enhanced performance on perceptual tests, but the training appeared to be closely related to the test tasks. Brown (1970) failed to demonstrate significant gains in reading accuracy or comprehension.

Stemming back to the observations by Thomas (1905) and Fisher (1905) on familial dyslexia, many studies have attempted to demonstrate that dyslexia is an inherited neurological defect. There is compelling evidence from twin and family studies for the importance of genetic factors (Critchley, 1970; Naidoo, 1972) in the manifestation of dyslexia.

Naidoo (1972) has attempted to isolate separate subgroups of dyslexics by seeking to discover whether different
patterns of disability might be associated with different etiological factors (p. 99). While no clearly defined subgroups emerged, there appeared to be a continuum:

in one half of which there was a predominance of boys with a family history of reading or spelling difficulty, while in the other half were found the majority of a smaller number of boys in whom there was evidence suggestive of neurological dysfunction but a negative family history (p. 114).

Currently, very sophisticated statistical approaches are being utilized in the study of genetic transmission in dyslexia. A recent study by Foch (1977), in which he was unable to determine a satisfactory mode of transmission, has led him to speculate that dyslexia may be a heterogeneous disorder with different modes of transmission.

Wender (1972) has included dyslexia, as noted earlier, in his broad theory about MBD and its relationship to a biochemical abnormality which is reversed by the drug dextroamphetamine. Wender pointed out that response to treatment is not proof of etiology since the treatment may reverse abnormalities anywhere "from the primary abnormality through its causal chain" (p. 78). Nevertheless, he stated strongly that if we knew how the amphetamines or other stimulants worked in the MBD child we would know the cause of the disorder. The use of drugs in the treatment of MBD was not, of course, introduced by Wender. As early as 1942 Bender and Collington were administering amphetamines to groups of children with symptoms similar to Wender's MBD children. Since that time there have been
numerous evaluative studies on the effects of stimulant drugs on MBD children. Kornetsky (1975) in an extensive review of drug treatment, notes that "the treatment of the MBD child with central nervous system stimulant drugs decreases attentional and motor disorders that interfere with the child's school performance; they do not directly improve learning" (p. 471).

Hinshelwood's (1917) observation that dyslexics are not unlike known brain damaged subjects has also resulted in an immense amount of related research. Most recent studies (Wikler, Dixon and Parker, 1970; Wender, 1971) have indicated that there is a high incidence of soft neurological signs in MBD children. Included in the term "soft neurological signs" are: abnormalities of resting muscle tone, some clumsiness of either gross or fine motor movements, hyperactive deep tendon reflexes, extensor plantar responses, abnormal extraocular movements, frequent tics and grimaces, disturbed position sense, choreiform movements, dyskinesias, mild ataxia, minimal gait abnormalities with asymmetries of associated movement, left-right confusion, poor visual-motor skills, dysphasia, finger agnosia, and dyslexia (Kornetsky, 1975, p. 455).

It should be noted here that much of the more explicitly neurological research has been performed on an "MBD" population sample, which unfortunately included children suffering from a wide variety of behavioral abnormalities, e.g., hyperkinesis, perceptual-motor
handicaps, and dyslexia. This fact makes it difficult to determine to what extent the findings can be applied to that population of children which evidences reading disorder as its primary clinical feature. Nevertheless, a discussion of the etiological theories of dyslexia would be incomplete without a look at their findings. This "minimal brain damage" view of dyslexia holds that some structural damage has occurred sometime between conception and the onset of the behavioral and learning problems. A considerable number of electrophysiological studies have been performed on dyslexics to support this view, since it is believed that abnormal brain wave activity signifies tissue damage. In general, most studies reported slowing of brain wave activity as one of the most characteristic features of their subjects' electroencephalograms.

Myklebust (1973) has done an EEG study which is more directly applicable to a dyslexic sample in that he defined his experimental population as "learning disabled". Although he used the somewhat less precise term, "learning disabled", he did break down his findings somewhat. He noted that "children with non-verbal disturbances of learning had abnormal EEG's much more often than poor readers ..." (p. 70). Thus, neurological abnormalities found in the MBD studies noted above may be a result of such findings in subjects other than dyslexics. In any case, the exact relationship of this neurological abnormality to dyslexia, and whether or not it signifies brain damage, is presently
unknown, owing largely to the lack of studies which have focused on the dyslexic group in isolation, as well as to the current lack of precise knowledge in the field of neurology.

Zangwill (1962) some time ago attempted to reconcile the etiological viewpoints of lateral dominance vs. brain damage vs. inherited defect. He considered that brain injury and familial dyslexia need not be mutually exclusive and that individuals lacking strong and consistent lateral preference might be particularly vulnerable to the effects of stress - such as minimal brain injury at birth. Many researchers feel that a resolution to these etiological issues must wait on the discovery of more sensitive means of neurological assessment.

Despite the difficulty with the construct of neurological impairment and the technical problems in studying the operation of the brain, the fact remains that the brain is the physical substrate of learned behavior and that it may operate differently in children with dyslexia. Thus rather than disregarding electroencelphalographic study as a fruitful avenue of research, many researchers have felt that such study should be expanded, refined, and related more directly to the nature of the learning impairment.

Stevens et al. (1968) had a particularly interesting finding in that they noted slowing of EEG frequencies to be associated with hyperactivity, while EEG spike activity was associated with disturbances in attention, time
sense, ideation, and finger agnosia. Hutt and Fairweather (1971) found that a child with evidence of paroxysmal spike wave pattern in her EEG was inferior in the amount of information she could process, and slower in speed of perception, as compared with her performance when her EEG was free of electrical disturbance and showed normal background activity. This suggests that abnormal electrical activity in the brain may interfere with attention, and hence learning, only while it is occurring.

Recent advances in computer technology have permitted the development of a specialized EEG technique known as the average evoked response (AER). The AER is a method by which specific brain responses can be abstracted for study from the mass of ongoing electrochemical activity in the brain. Connors (1971) and Shields (1973) have found differences between normal and learning disabled children on the AER when they are required to process a variety of visual stimuli. Shields (1973) found that in every case the latency of the AER wave components was longer in the learning disabled group than in the normals. She suggested that the longer latencies in this group indicated that "these children may require longer to process information and that their nervous systems may operate more slowly than those of normal children" (p. 40). Such findings have direct relevance to contemporary psychological research in dyslexia and to the present paper. Psychologists are applying theories which are derived from information processing...
models to dyslexia in an attempt to determine at what level of processing the dyslexics' difficulty occurs. Finding a longer AER latency is suggestive of differential processing in normal and dyslexic children.

Before proceeding to the information processing literature, it is necessary to examine the past psychological research on dyslexia. It will become apparent, after such examination, that two important issues need to be considered.

**Behavioral and Phenomenological Research on Dyslexia**

In addition to the many research studies generated by the etiological and treatment issues described in the preceding section, much work has gone into defining the psychological characteristics of "learning disabled" children. Unfortunately, the research has proceeded, in the main, without a carefully defined statement which delimits the term "learning disabled".

Hallahan (1975) points out that the oldest approach to investigating the psychological characteristics of learning disabled children has been to administer existing standardized tests such as the WISC, Bender Gestalt, and Frostig to learning disabled and control groups. Usually a consistent pattern of results emerges. Huelsman (1970) and Klasen (1972), in their reviews of the many different studies using the WISC, noted that the dyslexics were consistently low on the subtests of Information, Arithmetic,
Digit Span, and Coding. Unfortunately, these studies are almost the only research area in which results can be reliably replicated. The limitations of administering tests are that they do not tell in which precise way dyslexics are different from normals. Given that the dyslexic scores low on the Arithmetic subtest, it is unknown if the low score is due to his difficulty with arithmetic concepts, a generalized anxiety which interferes with his concentration, or memory problems. Consequently, much research has been conducted in order to compare the memory, perceptual, language, cognitive, and attention abilities, of "learning disabled" and normal children. For a fairly comprehensive review of these areas, the reader can consult Hallahan (1973, 1975).

