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# ANALYSIS OF VISUAL SCANNING STRATEGIES IN DYSLEXIC CHILDREN

*City University of New York* PH.D. 1979

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# ANALYSIS OF VISUAL SCANNING STRATEGIES IN DYSLEXIC CHILDREN

by

BRENDA ESKENAZI

A dissertation submitted to the Graduate
Faculty in Psychology in partial fulfillment
of the requirements for the degree of Doctor
of Philosophy, The City University of New York.

1979

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## Abstract

### ANALYSIS OF VISUAL SCANNING STRATEGIES IN DYSLEXIC CHILDREN

by

Brenda Eskenazi

Advisor: Professor Sidney P. Diamond

The purpose of the present study was to determine the nature and extent of visuoperceptive deficits in a sample of dyslexic children and to investigate the eye movement strategies used by these children in the processing of "non-verbal" information.

Fifteen matched pairs of dyslexic boys and normal male readers, with a mean age of 12 years, of at least average intelligence were evaluated on an assortment of visuospatial tasks including the Ravens Coloured Progressive Matrices, two embedded figures tasks, and a circle-size matching test. In addition, measures of scanning eye movements were recorded during visual search, location of embedded figures (EFT), survey of the Elkind triangle, and reading. The field of search task, which required the subject to locate a target matching a central standard, also included variations in array density, in the relative familiarity of the elements in the array, and in the tilt of these elements.

The following significant results were obtained:

1. Dyslexic children made more errors than controls on the more difficult EFT but showed no differences from controls on the remaining visuospatial

tasks.

2. Dyslexic children showed longer latencies than controls on the field of search task.

3. Dyslexic children had longer search times than controls in finding an unfamiliar symbol than a familiar object in a field of search task,and in locating a target that is oriented differently from the central standard.

4. There were no differences between groups in eye movement strategies during the performance of the complex embedded figures task or in the scanning of the Elkind triangle.

5. The dyslexic children, in comparison to normal controls, made more fixations and regressions when reading. They also had a slower reading time and paused longer at the beginning of the line before proceeding to scan.

The results of this study were discussed in a cognitive/linguistic context. The dyslexic children appear to show a visuospatial profile similar to aphasic adults. It is proposed that poorer performance of dyslexics on some field of search tasks may be the result of their inadequate use of verbal coding and their inappropriate organization and selection of visual information. It is further concluded that eye movement aberrations do not play a causative role in reading disability; rather that differences in the reading eye movements of dyslexic children merely reflect their difficulty in processing semantic information. It is suggested that in both verbal and non-verbal performance there is a disturbance in the capacity of dyslexic children to utilize left hemisphere processing in filtering and categorizing visual information.

To my mother
FLORENCE ESKENAZI
with love and respect

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# INTRODUCTION

Within the population of learning-disabled children, there appears to be an identifiable subgroup of children who "despite conventional instruction, adequate intelligence, and sociocultural opportunity," are not able to read (World Federation of Neurology, 1968). This putative disorder, originally described in 1896 by W. Morgan, was called developmental dyslexia. Since that time, the actual existence of dyslexia as a separate and specific nosological entity has been ardently debated (Gates, 1927; Burt, 1935; Witty & Kopel, 1936; Drew, 1956; Critchley, 1970; Rutter & Yule, 1975). Consequently, there has been little agreement regarding the criteria for its diagnosis, and the dyslexic child is usually identified by excluding all known factors that may contribute to a reading disorder. Some of these contributing factors, which are usually ruled out before a child is diagnosed as dyslexic, include environmental and educational deprivation, mental retardation, and emotional instability.

Despite the absence of any clearly defined set of specific reading errors that typify this disorder, certain characteristic abnormalities have been associated with it. These include delayed or inadequate spoken language, reversal of letter orientation and word sequence, confusion about directions in space or time, illegible penmanship, and a history of similiar difficulties among relatives (Orton Society).

The incidence of dyslexia in the population depends on the diagnostic criteria employed. Conservative estimates suggest an incidence of approximately 3% (Critchley, 1970; Benton, 1975), although a broad range of values has been proposed from a low of .02% (Bachmann,

1927) to a high of 20% (Preston, 1940). In an epidemiological study of the Isle of Wight population, Yule, Rutter, Berger, and Thompson (1974) found that 3.5% of the 10 year olds and 4.5% of the 14 year olds showed specific reading retardation (defined in terms of underachievement at least 2 standard errors, or for 10 year olds, approximately 2.4 years, below that predicted on the basis of age and IQ).

Because of the relatively higher incidence in males (Lovell, Shapton, & Warren, 1964) and the occurrence among siblings, a genetic factor has been implicated (Hallgren, 1950; Herman, 1959; Finucci, Guthrie, Childs, Abbey, & Childs, 1976). This in turn has led to the theoretical generalization that dyslexia is a neurological entity, of "constitutional origin" (Critchley, 1970). Further evidence of organicity is that "soft" or disputable neurological signs have often been described in dyslexics. These include motor awkwardness, reflex asymmetry, and EEG abnormalities. The organicists have aligned themselves with one of two theories about which essentially all research has centered. One group, adopting a holistic point of view, has tried to characterize the nature of postulated alterations in overall cerebral organization, e.g., changes in cerebral dominance (Orton, 1925; Witelson, 1977). The other, holding that there is a more focal defect in the substrate, has attempted to localize it (Geschwind, 1962). Each has contributed neurological models in an attempt to elucidate etiologic factors in developmental dyslexia.

Those theorists who postulated anomalous cerebral dominance as the basis of developmental dyslexia argue that altered hemispheric dominance may indirectly affect the perceptual and linguistic abilities required to read. A perceptual deficit hypothesis has evolved from the observation that some dyslexic children display reading and writing reversals. However, since reading is a linguistic skill, often lost in aphasic adults, many theorists have contended that developmental dyslexia is a disorder analogous to adult aphasia, and therefore, the result of left hemisphere dysfunction.

## Postulates of Cerebral Organization

### Cerebral Dominance

It has been suggested that if developmental dyslexia is a result of a delay in the maturation of cortical structures, it is probably of functional rather than anatomical origin (Apert, 1924; Pick, 1924). Orton (1925) proposed that this functional abnormality may be a disturbance of normal hemispheric balance or cerebral dominance. Evidence for this theory included a high incidence of mixed dominance, left-handedness and ambidexterity in dyslexics, as well as the mirrored reversals of letters and words in the graphic productions of dyslexic children. Orton suggested that these characteristics reflected a rivalry of the cerebral hemispheres for the same motor, language, and visual functions. For example, he thought strephosymbolia or letter reversals to be the result of sensory impressions registered simultaneously in the two hemispheres, and the subsequent "incomplete elision of memory patterns" (Orton, 1925, p. 608) that are present in reversed form and order in the non-dominant hemisphere.

There have been numerous investigations calling into question the association of inconsistent lateral preference, left-handedness, left-eyedness, and disordered left-right directional selection, with reading disability (Dearborn, 1933; Monroe, 1932; Gates & Bennet, 1933; Rabinovitch, Drew, DeJong, Ingram, & Withey, 1954; Harris, 1957). Studies have also questioned whether these characteristics, if indeed they are correlated with dyslexia, are fair indicators of incomplete cerebral dominance (Zurif & Bryden, 1969; Malmquist, 1958).

Recently, non-invasive techniques for assessing cerebral asymmetry have been refined. These include the use of lateral visual tachistoscopic stimulation, dichotic listening tasks, and dichaptic tests. It has been inferred from most of these studies that the left hemisphere is the major hemisphere for language in reading-disabled as well as normal children (right visual-field superiority and right ear advantage) (Bryden, 1970; McKeever & Huling, 1970; Yeni-Komisian, Isenberg, & Goldberg, 1975). Yeni-Komisian et al. (1975) noted that although there was a right visual-field superiority for numbers and words in normal and dyslexic children, there was poorer performance in the left visual-field for verbal stimuli in dyslexic children. It was suggested that stimuli projected to the right visual cortex are the ones with which the poor readers have the most difficulty. Yeni-Komisian et al. postulated that poor readers suffer from some kind of processing deficit in the right hemisphere in the "abstraction of physical characteristics of words or transmission of this abstraction to the left hemisphere" (p. 92). By inference from tachistoscopic field presentation of human figures and dichaptic stimulation, Witelson (1977) found that compared to controls, dyslexic children manifested significantly less signs alleged to signify right hemisphere dominance for spatial perception. Instead, she thought that there was evidence of bilateral hemispheric representation of spatial information in dyslexia. Witelson further observed that although the left hemisphere was supposedly dominant for language in dyslexic children, their overall accuracy in verbal dichotic listening was inferior to that of normals. Witelson concluded that there may be some failure in left hemisphere function due to the additional load of spatial information processing imposed upon it.

It has also been suggested that certain cerebral functions assume separate loci during the course of evolution as a result of their mutual antagonism (Lashley, 1937; Levy, 1969), since it is clearly less efficient for two incompatible mechanisms to be located in the same hemisphere (Witelson, 1977). In contrast to Witelson's suggestion concerning the bilateral representation of spatial processing, Sperry (1970) had postulated that in dyslexia there is an "overly strong or extensive, perhaps bilateral development of the verbal, major hemisphere type of organization that tends to interfere with an adequate development of spatial gnosis in the minor hemisphere" (p. 176). This intrahemispheric competition which results in the overburdened hemisphere, is supposed to result in poor performance, especially in those tasks testing Gestalt synthetic perceptual functioning (Levi-Agresti & Sperry, 1968; Levy, 1969).

Thus, a disturbance in hemispheric balance, resulting from the presence of two incompatible mechanisms in the same hemisphere, has been considered to support two different theories of dyslexia, the perceptual deficit hypothesis and the aphasia model of dyslexia.

### Perceptual Deficit Hypothesis

The idea that developmental dyslexia is a fundamental disturbance in Gestalt function -- a difficulty in separating figure from ground -- is not new (Krise, 1949; Bender & Schilder, 1951) and many investigations have studied visual perceptual difficulties in dyslexic children.

Goins (1958) isolated two factors of visual perception (previously described by Thurstone, 1944) that had a substantial correlation with reading achievement. These two factors were (a) the speed of closure (the ability to make closure of a figure in a disorganized field), and (b) strength of closure (the retention of figure in a distracting field). Defective performance on a strength of closure task, the embedded figures test, was subsequently confirmed in young dyslexics (Tjossem, Hansen, & Ripley, 1962) and using the more difficult patterns in the test, in older dyslexics (Goetzinger, Dirks, & Baer, 1960).

Although Bortner and Birch (1962) recognized that elementary perceptual discrimination abilities may not be defective in dyslexic children, they also postulated that tasks examining the more complex perceptual abilities such as perceptual analysis (similar to Goin's concept of strength of closure) and perceptual synthesis (the ability to combine parts to form it figural whole) were more readily affected by central nervous system damage, and therefore, might contribute to the identification of dyslexia.

Though there is some evidence supporting the notion that dyslexia is associated with an impairment in higher perceptual functions, this pattern is far from consistent in groups of dyslexic children. As a matter of fact, the opposite has been noted in some dyslexic children. Higher Performance than Verbal IQ has been found and presented as evidence of superior spatial abilities in dyslexic children (Symmes & Rapoport, 1972).

## An Aphasia Model of Developmental Dyslexia

The aphasia model, representative of a localizationist approach to dyslexia, stems from the parallels frequently drawn between acquired dyslexia (aphasia) and developmental dyslexia. (In fact, discrete cerebral malformations have been postulated to account for different types of dyslexia (Denckla, 1972).) Dējérine (1892) noted that a lesion of the medial and inferior portions of the left occipital lobe could produce acquired alexia. However, Henschen (1920-2) placed the critical locus somewhat more anteriorly. He observed that word-blindness accompanied by difficulty in writing was due to a lesion of the left angular gyrus, "the center of visual words and letters" (Hinshelwood, 1900). But a thorough anatomical study of acquired alexic cases indicated that the associated lesions are more widespread, ranging anywhere from the occipital to frontal regions, usually in the left hemisphere (Nielsen, 1946). Critchley (1953) noted that there were distinct subgroups of individuals with acquired alexia:

> It is scarcely surprising that an impaired power of reading should be anything but a uniform clinical event. Some of the difficulties in the matter of alexia can be overcome by looking upon this syndrome as representing either a partial affection of language or else a fragment or a residuum of a visual agnosia. In this way there has grown up the notion of a two-fold type of alexia -- the aphasic and the agnostic varieties, respectively. (p. 308)

Dyslexic children are clinically similar to those cases of alexia associated with agraphia (Denckla & Rudel, 1976), or in Critchley's dichotomy, the aphasic-alexia subgroup.

Since it was well-accepted that restricted lesions of the left cerebral hemisphere could produce a dyslexic type of aphasia in adults, it was originally thought that agenesis of the left angular gyrus was responsible for dyslexia in children (Fisher, 1910). (Suggestive evidence was advanced in a controversial study of a family of dyslexics, which reported a reduction in amplitude of the response waveform evoked from the left parietal area by photic stimuli (Conners, 1970), but the electrophysiological procedures and analysis have been criticized (Kooi, 1972).) However, most young children with right hemiplegias indicative of left brain dysfunction (Marie, 1922; Apert, 1924), and children with left hemispherectomies are not aphasic (Kohn & Dennis, 1974) nor is the acquisition of language prevented. Lansdell (1969) reported that the earlier a child becomes brain-injured (even if damage was to the left hemisphere), the more likely the brain would show normal verbal mechanisms but the greater the likelihood that there would be a non-verbal deficit. Anticipating Sperry's conjectures about dyslexia, Lansdell proposed that when the left hemisphere is damaged, the language mechanism appropriates much of the right hemisphere tissue, thereby usurping the space of those functions that are normally mediated by the minor hemisphere. Because of this plasticity of the brain in compensating for early cerebral dysfunction, Geschwind (1962) suggested that bilateral involvement of the angular gyrus was the minimum pathological substrate necessary to account for a difficulty in learning to read. (In a recent neurophysiological study, Symann, Louett, Gascon, Matsumuya, and Lombroso (1977) found that a small group of dyslexics actually did show abnormal visual evoked potentials bilaterally in the parietal areas.)

## Limitations of the Perceptual and Aphasia Models of Dyslexia

Studies examining the presence of visual perceptual dysfunction in dyslexic children have been inconsistent in their findings. Discrepant results may be due to inherent methodological differences in these investigations, such as the definition of dyslexia employed, the age of the subjects tested, their intellectual level, and the complexity of the perceptual task (Bronner, 1917; Fildes, 1921; Gates, 1922; Fendrick, 1935; Vernon, 1958, etc.). For example, most studies examining visual perceptual abilities in dyslexic children have employed visual discrimination tasks (Phelan, 1940; Benton, 1962). It is possible that such tasks would not be sensitive to minimal cerebral dysfunctions (Bortner & Birch, 1962) especially in the older dyslexic child.

Although the aphasia model of developmental dyslexia is particularly attractive, Critchley (1970) cautions that while there is some "utilitarian merit" to this comparison, there are profound psychological and linguistic differences between a developmental dyslexic and an adult with a long-standing reading history who has recently lost the ability to read. The performance profiles of the dyslexic children may be indistinguishable from that of the adult aphasic. Nevertheless, because of the plasticity of the developing injured brain, the functional similarity of these disorders, does not indicate an identical structural basis.

A further limitation of a unitary theoretical approach to dyslexia, whether it utilizes an aphasia or perceptual deficit model, is that it does not consider the complexity of the reading process. Since the ability to read appears to be a complex process dependent on numerous, diverse linguistic, perceptual, and cognitive skills, there may be different varieties of dyslexia distinguished by different clusters of impairment. According to this view, dyslexia is not to be viewed as a homogenous, unitary syndrome with a single causal defect, but instead as a product of multiple independent causal defects (Mattis, French, & Rapin, 1975). Thus, there are those children with predominant language difficulties called audiophonic (Ingram, 1970), dysphonetic (Boder, 1971), language retarded (Kinsbourne & Warrington, 1966) or language disordered (Mattis et al., 1975) dyslexics. These children would probably have a higher Performance IQ and show different types of reading errors, e.g., insertion of extraneous letters during dictation (Kinsbourne & Warrington, 1966). They may also show other language difficulties as object and color anomia (Denckla, 1972) and the inability to follow complex verbal commands (Mattis et al., 1975). For example, Denckla and Rudel (1976) have observed that on the Oldfield picture naming test, a mixed group of ten dyslexic children (8 to 10 years old), performed slower and named fewer pictures correctly than a nondyslexic MBD group and a normal control group.

Another dyslexic subgroup consists of children with difficulty especially in visuospatial perception (Ingram, 1970; Boder, 1971; Mattis et al., 1975), who expectedly have higher Verbal IQ's. According to Kinsbourne and Warrington (1966), this group has difficulty in spatial-temporal sequencing and frequently shows a higher proportion of errors related to letter order. They also have difficulty in naming fingers, a deficit found in patients with developmental Gerstmann syndrome. Mattis et al. (1975) indicated that the visuospatial group makes up only 10% of the dyslexic population. Mattis et al. also proposed that there is a third type of dyslexic profile, the articulatory-graphemotor variety. This group has difficulty in blending sounds and shows diminished buccolingual skills as well as poor graphemotor coordination. Mattis (personal communication) has also noted that some dyslexic children do not seem to fall into any of the above categories.

Therefore, whether a perceptual or aphasic model is supported, to some extent, is dependent on the proportion of dyslexic children, in a studied sample, who are visuospatially or linguistically impaired. Since a larger portion of the dyslexic population display linguistic deficits rather than visuospatial deficits, it is more likely that an aphasia model would be supported.

## Disturbances of Eye Movements in Disorders of Higher Cortical Function

An approach to understanding the nature of developmental dyslexia, and the contributions of visual perceptual and linguistic processing defects, might be to explore differences in cognitive strategy rather than performance scores which reflect the final pathway of complex processes. One method of study which has illuminated perceptual, cognitive,and linguistic functioning employs eye movement measures. The empirical literature discussed below is confined to that pertaining to linguistic dysfunction, specifically, adult aphasia, and developmental dyslexia. The reason for this focusing is because of the indetermined degree of parallelism between these disorders to which Critchley alludes.

## Scanning Strategies of Adult Aphasics

Unusual scanning strategies may be related to a defect in visual perception (Tyler, 1968), a restriction of attention, the deviation of normal relations between peripheral and central vision in the control of fixation (Luria, 1966), or a general disturbance in hemispheric balance (Lhermitte & Cambier, 1960). Abnormal eye movement strategies have also been described in patients with language disorders.

Kirshner and Sidman (1972) noted that "recovered" aphasics scanned differently from controls, on tasks which the patient performed errorlessly. They suggested that "scanning patterns were more sensitive than error scores in detecting language difficulty" (p. 183). Eye movement recordings have also revealed information concerning the processing of "non-verbal" information in adult aphasics.

Mackworth, Grandstaff, and Pribram (1973) observed that three aphasic children with high nonverbal IQ's (aged 5 to 8 years) showed prolonged staring at a novel stimulus. They suggested that this failure to habituate was related to the children's difficulty in naming the display.

Some adult aphasics with mostly receptive language difficulty are also unable to scan a pictorial display meaningfully (Luria, 1966). Tyler (1969) noted an almost total absence of normal scanning activity in four adults with receptive aphasia; no attempt was made by these patients to explore the visual presentation of even simple pictures. Tyler suggested that this severe defect in visual exploration reflected an interference with the mental processes which normally aid in the critical reception of visual stimuli, and that this inability to selectively attend to visual stimuli is the result of a language defect.

Aphasics with a more predominant expressive language disorder manifest simple patterns of search, characteristically paying attention to appropriate informative areas of a picture. However, their effort is poorly maintained, resulting in a rapid reduction in the number and speed of their eye movements (Luria, Karpov, & Yarbuss, 1966; Tyler, 1969).

Aphasic patients with primarily naming difficulties explore the informative areas of even complex displays in a fashion indistinguishable from normal controls (Tyler, 1969).

Left brain-damaged patients, in general, require a longer search time than controls to locate objects in a field of search task, especially those in the right visual field. However, left brain-damaged patients unlike right brain-damaged patients do not show a lateral asymmetry of overall exploration time, i.e., they do not prefer to search one side of space (Chèdru & LeBlanc, 1972; Chèdru, LeBlanc, & Lhermitte, 1973).

There is inconsistent evidence that alexic aphasics show faulty eye movements when reading. Hartje (1972) found normal reading patterns in some severely aphasic and alexic patients and observed abnormal scanning in others. Benson (1977) observed a deliberate word-to-word, line-to-line scan in aphasics with anterior lesions while aphasics with posterior lesions rapidly scanned the text. Pirozzolo and Rayner (1978) reported a case of abnormal reading eye movements in an anomic aphasic with severe alexia and agraphia. (Neuroradiological report indicated a lesion in the inferior parietal area extending posteriorly into the occipital cortex.) This patient (as the one described by Benson) seemed to dwell on every letter of the text.

Thus, eye movement recordings have been informative about the attention, preference, and cognitive strategies of adult aphasics while viewing verbal as well as non-verbal arrays. Comparatively few investigations have recorded eye movements in developmental dyslexics and most of these studies have concentrated on eye movements during reading.

## Visual Exploration by Dyslexic Children

Javal (1878), a French oculist, noticed that during reading, the eye traverses a line in a sequence of discrete movements and pauses. The number of pauses, or fixations, and the number of regressions in the scan were correlated with the age and reading level of the child (Dodge & Cline, 1901). Buswell (1922) noted in poor readers as many as 35 to 40 fixations in a line with a disproportionate number of regressions. Orton (1925, 1937) described a tendency of some dyslexics to read from right to left and for some, it was actually easier to read from a mirror. He suggested that "static" (orientational reversal of letter form) and "kinetic" (sequential reversal of letter order) reversals were due to an inability to develop a consistent automatic left to right pattern of scan. While recording eye movements, Zangwill and Blakemore (1972) noticed that a 23 year old dyslexic showed an "irrepressible tendency" to move his eyes from right to left when reading.

The increased number of regressions and fixations seen in the scanning of dyslexics will obviously influence reading time but not necessarily comprehension (Rubino & Minden, 1973). The increase in the number of fixations may reflect an overall increase in the number of useless eye movements, for example, in verifications, adjustments and rectifications (at the beginning of the line) ( Lesevre, 1967). An increase in the number of fixations implies that dyslexics assimilate smaller word parts and less information each time the eye pauses.

Recently, Pirozzolo and Rayner (Pirozzolo & Rayner, 1978; Pirozzolo, 1978) suggested that not all dyslexics show the same eye movement patterns when reading. For example, the auditory-linguistic dyslexic shows an increased number of fixations, longer fixation durations, and mixed periods of short regressions and forward saccades, while the visuospatial dyslexic usually shows return sweep inaccuracies.

It is reasonable to inquire whether the abnormal scanning patterns noticed during reading is primary (causal) or secondary to the reading disability. In support of the former alternative, it must be noted that other oculomotor aberrations in dyslexics, such as asymmetrical nystagmus (Bogacz, Mendilaharsu, & deMendilaharsu, 1974), dysmetric ocular pursuit (Frank & Levinson, 1973), slower oculomotor reaction time (Lesevere, 1967), and defective optokinetic nystagmus (Frank & Levinson, 1973) have been reported. However, methodological limitations of most of these studies restrict their interpretations. For example, in an uncontrolled study of 17 cases tested for cerebellar deficits and of 30 cases tested with electronystagmography for vestibular deficits, Frank and Levinson (1973) reported that 97% of dyslexic children showed evidence of cerebellar-vestibular dysfunctions. They hypothesized that this cerebellar-vestibular dysfunction, together with its resulting "dysmetric" visual perception, was the cause of the poor ocular fixation and the scrambling of letters and words seen in 97% of dyslexics. Bogacz et al. (1974) suggested that the mechanism involved in the right to left scan preference seen in the reading patterns of dyslexic children, required an impairment of the cortico-mesencephalic system. They also postulated that an asymmetrical nystagmus was correlated with an involvement of the parieto-temporal-occipital area. According to Bogacz et al., these ocular-pursuit disturbances could possibly limit the visual input necessary to read. However, Bogacz et al. did not clearly define the level of reading for the dyslexic group nor did they present the comparative mean ages and intelligence of the dyslexic and control samples. No statistical tests were performed.

Dossetor and Papaioannou (1975) found no difference in optokinetic nystagmus between an undefined group of 10 dyslexic children (age 6 to 15) and a control group, matched for age and IQ. However, they did find that dyslexic children had a longer oculomotor reaction time than controls to a xenon light presented at an angular distance of 40 degrees. The dyslexic children had shorter reaction times when they moved their eyes rightward than when they moved them leftward; the controls had shorter leftward reaction times. However, Cohen and Ross (1971) found that reading-disabled and control children had almost identical latencies. This result was confounded by the fact that poor readers made more anticipatory responses than good readers and were less able to maintain fixation. The unusual distractibility of the reading-disabled children in their study, suggests that some of the children may also have been hyperactive. Nevertheless, oculomotor reaction time (OMRT) or latency differences between dyslexic and normal reader groups have also been reported by Lesevre (1967) and Pirozzolo (1978). Lesevre recorded OMRT to a light stimulus in 24 dyslexic children, 18 visual-spatial dyslexics and 6 linguistic dyslexics. She observed that the OMRT of dyslexic children were significantly slower than those of the normal readers. Unlike the controls who showed faster rightward reaction times, the dyslexic children displayed no directional asymmetry. However, Pirozzolo (1978) observed that although auditory-linguistic dyslexics had shorter rightward latencies as do normal readers, the visual-spatial dyslexics had shorter latencies to the left. Therefore, the use of a mixed group of dyslexics as in Lesevre's study, may have obfuscated the directional preference. Thus, latency differences and directional latency differences are the only oculomotor aberrations reported in well-controlled studies of dyslexic children.

The view that defects in ocular motility are causal factors in dyslexia, has led to the idea that eye movement reeducation may improve reading (Hildreth, 1947; Lesevre, 1968; Boutet et al., 1972; Zangwill & Blakemore, 1972). One of the arguments for the contrary view that eye movement aberrations are the result rather than the cause of dyslexia, is that patients with gross eye movement disturbances do not show the particular characteristics of dyslexia, although their reading may also be affected (Cogan, 1970; Hartje, 1972). In fact, there is a wide range of eye movement patterns within which normal reading performance is possible (Hartje, 1972).

