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City University of New York, 1989

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UNIMANUAL AND BIMANUAL VISUOMOTOR TRACKING
BY DYSLEXIC AND NORMAL CHILDREN

by

CHARLOTTE ANNE TOMAINO

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.

1989

This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

September 24, 1989 L J Gerstman

Date Chairman of Examining Committee

September 27, 1989 Herbert D. Saltzstein

Date Executive Officer

Judith Marti Baumrin, Ph.D
Martha Bridge Denckla, M.D
Stanley Habib, Ph.D.
Jane M. Healey, Ph.D

Supervisory Committee

The City University of New York

Abstract

UNIMANUAL AND BIMANUAL VISUOMOTOR TRACKING BY DYSLEXIC AND NORMAL CHILDREN

by

Charlotte A. Tomaino

Adviser: Professor Louis J. Gerstman

The purpose of this study is to examine the development of unimanual and bimanual motor skills of dyslexic children and compare their abilities with age/IQ matched normal readers and reading matched younger readers. Hypotheses were generated to examine the development of motor function as it relates to right/left differences, use of visual feedback, effects of direction of overflow in bimanual tasks and effects of direction of hand movement in bimmanual coordination. The study also investigates the hypotheses suggesting that adolescents with poor reading ability will be characterized by bimanual motor skills below age expectancy and perform similarly to young children who have not as yet developed these skills due to incomplete neurological development such as myelinization of the corpus callosum.

In Experiment I, (unimanual skill) subjects manipulated a joystick for visuomotor tracking on a computerized video game. Dyslexics were significantly

superior in both accuracy and speed to normal readers and demonstrated a significantly greater difference between right and left hand performance. In Experiment II, (bimanual skills) subjects simultaneously manipulated two potentiometer knobs on an Etch-a-Sketch like mechanism controling the horizontal and vertical movement of the cursor on the computer monitor. The dyslexics remained faster but were no longer superior in accuracy. When the bimanual task was performed without visual feedback, dyslexic performance was no longer superior but was equal to normal controls in both accuracy and speed.

This finding argues against previously hypothesized perceptual-motor deficiency in dyslexia. The results of these three experimental tasks indicate that this pure dyslexic group is not equal to, nor deficient in perceptual motor skill, but is superior in the perceptual ability guiding their fine motor function. This conclusion argues that the differences between the dyslexic and age matched readers are in a perceptual superiority rather than a perceptual-motor deficiency.

Dyslexics were also compared to younger normal readers. Although the dyslexics performance was superior to younger readers in both experiments, arguing against interhemispheric collaboration difficulties in dyslexia, a subgroup of dyslexics

(8/23) displayed similar characteristics to the younger readers in the quality of their bimanual motor function which was never observed in older readers. Developmental interpretations, implications for educational practice and directions for future research are discussed.

ACKNOWLEDGEMENTS

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CHAPTER I

THE PROBLEM - RATIONALE FOR THE STUDY

Specific Aims of the Research

The proposed research focuses on the development of fine motor skills in dyslexic and normal reading boys. This includes both perceptual motor skill in precise movement of each hand separately and coordination of the two hands in unison, with and without the assistance of visual feedback. Examination of the development of bimanual skill in dyslexics, which requires the cooperative interaction of the right and left hemispheres through the corpus callosum, is a method for studying the relationship of interhemispheric cooperation to the acquisition of reading skills. Support for this method has been established since bilateral coactivation has been found to be deficient in three populations, partial commissurotomy patients (Preilowski, 1972), young children prior to the age of mylelinization of the corpus callosum (Fagard, 1985; Jeeves, 1988), and acallosals (Jeeves, 1988).

This study will investigate the hypothesis that adolescents with poor reading ability are characterized by bimanual motor skills below age expectancy and perform similarly to young children who have not as yet developed these skills due to incomplete neuronal development such as myelinization of the corpus callosum. The specific aims of this study are three-fold: First, to demonstrate the validity of a computerized task in assessing unimanual and bimanual fine motor and visuospatial skill; Second, to demonstrate differences in manual interhemispheric cooperation skills between younger and older children; Third, to evaluate these skills in older children with reading failure.

Questions Raised by this Problem

1. Can the developmental acquisition of fine motor unimanual and bimanual skills be measured on a computerized task utilizing visual feedback and differentiate between normal children between 7 and 16 years of age?

2. Do reading disabled children differ from age-matched normal readers in either fine motor control engaging the hands seperately or in bimanual coordination?