Perhaps the most thoroughly investigated area from those listed above is that of perceptual abilities. Numerous investigations, e.g., Coleman (1968), Lyle (1969), Skubic and Anderson (1970), have shown "learning disabled" readers to perform poorly on visual tasks. While this perceptual focus has produced a large body of literature investigating various aspects of perceptual development in learning disabled children, almost no research has been done on higher thought processes. Much of the research that is available, however, is contradictory and questionable, since many investigators do not define very carefully what they mean by "learning disabled". Furthermore, since no solid evidence supports the effectiveness of perceptual-
motor training programs as an educational approach, the exact relationship of perceptual handicaps to reading is indeterminate at present.

It is unfortunate that Hallahan (1975) has to conclude his review of the literature with the statement that lack of concern for specification of population characteristics is the most frequent methodological weakness, specifically either large differences in IQ or mental age are present between the learning disability and control groups or no data on this variable are reported (pp. 47-48).

He blames this deficiency for the lack of consistent empirical observations in the dyslexia field. Klasen (1972) places the blame for the discrepancies in the research on a different defect. She feels that many hypotheses have been verified with regard to only one feature or narrowly defined aspect of dyslexia. She notes that some researchers:

- go on trying to delineate well defined (at least theoretically) forms, such as "developmental", "specific" or "congenital" dyslexia, requesting exclusive application of these terms to cases and groups meeting the selective criteria established for their definitions. The danger of the circularity in this kind of reasoning is obvious. In practice, few if any cases fit these models of "pure" dyslexia (p. 186).

She continues: "The principles and methods by which to obtain scientific knowledge must not only be well defined but also verifiable on given realities" (p. 187).

The fact remains that we must find those important characteristics that dyslexics share as a group (if any,
in fact, exist), whether they be neurologic, physiologic, or behavioral if we are to develop more efficient methods of diagnosis and treatment. If we are unable to find these common factors, then dealing with each dyslexic becomes a research project in itself— a rather insurmountable task.

In summary, then, the field of "dyslexia" has struggled since 1896, and continues to struggle against global theories like Wender's which threaten to subsume it. Over the same time span, it has evolved from a large body of descriptive observations to an almost equally large body of "empirical" contradictions.

As a result, the two most important controversies that face the researcher in the field of dyslexia today are: (a) how can the dyslexic population be defined and (b) how can a dyslexic subject and/or group be equated with a normal one on that abstract variable of "intelligence". Consequently, a discussion of these two issues follows.

Current Issues in Dyslexia Research

How Can the "Dyslexic" Population be Defined?

On a case by case basis, many clinicians feel very comfortable in making the differential diagnosis of "dyslexia", in spite of the fact that there is no specific group of symptoms that are always associated with dyslexia. However, many would agree that dyslexia is most frequently
associated with neuropsychological symptoms such as disorders of: speech, lateral dominance, spatial orientation, perception, co-ordination, and motor activity. Emotional disturbance, frustration intolerance, behavior difficulties, social maladjustment, and disturbed family relationships, appear to be less frequent and of secondary importance. Money (1962) explained this state of affairs as follows:

If is not at all rare in psychological medicine, nor in other branches of medicine, that a disease should have no unique identifying sign, that uniqueness being in the pattern of signs that appear in contiguity. Out of context, each sign might also be encountered in other diseases or in the healthy. Specific dyslexia is no exception in this respect (p.16).

Many contemporary researchers (for example, those in the early visual information processing field) are adopting a working definition of dyslexia. Usually, it is a descriptive expression for a reading retardation of two years or greater, otherwise satisfactory performance in the classroom, normal or better than average general intelligence, and adequate senses. The phrase, "otherwise satisfactory performance in the classroom" is the "catch". If a researcher means by this that all other subject areas are at age level, with the exception of reading, one has to wonder: "how realistic are his criteria?" As noted in the preceding section of the paper, the fact that dyslexics, as a group, perform poorly on the Arithmetic subtest of the WISC is one of the few consistently replicable findings in the psychological literature on dyslexia. A common factor to
reading and arithmetic impediment has not yet been found. Many hypotheses have been forwarded. Mussen (1965) speculated that it may be the frequently noted "anxiety" in dyslexics which interferes more with conceptual learning, mathematics, and other tasks demanding abstraction and logical reasoning than with routine tasks and discrimination. However, Klasen (1972) mentioned the strongly cumulative component to arithmetic in her study. She wrote, "should a child, on the basis of verbal sequencing, or similar weakness, fail to master the multiplication tables or other arithmetic or geometric sequencing processes; should he miss out on the first word problems, then he could not cope adequately with any other mathematical steps building on the ones missed" (pp. 132-133). Critchley (1966) pointed out that arithmetical retardation may be associated with dyslexia but isn't always so. However, dyslexics do frequently have difficulties in arithmetic. Rather than attempting to find subjects who are more or less average in areas other than reading (as measured by the accuracy of the teacher's judgment or the individual researcher's strict adherence to the criterion he has set) it seems far more realistic to specify the levels of the other academic subjects. While a suspicion that dyslexia may be a heterogeneous disorder in both etiology and nature is growing, we still do not know who to isolate "types" of dyslexia. Therefore, to limit the sample to subjects who have reading disability alone may be most unwise. For
example, dyslexic subjects with reading, spelling, and/or arithmetic problems may have such weaknesses in early visual information processing, whereas subjects with only reading disabilities may have problems stemming from other higher order cognitive processes.

How Can a "Dyslexic" Group or Individual Subject be Equated with a Normal One on "Intelligence"?

Hallahan (1975) speculated that the reason many studies do not report IQ data on their subjects is due to the fact that "the mean IQ for children identified as learning disabled is substantially under 100" (p. 50). However, Schiffman and Clemmens (1966) and Klasen (1972) have both demonstrated (using large samples of dyslexic subjects) that their mean IQ as measured by the WISC is very close to 100. Klasen (1972) has taken the analysis of her data one step further and has determined (via a chi square goodness of fit technique) that Peabody, Goodenough, and WISC data, all fit the normal curve and can be considered as normally distributed (p. 118).

Hallahan (1975) warned researchers that matching dyslexic and normal subjects is risky until the mean IQ of the dyslexic population can be determined. However, on the basis of Klasen's (1972) data, it would seem that dyslexics can be safely matched with normals on the basis of Peabody, Goodenough, or WISC scores.

The Klasen (1972) study is a valuable contribution to the field in view of its objective selection of subjects
and broad empirical and statistical basis. A particular contribution of this study is that it challenges a still widely held belief that dyslexics typically have higher performance than verbal IQ's. Neville (1961) reported that four of seven studies comparing the performance and verbal IQ's found the performance IQ higher for poor readers. Spache (1976) reported that he has checked this verbal IQ - performance IQ difference in some fifteen studies of retarded readers - ten reported higher performance IQ and five found no significant differences. However, none of these studies can match the objective selection of subjects and the large sample size that Klasen studied.

Klasen (1972) has examined the test results of her large dyslexic sample and has found that they fall neatly into groups on the basis of their WISC scores. She was able to differentiate four Wechsler profiles which she feels may later prove to be related to specific neurological deficits. The four profiles were i) 22.3% have significantly higher performance IQ's; ii) 18.9% have significantly higher verbal IQ's; iii) 48.6% have significant subtest variability; and iv) 10.2% show no significant disparities. She speculated that those dyslexics with low verbal scores may have left hemisphere damage or dysfunction, those with low performance scores may have right hemisphere disorders, and those with significant overall subtest variability may have diffuse or bilateral central nervous system disorders. Whether or not further research
bears out Klasen's hypotheses remains to be seen. Nonetheless, she has demonstrated the remarkable heterogeneity of intellectual functioning among dyslexics.

Given that dyslexics are a heterogeneous group in terms of intellectual functioning, it is conceivable that experimental results might vary as a function of the particular IQ test used and its relationship to the experimental task. Thus, while Hallahan (1975) recommended a quick administration of the Peabody to both dyslexic and normal groups as a cursory check on IQ, it must be remembered that the Peabody is primarily a language test. Other nonverbal cognitive functions are being allowed to vary freely, and depending on the experimental task, may affect the findings. Consequently, the full WISC score seems the fairest means of equating IQ's, since (a) both verbal and nonverbal skills are reflected in the total score, and (b) dyslexics' scores on this test have been demonstrated by Klasen (1972) to follow a normal curve.