A major difficulty of the dyslexic may not be in the scanning of words and text but in the linguistic decoding (Katz & Wicklund, 1971;

Shankweiler & Liberman, 1972). Therefore, misperceptions of words may not be merely an automatic consequence of reversibility of symbols or right to left scan. One way to determine if there exists an overall scanning deficit associated with dyslexia or a difficulty in linguistic processing reflected in abnormal scanning of text, is to evaluate eye movements of dyslexic children during free scanning of "non-verbal" arrays. Few studies have investigated dyslexic scanning strategies during the performance of a "non-verbal" task.

Lesevre (1968) studied the performance of dyslexic children on the test, "Croix de St. Andre". This test consisted of scanning 51 identical crosses irregularly spaced on seven lines with the interspace between the lines the same as in a reading passage. The instructions to the child was to fixate each cross successively as rapidly as possible, first from left to right and then from right to left. She noted that there were no significant differences in the latency of the eye movements to the right versus those to the left (oculomotor reaction time) in the dyslexic children. Normals display a strong preference to the right in both measures of scanning efficiency and speed of movements. Boutet, Ghiloni, and Gabersek (1972) also found no lateral preference of gaze in dyslexics on this same test as well as on a similar test consisting of the scanning of symbols on each of six lines spaced equidistant from each other and from one line to the next. Griffen, Walton, and Ives (1974) evaluated 13 children (aged 9 to 11) who read at least 1.5 years below grade level and controls, on two "nonverbal" arrays, one composed of 25 equally spaced dots and the second consisting of a similar arrangement of animal drawings. The children were instructed to look at each card as in a reading situation. The poor readers showed more regressions (leftward movements) on the dot card than controls. However, there were no significant differences between groups in the number of regressions for the animal card or the number of fixations for either the animal card or the dot card.

The question still remains as to whether dyslexic children display aberrant scanning during reading because of a difficulty in processing such linguistic material, or because of a defect in ocular motility, i.e., the dyslexic children may not properly direct their eyes to fixate on the information needed for processing.

## Factors Affecting Eye Movement Patterns

Visual scanning behavior is affected by the nature of a visual stimulus, by the type of cognitive processing required to perform a particular task, and by the integrity of the oculomotor system to execute the perceptual/cognitive requirements for accurate information processing.

### Visual stimulus parameters.

A convenient paradigm for evaluating the effects of such stimulus variables as the familiarity, density and the orientation of a visual display, is the field of search task.

Array density: The pattern density in the peripheral array can influence scanning strategies (Mackworth, 1965; Mackworth & Bruner, 1970). According to Mackworth (1965), when the peripheral fields are overloaded with visual information, scanning seems to cluster in the center of the display, i.e, "visual noise causes tunnel vision". This peripheral contraction has also been observed in patients with diffuse cerebral dysfunction (Bender & Diamond, 1965; Diamond & Epstein, 1974). Bender and Diamond (1975) suggested that this centering of eye movements may also reflect a diminished processing capacity relative to the information content of the stimulus. Young children also show a "centering" of their visual field that tends to expand with age (Piaget & Inhelder, 1969). Since visual noise impairs peripheral matching (Mackworth, 1965), a subtle pattern recognition deficit may become magnified with increased peripheral information. This may be revealed in a "centering" of scanning.

Array content: Left brain-damaged patients show impaired performance on matching familiar objects to a picture (DeRenzi, Scotti, & Spinnler, 1969). Recognition of tachistoscopically presented familiar figures is defective in left temporal lobe patients while right temporal lobe patients have more difficulty in perceiving overlapping shapes not easily verbally identifiable (Kimura, 1963). Therefore, in an aphasiological context, dyslexic children would probably have more difficulty matching figures that are linguistically processed than those that can be spatially coded.

Array orientation: Young non-reading children have difficulty discriminating rotated transformations of letters (Gibson, Gibson, Pick, & Osser, 1962). Dyslexic children characteristically also rotate letters, especially b, d, p, q, and words such as was and saw. Lovegrove, Billing, and Slaghuis (1978) recently observed that dyslexic children have particular difficulty in the visual storage of tilted lines. Therefore, dyslexic children may also have more difficulty in searching for a rotated stimulus.

Cognitive processing mode. Linguistic processing may be essential in the performance of "non-verbal" as well as "verbal" tasks. Thus, as described in adult aphasics a linguistic impairment can interfere with processing of visual "non-verbal" information. Those cognitive tasks on which aphasics perform poorly, regardless of their manifest verbal content, may also be performed poorly by dyslexic children. For example, aphasic adults perform significantly worse than other brain-damaged individuals on the embedded figures test (Teuber & Weinstein, 1956; Russo & Vigniolo, 1967). Interestingly, similar findings have been reported in reading-disabled children (Tjossem et al., 1962; Goetzinger et al., 1960); eye movement patterns should reflect their difficulty in task performance.

Oculomotor component. Dyslexic children may show defective scanning strategies in the exploration of "non-verbal" as well as "verbal" materials possibly because the motor habits practiced in reading may influence the way they organize and process all visual information. For example, in a preliminary study with second-grade reading-disabled children, Elkind and Weiss (1967) found that when the children were asked to scan an isosceles triangle composed of common figures forming its outline, they scanned following a left to right reading pattern. This scanning strategy was more typical of younger children that were not reading-disabled. Second-grade reading children tended to look at the figures following the form of the triangle. Elkind and Weiss suggested that children with difficulty in learning to read continue to use the spontaneous practice of eye movements needed for reading that average readers have outgrown. They alleged that the need for practice continues in the reading-disabled children because the motor skills have never been completely developed.

Another postulated oculomotor theory of reading disability suggests that dyslexic children may have a tendency to move their eyes from right to left regardless of the content of the material (verbal or "non-verbal") and this, to some extent, may be a causative factor of their reading disability.

The purpose of the present study is to determine the nature and extent of visuoperceptual deficits in a sample of dyslexic children and to systematically study the eye movement strategies used by these children in processing "non-verbal" visual information. Specifically, the effects on oculomotor patterns of stimulus parameters, such as density, content, and orientation, will be examined. In addition, this study will investigate the effects of linguistic processing demands on the scanning of dyslexic children. The contribution of oculomotor integrity and efficiency on task performance will also be evaluated.

## Hypotheses

The study was designed to investigate the nature of perceptual deficits and associated visual scanning strategies in dyslexic children, testing the aphasia model of dyslexia. The following hypotheses are advanced:

1. Dyslexic children will exhibit performance deficits on visual perceptual tasks. However, it will be established that the impairment of visual perceptual functions is selective and not universal.

2. Operationally, the functional subset of perceptual abnormalities will be defined by tests of cognitive/linguistic abilities. Therefore, dyslexic children will do poorly in identifying embedded figures and in locating familiar objects in a field of search task, as do aphasic adults.

3. Defective visual spatial functions in dyslexic children will be delineated further by those tasks that present to the system a large quantity of visual information relative to the channel capacity of that system. Since the resultant overload will produce a centration of the

functional visual field, it is explicitly hypothesized that an increase in array density in a field of search paradigm will produce a greater decline in the performance of the dyslexic children than of the control group.

4. Dyslexic children are also expected to have more difficulty than a control group in storing and/or retrieving rotated visual forms.

5. Differences in eye movement patterns between dyslexic children and control will exist independently of specific motoric deficits.

# METHODS AND MATERIALS

## Subjects

Fifteen dyslexic children and fifteen normal readers were included in this study. Children with reading disabilities who met the following criteria were selected for the dyslexic sample:

1. Between eight and thirteen years of age
2. Male
3. Right-handed writer
4. Normal hearing and correctable visual acuity
5. No known neurological disorder; no hard neurological signs
6. Score below 1.5 on the short form of the Conners Hyperactivity Rating Scale as rated by parent or teacher (Conners, 1969)
7. Chronic history of reading problems
8. Normal intelligence as measured by the Wechsler Intelligence Scale for Children-Revised (WISC-R) with at least 85 Full-scale IQ (FS IQ) and 90 IQ on either the Verbal or Performance subtests (Wechsler, 1974)
9. No primary emotional problems
10. No educational and environmental deprivation
11. Only English spoken at home
12. Reading at least 2.4 years below mental age on the Gray Oral Reading Test (Gray, 1967) and the Wide Range Achievement Test (WRAT) (Jastak and Jastak, 1965).

Children in the dyslexic sample were drawn from two private schools for minimally brain-dysfunctioned and learning-disabled children, the Child Development Centers at The Elmhurst General Hospital, The Long Island Jewish Hospital-Hillside Division, and the Neuropsychology Department at Montefiore Hospital. Approximately 1000 records were reviewed in the selection process.

For purposes of control, children without reading disability were selected from those who met the following criteria:

1. Between eight and thirteen years old and within four months of age with a dyslexic child
2. Male
3. Right-handed writer
4. Normal hearing and correctable visual acuity
5. No history of reading problems
6. Normal intelligence as measured for the dyslexic child and within seven FS IQ points with one dyslexic child who also matched for age
7. Fluent English spoken
8. Reading on or above grade level as measured by the Gray Oral and the WRAT reading tests.

Children in the control group were selected from three private (parochial) schools. Of sixty children evaluated, 15 were suitable given the sampling restrictions.

## Sample Characteristics

The groups were matched for socioeconomic status by selecting children from middle-class families. Each child was matched with a normal child with regards to Full-scale IQ and age. The dyslexic boys ranged in age from 9 years 5 months to 13 years 5 months (*M* = 12 years 0 months, *SD* = 1 year 3 months). The ages of the normal readers ranged from 9 years 4 months to 13 years 6 months (*M* = 12 years 0 months, SD = 1 year 2 months). FS IQ ranged from 91 to 123 (M = 105.1, SD = 10.0) for the dyslexic sample and 95 to 123 (M = 106.8, SD = 7.8) for the control group.

The results of neuropsychometric evaluation (v.i.) was reviewed by Dr. Steven Mattis, who classified the dyslexic children. Eight of the dyslexic children were classified as articulatory-graphemotor dyslexics, five were language-impaired dyslexics and two were of a miscellaneous group with predominant sequencing difficulties. (None were identified as visuospatial dyslexics.)

## Procedure

### The Evaluation of the Dyslexic Children

The dyslexic children were evaluated in the following manner in order to ascertain the extent and nature of their reading disability and to decide their appropriateness for this study:

Neurological examination. The dyslexic children were examined by a neurologist, Dr. Sidney Diamond. The examination included the evaluation of gait, motor power, reflexes, gross and fine motor coordination, sensory-perceptual functioning, gross visual fields, and oculomotor functions including pursuit, saccadic eye movements, and optokinetic nystagmus.

Neuropsychometric evaluation. An extensive battery of neuropsychological tests were administered in order to define the proportion of the sample that were visuospatial, articulatory-graphomotor or language-disordered dyslexics (Mattis et al., 1975). The complete battery included:

1. WISC-R including the following subtests:
    a. Verbal subtests: Information, Similarities, Arithmetic, Vocabulary, Comprehension, and Digit Span
    b. Performance Subtests: Picture Completion, Picture Arrangement, Block Design, Object Assembly, and Coding
2. Wide Range Achievement Test (WRAT): Reading, Arithmetic and Spelling subtests
3. Gray Oral Reading Test (Form A)
4. Ravens Coloured Progressive Matrices (RCPM)
5. Modified Harris Laterality Test (Mattis, personal communication)
6. Language Battery
    a. Token Test for Aphasia
    b. Spreen-Benton Naming Test
    c. Auditory Reception and Sound Blending subtests of the Illinois Test of Psycholinguistic Aptitude (ITPA)
    d. Sentence Repetition from the Boston Aphasia Battery
    e. Wepman Test of Auditory Discrimination
7. Purdue Pegboard Test of Fine Motor Coordination
8. Benton Test of Visual Retention (copying, recall, and graphemotor skills).

## Visuospatial Testing

The visuoperceptive tasks employed in the present study are classically known to be sensitive to cerebral dysfunction and to normal developmental changes. These tests, including a circle-size matching test, the Ravens Coloured Progressive Matrices (Ravens, 1962), the Ghent Embedded Figures (Ghent, 1956), and the Modified Valcuikas

Embedded Figures (Valcuikas, personal communication) were administered to both dyslexic and control groups. Most of these tasks were selected from a larger battery of visuospatial tests employed in a pilot study (see Appendix A ).

Circle-size matching. The circle-size matching test is a difficult perceptual discrimination test that requires intact abilities of magnitude estimation. Nebes (1974) observed that split-brain patients show right hemisphere superiority on a task which required them to choose from different size circles, the one from which a particular arc had come. Although this task is different than the one used in the present study, both require a judgment of the size of an arc. Other researchers have also suggested that right hemisphere processing is required to perform a circle matching test (Galin, 1976). It was expected that dyslexic children would probably have little difficulty on a task of perceptual discrimination (Birch, 1962), especially if right hemisphere processing was required.

The present task consisted of a standard size circle at the top center of a sheet of paper. Arranged in two rows below this circle were a total of eight circles of varying sizes (four per row) (see Appendix A , Figure C ). Each child was required to locate the circle that was the same size as the standard. Three standard circle sizes, each with answers in four different positions were presented in random order (12 presentations). The percentage of correct answers for each child was determined.

Ravens Coloured Progressive Matrices (RCPM). The Ravens Coloured Progressive Matrices (RCPM) is a standardized test, widely recognized as an index of "non-verbal" intellectual performance. It has been used to assess spatial deficits in brain-damaged populations (Gainotti, 1968; Costa, Vaughan, Horwitz, & Ritter, 1969). Patients with right hemisphere lesions show significantly poorer performance on the RCPM than left brain-damaged patients (Costa et al., 1969). Costa et al. reported a higher incidence of a lateralized response position preference in right brain-damaged than in patients with left cerebral lesions. Within the left brain-damaged group, receptive aphasics had more errors than non-dysphasic or expressive aphasic groups. Basso, DeRenzi, Faglioni, Scotti, and Spinnler (1973) also confirmed that within the left brain-damaged group, patients without aphasia performed better than an aphasic group. However, Basso et al. noted that the failure of aphasics could not explained by the presence of a language disorder, since the correlation between Ravens scores and measures of oral comprehension and naming was practically zero.

Costa (1976) suggested that different designs of the RCPM may be differentially sensitive to brain dysfunction. For example, those designs which require Gestalt processing (A set) would be more likely to show impaired performance in right brain-damaged subjects while those which require the use of analogy would be more sensitive to left brain dysfunction (B set). However, right brain-damaged patients performed significantly poorer than left cerebral-lesioned patients on both subsets.

Goetzinger et al. (1960) found that poor readers performed significantly worse than good readers on the RCPM.

RCPM consists of a series of designs, each of which, is missing a section in the lower right-hand corner. The subject is required to find the piece (six choices) which best completes the design. The number of correct answers was tabulated for each child.

Embedded figures tests. The embedded figures test (EFT) was originally devised by Gottschaldt (1926, 1929), in order to study the role of past experience in perception and was later popularized by Thurstone (1944) in identifying the "flexibility of closure" factor. Ghent (1956) adopted Thurstone's figures and studied perceptual development. She noted that younger children have greater difficulty in separating figure from ground especially if their contours coincide as in embedded figures. This test has been shown to be particularly sensitive to cerebral damage in children (Werner & Strauss, 1941) and in adults (Gelb & Goldstein, 1920). It has been suggested that a specific form of a central visual disturbance underlies the inability to do EFT. This hypothesis has been indirectly confirmed by the investigations of Teuber, Battersby, and Bender (1951) which indicated that patients with retro-rolandic lesions performed worse than patients with either anterior or intermediate lesions. Gelb and Goldstein (1920) hypothesized that a general loss in abstract intelligence, not specific to any modality or language functioning, was responsible for impaired performance of EFT. This intellectual defect was related to a "loss of ability to discriminate any unit of perception from its context" and could therefore, be attributed to cerebral lesions in any lobe. Battersby, Krieger, Pollack, and Bender (1953) found that "intellectual" impairment as measured by the EFT (as well as other tests) could be produced by lesions in any portion of the cerebral hemispheres. These results, to some extent, confirmed the Gelb-Goldstein hypothesis. Although Teuber and Weinstein (1956) also found that brain-damaged patients, regardless of the locus of their lesions, showed defective performance on embedded figures, they noted that within this population, aphasics performed significantly worse than other brain-damaged patients. Right brain-damaged patients also perform poorly on EFT, although their performance is not as impaired as the left brain-damaged aphasics but significantly better than left brain-damaged non-aphasics (Russo & Vignolo, 1967). Russo and Vignolo concluded that poor visual figure-ground discrimination (as measured by EFT) may be due to an impairment of at least two abilities, language or a similar intellectual factor, and a visuospatial ability, subserved by the right hemisphere. According to Teuber and Weinstein (1956), this language factor may not be merely a disturbance in linguistic reception or expression, but may be a manifestation of a faulty selection of relevant information.

Defective performance on EFT has also been observed in reading-disabled children, aged seven to nine (Tjossem et al., 1962). In an older sample of 10 to 12 year olds, only the more complex sections of the Gottschaldt EFT differentiated the good from the poor readers (Goetzinger et al., 1960). This may be indicative of subtle brain damage manifested in a difficulty in separating figure from ground or of selecting and attending to the important elements of a visual stimulus. This disturbance may be specific to a difficulty in processing linguistic information. It is expected that the dyslexic children will have more difficulty than controls in performing the embedded figures test. Two types of embedded figures tasks were employed: The Ghent Embedded Figures and the Modified Valcuikas Embedded Figures Test.

Ghent Embedded Figures: The subject was required to find a simple figure embedded in a more complex figure located below it (see Appendix A, Figure I ). Each child was asked to outline the correct answer. The percentage of correct answers was ascertained (14 figures).

Modified Valcuikas Embedded Figures Test: A simple figure was hidden in one of four complex figures located below it. The complex figures were arranged so that there were two choices on each of two rows (see Appendix A, Figure J ). The format was modified from the original Valcuikas Embedded Figures to insure that an equal number of correct answers were in each hemifield. Eleven figures were presented in a fixed order of approximately increasing complexity. The first figure served as a sample figure and was not included in the analyses. The children were asked to find the hidden figure and then to outline the correct answer. The percentage of correct answers was tabulated for each child. The eye movements recorded during the performance of this task were also analyzed (v.i.)

## Eye Movement Testing

Testing was conducted in an air-conditioned laboratory at Queens College of the City University of New York. During the procedure, carried out in dim ambient light, the subject sat on an adjustable stool with his head resting on a chin and forehead support. A bite bar with individually molded mouthpieces was used to control head motion. Horizontal and vertical eye movements were recorded by a Whittaker Eye-View Monitor and Pupillometer System (model 1992 S), an infrared (IR) system, which is accurate to approximately 30 minutes for eye movements in a range from one to thirty degrees in the horizontal plane and one to twenty-five degrees in the vertical plane.

The output of the detection apparatus was recorded on a Sangamo FM seven track instrument tape recorder (model 1900), and simultaneously charted on a Beckman polygraph recorder (model T) with both DC and RC coupling for positional and velocity (directional) information, respectively.

Eye movements were induced by slides, rear-view projected onto a white translucent screen. The field presented subtended a visual angle of 18 degrees horizontally, by 13 degrees vertically at the subject's eye. A total of 81 slides were presented including 39 on which the present study is based. Five calibration slides were incorporated in the set.

A calibration slide consisted of the numbers one to nine in a rectangular array of three rows and three columns (see Appendix B , Figure M ). All succeeding slide displays fell within the limits set by the numbers of the calibration slide. The centers of the remaining slides superimposed on the number "5". During the calibration procedure, the subject was asked to look at the number "5", which was the central cipher, and then at the remaining ones in numerical order, returning finally to the "5". In this way, the amplitude of all succeeding horizontal and vertical saccades was known and could be used for calibrating the record. Figures U and V (Appendix C) illustrate an eye movement trace induced by the calibration pattern. A full calibration procedure was carried out at the beginning and end of the test sessions, and before and after each of the three rest periods. Each stimulus slide was presented for 40 seconds and the total testing time was approximately two and one-half hours including calibration time. At the end of each stimulus slide, the calibration slide was projected and the subject was asked to fixate on the "5". This allowed for adjustments to be made for head movement. Prior to each slide change, the experimenter gave the relevant instructions (at the beginning of a new slide set) and said "Ready". The onset of a new slide was automatically coded on the tape and record, by a pulse. When the subject completed a task before the 40 second time limit, he was told to close his eyes and take his head out of the equipment with his eyes closed.

### Tasks Employed for Analysis of Eye Movements

Visuospatial tasks particularly sensitive to cerebral dysfunction, or of specific relevance to reading disability were used in conjunction with eye movement recordings. Scanning of reading material was also recorded for purposes of comparison with eye movements during the viewing of "non-verbal" information.

It is standard experimental procedure to administer tasks in random order so that the relationship between the order of task presentation and performance can be assessed. This randomization procedure was followed for types of tasks, i.e., field of search, EFT, etc., but not for the individual blocks or trials within a task. This was not considered to be a serious methodological flaw, since the analyses needed to determine an order effect could not have been performed. Due to the large number of variables, the sample size did not provide sufficient statistical power to perform an analysis of variance. Given the great likelihood of a Type II error in the analysis for order effect, it was felt that it was preferable to keep order constant so that the data could then be examined directly to estimate whether the results were compatible with a trend over time. Thus, the following tasks were presented in random order, keeping a fixed order of blocks or trials within these tasks:

Field of search. In order to study visual searching disorders associated with cerebral lesion, Poppelreuter (1917) constructed a field of search test, which was later modified by Teuber, Battersby, and Bender (1949). Teuber et al. (1949) found that among brain-damaged children and adults, there was a significant increase in the amount of time needed to search the field and locate the figure. In some cases, an asymmetrical search strategy was noted. In order to obtain a more precise measure of this asymmetrical gaze especially seen in patients with unilateral inattention, Chèdru, LeBlanc and Lhermitte (1973) coupled the revised Poppelreuter test with eye movement recordings. They were particularly interested in information about the direction of the initial scan and the general strategy of exploration. Normal adults looked initially to the upper left quadrant but spent equal exploration time in both halves of space. Brain-damaged patients had more difficulty finding the target in the field opposite to their lesion.

The field of search task, in this study, consisted of 0.5 degree patterns distributed irregularly over the projected field with an equal number of patterns in each quadrant. In the center of the array, one of the patterns (the standard) was duplicated. The subject was asked to find in the surrounding field, the pattern which was identical (the target) to the standard. The subject was asked to fixate deliberately on his choice and then to close his eyes. The number of figures in the array (array density), the level of the familiarity of the targets in the array (array content), and the angle of rotation of these targets (array orientation) was varied.

Six blocks consisting of a total of 20 Field of Search (FOS) slides were presented in the following order (see Appendix B ):

1. Butterfly 32: This block consisted of 32 drawings of familiar objects in the array with a butterfly as the standard. The location of the butterfly target in each of four slides was randomized so that the target appeared once in each quadrant at about 11 degrees from the center on an oblique (see Figure N ).

2. Butterfly 64: This block of four slides also had a butterfly as the standard and was identical to the Butterfly 32 except that the number of objects in the array was doubled (see Figure O ).

3. Psi (Ψ) 32: Thirty-two unfamiliar symbols (including Greek and Russian letters and apothecary symbols) constituted the array. The Ψ was the central standard in each of the four slides and the location of the answer was randomized with respect to quadrant (see Figure P ).

4. Butterfly 32 T: This block was the same as the Butterfly 32 block (v.s.) but now the object in the array were tilted approximately 45 degrees. Thus, the target butterfly was tilted, whereas the standard butterfly was erect. The location of the butterfly target appeared on one slide in the lower left quadrant and in another slide, in the lower right quadrant. The order of presentation of the two slides was randomized (see Figure Q ).

5. Butterfly 64 T: As in the Butterfly 32 T, the objects in the array were tilted 45 degrees and the butterfly was erect. There were a total of 64 elements in the field of search. The target location was the same as in Butterfly 32 T (see Figure R ).

6. Ψ T: As in the Ψ 32 there were 32 unfamiliar symbols in the array. The symbols were tilted by approximately 45 degrees. The central Ψ standard was erect. The target was located once in each quadrant (see Figure S ).

The following eye movement measures were derived for analysis:

1. Latency which is defined as the time from slide onset to the initiation of the first eye movement, horizontal or vertical.

2. Search time measured as the elapsed time from slide onset to the location of the target.

3. Exploration time (search time minus latency) which refers to the time from the initiation of the first eye movement to the location of the target.

4. Refixations, i.e., the number of times the central standard was reexamined after the initial eye movement.

5. The direction of the initial eye movement, i.e., left or right.

Modified Valcuikas Embedded Figures (v.s., for background and method). The following eye movement measures were employed for analysis:

1. Search time as the total time taken to locate the hidden simple figure.

2. Localized search time as the percentage of the total search time spent in each of the five boxes including the simple figure.

3. The total number of fixation shifts across the five boxes.

4. Refixations -- the number of return shifts to the simple figure.

5. The direction of the initial saccade.

6. The time taken to find figures hidden in the left boxes versus those hidden in the right boxes.

Elkind triangle. The Elkind triangle (v.s.), an array of twenty pictures arranged in the form of an isosceles triangle, was scanned differently by a reading-disabled group and a group of normal readers in a preliminary study (without eye movement recordings) (Elkind & Weiss, 1967) (see Appendix A, Figure F ). Elkind and Weiss noted that reading-disabled children scan this triangle from left to right as though they were practicing the motor habits of reading.

In the pilot study (see Appendix A ), most of the reading-disabled children named the objects in the form of a triangle. However, they frequently named the objects in a clockwise fashion rather than the predominant counterclockwise method used by good readers. This clockwise naming required that the child name the bottom row right to left. Previously, this left lateralization of scan was only noticed in association with reading material (Orton, 1937; Dearborn, 1933;

Zangwill & Blakemore, 1972). In addition, a few reading-disabled children in the pilot investigation were unsystematic and almost random in their naming. Elkind and Weiss only noticed this type of scanning in young preschool children. Eye movement recording are expected to verify these findings.