3. Do the bimanual coordination skills of dyslexic children resemble those of younger, normal readers?

Problems in the Assessment of Fine Motor Skills

The problem addressed in this study is twofold. The first aspect is the development of a method for assessing fine motor skill that is designed to be ecologically relevant and can deal with some of the current assessment limitations encountered in clinical settings. Second, the availability of a method for assessing fine motor, unimanual and bimanual skills would allow for the further understanding of the development of those skills in normal children and the investigation of possible motor deficits in research populations. Specifically, this study is concerned with the perceptual motor difficulties or eye-hand problems observed in developmentally dyslexic children (Critchley, 1970; Benton, 1978) and with obtaining measures of these motor skills on a computerized task. It is argued that certain bimanual coordination deficits that are often observed in dyslexic populations are due to immature maturation or inadequate development of either callosal pathways or the underlying neural systems that transmit information between the hemispheres. Further, it is suggested that a primary difficulty lies in the callosal function of corollary inhibition or the ability of the hemispheres to share information while shielding or inhibiting motor irradiations or 'overflow', that is necessary to sustain certain fine coordinative acts. Although the use of complex computerized equipment that is proposed here, limits the general availability of this assessment measure, it is expected that its high level of precision in measuring accuracy and speed and the incorporation of visual feedback in motor regulation will make this method a valuable research tool.

The challenge of the first problem is to employ a method of assessment for fine motor skills which is relevant to both daily motoric functioning and the clinical problems reported regarding poor motor coordination in dyslexics. It is clearly not possible to replicate the environments of daily living for research purposes. However, the proposed method in this study attempts to simulate aspects of real-life motor tasks by utilizing a task that combines visual feedback with considerable precision in the execution of fine motor skills. The task is similar to graphomotor tasks, the manipulation and construction of small objects or pieces of objects, etc. and allows for obtaining measures of both accuracy and speed. The use of sensory feedback or knowledge of results is, of course, an integral part of most fine motor tasks and thus argues for the importance of utilizing assessment procedures that include the use of feedback.

Specific problems in assessment of motor skills include both the validity of the assessment measure for its stated purpose and the reliability of the assessment over time. For instance, subtle anomalies in motor development have been observed in dyslexic and learning disabled populations (Tomaino, 1986) and have been shown to be prevalent in populations with other signs of cerebral dysfunction (Mass, 1985; Tupper, 1987). However, the question of the relevance of these signs of motor dysfunction for the execution of fine motor tasks in daily living remains unclear, limiting the assessments' prognostic utility. In addition, reliability difficulties in assessing speed of performance have been described (Shaffer, 1983) and include such concerns as the effect of examiner reaction time in starting and stopping the timing mechanism. Similarly, problems in assessing accuracy of motor movements include variability in clinical judgement and difficulty in establishing sufficiently high interater reliability.

Since a low correlation has generally been found between abnormalities on clinical examination of motor skill and functional athletic ability (Denckla, 1985) it appears that often clinical findings cannot be used to extrapolate to real-life skills. Consequently, the use of a computerized assessment method which engages very precise unimanual and bimanual fine motor skill guided by visual feedback is an attempt to replicate some of the characteristics of real-life fine motor tasks while minimizing clinical reliability obstacles.

Clinical Significance of Assessment of Motor Function

The clinical significance for assessment of fine motor skill is a question of current debate (Szatmari, 1984), particularly in relation to the diagnostic implications. It is well established in the literature that motor incoordination may be an indicator of cerebral dysfunction and has been associated with specific populations such as hyperactive children (Cantwell, 1977).

Motor incoordination has been the most frequently found neurological sign (Werry, 1972) in hyperactive groups. Clumsy children have been of particular interest due to associations between behavior, learning problems and poor motor coordination (Walton, 1962; Gubbay, 1965). Of all neurological signs, motor incoordination is the one most frequently found in children with behavioral disorders and learning disabilities (Rutter, 1970; Nichols, 1980).

With regard to motor incoordination that is specific to dyslexic populations, research findings suggest substantial clinical significance. Owen (1971) found poor alternating finger movements and graphomotor skills in design copying to be the primary discriminators in screening an entire town of reading delayed children, same sex, normal reading siblings and same age normal readers. Similarly, Denckla (1980) found dyslexics prior to 10 years of age to have the greatest difficulty on a map walking test when compared to other learning disabled children and normally reading controls. One particularly difficult aspect of interpreting these findings lies in the considerable difference between these motor tasks. In other words, graphomotor skill and map walking rely heavily on visuospatial ability to guide the fine and gross motor movement. Alternatively, alternating finger movments are "driven" by motor programs that engage a sequence of movements. Consequently, the underlying nature of the specific motor tasks may indicate differences in the etiology of the difficulty.