If full WISC IQ data are impossible to obtain then the researcher should have access to both Peabody and Goodenough data if findings are to be accurately interpreted. At the very least, subjects must be equated on that particular dimension of intelligence (i.e., verbal or nonverbal) which appears to be most related to the task that is being administered.

Recently, an information processing approach (described in the next section) has been applied to the
phenomenon of dyslexia. It allows for a more experimental approach to the problem and may ultimately provide the elusive answer. Nevertheless, it will be important for the researcher to be aware of the difficulty in selecting the dyslexic group and equating it with a control group on intelligence.

Gollin and Moody (1973) define the information processing approach to perception as being "characterized by a level and component analysis of information reduction ranging from early registration of stimulus events in the sensory neural network to encoding in higher cognitive structures and long term memory" (pp. 17-18).

It is believed by some (e.g., Atkinson and Shiffrin, 1968) that, once information has been transferred from sensory storage to short term storage (STS), the subsequent fate of the information is largely under an individual's control. While in STS, information can be rapidly recovered or transferred to long term storage (LTS), from which recovery can occur at some later time. Atkinson and Shiffrin (1968) argued that this transfer continued as long as the information was in STS and that transfer could be facilitated by various "control" processes, i.e., one can choose whether to actively manipulate the information to achieve some end or discard the information.

Torgeson (1975, 1977) has noted that children with learning disabilities have often been shown to be deficient on tasks designed to measure short term memory. Drawing on several different lines of developmental research (many
performance differences among children of different ages have been found to be due to the older child's more active, flexible application of mnemonic strategies), Torgeson proposed an explanation for many of the difficulties of learning disabled children in terms of their inability or lack of inclination to develop and use efficient strategies.

To test these hypotheses, two recent studies have been performed. The first (Torgeson and Goldman, 1977) demonstrated that poor readers in second grade were less apt to use verbal rehearsal on a sequential memory task than were good readers of the same level of intelligence. Tarver, Hallahan, and Kaufman (1976) studied the performance of learning disabled children on a serial recall task. The pattern of performance of the learning disabled children suggested that they developed more slowly than normal children in their use of efficient encoding strategies such as verbal rehearsal.

Torgeson (1977) compared the performance of fourth grade good readers and poor readers on two tasks which allowed direct observation of the children's study behavior as they tried to memorize various materials. Children in the two reading groups differed significantly in their recall scores on both tasks and also engaged in different kinds of study behavior. The good readers consistently approached both tasks in a more active and organized manner. However, when all of the children were instructed in the use of efficient strategies, the poor
readers performed as well as the good ones.

Torgeson's results suggest that, if real differences indeed exist in information processing between dyslexics and normals, they may well exist at an earlier less cognitive stage in the information processing continuum. The many behavioural and phenomelogical observations that show differences in visual perception between normals and dyslexics suggest that if differences in information processing are to be found, they may be in the early visual information processing area.

**Early Visual Information Processing Theory**

Turvey (1973) describes the information processing approach as it applies to visual perception as follows: "In brief, the information processing analysis represents visual perception as a hierarchically organized temporal sequence of events involving stages of storage and transformation of information" (p. 2). This initial "storage" stage was called "iconic storage" by Neisser (1967) who conceived of it as a stage of processing in which the visual input could be held in a literal form for several hundred milliseconds during the course of conversion to a response and/or short term categorical storage. Sperling (1970) and Stanley (1970) conceived of this stage of processing similarly, i.e., as a static storage stage, each naming it respectively, "sensory persistence", and "visual information store". 
Some relatively recent research concerning iconic memory has been outlined by Craik (1979). The results of one study challenge the view that iconic memory is a "static" phenomenon. DiLollo (1977) has proposed that iconic memory can more properly be regarded as an ongoing feature extraction process rather than as the decaying contents of a sensory store. Based on his research, DiLollo argues that "iconic memory" represents ongoing neural processes which are trying to extract features (such as bars, dots, and forms) from the stimulus. When these features have been extracted, the stimulus no longer persists in the visual system even if it is still physically present.

Craik (1979) observed that the results of Meyer and Maguire (1977) who found longer iconic persistence for visual gratings of higher spatial frequencies supports DiLollo's view. Since these gratings were harder to see, the necessity of extracting further visual information lengthened the duration of the icon. It is noteworthy that Sperling (1960) believed that the representation of a stimulus persisted about 250 msec after its offset. DiLollo (1977) has presented convincing evidence that persistence starts with the onset of the physical stimulus and for his task at least, lasts 100 - 150 msec. (Scheerer has pointed out that the search for absolute values for the duration of persistence and processing may have to be abandoned in favour of relative processing rates, since
processing rate may be influenced by variations in experimental tasks. However, the important point to note here is that persistence is probably a more dynamic phenomenon than was once believed).

Both Haber (1969) and Sperling (1963) have used a particular experimental paradigm (backward masking) wherein the characteristics of visual information processing could be explored. Essentially, backward masking is the presentation of a pattern mask following a briefly presented target stimulus after some delay. The identification of test stimulus is impaired when it is followed by the masking stimulus. Two theories have been put forth to account for this effect (Turvey, 1973; Scheerer, 1973). According to an interruption theory, processing is assumed to have occurred during this delay period but is terminated or interfered with by the mask. A second interpretation is called the integration theory which holds that the test stimulus and the masking stimulus are combined into a single visual impression in which the test stimulus is degraded by the contours of the masking stimulus. Turvey (1973) points out that the interruption theory localizes the effect of backward masking subsequent to the iconic storage stage. In other words, a clear icon has been formed from the test stimulus and a subsequent pattern mask stimulus interferes with the processing into higher levels. Integration, however, assumes that the effect of the subsequent stimulus is that a clear iconic representation is
never achieved because the target and mask stimuli are amalgamated.

Scheerer (1973) has reviewed the methods used to decide between the two theories and concluded that backward masking by visual noise requires a two factor theory: integration for "short" (less than about 100 msec) and interruption for "long" test stimulus to masking stimulus delays. In other words, both interpretations of backward masking appear to be valid ways of describing two different stages in the flow of information processing.

In keeping with these observations, Di Lollo (1977) has proposed a two level processing system in which the first stage is "the level of feature encoding" which determines the duration of sensory persistence, as outlined earlier. The second level Di Lollo labels "the level of meaning abstraction". It is here that the information from the feature encoding level is labeled or identified and made available for long term storage or higher order cognitive manipulations. Regardless of the conceptual framework adopted, most of the relatively few studies which have dealt with early visual information processing and dyslexia have concerned themselves with comparisons in which the speed of information extraction from the short term visual store or icon has been assessed through the use of backward masking techniques. These are examined in detail in the next section.
Early Visual Information Processing and Dyslexia

Young and Lindsley (1970) were the first to speculate on the relevance of visual information concepts to the study of reading disability, but little direct research within this framework was reported until Stanley and Hall's (1973a) comparisons of dyslexic and control subjects. Basically, Stanley and Hall (1973a) and later other researchers (Stanley and Hall, 1973b; Stanley, 1976; O'Neill and Stanley, 1976; Arnett & Dilollo, 1979; and Fisher and Frankfurter, 1977) used various stimuli and tasks to determine if there are differences in early information processing between dyslexics and normals. Unfortunately, several of these studies have serious methodological weaknesses which qualifies the value of their findings. The purpose of the present study is to overcome the shortcomings apparent in these earlier studies, as well as to integrate both the hypotheses generated and the findings obtained into the context of recent information processing research and theory.

Critical Analysis of the Early Visual Information Processing Studies on Dyslexia

There are six studies which attempted to compare early visual processing of dyslexics with that of normals. These studies are summarized in Tables 1 and 2 which indicate that three studies support the hypothesis of
dyslexic/normal differences in early visual information processing, while the other three studies found no differences between groups.

Insert Tables 1 & 2 about here

In looking at these studies, it is apparent that the contradictory results could stem from subject-related differences, and/or methodological weaknesses which can be found in all six studies. A discussion of how both supportive and non-supportive studies have shortcomings in both of these categories follows.