In the present study, each child was asked to look at all the objects and to try to remember them. He was told that he might be questioned about the array. The following eye movement measures were derived for analysis:

1. The number of children in each group who showed a "reading" left to right scan

2. The number of children in each group who outlined the triangular form with their scanning movement; also, whether the scan pattern was clockwise or counterclockwise

3. The number of children in each group who showed any random quality to their eye movement patterns.

Reading. Two reading slides composed of four lines of text each, were selected from the Gray Oral Reading Test (Form B). The lines were of increasing complexity and ranged from preprimer level to eighth grade reading. These slides were always presented last in the slide series to avoid anxiety in the dyslexic children. The slide with the relatively easier reading material was always presented first. The following eye movement measures were obtained for analysis:

1. Fixations: the number of forward dwells (left to right)

2. Regressions: the number of backwards fixations (right to left)

3. Reading time: time from scanning onset to completion of the four lines

4. Corrective movements: the number of small fixations following the end of the preceding line and made before left to right scanning of the next line of text

5. Initiation of reading scan: the elapsed time from the pause at the beginning of a line to the onset of a left-right scan

6. Jumped lines: the number of times the eye (as measured by the vertical channels) jumps to a different line ahead and then returns

7. Regressed lines: the number of times the eye returns to a former line of text.

## Statistical Analyses

Since the data consisted of two samples of equal size, and since each member of one sample was paired with specific member of the other sample (for age, FS IQ, sex and handedness), dependent *t* tests were used for data analyses. An underlying normal distribution of population differences is assumed in this test. The degrees of freedom as determined by (n - 1) pairs was equal to 14. The alpha level used for significance level was p = .05, two-tailed test (one-tailed tests were used in tasks that had been used previously in the pilot, Appendix A ). These *t* tests were analyzed by computer (IBM 360) and the Statistical Package for Social Science (SPSS) for dependent *t* tests was employed. A difference of differences *t* test was used to examine the effects of changes in the density, content, and orientation of the FOS arrays on the performance of dyslexic and control children. A test of correlated proportions was used to evaluate group differences on the scanning of the Elkind triangle.

The experimenter was blind to the group identity of 75% of the subjects during the scoring of the eye movement records.

# RESULTS

## Sample Characteristics

The two groups did not differ significantly with regard to age and FS IQ, thus, not refuting the pair match of dyslexic and control children for these variables. Although the groups were closely matched for FS IQ, they differed significantly on both Performance and Verbal IQ's, $\underline{t}$ (14) = -3.18, $\underline{p}$ = .007, and $\underline{t}$ (14) = 5.92, $\underline{p}$ = .001, respectively. The dyslexic children obtained significantly higher scores than the controls on the Performance scale, but obtained significantly lower scores on the Verbal scale. Table 1 presents the group contrasts for age and IQ.

Table 1

Sample Characteristics

| Measures | Dyslexic n=15 | | Control n=15 | | $\underline{t}^a$ $\underline{df}$=14 | $\underline{p}^b$ |
|---|---|---|---|---|---|---|
| | $\underline{M}$ | $\underline{SD}$ | $\underline{M}$ | $\underline{SD}$ | | |
| Age (months) | 143.7 | 14.3 | 143.9 | 14.6 | .30 | .77 |
| WISC Full Scale IQ | 105.1 | 10.0 | 106.8 | 7.8 | 1.62 | .13 |
| WISC Performance IQ | 108.5 | 10.6 | 101.4 | 9.1 | -3.18 | .007 |
| WISC Verbal IQ | 101.4 | 9.3 | 110.2 | 9.8 | 5.92 | <.001 |
| GRAY Oral Reading | 2.0 | .4 | 9.3 | 2.9 | 10.16 | <.001 |
| WRAT Reading grade | 3.3 | 1.2 | 9.1 | 1.8 | 13.71 | <.001 |
| WRAT Reading S.S.[c] | 76.7 | 7.9 | 117.2 | 11.7 | 13.41 | <.001 |
| WRAT Spelling S.S. | 74.5 | 6.2 | 107.9 | 15.2 | 8.96 | <.001 |
| WRAT Arithmetic S.S. | 82.9 | 7.9 | 95.2 | 8.4 | 3.70 | .002 |
| Hollingshead index (SES) | 2.6 | 1.3 | 3.1 | .9 | 1.10 | .29 |

[a] paired $\underline{t}$ tests

[b] two-tailed tests

[c] standard score

Subjects were selected from schools drawing children from similar middle-class backgrounds. The children's socioeconomic status (SES) was determined by the two factor Hollingshead Index for Social Position (Hollingshead, 1958). Most of the children were from middle-class families (Classes 3 and 4) and the groups were not statistically different with regard to SES (see Table 1).

As expected, the dyslexic group obtained significantly lower scores on both the Gray Oral Reading Test (a test of paragraph reading) and the WRAT reading subtest (word recognition), $\underline{t}$ (14) = 10.16, $\underline{p}$ < .001, and $\underline{t}$ (14) = 13.71, $\underline{p}$ < .001, respectively. The dyslexic children read on an average, about 3.3 years below grade level on the WRAT and lagged approximately 4.6 years on the Gray Oral Test. The control group read approximately 2.5 years above grade level on both reading tests. In addition, the dyslexic group obtained significantly lower scores on WRAT spelling and arithmetic than the control children, $\underline{t}$ (14) = 8.96, $\underline{p}$ < .001 and $\underline{t}$ (14) = 3.70, $\underline{p}$ < .002, respectively (see Table 1).

## Visuospatial Tasks

As shown in Table 2, of the four tests of visual-spatial function employed in this study, the dyslexic children had significantly more errors than the control group on the Modified Valcuikas Embedded Figures only, $\underline{t}$ (14) = 1.94, $\underline{p}$ = .035. The other tasks did not significantly distinguish between the groups.

Table 2

Performance on Visual-Spatial Tasks

| Visual-Spatial Tasks | Percent Correct | | | | $t^a$ | $p^b$ |
|---|---|---|---|---|---|---|
| | Dyslexic | | Control | | df = 14 | |
| | *M* | *SD* | *M* | *SD* | | |
| Circle-Size Matching | 70.4 | 18.0 | 78.1 | 13.6 | 1.13 | .14 |
| Ravens Coloured Progressive Matrices | 83.7 | 2.9 | 85.0 | 3.8 | .72 | .24 |
| Modified Valcuikas | 58.7 | 16.8 | 70.0 | 12.0 | 1.94 | .04 |
| Ghent Embedded Figures | 80.1 | 9.0 | 82.7 | 15.8 | .57 | .29 |

[a] paired *t* tests

[b] two-tailed tests

## Field of Search

The eye movement data for the field of search task are presented for three types of stimuli:

1. Array density which contrasts the performance of dyslexic and normal children on the butterfly array with 32 objects versus the butterfly arrays with 64 objects (Butterfly 32 and Butterfly 32 T vs. Butterfly 64 and Butterfly 64 T).

2. Array content which compares the groups' performance of the familiar figure arrays (Butterfly 32 and Butterfly 32 T) and the unfamiliar arrays ($\Psi$ 32 and $\Psi$ T).

3. Array orientation which contrasts the difference in dyslexic and control group performance on arrays that are erect (Butterfly 32, Butterfly 64, and $\Psi$ 32) with their performance on arrays that are tilted

(Butterfly 32 T, Butterfly 64 T and Ψ T).

A difference of difference _t_ test, i.e., a second-order dependent _t_ test, was employed to test the significance of changes in the density, content, and orientation for the two groups. In addition, a dependent _t_ test was used to evaluate the difference between dyslexic and control children performance on each array-type, e.g. Butterfly 32.

Five eye movement measures were obtained. They were latency, search time, exploration time, number of refixations, and the percent left initial gaze.

## Array Density (Butterfly 32, Butterfly 32 T vs. Butterfly 64, Butterfly 64 T)*

Table 3 shows that differences in the dyslexic children's performance between the arrays with 32 targets and those with 64 targets were not significantly different from the differential performance of the controls with respect to any of the eye movement measures: latency, search time, exploration time, and number of refixations.

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*A second order dependent _t_ test was analyzed to test the significance of differences between differences.

Table 3

The Difference between the Differential Scores for the Dyslexic and Control Children on FOS Arrays of 32 and 64 Targets (Butterfly 32 and Butterfly 32 T vs. Butterfly 64 and Butterfly 64 T)[d]

| Eye Movement Measures | Dyslexics | | Controls | | $t$[a] $df = 14$ | $p$[b] |
|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | | |
| Latency (sec.) | .04[c] | .25 | .11 | .16 | 1.00 | .33 |
| Search Time (sec.) | -.50 | 1.95 | -.45 | 2.80 | .05 | .96 |
| Exploration Time (sec.) | -.54 | 1.94 | -.56 | 2.82 | - .02 | .99 |
| Number of refixations | .44 | .37 | .30 | .34 | -1.12 | .28 |

[a] paired *t* tests

[b] two-tailed tests

[c] A negative number indicates that the value for the arrays of 64 was greater than the arrays of 32, i.e., all "64" values were subtracted from the "32" values. Therefore, a positive number indicates that the value was greater for the array of 32.

[d] Note that the values tabulated here and on Tables 6 and 8 refer to difference of difference scores, whereas the other FOS tables apply to first-order differences between groups.

Separate comparisons of the two groups with respect to performance on the 32 target arrays and on the 64 target arrays (see Tables 4 and 5 respectively), revealed the following:

Butterfly 32 (tilted and erect). The mean scores of dyslexic and control groups did not differ significantly in latency, search time, exploration time or in the number of refixations to the central target.

Table 4

The Differences between the Performance of Dyslexic and Control Children on the Butterfly Target with 32 in the FOS Array (Tilted and Erect)

| Eye Movement Measures | Dyslexics | | Controls | | $t^a$ df = 14 | $p^b$ |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | | |
| Latency (sec.) | .90 | .28 | .78 | .17 | -1.64 | .12 |
| Search Time (sec.) | 4.21 | 1.33 | 4.27 | 2.21 | .10 | .92 |
| Exploration Time (sec.) | 3.31 | 1.29 | 3.49 | 2.18 | .32 | .75 |
| Number of refixations | .63 | .38 | .49 | .35 | -1.18 | .26 |

[a] paired t test

[b] two-tailed tests

Butterfly 64 (tilted and erect). The dyslexic group had significantly longer latencies, i.e., initial fixation time on the central standard, than did the normals, $t$ (14) = -2.14, $p$ = .05. On Butterfly 64, no significant group differences were found on the remaining measures: search time, exploration time, and number of refixations.

Table 5

The Differences between the Performance of Dyslexic and Control Children on the Butterfly Target with 64 in the FOS Array (Tilted and Erect)

| Eye Movement Measures | Dyslexics | | Controls | | $t^a$ df = 14 | $p^b$ |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | | |
| Latency (sec.) | .87 | .38 | .67 | .16 | -2.14 | .05 |
| Search Time (sec.) | 4.71 | 2.17 | 4.72 | 3.20 | < .01 | .99 |
| Exploration Time (sec.) | 3.84 | 2.12 | 4.04 | 3.17 | .21 | .84 |
| Number of refixations | .19 | .19 | .19 | .18 | < .01 | 1.00 |

[a] paired *t* tests

[b] two-tailed tests

Array Content (Butterfly 32, Butterfly 32 T vs. Ψ 32, Ψ T)*

Analyses of differences across groups on differential performances between the familiar and the unfamiliar arrays showed significantly greater search time and exploration time differences for the dyslexic children as compared to the control group, $t$ (14) = 2.58, $p$ = .02, and $t$ (14) = 2.40, $p$ = .03, respectively. The dyslexic boys spent a longer time searching for the Ψ in the unfamiliar arrays than the butterfly in the familiar arrays, while the control children spent a longer time looking for the butterfly than the Ψ. No significant

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*A second order dependent *t* test was analyzed to test the significance of differences between differences.

differences between groups were found for latency differences or for number of refixations. These results are presented in Table 6.

Table 6

The Difference between the Differential Scores for the Dyslexic and Control Children on the Familiar and Unfamiliar FOS Arrays (32 in Array, Tilted and Erect)

| Eye Movement Measures | Dyslexics | | Controls | | $t^a$ $df = 14$ | $p^b$ |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | | |
| Latency (sec.) | -.07[c] | .17 | .05 | .25 | 1.34 | .20 |
| Search Time (sec.) | -.98 | 1.77 | .70 | 2.52 | 2.58 | .02 |
| Exploration Time (sec.) | -.90 | 1.75 | .65 | 2.54 | 2.40 | .03 |
| Number of refixations | -.67 | 2.92 | -.33 | 2.66 | .45 | .66 |

[a] paired t tests

[b] two-tailed tests

[c] A negative number indicates that the value for the Ψ was greater than the butterfly, i.e., all Ψ values were subtracted from butterfly values. Therefore, a positive number indicates that the value was greater for the butterfly.

Across-group comparisons of performance on the familiar and on the unfamiliar arrays showed the following:

Familiar arrays (Butterfly 32 and Butterfly 32 T). As reported in Table 4, there were no significant differences between the groups on any of the eye movement measures for the familiar arrays.

Unfamiliar arrays (Ψ 32 and Ψ T). Table 7 indicates that the dyslexic group had significantly longer latencies than the control group on the unfamiliar arrays, $t$ (14) = -2.34, $p$ = .03. The dyslexic children also had longer search times ($t$ (14) = -3.21, $p$ = .006), and exploration times ($t$ (14) = -2.64, $p$ = .02) than the controls. A nonsignificant trend was indicated for the difference in number of refixations, $t$ (14) = -1.99, $p$ = .067.

Table 7

The Differences between the Performance of Dyslexic and
Control Children on the Ψ Target
with 32 in the FOS Array (Tilted and Erect)

| Eye Movement Measures | Dyslexics | | Controls | | $t^a$ df = 14 | $p^b$ |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | | |
| Latency (sec.) | .94 | .28 | .72 | .19 | -2.34 | .03 |
| Search Time (sec.) | 4.78 | 1.66 | 3.43 | .83 | -3.21 | .006 |
| Exploration Time (sec.) | 3.85 | 1.69 | 2.71 | .83 | -2.64 | .02 |
| Number of refixations | 5.40 | 3.48 | 3.73 | 2.12 | -1.99 | .07 |

[a] paired $t$ tests

[b] two-tailed tests

Array Orientation (Butterfly 32, Butterfly 64, and Ψ 32 vs. Butterfly 32 T, Butterfly 64 T, and Ψ T)*

Across group differences on the differential performances between

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*A second order dependent $t$ that was analyzed to test the significance of differences between differences.

the tilted and erect arrays, showed significantly longer search time and exploration time for the dyslexic children as compared to the control group, _t_ (14) = 2.18, _p_ = .05, and _t_ (14) = 2.20, _p_ = .04, respectively. The dyslexic children took slightly longer to explore and search the tilted array than the erect arrays, while the normal group spent a longer time searching the erect arrays than the tilted. An example of exploration patterns of the tilted arrays is shown for a dyslexic and control child in Appendix C, Figure W. There were no significant between-group differences in the latency or number of refixations on tilted and erect arrays (see Table 8).

Table 8

The Difference between the Differential Scores for the Dyslexic and Control Children on the Erect and Tilted FOS Arrays (Butterfly 32, Butterfly 64, Ψ 32 vs. Butterfly 32 T, Butterfly 64 T, Ψ T)

| Eye Movement Measures | Dyslexics | | Controls | | $t^a$ df = 14 | $p^b$ |
|---|---|---|---|---|---|---|
| | _M_ | _SD_ | _M_ | _SD_ | | |
| Latency (sec.) | .08[c] | .13 | .10 | .18 | .41 | .69 |
| Search Time (sec.) | -.01 | 1.95 | 1.81 | 2.14 | 2.18 | .05 |
| Exploration Time (sec.) | -.09 | 1.87 | 1.71 | 2.15 | 2.20 | .04 |
| Number of refixations | .20 | .40 | .40 | .38 | 1.54 | .14 |

[a] paired _t_ tests

[b] two-tailed tests

[c] A negative number indicates that the value for the tilted arrays was greater than that for the erect, i.e., all tilt values were sub-

tracted from the erect. Therefore, a positive number indicates that the value was larger for the erect array.

When the two groups were compared on the erect and tilted arrays separately, the following was revealed:

Erect arrays (Butterfly 32, Butterfly 64, and Ψ 32). Table 9 shows that latencies of the dyslexic group were significantly longer than those of the control group, $t$ (14) = -2.21, $p$ = .04. There were no differences between dyslexic and control children in search time, exploration time, or number of refixations.

Table 9

The Differences between the Performance of Dyslexic and Control Children on the Erect FOS Arrays (Butterfly and Ψ Targets)

| Eye Movement Measures | Dyslexics | | Controls | | $t^a$ df = 14 | $p^b$ |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | | |
| Latency (sec.) | .96 | .28 | .76 | .20 | -2.21 | .04 |
| Search Time (sec.) | 4.69 | 1.17 | 5.14 | 2.47 | .75 | .47 |
| Exploration Time (sec.) | 3.73 | 1.12 | 4.37 | 2.41 | 1.06 | .31 |
| Number of refixations | .63 | .38 | .61 | .26 | - .23 | .82 |

[a] paired $t$ tests

[b] two-tailed tests

Tilted arrays (Butterfly 32 T, Butterfly 64 T and Ψ T). When the array was tilted, dyslexic children showed longer latencies and search time than the controls, $t$ (14) = -2.62, $p$ = .02, and $t$ (14) = -2.17, p = .05, respectively. They also displayed a greater number of refixations (t (14) = -2.77, p = .01). The difference between control and dyslexic children in explorations time approached, but did not reach signficiance, t (14) = -1.83, p = .09 (see Table 10).

Table 10

The Difference between the Performance of Dyslexic and
Control Children on the Tilted FOS Arrays
(Butterfly and Ψ Targets)

| Eye Movement Measures | Dyslexics | | Controls | | t[a] df = 14 | p[b] |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | | |
| Latency (sec.) | .88 | .34 | .66 | .13 | -2.62 | .02 |
| Search Time (sec.) | 4.70 | 2.11 | 3.32 | 1.47 | -2.17 | .05 |
| Exploration Time (sec.) | 3.82 | 2.10 | 2.66 | 1.44 | -1.83 | .09 |
| Number of refixations | .43 | .35 | .21 | .27 | -2.77 | .01 |

[a] paired t tests

[b] two-tailed tests

Overview

As presented in Table 11, the only significant difference between the control and dyslexic groups on overall performance on the field of search task, was in the longer latencies of the dyslexic children, t (14) = -2.36, p = .03. Search time and exploration time were not significantly different. In addition, there was no significant difference in the percentage of initial leftward saccades. The number of refixations to the target approached a significant difference between groups, *t* (14) = -1.86, *p* = .08.

Table 11

The Differences between the Performance of Dyslexic and Control Children on All Field of Search Arrays

| Eye Movement Measures | Dyslexics *M* | Dyslexics *SD* | Controls *M* | Controls *SD* | *t*[a] *df* = 14 | *p*[b] |
|---|---|---|---|---|---|---|
| Latency (sec.) | .91 | .30 | .72 | .14 | -2.36 | .03 |
| Search Time (sec.) | 4.59 | 1.32 | 4.07 | 1.46 | -1.39 | .19 |
| Exploration Time (sec.) | 3.69 | 1.30 | 3.34 | 1.41 | - .88 | .39 |
| Number of refixations | 10.33 | 5.63 | 7.80 | 3.34 | -1.86 | .08 |
| Percentage of Left initial gaze | 56.9 | 16.2 | 51.0 | 18.0 | - .77 | .45 |

[a] paired *t* tests

[b] two-tailed tests

In general, both groups explored approximately .8 seconds longer for answers in the left field versus answers in the right field (see Table 12), but these within group differences were not significant. There were no differences between the dyslexic and control children in their exploration time for answers on the left or for answers on the right.

Table 12

Within and Between-Group Differences in Exploration Time When Answers Are Located in the Left vs. Right Fields on the FOS Arrays

| Location of Answer in Visual Field | Dyslexics | | Controls | | Between Groups | |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | $t^a$ | $p^b$ |
| Right | 3.28 | .74 | 2.96 | 1.5 | -.76 | .46 |
| Left | 4.09 | 2.29 | 3.72 | 1.8 | -.68 | .51 |
| Within Groups $t^a$ | 1.52 | | 1.44 | | | |
| $p^b$ | .15 | | .17 | | | |

[a] paired *t* tests

[b] two-tailed tests

There was no significant difference in latency whether the subject elected to move his eyes to the left or the right in the dyslexic and control groups (see Table 13).

Table 13

Within and Between Group Differences

in Rightward and Leftward Latencies on the FOS Arrays

| Direction of Eye Movement | Latency (sec.) | | | | Between Groups | |
|---|---|---|---|---|---|---|
| | Dyslexics | | Controls | | $t^a$ | $p^b$ |
| | *M* | *SD* | *M* | *SD* | | |
| Right | .85 | .30 | .80 | .20 | -1.61 | $<.10$ |
| Left | .91 | .37 | .76 | .15 | -1.56 | $<.10$ |
| Within Groups $t^a$ | -.59 | | -.70 | | | |
| Within Groups $p^b$ | $>.50$ | | .50 | | | |

[a] paired *t* tests

[b] two-tailed tests

The pattern of significant differences in task performance was examined for each group. No monotonic pattern of change was observed that would suggest a relationship between group differences in performance and order of task presentation. Therefore, it is felt that the performance differences reported represent contrasts which are not due to order of stimulus conditions.

### Summary

*Array density*. There were no significant differences between groups with a more crowded array than a less dense one in any of the eye movement measures. However, the dyslexic children had significantly longer latencies than the controls on the Butterfly 64 but not on the Butterfly 32 arrays.

Array content. The dyslexic children had significantly longer search times and exploration times than the controls, when the array was unfamiliar than when it was familiar. The familiar array showed no across-group differences, while the unfamiliar array indicated group differences in latency, search time, exploration time and a non-siginificant trend in the number of refixations.

Array orientation. The dyslexic children had significantly longer search times and exploration times than the control group when the array was tilted than when it was erect. The only significant difference between the control and dyslexic boys for the erect arrays, was for latency, whereas, there were across group differences on search time, latency, and number of refixations on the tilted arrays.

## Modified Valcuikas Embedded Figures

The dyslexic children made significantly more errors than the controls on the Modified Valcuikas Embedded Figures, but few differences in the eye movement measures were obtained. For example, as shown in Table 14 the groups did not differ significantly in their total search time (time spent looking for the embedded figure) nor did they differ in the percentages of total search time spent in each answer box and in the simple figure box. As can be seen in Table 15, both groups spent a greater percentage of time scanning the simple figure box than any of the answer boxes. Both dyslexic and normal children spent the most time exploring the upper left answer box and the least time in the lower left box.

Table 14

Difference between Dyslexic and Control Children in Search time and Number of Eye Movement Shifts on the MEFT

| Eye Movement Measures | Dyslexics | | Controls | | $t^a$ df = 14 | $p^b$ |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | | |
| Search time - Total (sec.) | 22.1 | 4.2 | 20.7 | 4.0 | -1.02 | .32 |
| Search time - Right (sec.) | 24.9 | 4.2 | 23.6 | 5.5 | - .72 | .48 |
| Search time - Left (sec.) | 19.3 | 6.2 | 17.7 | 4.8 | - .94 | .36 |
| Number of Shifts | 20.0 | 4.7 | 18.4 | 4.8 | - .83 | .42 |
| Number of Shifts to Simple Figure | 6.6 | 1.9 | 6.3 | 1.8 | - .47 | .65 |

[a] paired *t* tests

[b] two-tailed tests

Table 15

Difference in Percentage of Total Search Time Spent

in Answer Boxes and Simple Figure

for Dyslexic and Control Children on the MEFT

| Eye Movement Measures | Percentage of Total Search Time | | | | | |
|---|---|---|---|---|---|---|
| | Dyslexics | | Controls | | $t^a$ df = 14 | $p^b$ |
| | M | SD | M | SD | | |
| Box | | | | | | |
| Upper Right | 18.0 | 4.0 | 17.7 | 3.5 | - .20 | .84 |
| Upper Left | 25.0 | 4.9 | 24.4 | 6.2 | - .33 | .75 |
| Lower Left | 16.4 | 6.0 | 16.6 | 4.1 | .11 | .91 |
| Lower Right | 12.5 | 4.5 | 13.5 | 3.0 | .71 | .49 |
| Simple Figure | 28.1 | 6.4 | 27.9 | 4.9 | - .07 | .94 |

[a] paired t tests

[b] two-tailed tests

Therefore, as seen in Table 16, both groups spent a significantly larger percentage of total search time scanning the left field than the right (Dyslexics: $t$ (14) = 3.67, $p$ = .003; Controls: $t$ (14) = 3.27, $p$ = .006). There were no significant between-group differences for the time spent scanning the right-field or for exploring the left-field.

Table 16

Within and Between Group Comparisons of Percentages of Total Search Time Spent in Left and Right Fields on the MEFT

| Visual Field | Percentage of Total Search Time | | | | Between Groups | |
|---|---|---|---|---|---|---|
| | Dyslexics | | Controls | | *t*[a] *df* = 14 | *p*[b] |
| | *M* | *SD* | *M* | *SD* | | |
| Right Field | 30.5 | 5.9 | 31.2 | 5.0 | .32 | .75 |
| Left Field | 41.4 | 7.2 | 41.0 | 7.3 | - .20 | .84 |
| Within Groups *t*[a] | 3.67 | | 3.27 | | | |
| Within Groups *p*[b] | .003 | | .006 | | | |

[a] paired *t* tests

[b] two-tailed tests

There were no significant differences between dyslexic and control children in the time required to find the correct answer, when the figure was hidden in a left-field or a right-field box (see Table 14).

As shown in Table 14, the groups did not differ significantly in the total number of shifts from one box to another or in the number of shifts made to reexamine the simple figure.

The majority of the initial saccades in both groups were in the horizontal direction and most of these were leftward; there were no significant differences between groups on these laterality measures. The dyslexic children made significantly more rightward initial saccades than the controls, $t$ (14) = -2.28, $p$ = .04. Although the controls initially scanned upward more frequently than the dyslexic group, this difference only approached significance, t (14) = 1.98, p = .07. The data on direction of initial saccades is presented in Table 17.

Table 17

Direction of Initial Saccade of the Dyslexic and Control Children on the MEFT

| Direction of Saccade | Dyslexic M | Dyslexic SD | Controls M | Controls SD | $t^a$ df = 14 | $p^b$ |
|---|---|---|---|---|---|---|
| Right | 1.47 | 2.03 | .20 | .41 | -2.28 | .04 |
| Left | 6.93 | 1.75 | 6.87 | 2.67 | - .08 | .93 |
| Horizontal | 8.40 | 1.35 | 7.07 | 2.66 | -1.98 | .07 |
| Up | 1.60 | 1.35 | 2.93 | 2.66 | 1.98 | .07 |

[a] paired t tests

[b] two-tailed tests

Summary for Modified Valcuikas Embedded Figures

The dyslexic and control groups did not significantly differ in search time, number of shifts, the percentage of the shifts to the simple figure, and the percentage of time spent in each of the five boxes. There were within group differences that were consistent for both dyslexic and control groups. For example, both groups spent more time exploring the answer boxes on the left than the right (especially the upper left box). Both groups spent about a third of their total search time exploring the simple figure box.