Since the presence of neurological soft signs are also frequently associated with Attention Deficit Disorder and behavioral difficulties, (Szatmari, 1984) and have been found to be conspicuously absent in a subtype of Pure Dyslexia (Symmes, 1972; Denckla, 1985) attention has turned to other measures of motor function in the learning disabled populations. On motor examination of pure dyslexics who were screened for ADD (Denckla, 1985), speed of repetitive and alternating movements were not found to be particularly slow like the unscreened dyslexic group. Rather, pure dyslexics were found to be faster than controls on several tasks. The distinguishing characteristics of the dyslexic subjects in this study was a tendency toward a large right-left difference. That is, the tendency of dyslexics was for movements on the left side to be excessively slow compared to controls.

This finding is consistent with results reported by Badian (1977). On an alternating tapping task which also engages motor programs for repetitive alternating movement of the hands but relies on auditory feedback from a metronome, dyslexics were also found to have left hand inferiority when performing without feedback. Arguments have been made that a left side slowing suggests a delay in interhemispheric cooperation. Since motor programs for planned sequential movement are thought to originate in the left hemisphere (Kimura, 1974), a slower left hand response, which is localized further away from the origination of the action in the central nervous system, would be expected to be most vulnerable in executing the task. Therefore, a slower left hand response may be caused by the inefficient transfer of motor programs from the left hemisphere to the right hemisphere, directing the precise movements of the left hand.

Wolff (1984), based on findings of deficient left hand movement in an alternating tapping task, proposes that motor tasks reflecting collaboration between the hemispheres best characterize motor anomalies related to reading failure. In addition, a series of studies (Preilowski, 1972; Fagard, 1985; Jeeves, 1988) have demonstrated that a task requiring interlimb coordination discriminates between normal controls and commissurotomy patients, acollosals and young children prior to the age of maturation of the corpus callosum and is a method of assessing interhemispheric collaboration. Consequently, obtaining assessment measures of unimanual and bimanual motor function on a pure dyslexic population has clinical significance for both further understanding of neurodevelopmental models of dyslexia and exploring greater ecological and prognostic relevance in motor assessment.

This study will conduct two experiments employing a computerized, fine motor assessment method. The first experiment will assess the unimanual fine motor skill of dyslexic and normal children. The second experiment will examine bimanual coordination of these subjects in an attempt to obtain a measure of interhemispheric collaboration.

CHAPTER II

RELATED LITERATURE

Reading Failure: Defining Dyslexia

Attempts to understand the failure of some children to develop the cognitively complex skill of reading has been the focus of research for over 90 years (Morgan, 1896). Orton (1928) noted that children who exhibit severe reading problems often reversed letters and symbols. He attributed this to competition between the hemispheres due to the fact that cerebral dominance had not been established. Drew (1956) proposed that selective reading disability was caused by a delay in development of the parietal lobe. Kinsbourne (1973) suggested that selective reading disability may be due to a developmental lag that is ultimately made good, but nonetheless does not allow the child to escape the reading failure and emotional resistances to reading which accompany failure.

Current thinking about dyslexia attempts to integrate the many studies on error patterns in reading and spelling, cognitive abilities, neurological abnormalities, neuroanatomical organization and electrophysiological differences (Benton, 1978). Theory relating brain structures to specific sensory and cognitive functions (Luria, 1980) has facilitated this integration. The diagnosis of Minimal Brain Dysfunction was such an attempt to associate academic, cognitive and neurological abnormalities (Denckla, 1978).

Dyslexia is now considered a heterogeneous disorder with numerous subtypes identified (Kinsbourne, 1963; Mattis, 1975; Boder, 1973). Maliphant (1974), in his review of the experimental research literature on reading failure, discussed evidence of 20 different cognitive processes found to impair reading. At that time, studies examining the cognitive abilities of poor readers focused on the many aspects of acuity and speed in visual perception, sound/symbol associations, sequential processing and auditory/visual integration and such higher order processing as semantic and syntactic features. Such demonstrations of the complexity of the skill of reading suggests the notion of multiple etiologies for reading failure. However, current dyslexia research suggests that linguistic and phonological problems are the most frequent and most influential cognitive deficits related to reading failure (Vellutino, 1978; Tallal, 1974; Wolf, 1980; Rudel, 1985).