Subject-related weaknesses. The subject variable of intelligence is probably the most crucial one in terms of defining and equating the dyslexic and control populations. Of the supportive studies, only the O'Neill and Stanley (1976) study matched for intelligence (see Table 1). Quite appropriately, they matched the subjects on a non-verbal test, the Progressive Matrices, and used a non-verbal task (the temporal segregation of lines). One cannot, however, conclude that the results of the O'Neill and Stanley study are accurate since it had several weaknesses in methodology which are discussed later.

Of the non-supportive studies, only Arnett and DiLollo (1979) used a standardized intelligence test, the Peabody Picture Vocabulary Test. However, the dyslexics
Studies Which Suggest That Dyslexic Children Have Longer Persistence and/or Processing

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Authors</th>
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<tbody>
<tr>
<td>Experimental: age range 8-12 yrs; mean age 10.88; reading retarded 2.5 yrs; average in other subjects. Control: age range 8-12 yrs; mean age 10.52.</td>
<td>Stanley &amp; Hall (1973a)</td>
<td>Stanley &amp; Hall (1973b)</td>
<td>O'Neill &amp; Stanley (1976)</td>
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<tr>
<td>Stimulus(i)</td>
<td>Experiment i: three, two-part stimuli (the letters, N &amp; O; two parts of a cross; &amp; a cross &amp; a square). Experiment ii: Part(a) one of the letters H, J, R, M, K, S, F, or C. Part(h) either the letter U or O.</td>
<td>The letters, F, J, H, M, S, R, &amp; K combined variously to make four, six letter arrays.</td>
<td>Experiment i: two identically oriented, spatially overlapping, straight lines. Experiment ii: a homogenous light, followed by a straight line at one of three orientations.</td>
</tr>
<tr>
<td>Method</td>
<td>Experiment i: each stimulus part was presented for 20 msec, separated by an ISI which was incremented in 20 msec steps. The subject was required to tell the experimenter what he saw. Experiment ii: Each stimulus was presented for 20 msec, &amp; then masked at various ISIs for 20 msec. The subject was required to identify the letter.</td>
<td>Each array was presented by computer on an oscilloscope for various durations (40-6000 msec). The subject was required to identify the letters.</td>
<td>Experiment i: The two lines (separated by various ISIs) were presented on a three channel tachistoscope. The subject was asked to tell whether one or two lines appeared on a given trial. Experiment ii: The light &amp; the straight line were separated by various ISIs. The subject was asked to report the presence of the line.</td>
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<tr>
<td>Results</td>
<td>Both experiments showed longer identification times for the dyslexic group. With the exception of the 40 msec condition, there was a tendency for greater differences between groups with longer duration.</td>
<td>Experiment i: At all orientations, the dyslexics required a longer ISI. Experiment ii: For each orientation, the dyslexics required longer.</td>
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Table 2
Studies Which Do Not Suggest Longer Visual Persistence and/or Processing in Dyslexics

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<tr>
<td><strong>Subjects</strong></td>
<td>Experimental i: age range 8-0 to 9-9 yrs; degree of reading retardation not stated.</td>
<td>Experimental i: Mean age 10.8 yrs; reading retarded 2.5 yrs on the Gates-MacGinitie; average in Arithmetic.</td>
<td>Experimental: four groups at mean age levels of 7, 9, 11 &amp; 13; reading retarded 1.8 to 2.1 yrs. on SAT; average on PPVT.</td>
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<td></td>
<td>Experimental ii: age range 9-3 to 12-3 yrs; reading retarded 2 yrs on GAP Rdg Comp.; mean WISC PIQ in the normal range.</td>
<td>Control ii: (reading-level matched); reading grade 2.5; normal reading and intelligence.</td>
<td>Control: four groups at same age levels as experimental; average in rdg and on PPVT.</td>
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<td></td>
<td>Control iii: same age range as in ii, n.s. different from ii on IQ.</td>
<td>Control iii: (age-level matched); mean age 10.8 yrs; average rdg &amp; intelligence.</td>
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<tr>
<td><strong>Stimulus(i)</strong></td>
<td>A single digit (0 through 9)</td>
<td>The letters F, H, N, V, W, X &amp; Z. On each trial, 2, 4, or 6 of them were presented in a 16 cell matrix.</td>
<td>Experiment i: two horizontally adjacent 25-dot matrices, with one dot missing from one of the matrices on each trial.</td>
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<td>Experiment ii: Same as above but with the centre dot missing from one of the matrices.</td>
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<tr>
<td><strong>Method</strong></td>
<td>Each stimulus was presented by computer on an oscilloscope for 20 msec, followed by a mask for 20 msec at ISIs of 8, 16, 24, 32, or 40 msec. The subject was required (through forced choice response console) to identify the numbers.</td>
<td>Each array was projected on a screen for 200 msec. A letter fragment mask followed immediately. The subject was required to identify and locate the letters.</td>
<td>Experiment i: The dots were plotted successively (by computer on an oscilloscope) over various plotting intervals. The subject was asked to decide which matrix had the missing dot.</td>
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<td>Experiment ii: The two dot matrices were plotted &quot;simultaneously&quot; and masked by random dot patterns at various ISIs. Subject's task was analogous to above.</td>
</tr>
<tr>
<td><strong>Results</strong></td>
<td>Both experimental groups had sig. more correct identifications than the control group. Groups were n.s. different in reaction time. Dyslexics showed more errors on digits with curved features.</td>
<td>The reading disabled group made more correct responses than groups matched for age and reading level. However, the disabled group's performance decreased slightly, though sig. over array sizes.</td>
<td>No significant differences were found on either task between groups.</td>
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</table>
were significantly different than the controls, but both were in the average range of intelligence. These researchers did not, however, employ a verbal task in their study. Consequently, the two groups could have been grossly different on that dimension of intelligence which had the most direct relevance to their experimental task.

Methodological weaknesses. Technological advances in recent years have allowed researchers to overcome some of the methodological shortcomings that are evident in earlier studies. The computer, in particular, has allowed for much greater precision in both administering visual tasks (via oscilloscope) and evaluating the subjects' responses instantaneously. Of the six studies reviewed here, the O'Neill and Stanley (1976) study illustrates possible problems inherent with less sophisticated technology. These researchers presented two identically oriented, spatially overlapping, straight lines on a three channel tachistoscope. On a given trial, the two lines could be presented with a particular ISI (target trial) or without an ISI (catch trial). According to Bloch's Law, within the critical duration of approximately 100 msec, light energy summates. During this period, individual pulses impinging on the visual system are temporally summated. Consequently, at all ISI conditions less than 60 msec (the first line stimulus is on for 20 msec and the one after the ISI for another 20 msec), the target trials may be distinguishable
from the catch trials on the basis of brightness alone. The catch trials will appear brighter than the target trials. If one wishes to be sure that the results are reflecting detection of the ISI, then brightness must be equalized across all ISI conditions. This is virtually impossible using the overlapping straight line stimulus and a tachistoscope. Moreover, it is virtually impossible to assure that the two overlapping lines forming the stimulus being displayed from two different channels of a tachistoscope will be identically aligned. Two stimuli not so aligned and presented sequentially, would give the sensation of blurring or apparent motion. Either the brightness differences, or the motion effects, could have acted as cues to discriminate target from catch trials. The dyslexics and controls may have made differential use of such cues. O'Neill and Stanley's stimuli were adapted for computer administration in the present study, but brightness and movement effects were eliminated by the techniques described in Appendix B.

A second methodological weakness found in several of these six studies is the failure to introduce a forced choice method. This is important because the dyslexics, as a group, have experienced a great deal of academic failure, and may bring to the test situation heightened anxiety or avoidance tendencies which may cause them to respond more cautiously than normals.

Among the supportive studies (Table 1), two studies
could clearly have been influenced by conservative response bias. Stanley & Hall (1973a) used relatively large incremental steps of ISIs (20 msec steps) so that even a slight conservative response bias on the part of the dyslexics would artifically inflate the results. The O'Neill and Stanley (1976) study can also be criticized in this regard. At first glance, the "target and catch" trials give the impression that the researcher has successfully eliminated the effects of possible conservative response bias on the part of the dyslexics. In fact, he probably has not. Notice that the "catch" trials are those in which both lines are presented without an ISI. Assuming that the dyslexic has a reluctance to state that he has indeed "seen" two lines until he is more than sure, he is likely to stick to a response of "one" line as a "safe" response. Thus, a "catch" trial, in which the correct response is "one", does not overcome the conservative response bias possibility.