Both dyslexic children and controls initially scanned to the left. The former group showed significantly more initial saccades to the right than the latter, whereas the controls showed more upward initial eye movements than the dyslexic children (non-significant trend).

## Elkind Triangle

Table 18 shows that the dyslexic children did not differ significantly from normals in their regard of the Elkind Triangle, by displaying either a "reading" left to right scan, or a clockwise or counterclockwise triangular scan. Their search patterns were not significantly more random than controls. An example of a triangular scanning pattern and a "reading" left to right scan is shown in Appendix C , Figure Y .

Table 18

Scanning of the Elkind Triangle

by Dyslexic and Control Groups

| Scanning Pattern | Number of Dyslexics[c] | Number of Controls[c] | $z^a$ | $p^b$ |
|---|---|---|---|---|
| Reading scan | 4 | 6 | 1.0 | .16 |
| Random search | 8 | 5 | 1.34 | .09 |
| Triangle pattern | 13 | 11 | .82 | .21 |
| clockwise | 4 | 4 | .00 | .50 |
| counterclockwise | 9 | 8 | .30 | .38 |

[a] test for differences of correlated proportions

[b] one-tailed

[c] $n$ = 15

## Reading

The following measures were analyzed: number of regressions and fixations, reading time, number of corrective movements, the dwell time at the beginning of a line, and the number of regressed or jumped lines. Reading eye movement patterns for a dyslexic and a control child are graphically presented in Appendix C , Figure X .

### Regressions and Fixations

The dyslexic children displayed significantly more fixations and regressions than the control group during reading, $\underline{t}$ (12)* = -4.23, $\underline{p}$ = .001; $\underline{t}$ (12) = -3.45, $\underline{p}$ = .005, respectively. This disparity between groups, as presented in Table 20, was noticeable at the pre-primer reading level as well as at the more difficult reading levels. Both dyslexic and control groups made more fixations as the line of text became longer and more difficult, yet spanned progressively more letters during one fixation.

### Other Measures

The reading time (in seconds) was significantly slower for the dyslexic group than for the control children on both reading levels (subtest 1: $\underline{t}$ (14) = -4.63, $\underline{p}$ < .001; subtest 2: $\underline{t}$ (14) = -4.90, $\underline{p}$ < .001). The incremental difference in the reading time with more difficult material (subtest 2) does not reach significance, both groups showing a slower reading time for the more difficult passages ($\underline{t}$ (14) = -1.42, p < .10). Reading time differences are reported in Table 20.

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*Two dyslexic children did not complete the reading material within the alloted time and therefore, could not be counted in this analysis, i.e., $\underline{df}$ = 12.

Table 19

Reading: Number of Fixations and Regressions

| Characteristics of the Reading Material | | | | Number of Fixations | | | | | | | Number of Regressions | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Grade Level | Number of letters | Number of words | Dyslexics | | Controls | | *t*[a] | *df* | *p*[b] | Dyslexics | | Controls | | *t*[a] | *df* | *p*[b] |
| | | | | *M* | *SD* | *M* | *SD* | | | | *M* | *SD* | *M* | *SD* | | | |
| SUBTEST I | | | | | | | | | | | | | | | | | |
| Line 1 | preprimer | 17 | 5 | 8.0 | 2.6 | 5.9 | 2.9 | -2.52 | 14 | .02 | 1.5 | 1.3 | .5 | 1.2 | -2.96 | 14 | .01 |
| Line 2 | 1 | 21 | 4 | 9.1 | 3.8 | 6.1 | 2.7 | -3.12 | 14 | .008 | 1.8 | 1.6 | 1.1 | 1.5 | -1.85 | 14 | .08 |
| Line 3 | 3 | 21 | 6 | 10.5 | 3.2 | 6.1 | 1.9 | -3.18 | 13 | .002 | 2.4 | 1.6 | .8 | .9 | -2.96 | 13 | .01 |
| Line 4 | 5 | 23 | 5 | 10.8 | 4.8 | 7.9 | 3.3 | -1.82 | 13 | .09 | 2.9 | 2.6 | 1.6 | 1.6 | -1.52 | 13 | .15 |
| SUBTEST II | | | | | | | | | | | | | | | | | |
| Line 5 | 2 | 35 | 9 | 13.9 | 4.7 | 9.3 | 2.7 | -3.32 | 14 | .005 | 2.7 | 2.4 | 1.2 | .9 | -2.17 | 14 | .05 |
| Line 6 | 4 | 34 | 7 | 12.7 | 5.8 | 8.7 | 3.0 | -3.07 | 14 | .008 | 3.2 | 2.9 | 1.6 | 1.3 | -2.35 | 14 | .03 |
| Line 7 | 6 | 36 | 6 | 12.7 | 4.0 | 9.4 | 2.3 | -2.57 | 13 | .02 | 2.9 | 2.1 | 2.0 | 1.5 | -1.27 | 13 | .23 |
| Line 8 | 8 | 36 | 6 | 13.1 | 4.3 | 8.9 | 2.5 | -3.15 | 12 | .008 | 2.9 | 1.3 | 1.9 | 1.6 | -1.70 | 12 | .11 |
| TOTAL | | | | 89.0 | 19.1 | 60.6 | 14.2 | -4.23 | 12 | .001 | 18.9 | 8.6 | 9.6 | 5.3 | -3.45 | 12 | .005 |

[a] paired *t* tests

[b] two-tailed tests

The dyslexic children did not return to a previously read line significantly more often than the control group. However, they jumped ahead significantly more often than the control children to a succeeding line, *t* (14) = -2.26, *p* = .04 (see Table 20).

There were no significant differences between groups in the number of corrective movements made at the beginning of a line to compensate for over- or underestimation of the location of the initial word.

The dyslexic group delayed for a significantly longer period of time before proceeding to scan the text than the control group, *t* (12) = -4.07, *p* = .002 (see Table 21).

Table 20

Other Reading Eye Movement Measures

| Eye Movement Measures | Dyslexics | | Controls | | $t^a$ | *df* | $p^b$ |
|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | | | |
| Corrective movements | 7.47 | 3.00 | 7.47 | 2.20 | .0 | 14 | 1.00 |
| Regressed lines | .73 | .88 | .73 | 1.58 | .0 | 14 | 1.00 |
| Jumped lines | .67 | .82 | .13 | .35 | -2.26 | 14 | .04 |
| Dwell at the beginning of a line | .89 | .24 | .56 | .16 | -4.07 | 12 | .002 |
| Reading time: subtest I (sec.) | 19.8 | 9.6 | 8.9 | 3.4 | -4.63 | 14 | <.001 |
| Reading time: subtest II (sec.) | 27.6 | 10.2 | 12.6 | 3.9 | -4.90 | 14 | <.001 |

[a] paired *t* tests

[b] two-tailed tests

## Summary

The dyslexic group had significantly more fixations and regressions, and significantly slower reading speed than the control group. They jumped significantly more lines and dwelled longer at the beginning of the line than did the control children. The dyslexic children did not show significantly more corrective movements on the return sweep.

# DISCUSSION

The experimental work herein reported represents an attempt to resolve some of the controversy regarding the visuospatial competence of dyslexic children. Although the data clearly indicate that dyslexic children perform less efficiently than normals on a variety of visuospatial tasks, it by no means follows that they suffer a pervasive visual perceptual deficit. There are alternative explanations. For example, since visual perception is not a unitary phenomenon, it is conceivable that the specific nature of a task, or the specific response measure employed, either of which can determine the mode of perceptive-cognitive processing utilized (Patterson & Bradshaw, 1975), is responsible for the observed deficits.

The dyslexic group examined in this study showed deficient performance on those tasks that require a more analytical or serial-type of cognitive processing, thus, implying that left-hemisphere functioning may be impaired in dyslexics. Indeed, striking parallels can be drawn between the performance of dyslexics recorded in the present study and certain functional characteristics of aphasic adults. One explanation for this similarity, is that all children in the experimental group have neuropsychological profiles indicating either receptive or expressive language difficulties.

Furthermore, the dyslexic children in this study performed significantly worse than the normals on tasks with high information load as do younger children or brain-damaged adults.

The objective of this discussion is to elaborate on the above points, and to evaluate how the data obtained relate to the following questions:

1. Is a pervasive visuospatial deficit associated with dyslexia?

2. Do dyslexic children perform less well than normals in a field of search task when the elements are familiar as compared with when they are unfamiliar? (Array content)

3. Do dyslexics perform less well than normals in a field of search task when there are relatively few elements in the array? or when the array is crowded? (Array density)

4. Do the dyslexic children have more difficulty than the control group in searching for a rotated stimulus? (Array orientation)

5. To what extent, can the dyslexic performance on the above tasks be accounted for by motoric efficiency or habit?

6. In light of the above, how can the eye movement patterns during reading of dyslexic children be interpreted?

## Perceptual Deficit Hypothesis

As hypothesized, the notion that a general ubiquitous visuoperceptive deficit is associated with dyslexia is not supported by the results of this investigation (Hypothesis 1). A set of 11 visual perceptual tests was administered to reading-disabled and control children in the pilot study (see Appendix A). This was in addition to the four tests presently reported with a different sample of children (a total of 12 different tests). Examination of the error scores on these perceptual tests showed the performance of the dyslexic children to be significantly inferior to normal readers only on the embedded figures tasks, and consistently so only on the more difficult Modified Valcuikas Embedded Figures (MEFT) (Hypothesis 2). The fact that the Performance IQ of the dyslexic children in this study was significantly higher than the controls' could signify that dyslexic children have certain superior visuospatial abilities (cf. Symmes & Rapoport, 1972). At least, the higher Performance IQ emphasizes the significance of low EFT scores of the dyslexic children.

One explanation is that the MEFT is a uniquely different visual perceptual test, possibly because it is a more complex perceptual task, or that it is a detection test rather than a discrimination test (which is often used to evaluate dyslexic visuospatial abilities), or that it requires analytical rather than holistic processing.

A direct parallel can be drawn between the visuoperceptive profile of dyslexic children found in the present study and that of adult aphasics. Unilateral brain-damaged adults have been evaluated on tasks similar to those used in the pilot and the present studies. For example, DeRenzi and Spinnler (1966) and DeRenzi, Scotti, and Spinnler (1969) reported that the Street Completion test (Street, 1931) and the Ghent Overlapping Figures

(Ghent, 1956) were performed significantly worse by right brain-damaged than left brain-damaged patients. Kimura (1963) also reported impaired performance in right brain-damaged patients compared to left brain-damaged subjects on a recognition task of overlapping nonsense figures tachistoscopically presented. However, no differences were found between right and left brain-damaged subjects on an overlapping familiar figures recognition test similar to the Ghent test. Identification of Mooney Closure faces, analogous to the Street, has been found to be impaired in right temporal lobectomy patients (Lansdell, 1961, cited by Kimura, 1963).

DeRenzi, Faglioni and Spinnler (1968) noted that right brain-damaged patients showed difficulty on a facial recognition test, where a face in profile had to be matched to one of ten faces in front view. (Right brain/left visual field superiority for facial recognition was also confirmed in normals (Rizzolatti, Umilta & Berlucchi, 1971).) The disconnected right brain was also reported to be superior to the left in facial recognition (Levy, Trevarthen,& Sperry, 1972).

The right hemisphere group performed significantly worse than the left hemisphere group on the Gollin incomplete figures test, and there were no significant performance differences between the left brain-damaged group and controls (Warrington & James, 1967).

Costa (Costa, 1976; Costa, Vaughan, Horwitz & Ritter, 1969) found that patients with right cerebral lesions performed less well than left brain-damaged patients on the Ravens Coloured Progressive Matrices. Basso, DeRenzi, Faglioni, Scotti, and Spinnler (1973), using a timed version of this test, found that although right and left brain-damaged patients made more errors than controls, left brain-damaged performed slightly but not significantly better than right brain-damaged patients. However, within the left brain-damaged group, dysphasic patients perform worse than the non-dysphasic individuals (Costa et al., 1969; Basso et al., 1973).

Of the tasks used in this study, the only one which has revealed impaired performance by left brain-damaged patients is the Gottschalt Embedded Figures Test* (Teuber & Weinstein, 1949; Russo & Vignolo, 1967). Within the left brain-damaged group, the aphasics were found to make significantly more errors than non-aphasics (Russo & Vignolo, 1967). Therefore, both dyslexic children and adult aphasics have particular difficulty with the embedded figures test that is inconsistent with their overall visual perceptive capacities.

It may be helpful in arriving at a general understanding of developmental dyslexia to examine some of the hypotheses concerning the disturbances thought to underly poor performance on the embedded figures in the adult aphasics.

In 1917, Poppelreuter maintained that the failure to isolate a figure from its background reflects a specific visuoperceptual deficit usually associated with visual field defects. However, both Teuber, Battersby, and Bender (1951) and Russo and Vignolo (1967) found that impairment on the hidden figures tests was independent of the presence of visual field disturbances.

Goldstein (1927) had suggested that poor performance on the embedded

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*The task used in the present study is a derivative of the Gottschalt; It requires the subject to choose in which of four boxes the figure is hidden. The Gottschalt does not provide a choice.

figures test (EFT) was associated with an impairment of abstract attitude or general intelligence often associated with brain-damage. This impairment manifested itself in the inability to shift from one aspect of a set to another or in discriminating any unit of perception, thought or language from its context (Goldstein, 1948). However, when general intelligence was controlled for, Teuber and Weinstein (1956) noted that aphasics still showed significant impairment on the embedded figures test. They concluded that aphasia must be associated with a deficit that transcends language but is not equivalent to intellectual deterioration. Therefore, they deduced that:

> an important aspect of aphasia is defective organization or selection of material (linguistic as well as non-linguistic) a disturbance manifested only partly in the obvious difficulties with linguistic reception or expression. (p. 376).

DeRenzi and Faglioni (1965) suggested that performance on "non-verbal" tasks such as the EFT may be facilitated by the mediation of covert verbalization. The disturbance of "inner language" may impair aphasic performance.

It is conceivable in a task as complicated as the EFT that disturbance of any one of several composite skills may contribute to poor performance. For example, Russo and Vignolo (1967) observed that although aphasics performed worse than any other group, right brain-damaged patients did worse than non-aphasic left brain-damaged. They contended that poor performance could not be explained only in terms of language impairment but also must involve a visuospatial disorientation factor. Both of these factors would then contribute to the defective performance of aphasics.

In reviewing the embedded figures literature, Rudel (1978) suggested that the left hemisphere serves some critical non-language function similar to the "g" factor of intelligence, or some "executive" function that guides or assists the right hemisphere. She also proposed (like Russo & Vignolo) that the left hemisphere may provide the subvocal language used as a vehicle in the performance of "non-language" tasks.

After performing numerous studies testing the validity of the perceptual deficit hypothesis of dyslexia, Vellutino (1977) concluded that developmental dyslexia could be interpreted more accurately at the cognitive level. Therefore, perceptual deficits, if they occur, could be explained as secondary manifestations of difficulties in verbal mediation. With two different populations, adult aphasics and developmental dyslexics, similar conclusions were drawn about the underlying influence of language functioning on the performance of "non-verbal" tasks.

Therefore, it seems that the separation of hemispheric functioning into a categorical visuospatial/linguistic dichotomy may not suffice to explain poor performance of language-impaired subjects on visual-spatial tasks. Rather, it may be easier to employ the holistic/analytical model similar to that often cited by Levy and others (Levy-Agresti & Sperry, 1968; Levy, 1969; Bever, 1976).

In communication theoretic terms, the EFT consists of a figure or a signal hidden in a noisy background. The analysis that is required to retrieve this signal from the noise may be impaired in some clinical populations. For example, Diamond, Epstein, and Bender (1969) noted that aphasics often display an inability to abstract the meaning of a word when it appears in a different background, e.g., verbal puns. They suggested that this difficulty in analysis may be analogous, in the sphere of visual perception, to the failure of these same patients to perform adequately on the EFT, where there are also figure-ground ambiguities. It might be explained that in both verbal puns and the EFT, the signal-to-noise ratio is high and therefore, the information load is taxing to the limited analytic capacities of the impaired left hemisphere.

In summary, the perceptual deficit hypothesis is not supported by the present study. Dyslexic children and adult aphasics perform similarly on visuoperceptual tasks. Although they do not show impairment on most tests of visual perceptual functioning, both groups have difficulty on the EFT. The implications of these findings are: (a) that there may be left hemisphere involvement in dyslexia, although the evidence is circumstantial, (b) left hemisphere damage can cause impairment of performance on non-verbal tasks. The inability of both the adult aphasics and the dyslexic children to successfully perform a "non-verbal" task suggests that either the EFT is mediated by covert verbalization or that the left hemisphere may not be only linguistic in function. It may be more accurate to describe left hemisphere functions in terms of mediating analytical functions, including language. This analytical description of left hemisphere functioning may explain impaired performance in figure-ground separation or in other tasks where the signal-to-noise ratio is high. Test sampling perceptual discrimination and synthesis may not be mediated by the left hemisphere unless accurate feature analysis or verbal coding is required; on tasks which do not require such analysis, dyslexic and aphasic individuals will probably perform adequately.

## The Array Content Effect

The hypothesis that dyslexic children would have more difficulty than controls in searching for a familiar "verbalizable" figure than an unfamiliar meaningless one (Hypothesis 2), was not supported by this study. This hypothesis was based on the notion that underlying dyslexia is a disturbance of left hemisphere functioning and that left brain-damaged have more difficulty than right brain-damaged on matching familiar figures (DeRenzi, et al., 1969) (There is some evidence that right brain-damaged have more difficulty than left with unfamiliar figures (Kimura, 1963).) However, the simplistic dichotomy specifying the distinction of left brain superiority for familiar figures and right brain superiority for perception of unfamiliar figures, may not be valid. For example, split-brain patients showed a left-field superiority for both perception of unfamiliar and familiar forms. This left-field advantage was dependent on whether the response was manual (left-field preference) or vocal (right-field preference) (Levy et al., 1972).

The dyslexic children showed more difficulty than the controls in finding the matching Ψ in an unfamiliar symbol array, then the butterfly in the familiar arrays. Since the discrepancy is particularly noticeable in the search time-exploration time measure, it may be informative to examine what this measure reflects and how it can be altered.

Neisser (1963) suggested that eye movements provide a measure of decision time without the contamination of manual or vocal reaction-time. This measure of time required to execute and complete a cognitive operation is the search time. The complexity of a stimulus or an array is positively correlated with search time (Locher and Nodine, 1973, 1974). Subjects take longer to search for unfamiliar symbols than familiar ones (Neisser & Lazar, 1964). Measures of search time are particularly sensitive to neurological dysfunction in children and adults (Teuber, Battersby, & Bender, 1949; Chèdru & LeBlanc, 1972; Chēdru, LeBlanc, & Lhermitte, 1973). Thus, search time may be altered by changes in cognitive functioning.

The dyslexic children in this study did not show an overall slowing of their search time on all the field of search tasks; rather, they showed a prolongation of search time only on specific arrays. It is important to question what is unique about those particular arrays, specifically the unfamiliar arrays, that makes performance more difficult for the dyslexic children than the controls.

Four possible explanations, which may be logically distinct but may not be mutually exclusive in nature, will be considered:

1. The Ψ array is more complex than the butterfly arrays.
2. By definition, the elements in the Ψ array are less familiar.
3. The symbols in the Ψ array are not easily verbalizable or linguistically coded.
4. For one or all of the above reasons, serial feature analysis rather than parallel holistic processing is required for performance.

## Complexity

Stimulus complexity has been a favorite topic for perceptual-learning and information theorists. In informational terms, complexity of a shape or pattern is considered to be inversely related to the quantifiable "uncertainty" of the stimulus (Allusi, 1960). Information theorists often define the complexity of a visual stimulus operationally by the number of edges or points in a randomly generated shape (Vanderplas & Garvin, 1959; Attneave, 1954), or by the number of cells in a fixed stimulus divided into a checkerboard (metric figure) (Hershenson, Kessen & Munzinger, 1967). "Figural goodness," as defined by the regularity, symmetry, and continuity of the stimulus, was considered to be the definition of simplicity for the Gestaltists (Law of Präegnanz) (Koffka, 1935); complexity would involve the opposite characteristics.

It does not seem by most of the above criteria that the Ψ and its array would be considered "complex". However, this array does provide greater "stimulus uncertainty" than the butterfly arrays and it is the relative complexity of the arrays which should be considered.

Studies have examined the tachistoscopic recognition of complex shapes in normal adults with inconsistent results. Fontenot (1973) reported that the recognition of complex figures (Vanderplas, 12 points) was superior in the left visual field, whereas there were no visual field differences in recognition of low complexity figures (6 points). A later study by Krynicki (1975) indicated that although 6, 8 and 12 point Vanderplas figures evoke no significant difference in visual field recognition, 16 point shapes were recognized more accurately in the right visual field. Krynicki had equated the figures for the ease of verbally labelling them.

Bisiach and Faglioni (1974), evaluating brain-damaged patients, reported results consistent with Krynicki's. Left brain-damaged subjects were more impaired than right brain-damaged in the recognition of random shapes (4, 6, 16, and 24 points) from a simultaneously presented multiple-choice display. The difference between groups was even more pronounced for the more complex shapes (16 and 24 points). Hence, recognition or matching of complex shapes may require left hemisphere integrity. Difficulty in this ability may be reflected in prolonged search times. The $\Psi$ array may be sufficiently complex to warrant left hemisphere mediation, and as a corollary, that dysfunction in left hemisphere processing may result in inadequate performance.

### Familiarity

Familiarity is a term used to describe the amount of experience the perceiver has had with the stimulus. The degree of familiarity is relative to the observer and not the stimulus (Haber & Hershenson, 1973). For example, letters are more familiar to reading children than to their non-reading peers.

The speed of visual processing varies directly with familiarity (Wickens, 1974). This relationship may be determined, at least in part, by the availability of verbal labels or that readily codable stimuli may be processed in parallel (Gould & Dill, 1969), whereas unfamiliar stimuli may be processed serially. In order to better assess the significance of the familiarity of a stimulus, it would be of value to examine the contributions of verbal codability and serial/parallel analysis.

### Verbal Coding

Glanzer and Clark (1964) suggested that the accuracy with which a subject can recognize shapes, can be predicted from the length of verbalization which the subject uses to label those shapes. Their verbal-loop hypothesis states that the difference in the recognizability between stimuli may be determined by the covert verbalization in the encoding process. If a long verbalization is necessary than a prolonged period of time may be required (latency may reflect this encoding time). Clark (1965) examined the correlation between form association, verbal codability (as measured in a postexamination questionnaire) and figure complexity (Vanderplas figures, 4, 6, 16, and 24 points). Verbal coding was positively related to the recognition accuracy for complex figures only. He suggested that complex forms were remembered by making associations to them with verbal coding, but that a simple figure was stored as an uncoded image of the entire shape. However, there is some evidence that verbalization increases short-term recall and recognition of even simple familiar figures (Kurtz & Hovland, 1953).

Common verbalizable forms and complex forms are said to be recognized more accurately in the right visual field of normal children and adults (Turner & Miller, 1975). On a paired-associate learning test, aphasics were found to have difficulty in recognition of both meaningful and meaningless figures (Boller & DeRenzi, 1967). Boller and DeRenzi (1967) concluded that wherever possible, patients try to transform meaningless figures into meaningful ones. Aphasics may fail to learn meaningless figures because appropriate names may not be available to them and therefore, they are unable to perform the requisite transformations. If they are successful in carrying out a transformation, the information may not be in a form that can easily be retrieved. Bisiach and Faglioni (1974) suggested that assigning meaningless shapes "verbal" labels at the preverbal level may "stress the more informative features of the shape which would result in a lesser memory load" (p. 107). It seems that complex figures can not be stored effectively with visual imagery alone, but must be coupled with some covert "verbal" coding.

Clinton-Everest (1976) hypothesized that the visuoperceptive difficulty that some dyslexics show, arises:

> not from an inability to extract and store visual features, but from a linguistic defect that precludes suitable verbal codes being selected to supplement information that is held visually. (p. 491).

It is contended that a linguistic defect may alter the ability to extract and store information; that language provides a tool to perform skills that are not overtly verbal in nature (Luria, 1973). According to Luria (summarizing Pavlov):

> speech, the basic means of communication, becomes also a means of deeper analysis and synthesis of reality and, more fundamentally important, 'a higher regulator of behavior' (p. 25).

It seems feasible that the Ψ required both visual and verbal coding for short-term storage. Due to the limited linguistic abilities of this dyslexic population, the verbal coding postulated to be a necessary supplement to the visual coding, may have been (a) totally unsuccessful, (b) successful but not specific enough to be adequate or efficient, or (c) successful but requiring a longer period of time to accomplish. Any difficulty in the encoding of the stimulus may contribute to a prolonged latency.

The principal reason for extracting latency from the search time (exploration time) was to determine whether after the initial prolonged latency period, did it still take longer for the subject to find the matching target. The observation that dyslexic children explored longer for the Ψ than the butterfly, suggests that perhaps the dyslexic children had difficulty in matching the standard. This difficulty may have occurred because the initial coding of the standard was not precise or exclusive enough to be completely adequate, and therefore, may have resulted in a longer exploration time composed of more references back to the central Ψ than they needed for the butterfly (and more than normals).

For example, suppose a normal child after viewing the Ψ thought he was required to locate a "pitchfork". This would certainly be a much more specific and succinct code (if a verbal code is necessary) than the code of a child with limited vocabulary and verbal skills, who might search for a "line with two arms coming out." The latter code may match to symbols other than the Ψ, e.g., a cross. It might be informative to assess what stimuli dyslexic children studied before refixating to the standard. This may have provided some insight into what visual or verbal code they used and what common distinctive features they searched for.

## Feature Analysis

Visual feature models describe perception as an analytical process. Familiar objects will have distinctive features that are easily discriminated (Gibson, 1969) and thus, with outstanding physical features, the object will be located rapidly (Broadbent, 1971). However, more complicated or unfamiliar targets may necessitate sequential or serial processing for recognition, e.g., letter recognition for the inexperienced reader. With perceptual learning, the ability to discern distinctive features improves (Gibson et al., 1962). Features are serially analyzed and compiled until adequate information is available for proper identification (Hebb, 1949). In a field of search task, the subject must sample a target until a feature is found that does not match the standard and then, the search is continued to another target, until he finds one where all features are identical. Obviously, the greater the similarity of the elements in the array, and the less experience the subject has with the array symbols, the greater the exhaustiveness of the feature processing (Neisser, 1967), and hence, the longer the search time. Gould and Schaffer (1967) reported that when subjects were required to determine the number of patterns that were similar to a central standard, their oculographic patterns indicated that the subject compared the features of the patterns analytically rather than undertaking a more holistic processing strategy.

Proficient readers scan a reading display in a similar manner. They selectively attend to the informative features and ignore those which are irrelevant or redundant (Nodine & Lang, 1971). Kagan (1965) noted that visually reflective and analytical children, as measured by their performance on certain visual perceptive tasks (Matching Familiar Figures), made fewer reading errors.

Mackworth, Grandstaff, and Pribram (1973) observed that speech-impaired children (most either deaf or slightly retarded) do not attend to novel informative stimuli. This suggests that a language-impairment may be correlated with the ability to attend selectively to informative features. It is possible that some dyslexic children may incompletely sample a display for the necessary informative features, because they cannot isolate these features. This limits their ability to recognize that figures are identical, and requires repetitive examinations to decide their equivalence. A normal child, knowing the informative attributes, may selectively search for them.

In sum, it is possible that each of the models discussed in this section, merely relate to different aspects of the same cognitive dysfunction: viz, the Ψ is a complex, unfamiliar symbol as were all elements in that array. The dyslexic children may have difficulty encoding the standard stimulus in a way that could be useful. When searching for the match of an unfamiliar figure they may be operating with inadequate codes bases on features which are neither clear nor specific. This may result in their reevaluation of their initial conception of the standard more often than the controls, which also contributes to their longer post-latency search time (exploration time).

## The Array Density Effect

It was postulated that peripheral information overload would result in a "centering" phenomenon (Hypothesis 3). Analysis of the array density data by a "difference of differences" t test failed to show significant group differences over the range of densities used in this study.

It is also clear that the information load is not only dependent on the number of elements in the array but also on the type of element. On testing for group differences, the only array-type that does not produce a significantly longer latency for dyslexic children than for controls is the Butterfly 32. Because this array is composed of familiar objects with relatively few elements it would be expected that it would generate the least informational load of any of the field of search tasks. Furthermore, since only two different array densities were employed, it is likely that neither the upper nor the lower limits of density effects were examined. Therefore, it is important to note in this limited sampling of array densities, whether the more dense array results in a greater difference between groups. This, in fact, was the case. The dyslexic children had longer latencies than the normal controls on the crowded field of search of 64 elements but not in the relatively less dense array of 32 elements.

In order to interpret the latency differences between groups on the crowded array as well as the other arrays, it is essential to consider the components of the latency measure and the factors that cause it to vary.

The latent period of a fixation shift can be subdivided into four major component stages (Miller, 1969; Wickens, 1974) which are, in sequence:

1. preperceptual or sensory storage, in which all stimulus information is briefly saved
2. perceptual processing, in which the sensory information is encoded
3. operation of a decision mechanism for selection of the next area of fixation
4. response execution involving the patterned activation of the appropriate ocular muscles, and their response

Although the physiological response time of the oculomotor system may be relatively constant, the first three components can be influenced significantly by several factors relating to stimulus and subject variables.

Most previous studies which have reported latency measures, employed an experimental paradigm requiring the subject to initially fixate a central light, and then to fixate on another light when it is noticed. Using this design, the reported latencies are in the order of 200 msec. for adult subjects. However, altering the physical characteristics of the stimulus can influence the absolute latency time. For example, a larger stimulus target induces a more rapid reaction (Miles, 1936); there is an increase in latency to a distally placed target (Miles, 1936; Miller, 1969); and latency time is equivalent for stimuli in the right or left fields (Miller, 1969; Bartz, 1962; Lesevre, 1968) although this ascertion is questioned (Dosseter & Papaioannou, 1975; Gabersek, 1963).

Subject variables can also influence latency. A warning period in the range of 300 to 600 msec. has been reported to reduce latency in adults and children (Cohen & Ross, 1977; Saslow, 1967). Also, it is often noticed that with practice, a subject's latency becomes less variable and shorter (Miles, 1936; Hackman, 1940; Bartz, 1962). Children usually have longer, more variable latencies than adults (Gabersek, 1963; Miller, 1969). This has been thought by some to reflect the immaturity of the oculomotor system (Piaget & Vinh Bang, 1961) and by others as evidence for differences from adults in central processing capacity (Wickens, 1974). As reviewed in the introduction, there is some evidence that dyslexic children have longer latencies than normal reading children.

Miller (1969) noted that the latencies of children (8 year olds) unlike adults, significantly increased with target eccentricity (6° and 13°). He suggested that an increase in the "reaction-time" to a distal stimulus was indicative of a more restricted field of view in children and therefore, less efficient recognition of peripheral material. Mackworth and Bruner (1970) also reported that children (6 year olds) tended to concentrate their eye movements, when instructed to inspect blurred or complex arrays. They concluded that children were not able to use efficiently the center and peripheral information simultaneously. Mackworth and Bruner (1970) deduced that young children suffer from an information overload that resulted in tunnel vision. Piaget (1950) had also found (in experiments of perceptual conservation) that the young child centers on the perceptually dominant part of the visual field and fails to take account of the other parts. This centering was confirmed by eye movement recordings (O'Bryan & Boersma, 1971). Tyler (1969) reported a narrowing of the range of regard by patients with severe receptive aphasia. The centering phenomenon was also reported in patients with diffuse cerebral dysfunction and those with unilateral hemispheric disorders (Bender & Diamond, 1965; Diamond & Epstein, 1974).

The prolonged latencies of the dyslexic children in the present study may be indicative of a restricted field of visual regard and possibly an inefficient recognition of peripheral material. It is possible that longer dwell in the center may be the result of a sensory restricted visual field. However, since no visual field deficit was observed on gross visual field confrontation* it would seem more likely that a prolongation of the latency is the result of a functional information overload.

As mentioned above, latency includes the time for encoding the information in the fixated area. The standard, present in the center, had to be perceived first and encoded in some form that could be utilized in the search. Since the dyslexic children had comparable latencies to the normal readers on the Butterfly 32, the encoding time for the butterfly in the array of 64 probably did not contribute to the prolonged latencies in this array (but may have contributed to other latency differences).

The latencies for both groups in this study were longer than reported for children in the literature. For example, on a simple task involving fixation to a light of known position at either 6 or 13 degrees (in the present study, the target was always located 11 degrees from the center on an oblique), Miller (1969) reported that eight year olds had a mean latency of 411 msec. with longer latencies to the further target. Dosseter and Papaioannou (1975) also found that 6 to 15 year old children had

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*Perimetry for color, form or CFF may be more sensitive to a subtle visual field deficit (Teuber, Battersby, & Bender, 1960).

latencies of approximately 400 msec. to a light at a visual angle of 40 degrees. However, Lesevre (1968) (6 to 15 year olds) and Cohen and Ross (1977) (M age = 8.7 years) reported latencies of 270 msec. to a target light at variable intervals and unknown spatial locations. As can be seen from the above studies, eye movement latency is a very variable measure especially in children (Miller, 1969). However, it is unlikely that a difference of 400 msec. (in the present study, M = 870 msec. for normals) can be explained by variability alone. It is more likely that a light would not require the same coding and processing time as a symbol or an object. The performance of the tasks reviewed are also not contingent on the proper processing of the light as is required in the present field of search tasks. Furthermore, it is possible that latency time was effected by the greater amount of peripheral information in this study than in the others cited above. For example, Gould and Dill (1969), using a field of search task which required the subject to determine how many of eight patterns matched the central standard, found latencies as high as 560 msec. for normal adults. Bartz (1962) noted that reaction time was significantly longer when a target could possibly appear in 11 positions than when there were four positions. Thus, the number of patterns in the array, the number of choices where the target could be located, as well as the required encoding of the central target, all contributed to the longer latencies observed in this study.

In conclusion, the significantly longer latencies found in the dyslexic group compared to controls on the Butterfly 64 array as well as most of the other arrays can be described as a type of centering phenommenon associated with information overload. It seems that the periphery may be functionally restricted and that this restriction may manifest itself in a less efficient recognition of material situated in the peripheral fields on some of the field of search tasks.

## The Array Orientation Effects

In accordance with Hypothesis 4, dyslexic children took longer than controls to locate a rotated figure that to locate an erect one in a field of search task (see Figure W). When the dyslexic children were compared with controls on their performance on the tilted arrays, there were significant differences in latency, search time and in number of refixation, whereas the dyslexic children only showed significantly longer latencies when compared with normal readers, on the erect arrays.

The prolongation of latency displayed by the dyslexic children can be explained by an overload of spatial information or by the additional time needed to encode and store central information (v.s.). Again, the longer search times can be accounted for by the increased time needed by the dyslexic children to make the proper feature comparisons for matching. Although the dyslexic children referred back to the central standard more than normal children in the Ψ arrays, the difference between groups is significant only in the tilted arrays. An evaluation of the meaning of the refixation measure may help to clarify the difficulty which the dyslexic children display on the tilted arrays.

Refixation on a central standard occurs either if initially the subject did not attend sufficiently well to the central standard to properly encode its distinctive features or if subsequently he forgot the identity of the standard (Gould, 1973). Refixations can also occur when the subject needs to obtain more information (Gould & Peeples, 1970), possibly to help eliminate those targets which are different from the standard (Drake, 1970). Gould (1973) found that there was a corresponding increase in the number of refixations with an increment in the array information. Gould also noted that there was an increase in refixations if the subject had difficulty finding the matching target. Gould and Peeples (1970) reported that refixations were more frequent when the standard was a meaningless figure than when it was an object. This finding was confirmed in the present study for both dyslexic and control children. For both groups, there was a greater number of refixations for the meaningless figures ( $\Psi$ ) than for the objects ( $\underline{\Psi}$ : controls, *M* = 3.7 refixations and dyslexics, *M* = 5.4; *butterfly*: controls, *M* = .5 refixations and dyslexics, *M* = .6). Nodine and Steurle (1973) suggested that the increase in the number of verifications was due to a:

> lack of a plan for extracting feature information, e.g., testing for the presence/absence of comparable features... or inability to utilize and remember feature information once obtained... (p.164).

As indicated by the increase in the number of refixations, the dyslexic children had more difficulty in the evaluation of "stimulus equivalence" when one figure was erect (the standard) and the other was rotated (the target). Yet, it is characteristic of the mature and intact sensorium that small perturbations in time or space should not disturb the recognition of "universals" unless otherwise programmed (Pitts & McCulloch, 1947).

However, it is well-documented that young children, dyslexic children and neurologically impaired adults do have difficulty in evaluating the equivalence of stimuli. For example, young children have particular difficulty in discriminating among the rotated transformations of letters (Gibson, 1969), i.e., they often confuse in reading and writing b, d, p, and q, which are all equivalent Gestalten (Birch, 1962). Gibson, Gibson, Pick, and Osser (1962) explained that transformations which are not critical for object identification, such as rotation and reversals, are learned later as distinctive features. When the child first learns to read and write, the remnants of having learned the equivalence of rotated forms, regardless of rotation, interferes. With practice he will learn to respond to relational cues and distinctive features and will successfully differentiate between rotated letters and words. Krise (1949) observed that even college students make reversals with unfamiliar symbols and noted that only within the semantic context of a word or sentence will the student quickly learn what a particular grapheme represents.

Nodine and Simmons (1974), using eye movement recordings, observed that young children appeared to be moving their eyes so as to physically superimpose one symbol over the other to compare features. For example, letters containing oblique lines as distinctive features are difficult for kindergarten children to learn (Rudel & Teuber, 1963; Nodine & Simmons, 1974). Nodine and Simmons (1974) noted that errors of this type were due to incomplete sampling of a letter display, resulting from the child's inability to detect and resolve distinctive feature information, and at the same time, ignoring that information which is redundant or irrelevant. However, as the child gains familiarity with a graphic symbol, he learns to encode it with a set of differentiating features stored in memory by name, label, or other form of feature code. Having done this properly, "the extraction and processing operations take direction, and information processing becomes more efficient" (p. 28).

Ghent and Bernstein (1961), studying 40 preschool children on a match-to-sample task, noted that the children were able to match forms that were identical in shape and different in orientation. Although this result was unexpected, Ghent explained that the children had been trained to develop a set to expect the array to be either erect or rotated. Royer (1971) proposed that the indexing of orientational information is especially difficult even for adults if a pattern appears in several different orientations. Rotating a figure, whether it is familiar (Egeth & Blecher, 1966) or non-representational (Chou, 1929; Arnoult, 1954), affects its discriminability adversely.

Therefore, two contributing factors may have affected the performance of the dyslexic children. First, the dyslexic children prior to the presentations of the tilted arrays, learned to recognize a butterfly or a Ψ in a particular context, an erect array, and thus, had learned a specific definition of equivalence. Subsequently, when the array is altered by symbol rotation, the performance of the dyslexic children deteriorates. Second, perhaps the form in which the dyslexic children had originally encoded the standard, or the manner in which they extracted and processed the information was not generalizable to the tilted array. The dyslexic children may have difficulty in using an analytical processing mode and instead, may holistically try to superimpose one form over the other to compare features (as noted in young children, v.s.). However, orientational information is probably more difficult to index and less accurately stored and/or retrieved without the help of feature analyzers or lexical markers.

It is conceivable that the difficulty some dyslexic children show in differentiating among transformed letters is related to the difficulty displayed in this study, in matching a rotated to an erect form. They may have difficulty in learning the unique features of letters and because they do not have the semantic context to attach meaning to the confusing graphemes, learning becomes even more difficult.

Nevertheless, the possibility that dyslexic children have particular difficulty processing orientational information can not be excluded. Lovegrove, Billing, and Slaghuis (1978) recently examined the processing of visual orientational information in reading-disabled children and normal readers. Four different experiments were presented to analyze visual information storage duration and contour orientation processing. Pairs of lines of the same orientation and of different orientations were tachistoscopically presented at varying interstimulus intervals. A group difference in visual information storage duration was indicated by the longer interstimulus interval required by the reading-impaired children to detect the appearance of two separate lines for oblique target stimuli. Forward contour orientation masking was used to compare the threshold for detection of a vertical target line following exposure to a tilted line. The significantly higher masking ratios shown by the reading disabled group then controls confirmed the visual information storage difference. Using a tilt aftereffect, a difference in contour processing was suggested also at the visual cortical level. They concluded that disabled readers process contour information more slowly than controls and have a more limited capacity than normal readers. This study is consistent with earlier work done by Stanley and Hall (1973), who also found that dyslexic children were significantly slower in processing visual information (separation thresholds were employed) especially with visually confusable letters.

The study by Lovegrove et al. (1978) implies that dyslexic children may have a specific difficulty in processing orientational information.

At least in lower mammals, it is well-known and accepted that there are certain columns of cells in the visual cortex that respond to lines of a particular orientation (Hubel & Wiesel, 1965). It is possible that dyslexic children have difficulty not only in the coding and storing of visual information, but also in processing orientational information, implicating a specific neural substrate. At the present time, these considerations are essentially conjectured, but they do merit further investigation.

The data offered in the present study suggests that dyslexic children may have difficulty in processing visual information particularly of the type which requires feature analysis rather than generating a holistic "photograph". However, the possibility of a specific difficulty in processing orientational information can not be excluded.

In conclusion, it may be the case as I.P. Pavlov (1927) once observed (in the context of stimulus generalization) that the development and stability of stimulus equivalence may be markedly disturbed in neurologically-impaired organisms. Adult aphasics, according to Schuell, Jenkins, and Carroll (1962), show difficulty in recognizing stimulus equivalence. Lacking a lexical marker and fine analytic ability, the aphasics similarly to the dyslexic children may fail to identify and utilize appropriate distinctive features of a stimulus.

## Oculomotor Contributions to Dyslexic Performance

The question has been posed as to the role that oculomotor abnormalities assume in reading disorders. It was hypothesized that dyslexic children do not have a primary motoric deficit (Hypothesis 5), and in consequence, the aberrant eye movement patterns seen, for example in reading, are not causal factors in dyslexia. In order to help clarify this issue, eye movements during the performance of non-reading tasks were examined. However, reading children may acquire certain motor habits that are practiced even during non-reading tasks. Therefore, the dyslexic children may show eye movement patterns different from controls because motor habits have never been established.

Because of the complexity of this problem, we can only hope to outline an approach to the issue of the primacy of oculomotor aberrations in reading disorders. In this endeavor the following two questions will be addressed: First, do the dyslexic children show an "irresistable urge" (Zangwill & Blakemore, 1972) to move their eyes to the left when not reading, as determined by (a) the proportion of right to left movements, (b) the differences in rightward versus leftward latencies, and (c) their relative ability to find targets on either side of space? Second, are they efficient in their approach to a visual perceptual problem as inferred from their eye movements, or do the dyslexic children display the same inefficiency as when they read?

### Laterality of Gaze

Neither the dyslexic nor the control children had a tendency for

for their initial horizontal saccade to be toward the left (51% controls vs. 56% dyslexics). Many studies have confirmed that normal adults will begin exploration in the upper left field (Brandt, 1945; Crovitz & Daves, 1962; Chèdru & LeBlanc, 1972; and Chèdru, LeBlanc, & Lhermitte, 1973). Although it is possible that this left-sided tendency is linked to motor habits, others have proposed that it is independent of reading, and instead may correspond to some aspect of cerebral dominance, e.g., the propensity of right-handed human adults to organize a series of items from left to right (Chèdru et al., 1973; Braine, 1968), or that only right ocular dominant subjects first looked to the upper left. Though, the dyslexic children and 13 out of the 15 normals in this study were right ocular dominant, they did not have a greater tendency to move their eyes to the left, regardless of the presence of dyslexia. Furthermore, dyslexic children do not have a greater propensity to move their eyes leftward than normals as Orton (1925, 1937) and Zangwill and Blakemore (1972) had proposed.

The dyslexic children, in general, showed longer latencies than the controls in the field of search tasks. Nevertheless, there was no directional effect within either group, i.e., the latency for initial leftward movements was equal to the latency toward the right. Other studies of latency with regard to the direction of gaze provide inconsistent results. These differences in results are probably dependent, to some extent, on the requirements of the task. Lesevre (1968), examining oculomotor reaction time to a light at irregular intervals in a predicted location, found that dyslexics showed no difference in directional latency, whereas normal children were faster in the rightward direction. Dosseter and Papaioannou (1975), contrary to Lesevre, found that for movement to a dot at a distance of 40°, dyslexic children had faster rightward movements while normals were faster in their leftward movements. It seems that if motor habits played a role in this oculomotor asymmetry that, at least for the normal reader, rightward latencies would be shorter. Rayner (1978) and Pirozzolo (1978) confirmed that skilled readers did display faster rightward latencies for parafoveally presented words. Pirozzolo (1978) also found that the auditory-linguistic dyslexics followed the same pattern as normal children, but that the visuospatial dyslexics show shorter leftward latencies.

In all of the above studies, the subject did not choose which direction to move his eyes; this was dependent on in which field the stimulus appeared. In the present study, the subject could elect to begin exploration in either field, since there were no suggestions made to insert a response bias, and since both fields were stimulated simultaneously. It should be emphasized that the dyslexics showed the same pattern as the normals. Because most of the dyslexic children had linguistic rather than visuospatial difficulties, this comparable performance would have been predicted by Pirozzolo's findings.

Although both groups tended to find a target faster in the right field than the left, the difference between-groups and within-groups was not significant. Chèdru et al. (1973) also found in normal adults no difference in search time between left and right field choices, but did find that both left and right brain-damaged patients spent a longer time searching for objects in the field contralateral to the side of their lesion.

One additional piece of evidence that dyslexic children do not show a greater tendency to move their eyes leftward than controls is that although both normal and dyslexic children tended to make more initial leftward movements on the Modified Valcuikas Embedded Figures, the dyslexic children made significantly more rightward movements than normals. The explanation for this result is not immediately apparent.

In summary, there is no evidence to suggest that dyslexic children have a greater tendency than controls to move their eyes leftward while performing a non-reading task such as the field of search.

## Motoric Efficiency

Modified Valcuikas Embedded Figures (MEFT). The dyslexic children employed search strategies similar to controls while performing the MEFT, yet made significantly more errors. For example, both groups searched for a similar length of time, spending a greater proportion of their time exploring the left-field choices, and thereby, taking a longer time to find correct answers on the right. They also made about the same number of shifts between answer boxes, and about a third of their eye movement shifts were directed to the simple figure. The dyslexics were certainly not different from the control children in gross search patterns. In light of the significantly greater number of errors made by the dyslexics on this task, it might have been expected that they would have spent a longer time searching, with more references to the simple figure. Although the dyslexic children seemed to be searching as efficiently as the controls, they probably performed less efficiently in relation to their skill on this task. One possible explanation is that the dyslexic children were more "impulsive" than "reflective" in their performance. Kagan (1964) suggested:

> a child may fear that the silence will be interpreted as an indication of his inability to provide a correct answer immediately, and in order to reduce his tension he may offer an answer impulsively (p. 34).

Drake (1970) examined the eye movement concomitants of impulsivity. She noted that impulsive children spend a greater percentage of their fixations on the standard and the answer figures while performing the Matching Familiar Figures Test (MFF). Impulsive children also concentrated their scan within a smaller portion of the stimulus figures, making about one-half as many comparisons between homologous parts. However, they responded faster and made more errors.

Boersma, Muir, Walton, and Barham (1969) used a similar dichotomy to establish a measure of analytical competence: field dependence versus field independence. While performing an embedded figures task, field dependent subjects made fewer shifts to a target and spent less time exploring.

The dyslexic children, in this study, did not show eye movement patterns similar to the impulsive child or the field-dependent adult. It seems more likely that after searching for a suitable answer and having a particular difficulty, the dyslexic children chose the best answer within their limited ability. The dyslexic children often reported that they knew their answer to be incorrect. Although they would search longer for a correct answer when encouraged by the experimenter, they could still not offer a correct answer.

As described in young children (Vurpillot, 1968), the scanning method of the dyslexics in this study was accurate but their answers were not related to the information they collected. It seems that their performance was not limited by eye movement strategies; in spite of sampling the appropriate information, they were not able to cognitively process it.

More extensive analysis of the oculomotor performance was limited by the resolution accuracy of the eye movement data acquired by the method employed. Therefore, although it appears that the gross eye movement strategies of the dyslexic children were the same as the controls, it is unknown to what specific features they attended. It is possible that the dyslexic children dwelled on the irrelevant details and ignored those features that were more informative. More accurate techniques would be needed to confirm this conjecture. However, within the limitations of the present study, there is no indication that the eye movements per se, i.e., motoric functioning, contributed to the performance deficits shown by the dyslexic children.

Elkind triangle. Elkind and Weiss (1967) observed that second-grade reading-retarded children practiced the left to right motor habits of reading when scanning a triangle array. The dyslexic children in the present study, did not show this characteristic reading scan more fre- than controls. (In fact, two more controls scanned in this manner than dyslexics). There was some nonsignificant evidence that the dyslexic children were slightly more disorganized in their scanning strategies.

In part, this may be due to their difficulty in assigning names to the objects that they were asked to remember (cf. Denckla and Rudel, 1976).

The age differences of the children used in this study and those tested in Elkind's may account for the disparity in results. Elkind suggested that older reading children and adults gain facility in systematic scanning and therefore, could choose from a variety of exploration patterns. It is possible that the older dyslexic children did not need to practice the motor habits of reading. Since most of these children were reading at a third grade level, the motor habits have probably been established.

In conclusion, the dyslexic children failed to reveal a tendency to move their eyes predominantly to the left. Neither did they reveal less systematic scanning strategies than the controls which would suggest a primary role of eye movements in developmental dyslexia. It seems more plausible that oculomotor bias and faulty search patterns, when they are displayed by dyslexics, are symptomatic of a higher-order defect in information processing.

## Reading

Reading eye movement patterns often reported to be characteristic of poor readers (Rubino & Minden, 1973) were apparent in the oculographic records of the dyslexic group in this study. Compared to the control children, the eye movements of the dyslexic children showed the expected increase in the number of fixations and regressions, a narrower perceptual span, and a slower reading speed. However, their sweep was not less accurate than normals as indicated by the comparable number of corrective eye movements at the beginning of the line. The dyslexics jumped ahead of the line more frequently than the control children and paused longer at the onset of a line. The reading eye movements of the dyslexic children may provide insights into other aspects of their information processing capabilities.

A reservation about the generalization of these results to all dyslexic children is that the different dyslexic subgroups may display characteristic reading eye movement patterns (Pirozzolo, 1978). According to Pirozzolo, visuospatial dyslexics show return-sweep inaccuracies and frequent demonstrations of right to left scanning. The auditory-linguistic dyslexics, the predominant subtype in the present study, show increased fixations and regressions, instances of short regressions mixed with forward saccades, and longer fixation durations. The dyslexic children in the present study also showed increased fixations and regressions, but did not show return sweep inaccuracies. To the extent that most of the dyslexics in this study were linguistically impaired rather than than visuospatially impaired, Pirozzolo's observations have been confirmed by the present study.

The locus, frequency, and duration of a reading fixation may be controlled by visual (Hochberg, 1970) or semantic information (Just & Carpenter, 1978). However, it is often questioned whether eye movements are flexible and adaptive to reading material or are motorically preprogrammed and thus, determined to move in the same manner independent of changes in information (Kolers, 1978). It is important to know if the additional regressions and fixations displayed by inadequate readers, are due to a faulty motor program, or whether they serve some purpose. The answers to these questions may help to evaluate the validity of eye movement reeducation programs for dyslexic children.

It is well-known that inexperienced readers (Taylor, 1957), poor readers, and even good readers reading an unfamiliar foreign language test (Buswell, 1922), all show more regressions than the usual 10-15% of total fixations. It would seem that an increased number of regressions and fixations are needed to aid comprehension (Pirozzolo & Rayner, 1978). It may be that the less competent reader must adapt to the information processing demands by incorporating smaller packets of information per fixational pause and thereby, requiring more fixations to digest unfamiliar material. Likewise, regressions occur when having taken in too large a chunk of information, the poor reader returns his eyes to abstract additional information from the previous fixation pause (Stern, 1978).