A final methodological weakness manifest in several of these studies is that they did not use techniques like backward masking and temporal integration to explore early visual information processing. Among the supportive studies, the Stanley & Hall (1973b) work illustrates this inadequacy. They simply presented six letter arrays for different durations on the oscilloscope. If sensory persistence is time-locked to the onset of the stimulus and not to stimulus duration as current theory and research suggest, then this study does not address itself to differences in sensory
persistence (or VIS) as Stanley and Hall call it. The Stanley and Hall (1973a) study, however, did use temporal integration and masking techniques. As noted earlier in this paper, the relatively large increments of ISIs in the temporal integration of two-part figures and in the backward masking of letters, weakened its credibility. Stanley later replicated the temporal integration task (Stanley, 1975) using smaller (5 msec, then 1 msec) increments of ISI.

In conclusion, there are weaknesses in the experimental literature such that additional studies would provide needed clarification. The present study was designed to improve on the past studies by: i) using a small clinically defined dyslexic population; ii) equating the dyslexics and controls on intelligence and age; iii) administering four different stimulus tasks to the same dyslexics and controls; iv) using a computer to administer and score the tasks; v) using a forced choice method to avoid response biases, and finally, by vi) eliminating both extraneous cues from one of the stimulus tasks through brightness averaging.

The Present Study

The purpose of the present study was to examine further the possibility that dyslexia may be a dysfunction in the early processing of visual information. Two separate aspects of information processing were considered. Firstly, the duration of visual persistence was compared
between a group of dyslexics and normals. According to DiLollo (1977), the duration of visual persistence may be viewed as corresponding to the duration of early perceptual processing. Secondly, the rate of information processing under conditions of backward masking was examined, to see how dyslexics and normals compare.

The Duration of Visual Persistence

Two paradigms have been used to study the duration of visible persistence: i) dark interval threshold and ii) temporal integration. In studies of dark interval threshold, flashes of light are presented in rapid succession and the ISI is varied to determine the threshold for the report of the occurrence of a dark interval. Hawkins and Shulman (1979) refer to this type of persistence as "Type I persistence" and define it as the minimal interval following stimulus offset necessary to yield a detectable decrement in the strength of the sensory residual. The detection of this decrement represents the subject's experience of stimulus offset. It is thought that the longer the ISI required to determine the occurrence of a dark interval, the more persistent is the visual trace.

The dark interval threshold has been found to decrease during childhood and adolescence and increase again beyond the age of 70 (Pollack, 1965). While threshold values for dyslexics and normal controls have not been extensively explored, a study by O'Neill and Stanley (1976)
suggests that dyslexics require a longer ISI to experience a sensory decrement between two successive line flashes. In this work an extension of the O'Neill and Stanley task referred to herein as the dark interval threshold task (or DIT) is used to obtain dark interval thresholds for dyslexics and normal controls.

The second paradigm used to measure the duration of visual persistence, temporal integration, was introduced by Eriksen and Collins (1967). Hawkins and Shulman refer to it as "Type II persistence". This type of persistence is described as relating to the duration of the after-effect of the stimulus rather than to the phenomenal duration of the stimulus itself. The subject is required to extract information from the visual residual after the phenomenal offset of the distal stimulus. They define this type of persistence as the interval between stimulus offset and the point at which information of a particular type no longer remains in the fading sensory residual.

The developmental research seems to indicate that there are probably no differences over age spans on temporal integration tasks (Spitz & Webreck, 1971; Arnett & DiLollo, 1979). The Arnett and DiLollo (1979) work suggests that this type of task probably does not differentiate dyslexics from normals either. In this study, the temporal integration task from the Arnett and DiLollo (1979) study was used to compare the dyslexics and normal controls on Type II persistence task and is hereafter referred to as the temporal integration of
matrices (or TIM).

Past research has resulted in contradictory outcomes for the two types of persistence tasks. Type I persistence (represented by the dark-interval threshold studies) have shown that the threshold increases with age and that dyslexics have a higher threshold value than normal controls. On the other hand, Type II persistence (measured by the temporal integration tasks) suggests that there are neither developmental nor dyslexic-normal differences on this aspect of processing. The present study proposes to compare the results obtained via the two paradigms in the same subjects. It is possible that the two methods measure different functions within the visual system. Type II persistence tasks require the subject to utilize as much of persistence as possible for integration of two successive inputs to occur. Type I persistence tasks however have logically nothing to say about the duration of persistence since the subject's task is to determine when the first stimulus has terminated and not when its after effects have ceased. Therefore, it is possible that the two methods measure two separate functions which may differ in the two (or four) populations of this work.

Rate of Information Processing Under Conditions of Backward Masking

Since the rate of processing or transferring information to other stages of processing, in order to result in a given level of stimulus identification might vary, it has
been traditional to try to define the rate of processing through the use of backward masking techniques. With this method a masking stimulus (or MS) is used to limit the time available for processing of a preceding target stimulus (TS). In this work, we are not fundamentally concerned with the issue of whether the masking was peripheral or central. Rather, given that processing time is limited by the onset of the mask, the purpose was to assess whether dyslexics are affected differently from normals on two different backward masking tasks. One task was the space matrix task used by Arnett and DiLollo (1979). It is a structurally oriented task and is hereafter referred to as the "backward masking of matrices" task (or BMM). The other was backward masking of single alphabetic characters. It is a verbally oriented task and is hereafter referred to as the "backward masking of letters" task (or BML).
METHOD

Design

The experiment was a simple two group (dyslexia vs. normal), two levels (young vs. old) factorial design with four dependent variables. Since there were multiple dependent variables, a multi-variate analysis of variance was performed on the data (see Appendix C).

Subjects

Ten 8-14 year old dyslexic subjects were selected from the Winnipeg School Division #1, with the help of the Manitoba Association for Children with Learning Disabilities (MACLD) Lions Learning Centre. All dyslexic subjects met the following criteria: (a) at least average intelligence (each was assessed within the preceding year on the WISC-R); (b) regular school attendance; (c) normal or corrected to normal vision and hearing; (d) Canadian national origin with English as the native tongue; (e) absence of emotional disturbance and social/cultural deprivation. The subjects were given the Wide Range Achievement Test (WRAT-Oral Reading, Arithmetic, and Spelling) as well as the Metropolitan Achievement Test (Reading Comprehension). A two-year lag in reading comprehension was evident in all but one of the cases. This student had been clearly identified as dyslexic, but at the point of testing had been
involved in the MacLD program and reading comprehension had begun to improve.

The dyslexic subjects were then matched for age and IQ to normal reading control subjects. All control subjects were average or better in reading, spelling, and arithmetic. For complete subject data, see Appendix B.

Visual Persistence

Stimuli and Apparatus

Temporal integration of matrices (TIM). The stimulus display was two horizontally adjacent 5 x 5 square dot matrices, each measuring 1.0 cm square and separated by 0.5 cm. The dots forming each of the two matrices were presented successively over time on an oscilloscope with one dot not plotted in one of the matrices on each trial. The matrix (left or right) and the precise location of the missing dot within the matrix varied randomly from trial to trial. On every trial, each dot was plotted only once, with the dots being evenly spaced within the plotting interval. (The term "plotting interval" refers to the total time that elapses between plotting the first and last dots). The temporal duration of each dot was 1.5 microseconds. Twenty-four non-corresponding pairs of dots and a single dot were plotted successively.

The luminance of the stimulus displays were adjusted so that a single square patch, plotted continuously in the centre of the screen, yielded a reading of approximately
0.35 lux, as measured by a United Detector Technology Model 40X Opto-Meter.

**Dark Interval threshold (DIT).** Two successive displays were used as stimuli in this task. Each display consisted of a vertical line which could be displayed in one continuous flash or in two flashes separated by an interstimulus interval (ISI). Each trial consisted of two successive line presentations, one of which was the discontinuous line. These successive lines were presented randomly in first or second positions and at various ISIs. These lines were approximately 0.5 mm wide and 300 mm long. The duration of the temporally continuous line on a given trial equalled that of the two flash line (10 msec) plus the ISI, i.e., the total durations of the temporally continuous line and the temporally discontinuous line were the same on a given trial. Luminance values for continuous and discontinuous displays of various durations were assessed independently, so that at a given duration, they would appear to be of equal brightness (see Appendix A).

**General Information.** Dim fixation dots (two dots for the temporal segregation task and a single, centred dot for all other tasks) were employed to aid and to standardize subject orientation to that portion of the screen where the stimulus would subsequently appear. The fixation dot(s) appeared with the onset of the stimulus display and reappeared following a response. To aid focusing and
convergence, the oscilloscope display surface was dimly illuminated. All displays were generated on a Tektronix 602 oscilloscope (equipped with a fast phosphor) controlled by a Digital PDP-8/L computer which performed all timing and scoring functions.

**Procedure**

Upon entering the laboratory, the subject was introduced verbally to one of the four tasks. To facilitate comprehension, several flash cards analogous to the actual display stimuli were used. When it was clear from the subject's performance (using the flash cards) that the task was understood, familiarization with the display stimuli, presented briefly on the oscilloscope, was conducted. Only those subjects who were able to perform the familiarization tasks at an accuracy rate of 85% or higher were allowed to proceed.

During the testing, the subject was seated in a quiet and dimly illuminated room and viewed the stimulus display binocularly through a viewing mask. The subject was instructed to focus on the fixation dot(s) and to initiate a trial, when ready, by depressing a footswitch. Following the stimulus display, he was required to respond by depressing one of two buttons. Immediately following the subject's response, the fixation dot(s) reappeared and the same sequence of events involving focusing on the fixation dot, initiating a display, and responding, proceeded
for the next trial. The subject was instructed to work quickly but carefully and to make a best guess when unsure.

Temporal integration of matrices (TIM). After initiating the display, the subject was asked to locate the dot matrix that had a single dot missing from somewhere in it. He was required to depress the response button that corresponded to the side of the oscilloscope in which the missing dot matrix was located. Pre-trial familiarization on the oscilloscope occurred having the stimulus display with the missing dot being presented effectively simultaneously.

Dark interval threshold (DIT). The subject was told to depress a footswitch to generate the first display, and then press it again to generate the second display. The computer imposed a minimum of 500 msec between the two displays. The subject's task was to decide which of the two displays contained the lines with the ISI. If he thought it was the first display, he was asked to press a particular response button. If it was the second presentation, he was to press an alternate button.

Instead of using flash cards, the task was demonstrated to the subject by allowing him to see the experimenter draw a single line for the one line presentation and two superimposed lines for the discontinuous or two flash line. Pre-trial familiarization on the oscilloscope was an "easy" trial, i.e. one of the successive line presentations had a long ISI.
Rate of Processing

Stimuli and Apparatus

**Backward masking of matrices (BMM).** The stimulus display for this task, including luminance, was fundamentally the same as that used in the temporal integration task with two exceptions. First, the unplotted dot was always randomly missing from the centre of either the left or right matrix, and not from any other location. And, second, all the dots forming the two matrices were presented effectively simultaneously on the oscilloscope for a duration of 3 msec rather than over various plotting intervals. In addition, a random dot visual noise masking stimulus of approximately equal luminance and temporal duration as the stimulus display was used in this task to limit processing duration. The mask followed the matrix at varying ISIs.

**Backward masking of letters (BML).** The stimulus display for this task was a single presentation of a randomly chosen alphabetic character. All of the dots forming the continuous-line alphabetic character were presented effectively simultaneously on the oscilloscope for a duration of 3 msec (target stimulus). In this case, a mask of randomly chosen letter fragments was used to limit processing. This mask was followed by the continuous presentation of a letter (test stimulus). The luminance was set at a constant, pleasing brightness. The subject's task was to
identify if the target and the test stimuli were the "same" or "different".

Procedure

**Backward masking of matrices (BMM)**. The subject was told that the task involved determining which one of the two dot matrices was missing a dot in the centre location. However, the subject was advised in advance that a masking pattern would follow and cover the stimulus display at various time intervals. After initiating the display, he responded by choosing a response button which corresponded to the side of the oscilloscope containing the matrix with the centre dot missing. Pre-trial familiarization on the oscilloscope was with no mask present.

**Backward masking of letters (BML)**. Once the subject pressed the footswitch a single alphabetic character (test stimulus or TS) was displayed followed by a pattern mask of fragmented letters (MS). Less than one second later a probe character was displayed until the subject responded. He was asked to decide whether the TS and the probe were the same or different. The use of the response buttons corresponding to "same" or "different" were demonstrated to the subject. Pre-trial familiarization on the oscilloscope occurred with the test stimulus and the probe stimulus only, i.e., no mask stimulus was used.
Determining the Parameter Estimate

The plotting or interstimulus interval, depending on the task, was allowed to vary under the control of an adaptive psychophysical method developed by Taylor and Creelman (1967), known as PEST (Parameter Estimation by Sequential Testing). The PEST program was under direct computer control and operated according to rules specified in advance regarding when to change plotting intervals or ISIs, what interval to try next, when to end a run, and the means by which the parameter estimate was calculated.

A run began with the computer randomly selecting a starting interval whose range depended on the particular task. A series of trials were conducted at that interval and the computer maintained a record of the subject's performance. In order to determine whether the subject's performance was above or below an accuracy criterion of 75% correct, a Wald (1947) sequential likelihood-ratio test (WALD), integrated with the PEST program, was performed on the data. Accuracy above 75% correct was considered too easy (i.e., too brief an interval) while accuracy below 75% indicated that the task was too difficult. If the task was too easy (or too difficult) the PEST program automatically increased (or decreased) the interval, initially by 16 msec, and conducted a new series of trials at that interval. Once again the results were stored by PEST and evaluated by WALD and a decision to increase or decrease the interval
was made on the basis of the subject's performance. Increases or decreases in plotting or inter-stimulus interval were doubled (until a maximum step of 32 msec was reached) on successive series of trials, in which the change required in the plotting of interstimulus interval was in the same direction as the immediately preceding change. However, when a change in the direction was required the interval was changed by half the amount of the immediately previous change. The process of increasing and decreasing intervals continued until an adjustment in the interval was required which was smaller than 8 msec. At that point the run ended and the parameter estimate was given at that interval in effect just prior to the required adjustment below 8 msec.

A series of five runs was conducted per subject on all four tasks and the estimate of the duration of sensory persistence or processing was calculated by determining the mean interval at which the task could be performed at criterion. A brief rest followed each run. The time to reach criterion on a given run was about three minutes. The testing took place over two days. On the first day the subject did five runs on each of two tasks. On the next day he performed the other two tasks. The tasks were ordered randomly for each subject.
RESULTS

The raw data for all subjects on each of the experimental tasks is given in Appendix B. This appendix also lists the pre-experimental data collected on the dyslexic and matched control subjects for age, grade, full scale IQ, oral reading, reading comprehension, spelling, and arithmetic. Appendix C presents a summary of the multi-variate analysis of the experimental data.

A summary of the comparisons between the dyslexic and control groups is given in Table 3.

| Insert Table 3 about here |

With the groups well-matched for both age and IQ, there are large differences between the dyslexic and normal samples on all three academic areas tested. This finding is consistent with observations in the general literature on dyslexia (eg. Klasen, 1972; Spache, 1976) where the dyslexic is found to have difficulty in a variety of school subject areas apart from oral reading and reading comprehension. The finding also suggests that the population from which these dyslexic subjects were chosen is different from the reading retarded subjects of other experiments (eg. Stanley &
Table 3
Summary of Dyslexic and Control Comparison

<table>
<thead>
<tr>
<th></th>
<th>Dyslexics</th>
<th>Controls</th>
<th>$t_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (months)</td>
<td>129</td>
<td>129</td>
<td>-0.96</td>
</tr>
<tr>
<td>Full IQ (WISC-R)</td>
<td>108.0</td>
<td>108.0</td>
<td>-0.24</td>
</tr>
<tr>
<td>Rdg. Comp. (MAT)</td>
<td>3.04</td>
<td>6.41</td>
<td>-7.11*</td>
</tr>
<tr>
<td>Oral Rdg. (WRAT)</td>
<td>3.17</td>
<td>6.84</td>
<td>-6.44*</td>
</tr>
<tr>
<td>Spelling (WRAT)</td>
<td>3.25</td>
<td>6.52</td>
<td>-4.38*</td>
</tr>
<tr>
<td>Arith. (WRAT)</td>
<td>3.9</td>
<td>5.86</td>
<td>-4.86*</td>
</tr>
</tbody>
</table>

*P < .01
Hall, 1973a) where the authors specify normal performance in school subjects other than reading. This difference will be examined further in the Discussion section.