A cognate phenomenon, well-known to aphasiologists, is that some aphasic children require decomposition of even a single syllable into its component phonemes to facilitate the learning of speech, e.g., "bat" is presented as "b/ æ / t". This process is found to assist in the acquisition of both the receptive and expressive skills, again pointing to the value of having the language-impaired child deal with smaller speech units (Goldstein, 1957).

In considering the results of the field of search task, it seems logical that dyslexics should display more fixations and regressions. The most parsimonious explanation for this is that the dyslexic children may not be able to process large amounts of information and thus, regulate incoming information to their capacity. The span of information processed by the dyslexic group in one fixation is about 2/3 that of the normal children (.43 versus .67 words/fixation). A result of a limited word span, and multiple fixations and regressions, is that reading speed slows down.

The amount of information that can be processed is dependent on peripheral visual field factors as well as cognitive aspects. Hochberg (1970) proposed a two-component theory to incorporate both peripheral and cognitive factors in reading. The first factor, a peripheral search guidance operates on low-acuity information picked up in the periphery which is used to direct the optic search system to where it must move foveal vision in order to receive potential information. The second factor, cognitive search guidance, utilizes knowledge about where the observer has been so far, which guides him to where he should go next. Cognitive search guidance is more efficient in the experienced reader. The good reader has strong guessing tendencies; given a few cues he will guess a word or a phrase to complete a sentence. He has certain expectations of the visual features and his perceptual span will increase with familiarity with the material.

The disabled reader may have difficulty at any of the above stages. For example, the dyslexic children may have limited peripheral processing capabilities as reflected in their smaller perceptual span. This constriction was hypothesized previously in relation to the prolonged latencies of dyslexic children on the field of search tasks. Fisher (1976) suggested that the inexperienced reader, because of his inability to use peripheral cues, functionally displays "tunnel vision reading". Possibly, the dyslexic children have limited use of their periphery because of an overload of peripheral information; their unfamiliarity with reading material, which translates into an increase in informational content, may restrict their regard to the paracentral region of the stimulus field. Since the dyslexic children also showed difficulty on the field of search tasks where the information load was higher, it seems plausible that the dyslexic child operates with a limitation of channel capacity relative to the normal children, and accordingly, their spatial span is restricted. The dyslexic children, relying heavily on foveal input, require more fixations with perhaps less information in return.

The cognitive search guidance of dyslexic children may also be impaired. According to Rayner and McConkie (Rayner, 1977), fixation durations are affected by the cognitive processes occurring during the fixation. Obviously, if the dyslexic child could not decode a word or selectively sample the pertinent information required to do so, more frequent or longer fixations would be expected. An analogous difficulty was postulated for the dyslexic children's performance on the field of search task.

The dyslexic children dwelled longer than normals at the beginning of a line of text before proceeding to scan. Hochberg (1970) proposed that the first letter of a word probably carries the most information and therefore, the reader would tend to look longer at or near a letter that immediately followed a blank space. The initial word of a line probably also carries more information than a later word, in part, because it begins with a larger letter. Therefore, the dyslexic child may dwell at this point because of the additional length of time needed to process more information. Another possibility, as Gilbert (1959) suggested, is that slow readers require more time to stabilize their fixations to a point of maximum efficiency. Although this stabilization is not apparent in the number of corrective movements at the start of the line, it may be reflected in the amount of time the dyslexic child needs to stabilize after the return sweep and before proceeding to scan the reading material. It is also possible that the longer initial fixation may be suggestive of overall longer fixation durations; however, this was not directly measured.

The word span measured for normal and dyslexic children in this study were considerably smaller than that typically reported in the literature. For example, the word span for 6th or 7th graders is reported to be about .8 words per fixation (Taylor, 1965); in this study, the word span was .67 words per fixation for normal children. The shorter span found in this study can be explained by the disparity in the angle subtended by the projected text in this study, with those often reported using reading machines. Also, the word span in this study, was based on a mean of many grade-level texts. The word span did not vary in a predictable fashion with the difficulty of the material. There is some qualitative evidence that as complexity increased, word span decreased. However, since only one line of text was sampled at each grade level, it is difficult to assess the relationship of text complexity to eye movement measures conclusively. Nevertheless, both groups did take a proportionately longer time to read the more complicated material as would be expected in a stimulus control model of eye movements, but not in a motoric preprogramming model.

In summary, the reading patterns displayed by the dyslexic children in this study, appear to reflect a dysfunction in the processing of reading material rather than an abnormal preprogram of motoric function. Furthermore, deficits in reading performance seen in the dyslexic group were paralleled by disturbances in performances of "non-verbal" tasks. In both verbal and non-verbal task performance, there is an evident breakdown in the capacity of the dyslexic children to fully utilize requisite left hemisphere skills in the analytical processing of information. The inadequate use of peripheral information in cognitive processing is also apparent in both types of tasks. A more precise characterization of left hemisphere involvement, specifically with regard to language function, may be provided by examining the differences in scanning strategies employed by articulatory-graphomotor and language-disordered dyslexics on verbal as well as non-verbal tasks.

## Summary

Dyslexic children perform comparably to controls on a variety of representative visual-spatial tasks. However, there are some specific visuoperceptive tasks with which they do have difficulty, and it is these particular tasks that are also poorly performed by adult aphasics. Such selective visuoperceptual impairment in adult aphasics has been explained by the possibility that a left hemisphere deficit may interfere with the performance of those tasks which are merely "covertly verbal" in nature. A similar explanation may account for the results found for the dyslexic children in this study.

Two possible mechanisms have been discussed concerning the role of left hemisphere function in the performance of "non-verbal" tasks:

1. Subvocal language may mediate in the performance of certain complex visuoperceptual tasks. For example, verbal coding appears to be required for some visuoperceptive processing, and therefore, a linguistic defect may limit the appropriate names that are available for coding. It may also limit the specificity and the exclusiveness of the code.

2. Left hemisphere dysfunction may interfere with the appropriate organization or selection of material, linguistic of non-linguistic in nature. Serial feature analysis, including the ability to detect and resolve differentiating features and to selectively sample a display for relevant information, may be limited by a language impairment. The inability to filter and categorize new information results in

a disconnection of related information. This in turn, limits the capacity to store and/or retrieve such information. With limited ability to select and organize material, the effective channel capacity of the organism is reduced and less information can be properly processed. This suggests that the neglect, or inadequate use of peripheral visual field information, may provide an adaptive mechanism for reducing informational load.

Another point that has been revealed in the present study is that the performance of the dyslexic children on non-verbal tasks did not seem to be restricted by their eye movement strategies, either by the efficiency or laterality of their scan. It is suggested that differences in scanning, when they do occur, are reflective of alterations in cognitive processing mechanisms and are not necessarily disruptive. For example, the reading eye movements of the dyslexic children, marked by multiple regressions and fixations, are adaptive in the sense that a smaller chunk of information will be sampled per pause.

Therefore, it seems that in both verbal and non-verbal task performance, dyslexic children show a breakdown in the capacity to utilize analytical, left hemisphere tools in processing information. It is suggested that the greater the informational load and the demand for the use of linguistic skills, the larger will be the differences between the two groups.

# APPENDIX A

## Pilot Study

The purpose of the pilot study was to select a representative battery of visuospatial tasks that could distinguish a reading-disabled group from a normal control group on the basis of performance, and that were particularly amenable to eye movement recordings.

### Subjects

The sample of reading-disabled children consisted of 23 boys who were reading at least two years below grade level on the Stanford Reading Achievement Test (SRA) (a group administered exam), and whose SRA IQ was over 90. In addition, the children were to be about two years below grade level reading in class and of normal intelligence as judged by the teachers.

The control group was 23 normal readers of average intelligence as rated by the SRA and by teacher's evaluation. The children were reading on grade level or above. Where possible, the control children were drawn from the same classes as the reading-disabled children. The children in both groups were right-handed. The age range was 8 to 12 years with a mean age of 10.1 for the reading-disabled group, and 10.2 for the control group.

### Method and Materials

Eleven visuospatial tasks were administered to the reading-disabled and control groups, including:

Street Completion Test (Street, 1931). The children were asked to identify 13 pictures within a one minute time limit per figure (see Figure A). The number of correct identifications was tabulated for each child.

Gollin Incomplete Figures (Gollin, 1960). Two series of five increasingly complete versions of a figure were presented (see Figure B). Each card was presented for three seconds. The child was asked to identify the figure as quickly as possible. The card number (1 to 5) at which the child was able to identify the figure in each series was determined, and the mean score for the two series for each child was recorded.

Circle-size matching (see Figure C). The children were asked to locate the circle that was the same size as the standard circle (top center). Two figures were presented and the number of correct answers for each child was scored.

Field of search. The children were required to locate a figure in the array that matched the central standard. Two figures with 20 in the array (see Figure D) and two with 100 in the array (see Figure E) were presented. The time taken to point to the match was recorded.

Elkind triangle (Elkind & Weiss, 1967). The boys were told to examine the array presented in Figure F and to name all the pictures aloud. The path that was followed during the naming was recorded, e.g., triangular versus a "reading" left-to-right scan.

Ghent Overlapping Figures (Ghent, 1956). Four figures composed of a total of 15 superimposed outlines of common objects were presented (see Figure G). The children were asked to name all the overlapping pictures. The number of correct responses was scored.

Valcuikas Overlapping Figures (Valcuikas, Lillis, Wolff, & Anderson, 1978). Four figures composed of a total of 40 overlapping outlines of common objects were presented (see Figure H). The instructions and scoring were the same as for the Ghent. One minute time limit for each figure was enforced.

Ghent Embedded Figures (Ghent, 1956). The children were asked to find a simple figure hidden in a more complex one below it as shown in Figure I, and to outline it. The number of correct answers within a one minute time limit, out of a total of six figures, was tabulated.

Valcuikas Embedded Figures (Valcuikas, personal communication). The children were required to locate and outline a simple figure hidden in one of four choice answer boxes as shown in Figure J. Ten different figures were presented. The number of correct locations within a one minute time limit was scored.

Upright faces. The task was to find the photograph from nine choices that matched the standard (top-center) as shown in Figure K. Two figures were presented and the number of correct responses were scored for each child.

Inverted faces. Each child was required to match a standard (top-center) of an upright face from a choice of six rotated photgraphs (see Figure L). Two figures were presented.

## Results

As shown in Table A, the only visuospatial tasks on which the reading-disabled group performed significantly worse than controls, were the Ghent and the Valcuikas Embedded Figures Tasks, $t(44)=-3.45$, $p<.001$;

*t*(44)=-3.36, *p*<.001, respectively. Although the reading disabled group showed a triangular scan more often than the controls, there were no significant differences between groups in the scanning of the Elkind triangle as shown in Table B.

Table A

Pilot Study: Performance on Visuospatial Tasks

| Tasks | Reading-Disabled | | Controls | | $t^a$ $\underline{df} = 44$ | $\underline{p}^b$ |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | | |
| Street Closure (number correct) N = 13 | 8.48 | 1.62 | 9.09 | 2.45 | - .57 | n.s. |
| Gollin Closure (card no. identified at) N = 5 | 2.89 | .71 | 2.69 | .76 | .90 | n.s. |
| Circle-size matching (number correct) N = 2 | 1.22 | .85 | 1.48 | .73 | - .42 | n.s. |
| Field of Search (20 objects) | 4.17 | 1.75 | 3.83 | 2.85 | .50 | n.s. |
| Time (sec.) (100 objects) | 6.91 | 4.89 | 5.37 | 3.54 | 1.23 | n.s. |
| Ghent Overlapping figures (number correctly named) N = 16 | 15.74 | .69 | 15.65 | .78 | .60 | n.s. |
| Valcuikas Overlapping figures (number correctly named) N = 40 | 28.52 | 3.69 | 30.26 | 16.20 | -1.45 | n.s. |
| Ghent EFT (number correct) N = 6 | 4.30 | .93 | 5.17 | .78 | -3.45 | <.001 |
| Valcuikas EFT (number correct) N = 10 | 6.22 | 1.54 | 7.78 | 1.62 | -3.36 | <.001 |
| Upright faces (number correct) N = 2 | 1.78 | .52 | 1.91 | .29 | -1.05 | n.s. |
| Reversed faces (number correct) N = 2 | 1.39 | .65 | 1.43 | .66 | - .22 | n.s. |

[a] independent $\underline{t}$ test

[b] two-tailed test

Table B

Scanning of the Elkind Triangle

| Scanning Pattern | Reading-Disabled[c] percent | Controls[c] percent | z[a] | p[b] |
|---|---|---|---|---|
| Reading Scan | 9 | 22 | 1.22 | .22 |
| Triangular | 91 | 78 | 1.24 | .22 |
| Clockwise | 26 | 9 | 1.52 | .12 |
| Counterclockwise | 65 | 69 | .29 | .78 |

[a] test for differences in frequency

[b] two-tailed tests

[c] n = 23

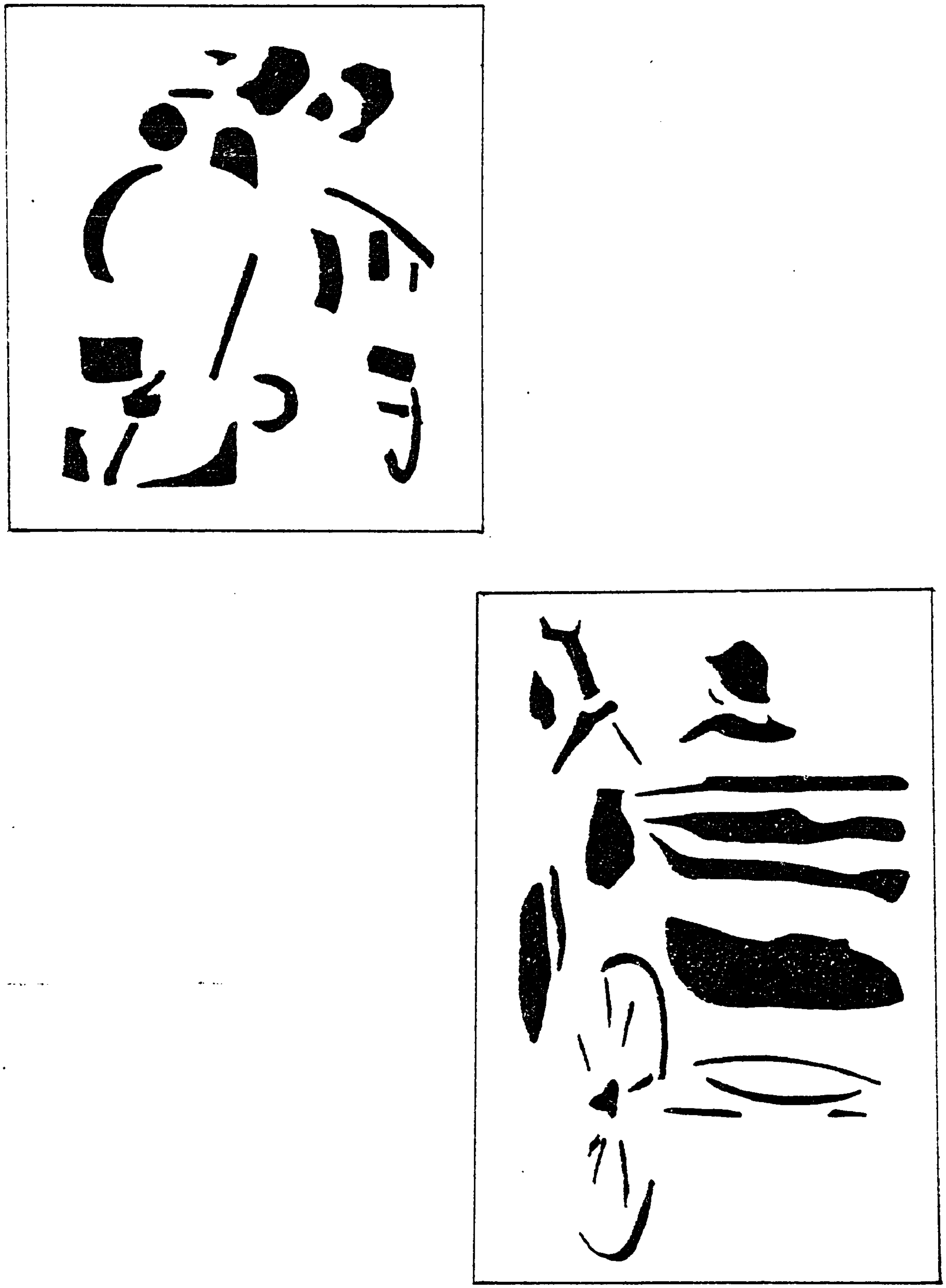


Figure A. Examples of the Street Completion Test.

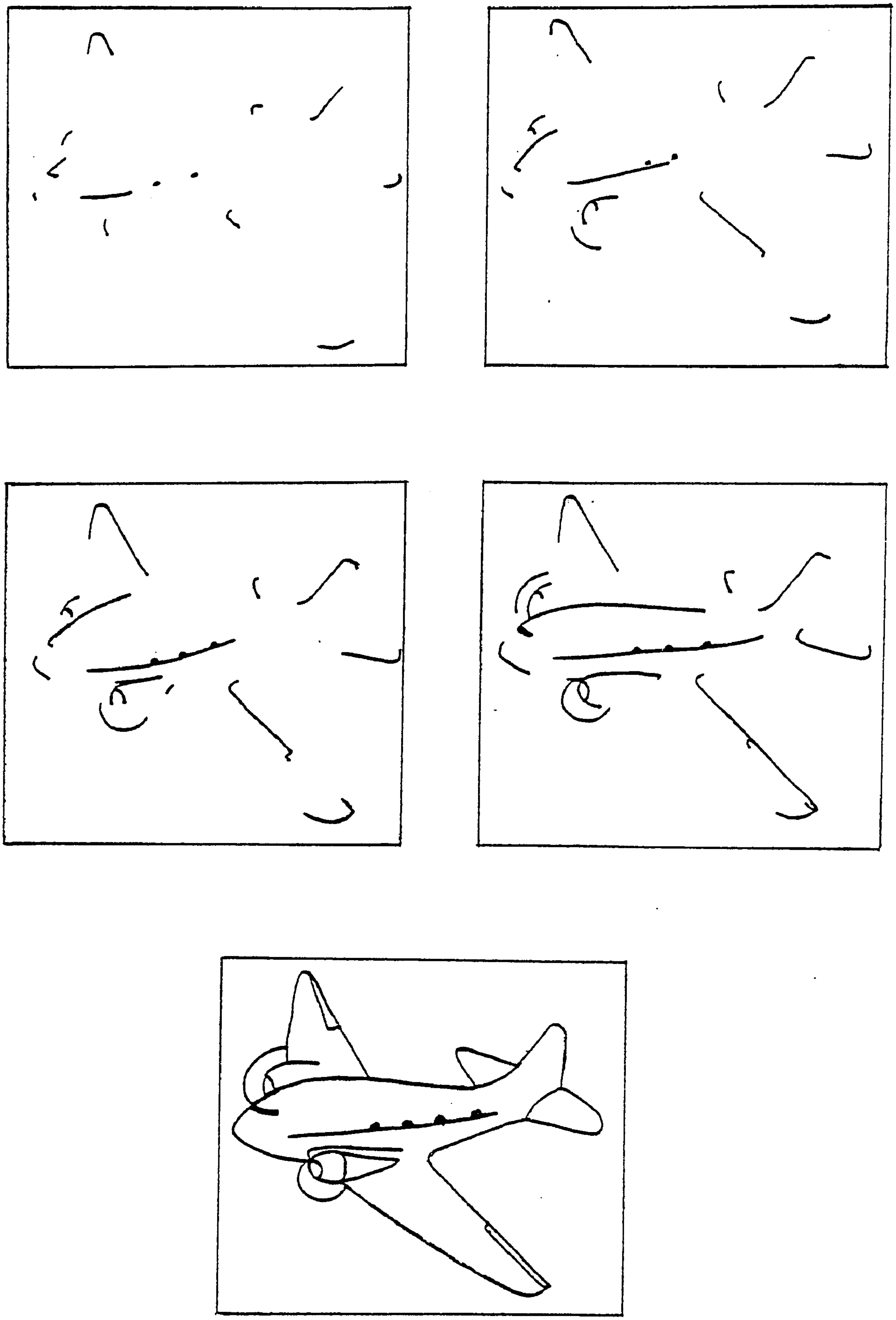


Figure B. One set of the Gollin Incomplete Figures test.

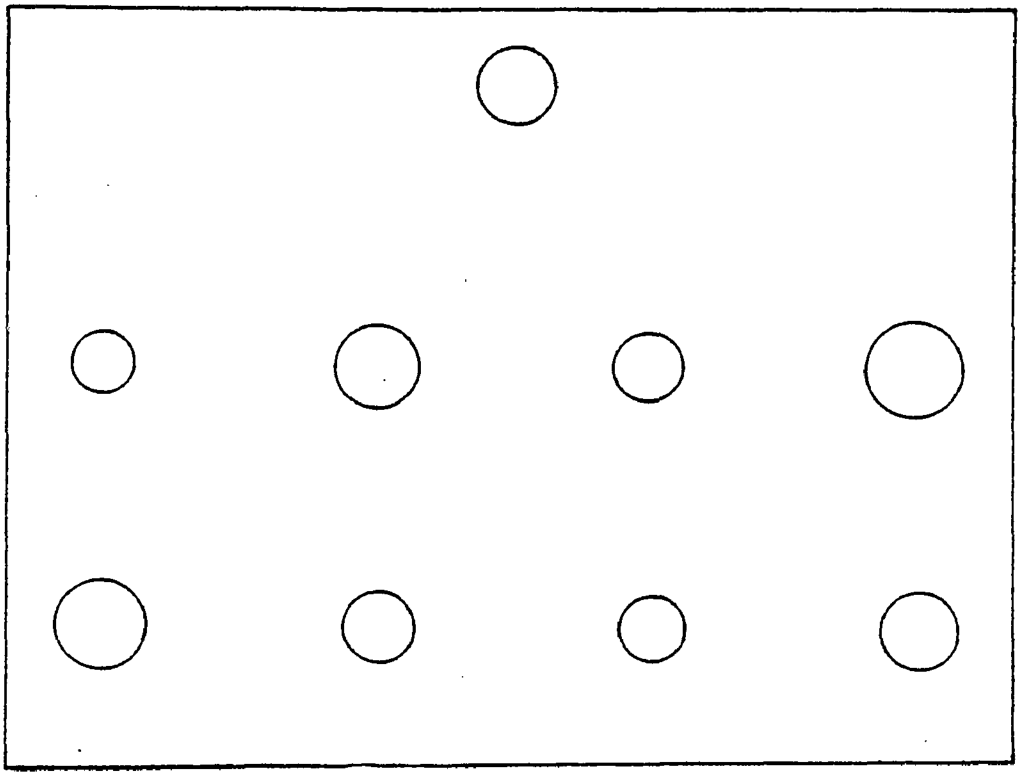


Figure C. Circle-size matching test

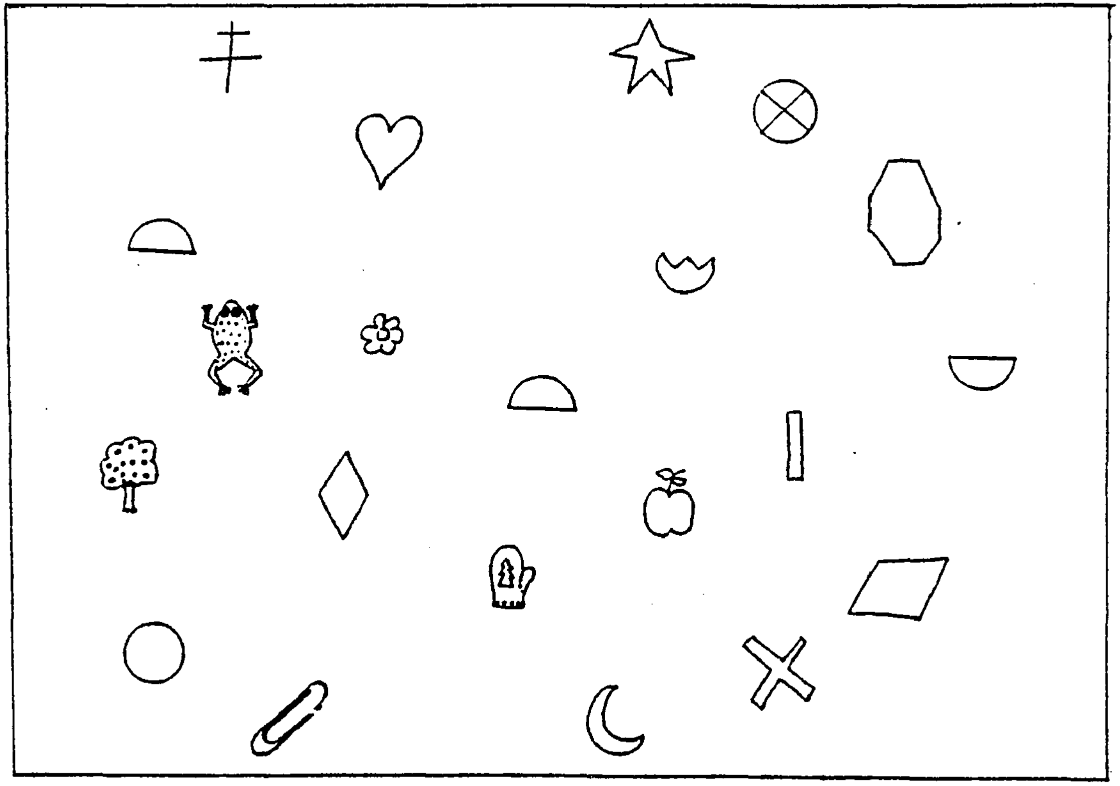


Figure D. An example of a field of search with 20 figures in the array.