---

**Insert Table 4 about here**

---

Table 4 gives the breakdown on the performance of the dyslexic and control groups for each of the experimental tasks. While testing the subjects it became apparent that some younger subjects had greater difficulty on some of the tasks. As a result, the two groups were divided arbitrarily (by a median split) into young and old subgroups. Age became a second factor in the multivariate analysis and the results in Table 4 are summarized by age as well as by task and group. The data in Table 4 are the mean ISIs (in milliseconds) at which the 75% accuracy criterion was reached for the BML, BMM, and TSL tasks, and the mean plotting interval at which criterion was reached for the TIM task.

A comparison of the overall dyslexic and control groups yielded a significant multivariate F (F = 5.52; df = 4,13; P < .01). Consulting the means in Table 4 and the univariate F's involved, it appears that the dyslexic sample demonstrated a consistently slower processing time on three of the four tasks (F_{BML} = 14.85; df = 1, 16; P < .01; F_{BMM} = 7.69; df = 1, 16; P < .05; F_{TSL} = 22.47; df = 1, 16; P < .01).
Table 4

Summary of the Results of the Four Experimental Tasks for the Dyslexic and the Control Groups

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Visual Persistence</th>
<th>Rate of Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TIM^a</td>
<td>DIT^b</td>
</tr>
<tr>
<td>Dyslexic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young</td>
<td>61.6</td>
<td>145.2</td>
</tr>
<tr>
<td>Old</td>
<td>57.8</td>
<td>84.2</td>
</tr>
<tr>
<td>Controls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young</td>
<td>49.2</td>
<td>65.2</td>
</tr>
<tr>
<td>Old</td>
<td>46.0</td>
<td>72.8</td>
</tr>
</tbody>
</table>

^a Mean plotting interval (in msec) at which criterion performance was reached.

^b Mean ISI (in msec) at which criterion performance was reached.
Although the overall multivariate F ratio for the age variable was non-significant ($F = 1.77; \text{df} = 4, 13$), the univariate F for the dark interval threshold task was significant ($F = 7.67; \text{df} = 1, 16; P < .05$). Younger subjects appear to process this task at a slower rate than the older subjects.

The results also indicated a significant multivariate interaction ($F = 3.59; \text{df} = 4, 13; P < .05$). In looking at the univariate F's, it was again on the temporal segregation of lines task where the difference appears to be based, although the backward masking of matrices also approaches significance. On both of these tasks the young dyslexics perform much more poorly, i.e., with much longer processing times than do any of the other groups.
DISCUSSION

This research began as an attempt to clarify a variety of issues in the literature on early information processing. It was hoped that by using a variety of different methodologies which measure either persistence or rate of processing and by defining the dyslexic population more completely that it would be possible to resolve a series of seemingly inconsistent results in the literature.

The duration of visual persistence measured by the temporal integration task (TIM) does not differentiate the four populations (Table 4, column 1). This is consistent with the findings of several other researchers (Arnett and DiLollo, 1979; Spitz and Webreck, 1971), but not with those of Stanley and Hall, 1973a. The latter were able to find identification time differences between a dyslexic and a normal group using a Type II persistence task (integration of two part stimuli). Since they did not control for IQ while the others did, the possibility of spurious intellectual differences affecting Stanley and Hall's findings is reinforced. Probably the type of sensory function (processing) manifest as Type II persistence is peripheral to the extent that it precedes processing stages where normals and dyslexics are differentiated.
An alternate explanation for the failure of the temporal integration task to discriminate the four populations may involve the sustained and transient mechanisms (which are possibly neural processes) that operate in human vision, (Legge, 1978). The transient mechanisms are believed to respond best to rapid temporal changes (as would be inherent in the DIT task?) while the sustained mechanisms respond best to steady or slowly varying stimuli (temporal integration?). Thus, the TIM task may have engaged the sustained channels of the visual system where normal and dyslexic populations may not differ. The dark interval threshold task (DIT), however, may have engaged the transient systems, where the two populations may indeed vary.

It is noteworthy in the TSL task the young dyslexics differ significantly from the old dyslexics (i.e., they require longer ISIs to detect the gap). This finding may be compared with Pollack's (1965) observation that less mature visual systems require longer ISIs at threshold for their task. Pursuing this line of reasoning, these results could be interpreted to mean that the young dyslexics have an abnormally immature system which then matures with age. This may be related to the deposition of myelin sheaths which starts about the sixth fetal month and continues until adolescence, (House and Pansky, 1967). This process may proceed in the nervous system of a dyslexic at a slower rate than in that of a normal reader.
The results obtained from the backward masking tasks, BMM and BML, indicates that dyslexics have a slower rate of processing than normals. Interference of the MS on the TS could have occurred through integration or interruption, but that is not of particular concern in this study. Interestingly the dyslexics had a slower rate of processing on both the verbally oriented and the structurally oriented tasks (BML and BMM, respectively). This suggests that the dyslexic's difficulty is not necessarily exclusive to verbal tasks.

One of the most important features of this study is that four separate perceptual tasks were given to the same subjects. Two of the tasks were persistence tasks, designed to examine the duration of visual persistence, while another two were backward masking tasks, used to compare rate of processing. No other study, to date, has been so comprehensive. The pattern of differences between dyslexics and normals allows for the following tentative conclusions.

Major differences were found in tasks that may be represented as engaging higher centers of processing, such as would be involved in extracting details from a geometrical configuration (i.e., a missing dot from a matrix) or in identifying an alphabetic character. Does this mean that lower centres or stages of information processing are not differentially involved in dyslexic and normal populations? The answer would seem to be "no". The results in the young vs. old dyslexics in the DIT task suggest that there may be
early differences which may give rise to faulty strategies at higher levels. Once established, these faulty strategies persist (for instance in the backward masking tasks) even when the initial (physiological?) cause has been outgrown.

A more general conclusion that may be drawn is that there do, indeed, appear to be differences in early visual information processing between dyslexics and normal readers. The results of this study are in agreement with those of researchers looking at this problem from another perspective, for instance, the Shields (1973) electroencephalographic study described earlier, as well as much of the work of Stanley (Stanley & Hall, 1973 a & b; O'Neill & Stanley, 1976).

Unlike some earlier studies the subjects in this work were clinically chosen, i.e., the presence of social and emotional problems were ruled out as primary causes of the dyslexia by a multi-disciplinary selection process. In doing so, the dyslexics were found to be significantly lower in reading, spelling and arithmetic than normal controls. If dyslexics do, in fact, have difficulties in early visual information processing this would not be a surprising observation since reading would not be expected to be exclusively affected. The criteria for the selection of subjects may be of some importance. The cause of the problem of subjects who have reading retardation alone may be quite different than the cause in those who have
difficulty in all core subject areas.

Of course much work needs to be done before it can be concluded that the persistence and masking performance differences reflect basic processing characteristics of the two populations compared rather than strategy, attentional, or motivational factors. Fixation dots were used in this work to attempt to control the attention of the subjects. The use of the pupillometer could be helpful in investigating both the possibilities of differential attentional phenomena or abnormal saccadic or other random eye movements. This might be a direction for continued research.

It appears that the information processing approach to dyslexia may be of considerable value. Clearly, further developments in technology and methodology in the visual information processing area will bring us closer to understanding the debilitating phenomenon, dyslexia.
REFERENCES


Stanley, G. The processing of digits by children with specific reading disability (dyslexia). *British Journal of Educational Psychology*, 1976, 46, 81-84.


APPENDIX A

Brightness Averaging for the
Dark Interval Threshold Task

The computer system used for this research was equipped with three digital-to-analog converters (X, Y, & Z) to drive the display oscilloscope. The Z axis defined the intensity of each dot from dimmest (invisible) to brightest (almost flaring) in 1024 steps.

While the display configurations for the dot matrices tasks were set equal to a fixed Z (42 lm/m²), and the letter task was set at a pleasing brightness, the straight line task posed special problems.

The displays for the line task each consisted of a vertical line which could be shown in one continuous flash or in two flashes of 16 msec each, separated by a ISI modulated by PEST. The subject's task was to decide which of the two displays contained the line with the ISI. The duration of the continuous line always equalled that of the two flashes (32 msec) plus the ISI, (i.e., the total duration of the two flashes is the same). The durations were automatically adjusted by the computer programme as PEST varied the ISI.

Bloch's Law (Boynton, 1972) states that a time/intensity reciprocity condition exists for light stimuli less than approximately 100 msec in duration. This means that a light pulse of approximately 16 msec would generate
only half the subjective brightness of a 32 msec pulse at the same intensity. Since the maximum duration of the "light on" portion of the two flash line is only 32 msec, intensity of this two flash line must be adjusted so that it is subjectively as bright as the one flash line with which it will be paired on a given trial. This was achieved by independently setting the intensity levels of both the one flash and two flash lines at every duration, such that they would appear subjectively as bright as a single flash line of 128 msec duration.

The first step was to determine the Z values at which one flash lines (which varied in duration from 32 msec to 128 msec) would appear as bright as a one flash line of 128 msec. The second step was to use the Z values of the one flash lines, whose brightness had already been set equal to that of a 128 msec one flash line, and adjust the Z value to each two flash line of the same total duration. Thus, the one flash and the two flash lines were of equal total duration hereby, cues related to total duration differences were eliminated, and since the lines were of equal brightness, extraneous brightness cues were eliminated.

Brightness matching tasks were administered to 4 adult subjects. In part one, a comparison line of fixed intensity (Z = 384) and 128 msec duration appeared simultaneously alongside a test line of duration between 32 and 128 msec, when the subject initiated the display. The initial intensity of the test line was randomly set within
‡ 17% of the comparison line. Buttons were provided which allowed the subject to increase or decrease the intensity of the comparison line. Subjects were instructed to adjust the intensity and re-initiate the display until the two lines appeared to be equally bright. Intensity values were obtained for lines ranging in duration from 32 - 220 msec.

In part two, the standard line was a continuously presented line of duration between 32 and 220 msec, and with intensity values for each duration derived from part one. The comparison line consisted of two 16 msec flashes separated by an ISI, such that the total duration equalled the standard line on each trial. The procedure was identical to part one. Figure 1 illustrates the results and the Z values inserted into the temporal segregation of lines computer program.

--- Insert Figures 1 & 2 about here ---

Figure 2 translates the data from Figure 1 into an illustration of the number of units of Z that had to be added to both "no" ISI and "with" ISI lines to make them equal in brightness to their respective standard. The no ISI function illustrates that 42 Z units had to be added to a 32 msec comparison line in order to make it equivalent in brightness to a 128 msec line fixed at a Z value of 384. The amount of Z units necessary to make "no" ISI lines of different durations equivalent in brightness to the standard
Figure 1

Mean Z Values Necessary to Make "Comparison" Lines Equivalent in Brightness to "Standard" Lines at Various Durations

Mean Z values for "no" ISI comparison lines when Z value of each 128 msec standard line is a fixed intensity (Z = 384)

Mean Z values for "with" ISI comparison lines when Z value of each standard line is set equal to Z ("no" ISI) at each duration

Intensity (Z value) of standard (128 msec) line for "no" ISI condition = 384
Figure 2

Number of Units of Z Added to the Intensity Values of Standard Lines Necessary to Make "no" ISI and "with" ISI Lines of the Same Total Duration Equivalent in Brightness

![Graph showing the number of units of Z added to the intensity values of standard lines to make "no" ISI and "with" ISI lines of various total durations equal in brightness.](image)

- Mean number of units of Z added to fixed intensity (Z = 384) standard line necessary to make "no" ISI lines of various total durations equal in brightness.
- Mean number of units of Z added to a brightness adjusted "no" ISI line necessary to make "with" ISI lines equivalent to "no" ISI lines at each duration.
line of 128 msec duration and 384 Z, decreased gradually until the duration of the comparison line was 120 msec. At that point, the effect of Bloch's Law appeared to become irrelevant and the amount of Z units added to the comparison lines seemed to be a function of random variability.

The "with" ISI graph illustrates that the number of units of Z necessary to make a two flash line equivalent to a one flash line of a given duration (subjectively equivalent in brightness to a 128 msec, 384 Z value line) increased as a function of total duration up until a duration of 136 msec. At that point, the units of Z required, as line duration increased, decreased slightly, then leveled off at about + 40 Z.
## APPENDIX B

### Raw Data

**Table 5**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (in months)</th>
<th>Grade</th>
<th>Full IQ</th>
<th>Comp</th>
<th>Oral Reading</th>
<th>Spelling</th>
<th>Arithmetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>J.T.</td>
<td>107</td>
<td>3.9</td>
<td>104</td>
<td>1.8</td>
<td>2.0</td>
<td>3.9</td>
<td>5.3</td>
</tr>
<tr>
<td>J.F.</td>
<td>109</td>
<td>3.9</td>
<td>104</td>
<td>1.8</td>
<td>2.0</td>
<td>3.9</td>
<td>5.3</td>
</tr>
<tr>
<td>K.W.</td>
<td>122</td>
<td>4.9</td>
<td>92</td>
<td>1.5</td>
<td>1.8</td>
<td>2.3</td>
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<tr>
<td>G.R.</td>
<td>125</td>
<td>4.9</td>
<td>92</td>
<td>2.5</td>
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<td>2.8</td>
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<td>S.P.</td>
<td>127</td>
<td>5.9</td>
<td>131</td>
<td>2.5</td>
<td>2.3</td>
<td>4.5</td>
<td>5.2</td>
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<tr>
<td>J.S.</td>
<td>136</td>
<td>5.9</td>
<td>98</td>
<td>4.8</td>
<td>5.0</td>
<td>4.2</td>
<td>5.2</td>
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<tr>
<td>P.B.</td>
<td>144</td>
<td>6.9</td>
<td>118</td>
<td>4.5</td>
<td>4.8</td>
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<td>L.D.</td>
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<td>7.9</td>
<td>121</td>
<td>5.5</td>
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<td>3.7</td>
<td>6.3</td>
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<td>T.W.</td>
<td>170</td>
<td>8.9</td>
<td>109</td>
<td>5.0</td>
<td>5.2</td>
<td>4.3</td>
<td>6.1</td>
</tr>
</tbody>
</table>

- **Mean** Subject: 129, 5.6, 108.0, 3.04, 3.17, 3.25, 3.9

a. Age in months
b. WISC-R

### Controls

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (in months)</th>
<th>Grade</th>
<th>Full IQ</th>
<th>Comp</th>
<th>Oral Reading</th>
<th>Spelling</th>
<th>Arithmetic</th>
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<tbody>
<tr>
<td>D.C.</td>
<td>97</td>
<td>2.9</td>
<td>122</td>
<td>6.0</td>
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- **Mean** Subject: 129, 5.6, 108.4, 6.41, 6.84, 6.52, 5.86

- **Note:**
  - Full RDG: Full Reading Grade
  - Oral: Oral Reading
  - Comp: Comprehension
  - Spelling
  - Arithmetic
  - *: Significant difference
### Table 6
Summary of the Results on the Four Experimental Tasks for the Dyslexic and the Control Groups

<table>
<thead>
<tr>
<th>Tasks</th>
<th>BML&lt;sup&gt;a&lt;/sup&gt;</th>
<th>BMM&lt;sup&gt;a&lt;/sup&gt;</th>
<th>DIT&lt;sup&gt;a&lt;/sup&gt;</th>
<th>TIM&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
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<td>129</td>
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<td>180</td>
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<td>86</td>
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</tbody>
</table>

<sup>a</sup> Mean ISI (in msec) at which criterion performance was reached.

<sup>b</sup> Mean plotting interval (in msec) at which criterion performance was reached.
### APPENDIX C

**Analysis of the Data**

#### Table 7

Summary of the Results of the Multivariate Analysis

<table>
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<tr>
<th>Variable</th>
<th>Groups</th>
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* *P < .05

** **P < .01