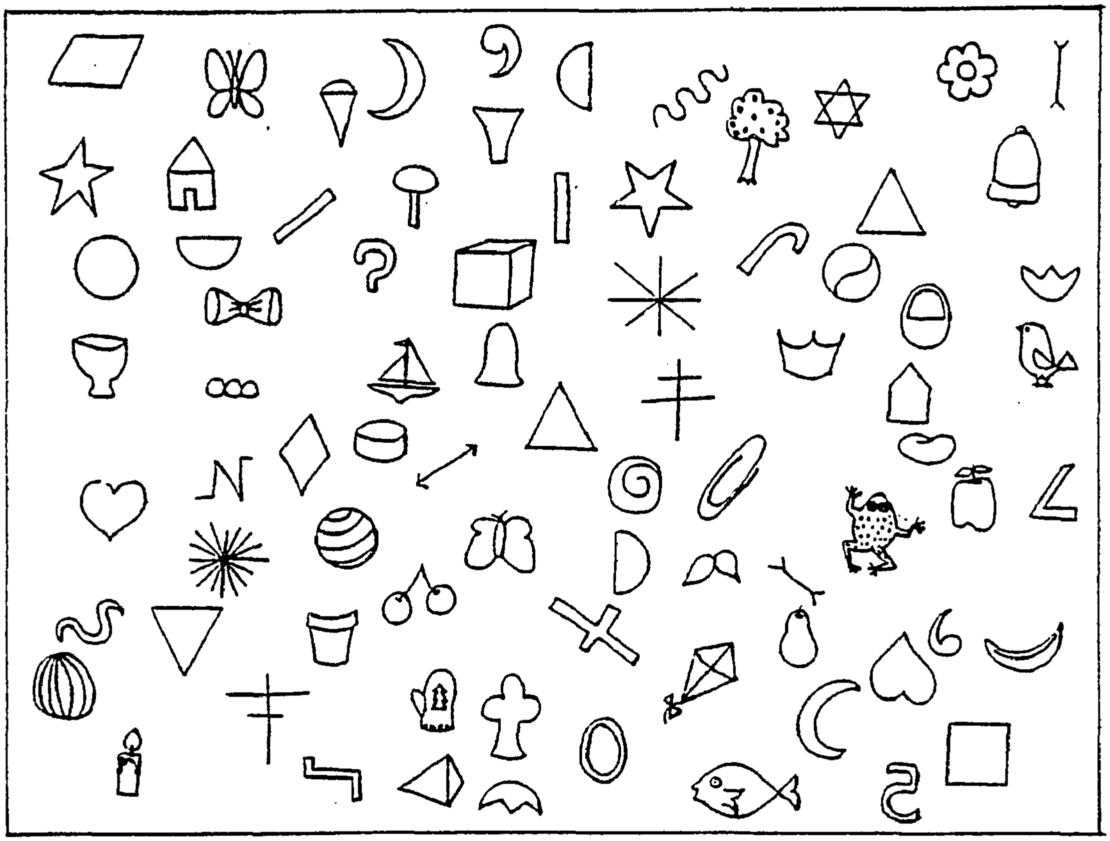


Figure E. Field of search with 100 elements in the array.

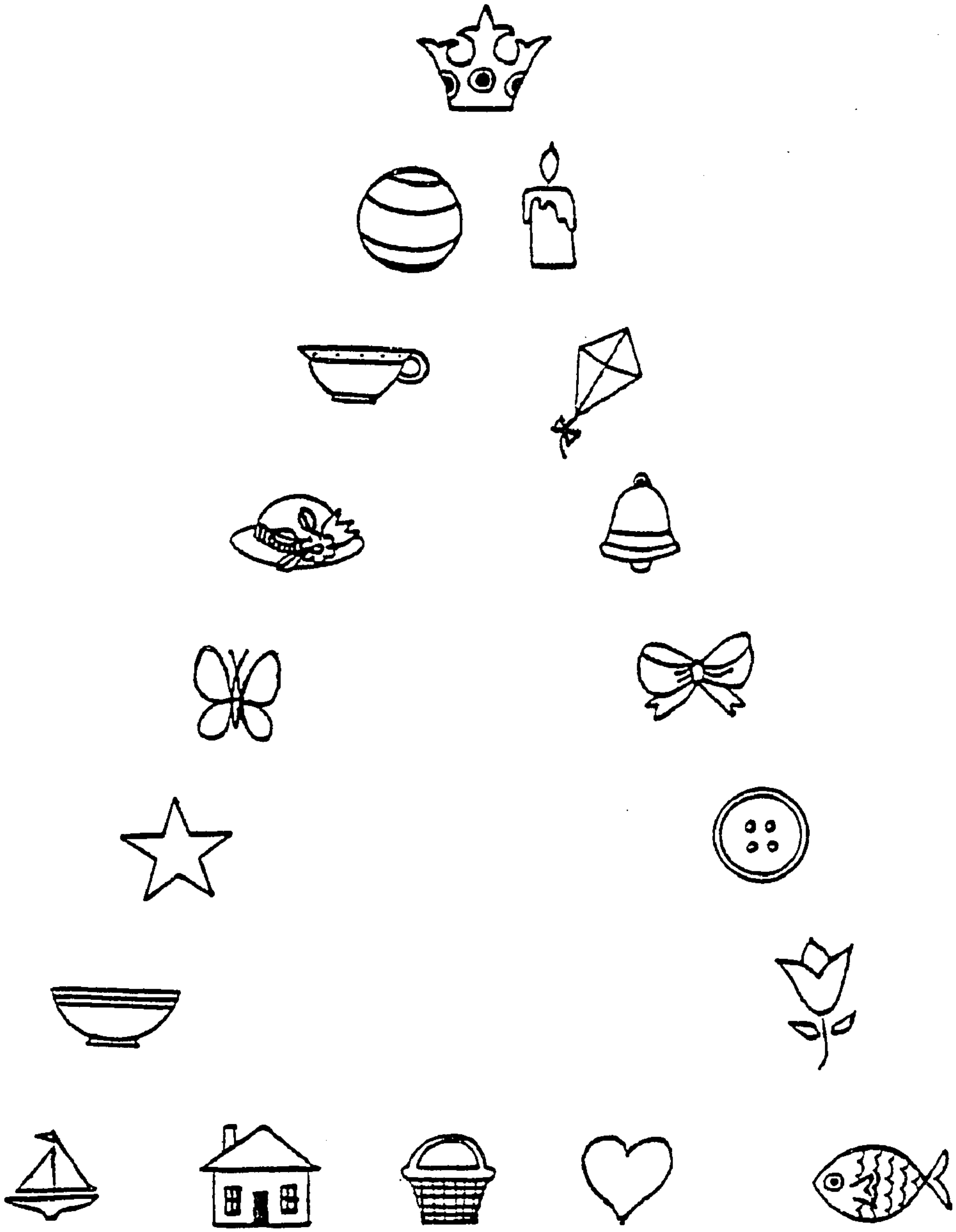


Figure F. The Elkind triangle

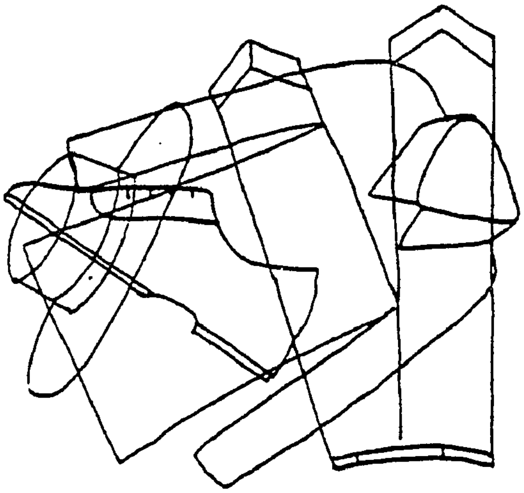


Figure G. An example of the Ghent Overlapping Figures.

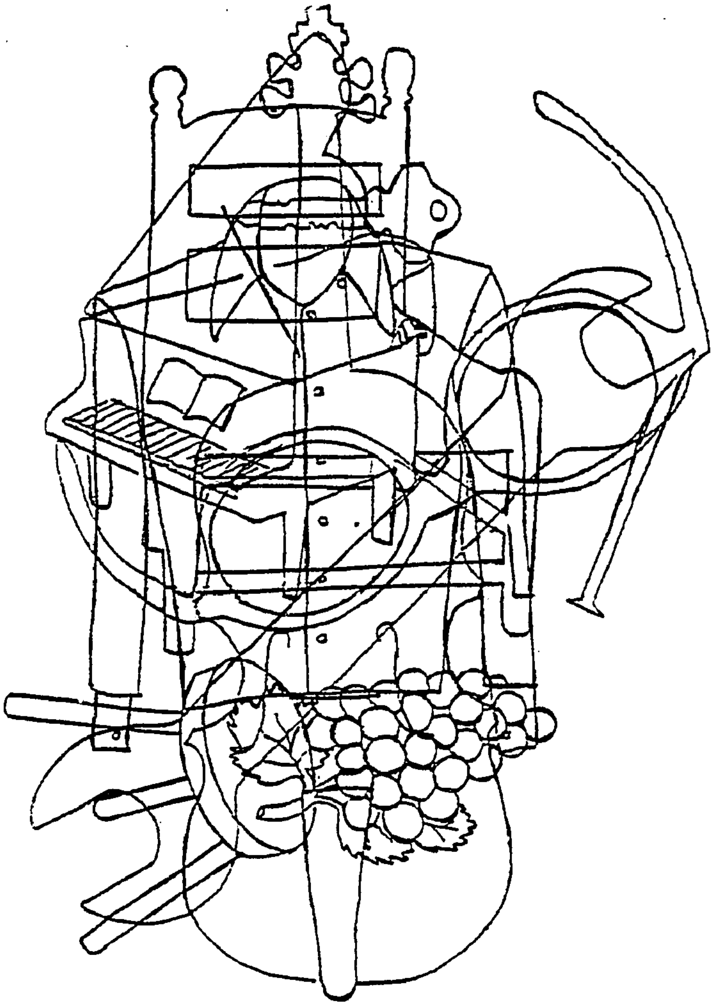


Figure H. An example of the Valcuikas Overlapping Figures.

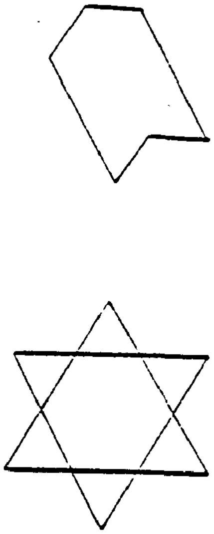


Figure I. A Ghent Embedded Figure

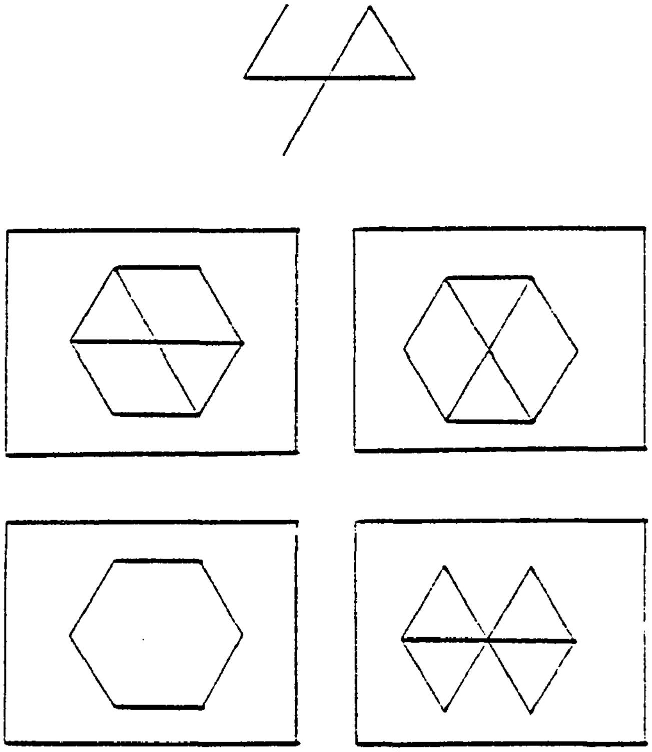


Figure J. An example of the Modified Valcuikas Embedded Figures.

Figure K.  Upright faces matching test.

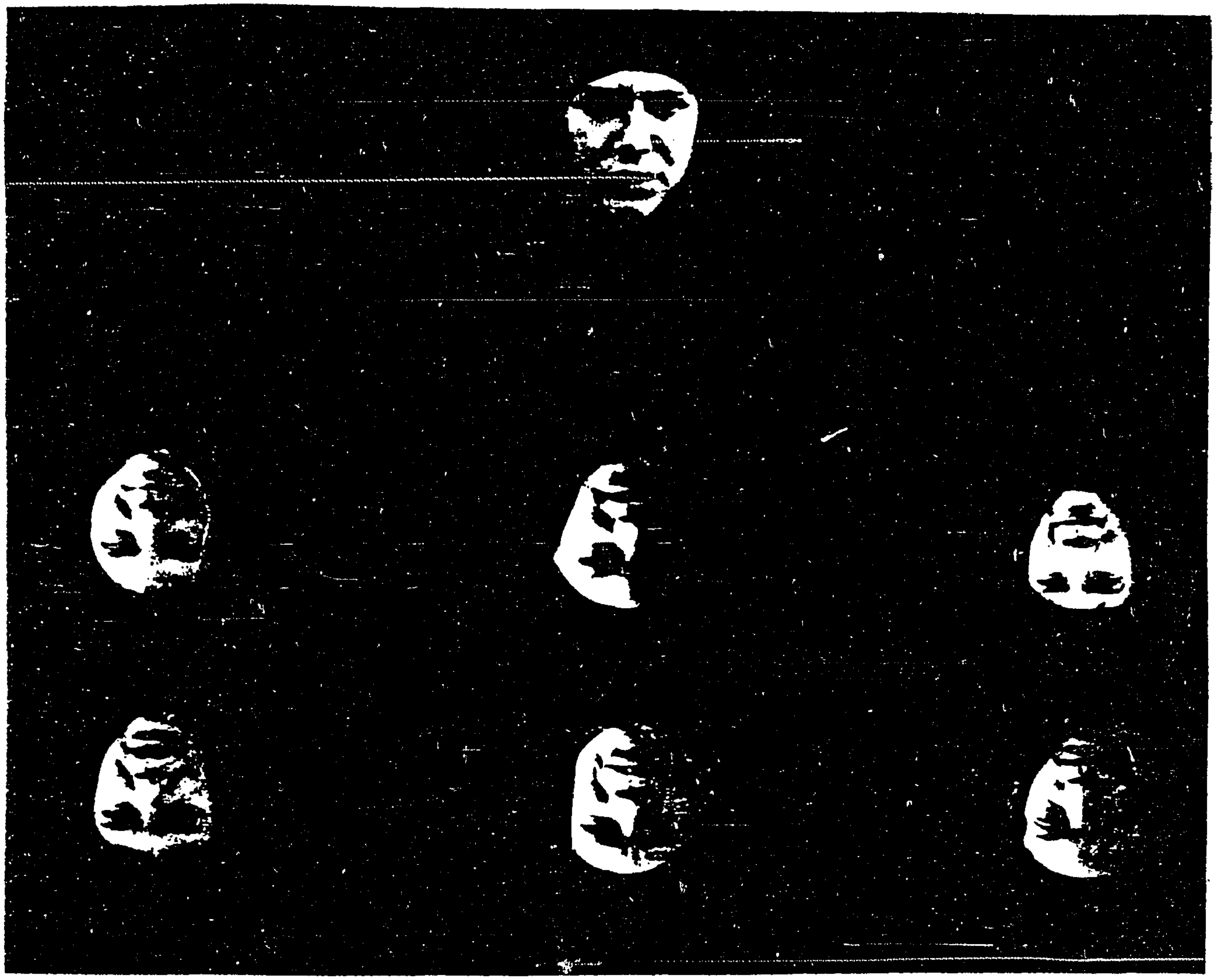


Figure L. Inverted faces matching test.

# APPENDIX B

## Additional Tasks Employed for Analysis of Eye Movements

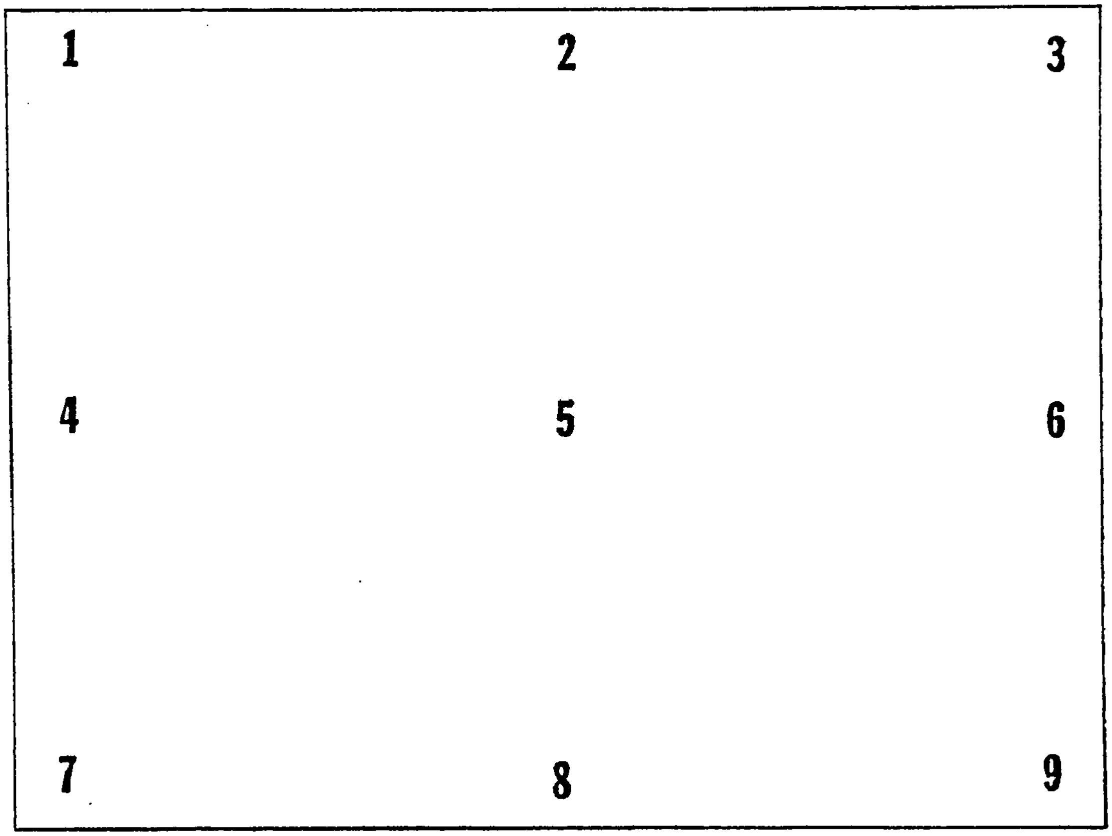


Figure M. Figure used for calibration of eye movements.

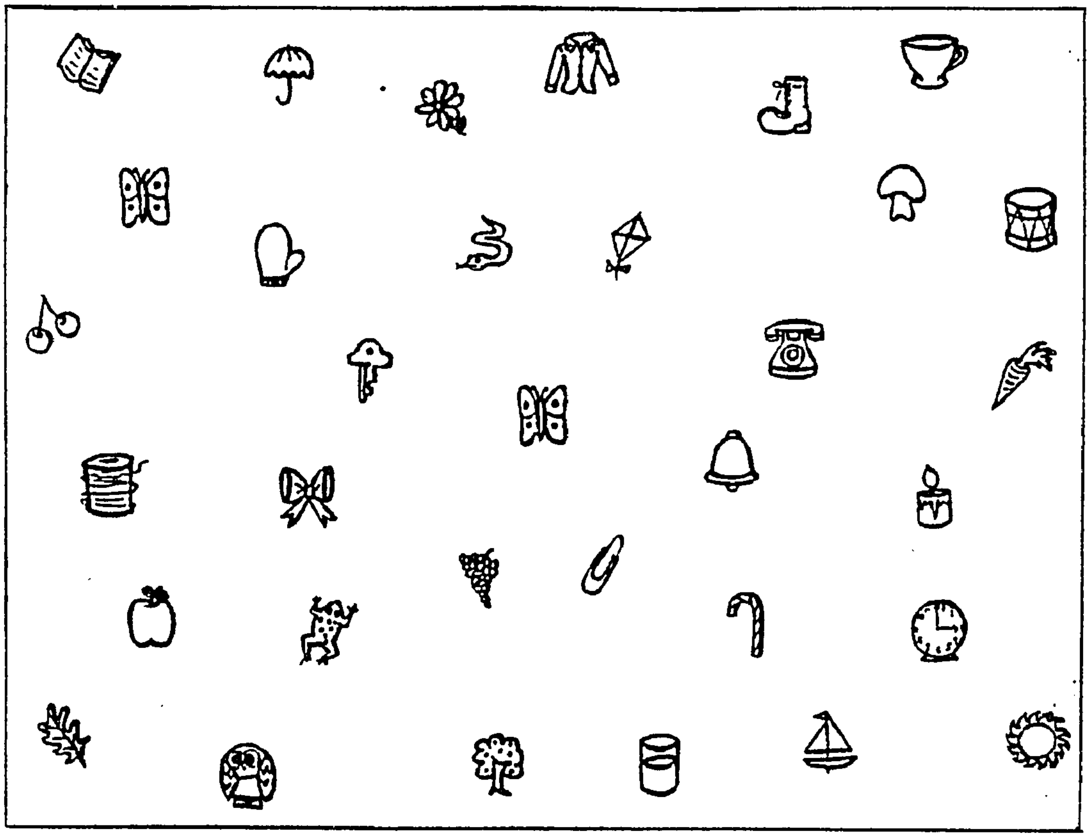


Figure N. Field of search: Butterfly 32.

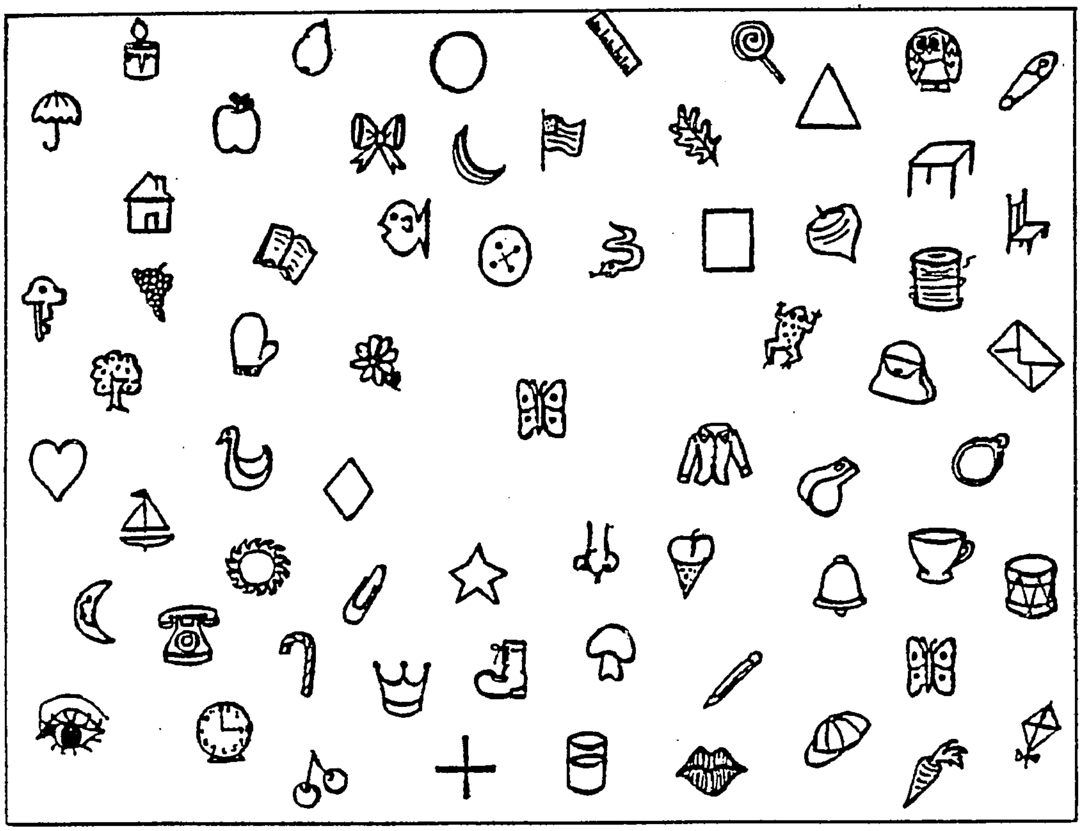


Figure O. Field of search: Butterfly 64.

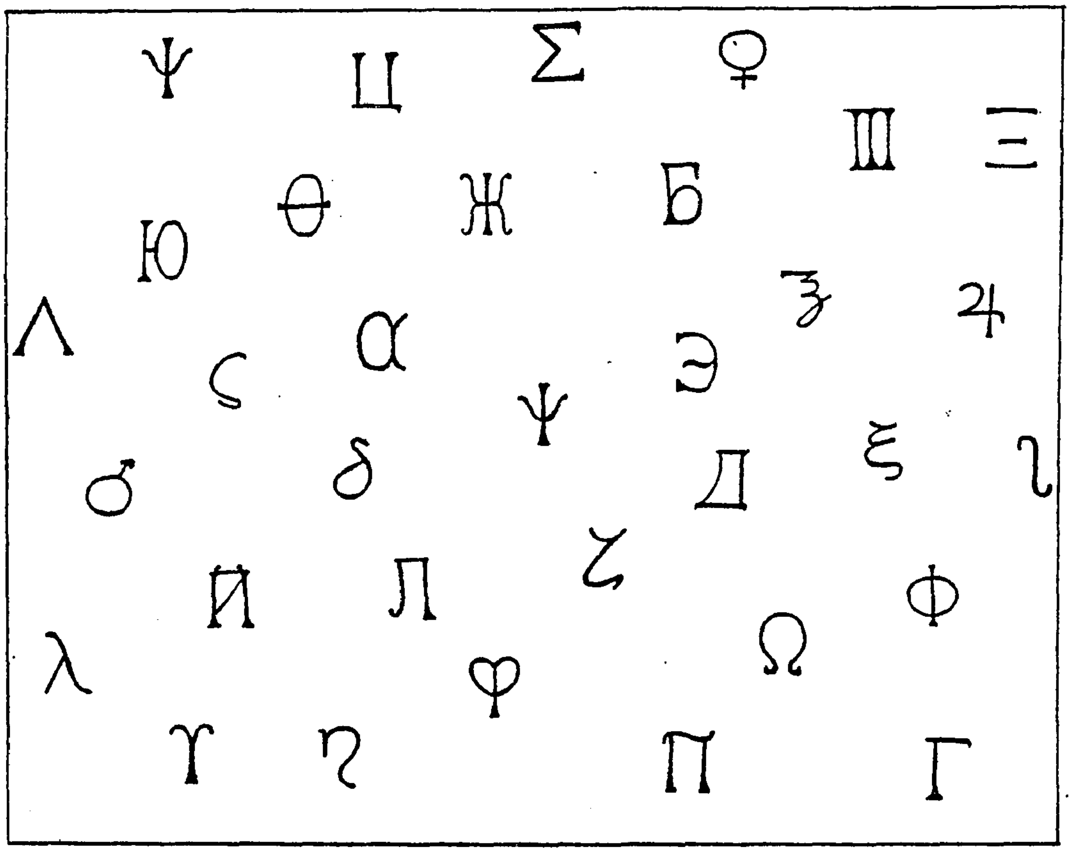


Figure P. Field of search: Ψ 32.

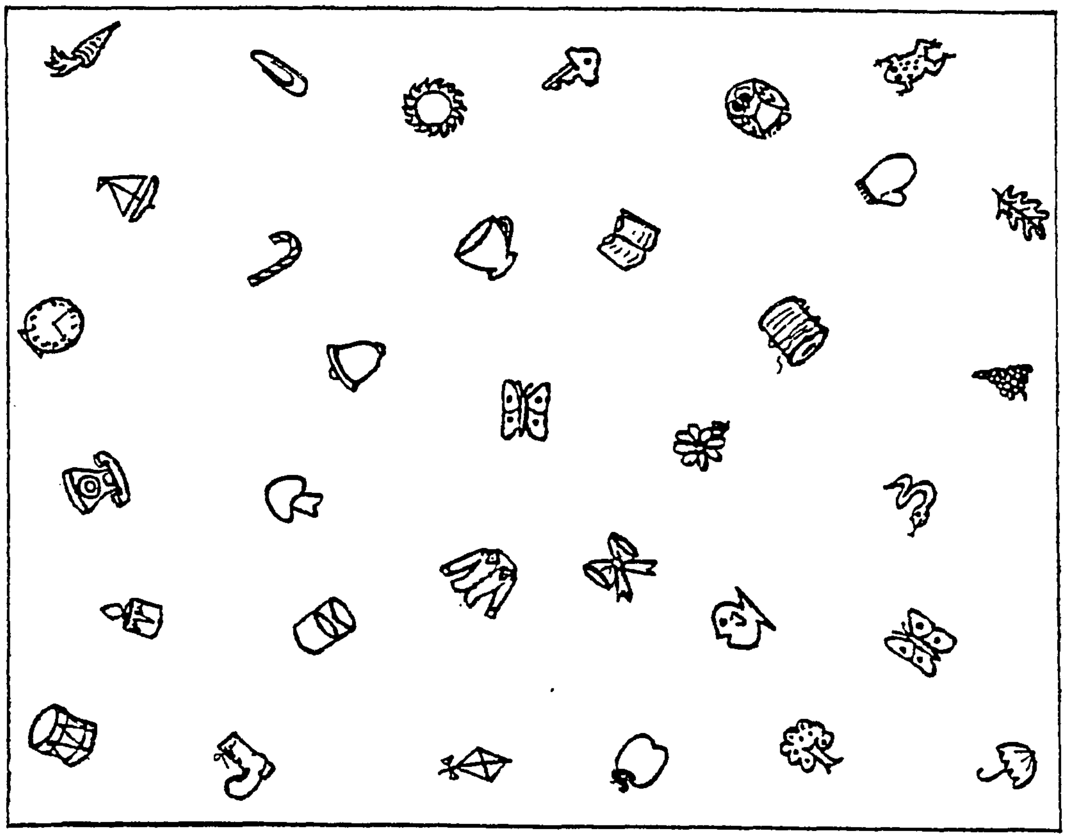


Figure Q. Field of search: Butterfly 32 T.

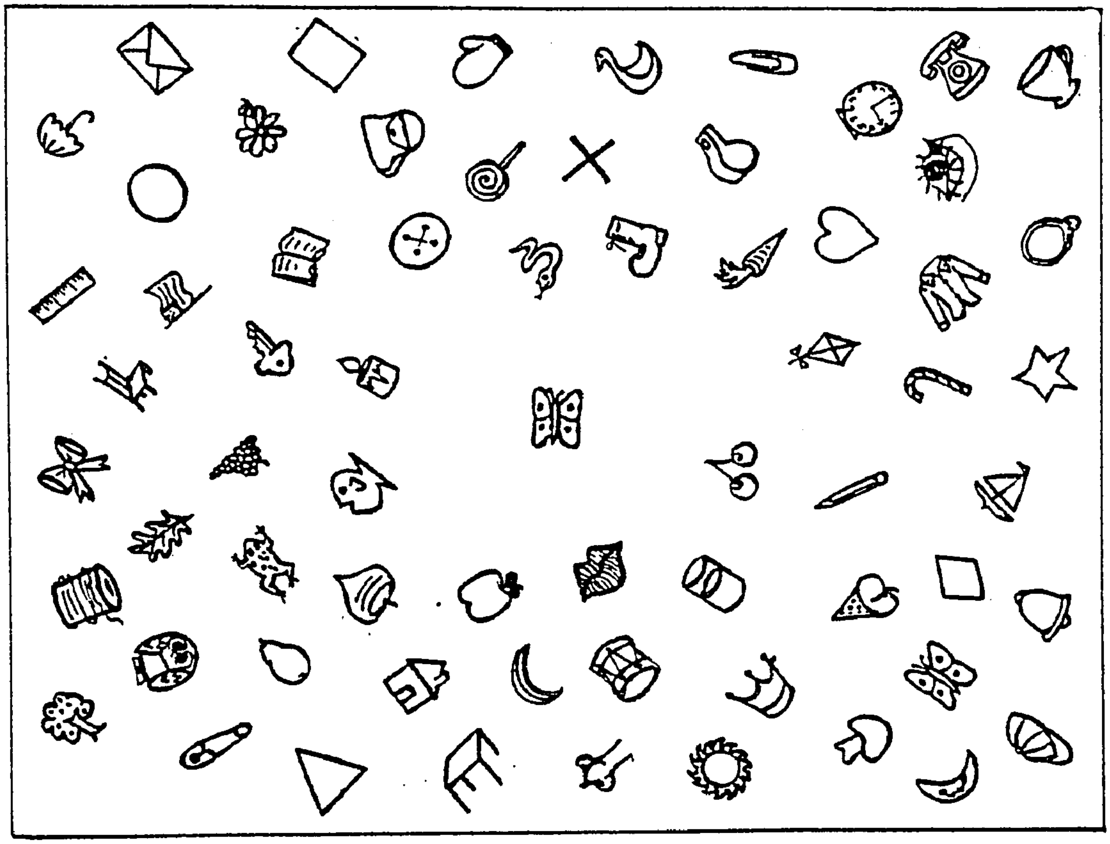


Figure R. Field of search: Butterfly 64 T.

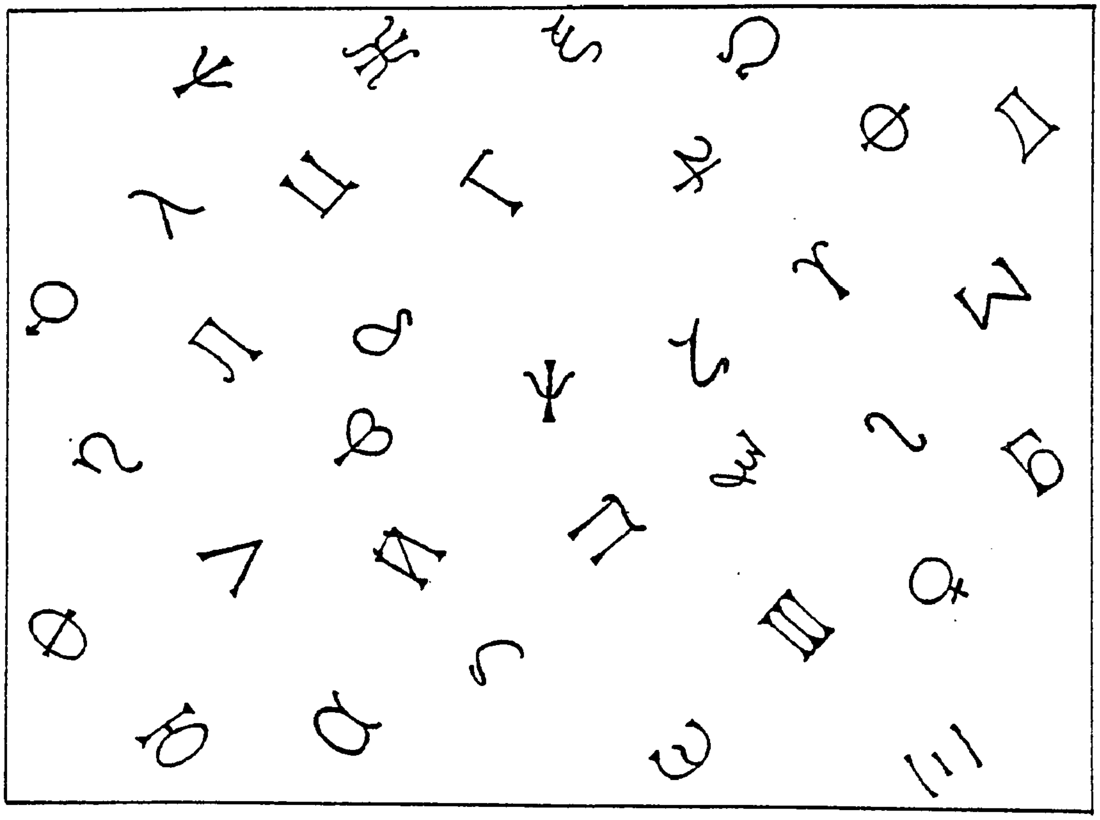


Figure S. Field of search: Ψ T.

We can play ball here.
Three kittens were there.
None of them won the prize.
He faces real dangers alone.

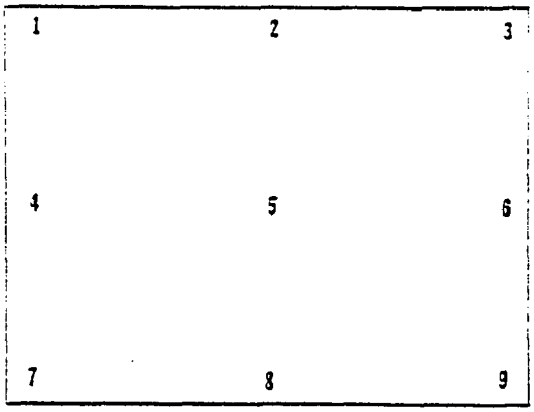
---

When the girl looked she had a big surprise.
Price tags were fastened to all articles.
Chemicals in many streams penetrate rocks.
A constitution was prepared and submitted.

Figure T. Reading material: Subtest I (top) and Subtest II (bottom).

# APPENDIX C

## Graphic Representations of Visual Scanning Patterns



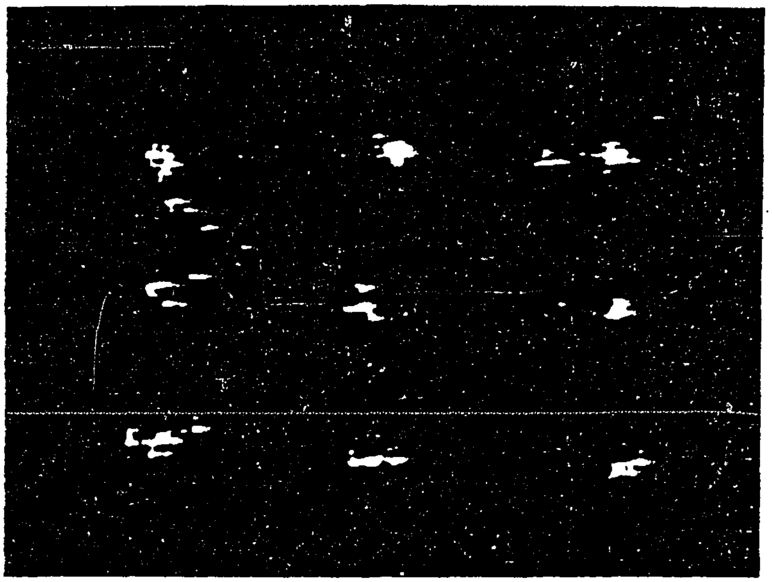


Figure U. Eye fixations of a dyslexic child (D.K.) during the calibration procedure.

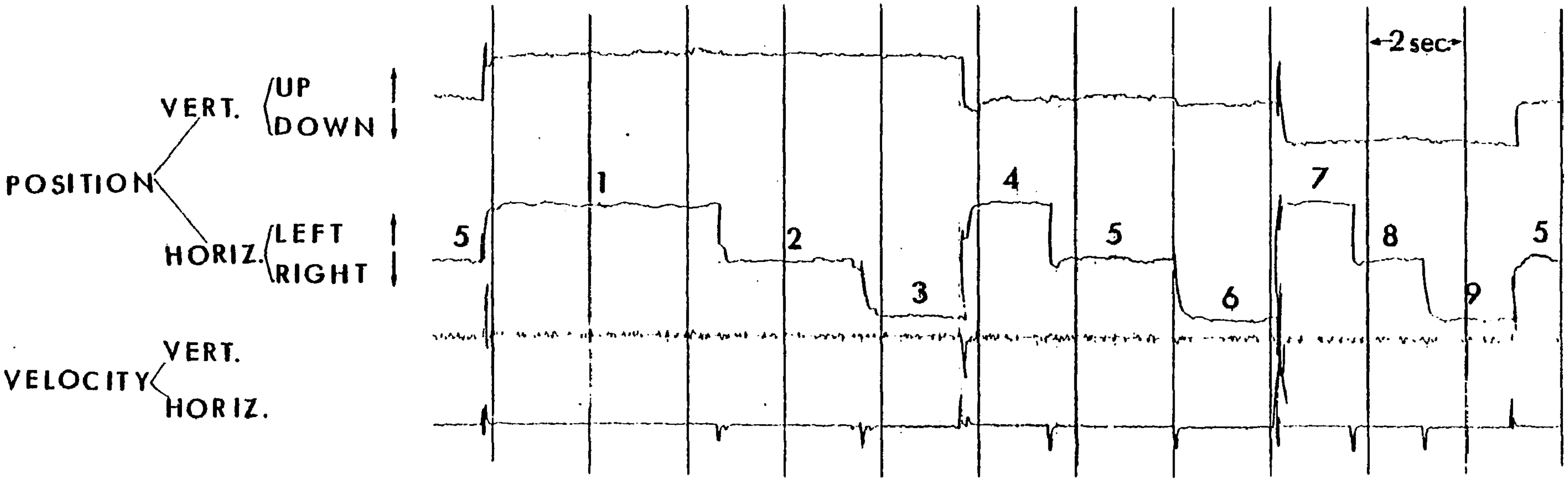


Figure V. Eye movement polygraph trace induced by the calibration pattern (Dyslexic child, D.K.). The DC coupled recordings (upper trace) were used to calibrate position, so that a deflection in mm. could be equated to a specific subtended visual angle for each child. Measurements of time, i.e., search time, latency, etc., could also be ascertained. The RC coupled recordings (lower traces) were used to eliminate high velocity artifacts, and as a check for change in eye position.

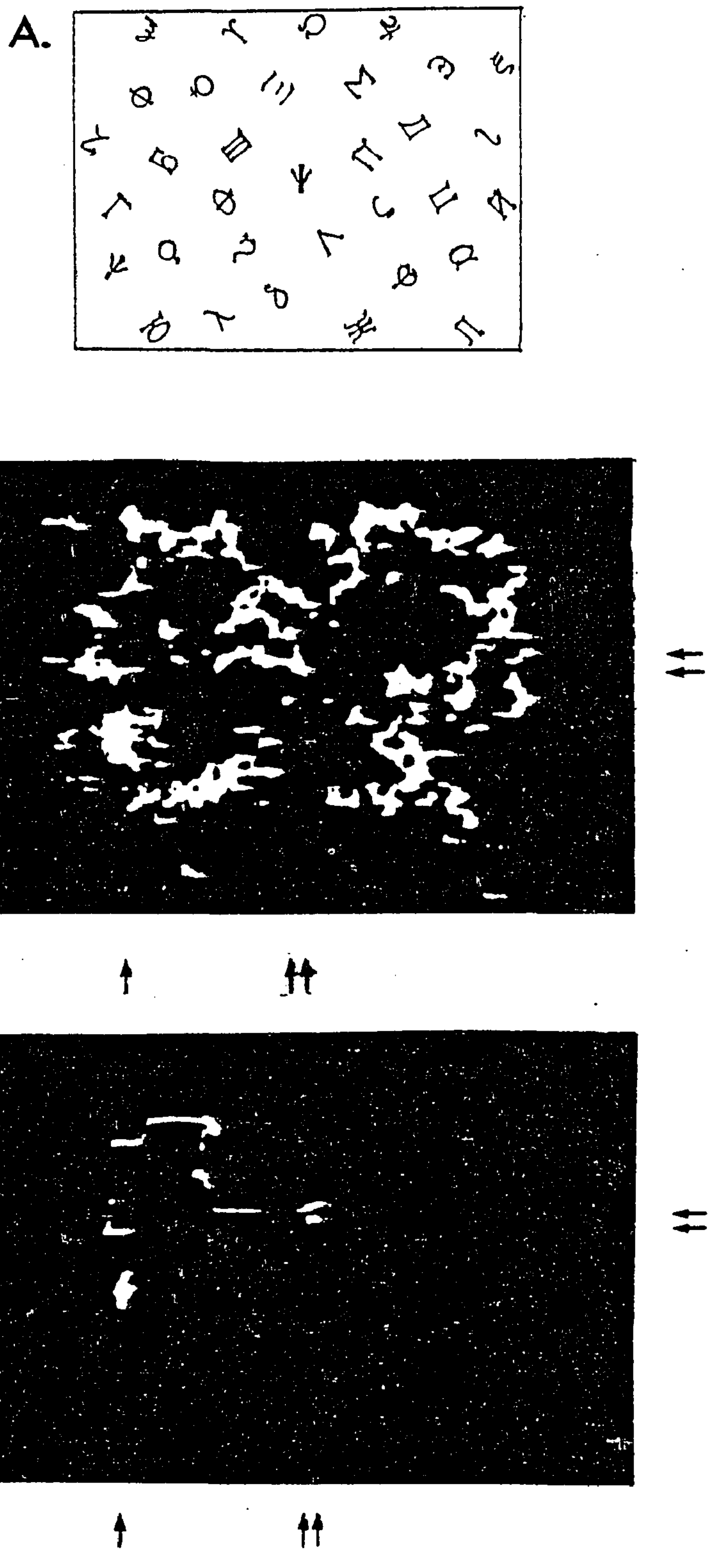


Figure W. Visual search patterns of the ψ T array (A) by a dyslexic (B) and control child (C). The single arrows are the coordinates for the ψ target and the double arrows represent the position of the central standard ( ψ ).

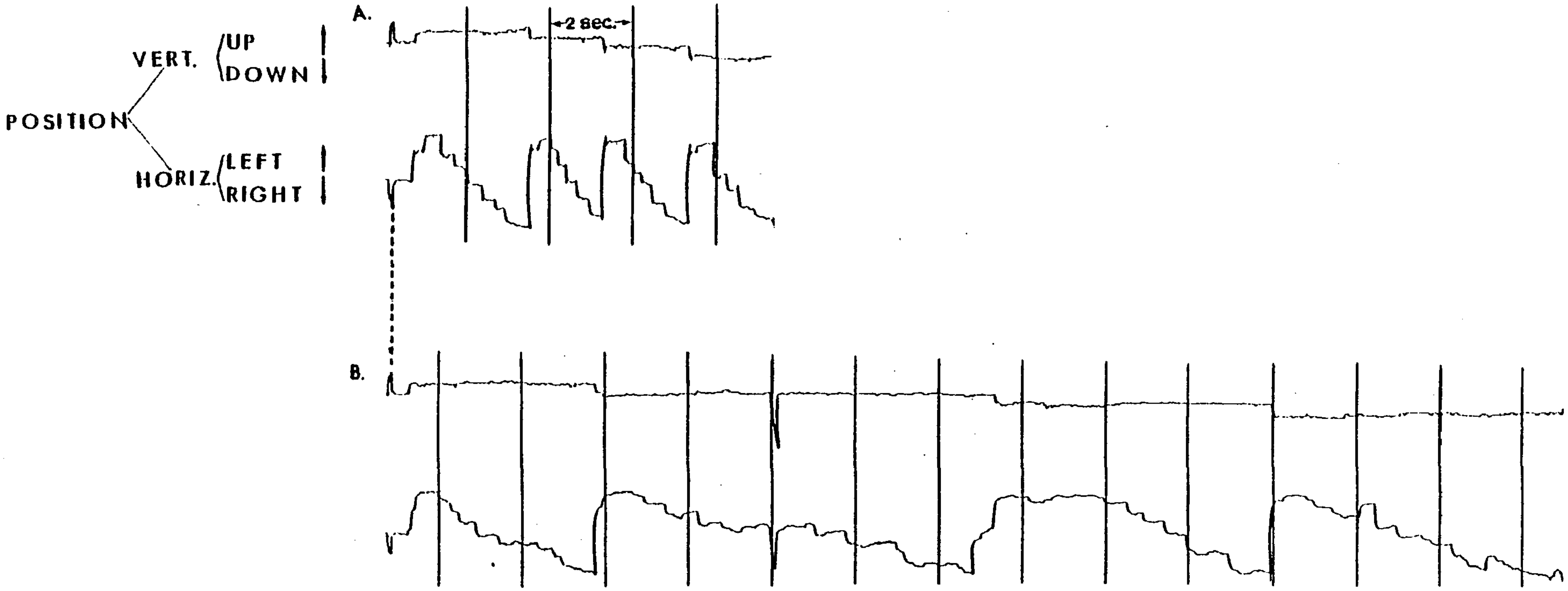


Figure X. Polygraph trace of a control child (A) and a dyslexic child (B) during reading (Subtest II). Note the significantly longer reading time, and the greater number of fixations and leftward eye movements in the record of the dyslexic child (B.A.) than the normal reader (E.D.).

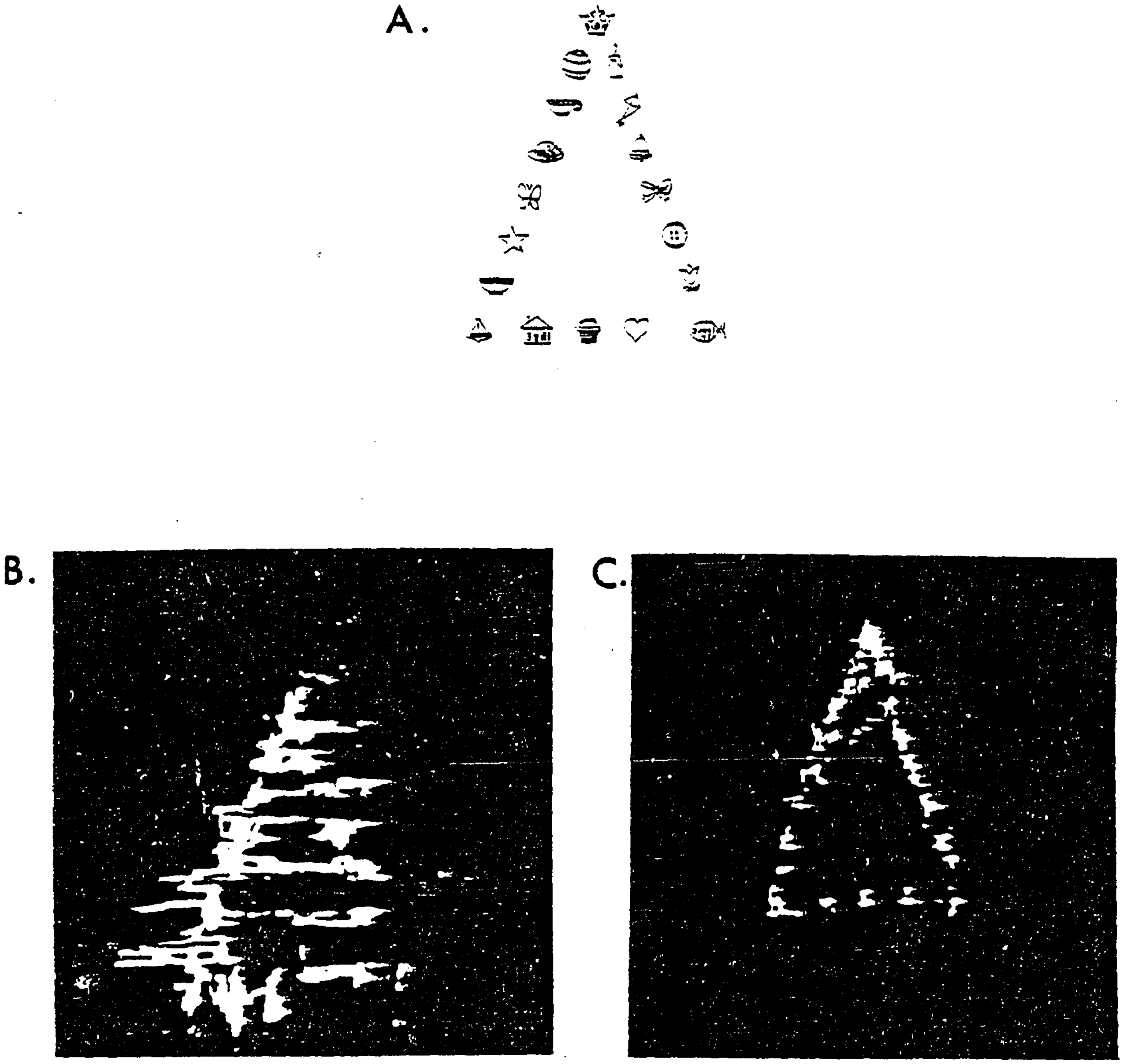


Figure Y. Examples of a "reading" (B) and a triangular (C) visual scan of the Elkind triangle (A). The "reading" scan is by a normal reader (W.F.) while the triangular scan is by a dyslexic child (K.S.).

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