Motor Function and Dyslexia

As the wide variability in the cognitive characteristics which accompany dyslexia became a means of identifying particular subtypes (Mattis, 1975; Denckla, 1978), motor abnormalities, often termed neurological soft signs, also emerged as related to specific learning disabilities. Since research findings on adults with localized lesions suggests that both skilled hand movements and language processes are preferentially programmed in the left cerebral hemisphere (Hammond, 1982; Kimura, 1977; Levy, 1973), motor abnormalities of dyslexics have been of interest (Annett, 1973).

Research studies examining neurological soft signs in poor readers have discussed five types of motor abnormalities: choreiform movements, unusually slow-rate of movement, synkinesis or overflow movement, mirror movements and dyspraxia. Choreiform movements were initially described by Prechtl (1962) as slightly jerky movements which occur quite irregularly and arhythmically in fingers, hands, neck, head, arms, legs and feet. They are characterized by their sudden occurrence and short duration and have been found to correlate with complications of pregnancy, unrestrained behavior, clumsiness, poor concentration and reading failure. Prechtl proposed that impulses which are transmitted to the nervous system are rendered slightly false or inadequate by these movements and affect the child's relationship to the environment. Most of these findings were replicated by Rutter (1966) and Wolff (1966) but were found to correlate with learning disabilities, not specifically with reading failure.

Assessment of the rate of fine motor movements requires determining the length of time to perform repetitive and alternating movement of the feet, hands and fingers on a standardized battery of tasks while evaluating the quality and rhythmicity of the movement. Slowness in rate of repetitive and sequential movements have been found to correlate with reading failure. Owen (1971) found that poor rapid alternating finger movements were the sole finding distinguishing a developmentally reading disabled group from controls in a sample of the children from the entire town of Palo Alto, California. Similarly, Rudel (1985) reports significant slowing of repetitive movements in a group of dyslexic boys. There was also a greater difference between left and right sided movements among the poor readers, with the left side movements much slower. Additional studies which employed measures of rate of movement as well as other neurological soft signs have also found an increased incidence among dyslexic and learning disabled populations (Peters, 1975; Adams, 1974; Nichols, 1981).

Synkinesis (also called associated or overflow movements) refer to motor irradiations or movements that are outside the subject's awareness and accompany, but are not necessary for the performance of an intended action. Examples of synkinesis would include movement of the lips or mouth during execution of a fine motor task with the hands or unconscious movement of the fingers of the left hand while manipulating the fingers of the right hand. Such overflow movements decrease with age (Wolff, 1983) but persist in children and adults with known neurological damage (Woods, 1978; Nass, 1985). Dennis (1976) describes associated movements in individuals with agenesis of the coropus callosum. She suggests from this finding that the corpus callosum might enhance the specificity of motor cortex action by helping to suppress or inhibit superfluous movements. Other studies (Kinsbourne, 1974, 1982; Lazarus, 1987) likewise argue for an inhibiting role in the corpus callosum since the amplitude of associated movements diminishes with increasing age and mylination of callosal fibers. Although the term inhibition is not always used precisely in the literature examining functions of the corpus callosum, it has a neurologically specific meaning. On neurological exam, inhibition indicates the prevention of extraneous or unintended movements in inactive body parts during execution of a particular intended movement (i.e., preventing the right hand or foot from moving while tapping with the left). Evidence of a possible relationship between synkinesis and reading failure is suggested in some studies (Cohen, 1967; Ingram, 1970; Szatmari, 1984).

Overflow movements are distinguished from mirror movements, which are characterized by involuntary movements executed by one side of the body that exactly replicate a movement on the other side of the body (Schott, 1981). Mirror movements that predominantly involve the hands, increase with the amount of effort expended in the intended movement and can be suppressed only partially. Mirror movements have not been associated with reading failure per se, but have been observed in the presence of neurological disorders which are congenital or acquired (Woods, 1978) and are commonly observed in the early stages of development.

Finally, the term dyspraxia is frequently used to describe minor motor abnormalities. Since this is a general term referring to impaired coordination of movement and not referring to a specific type of abnormal motor movement its use may include any of the soft signs previously discussed. The terms clumsy, uncoordinated, dyspraxic are frequently used when describing dyslexic children. However, no causal or incidental relationship between movement characterized by these terms and dyslexia has been established (Benton, 1975).

Since reading is such a complex skill requiring both linguistic and visual-perceptual abilities, both hemispheres and involvement of many regions within hemispheres are engaged. Gaddes (1980) points out that reading circuits in the brain are extremely complex and emphasizes "There are most likely as many types of selective reading disability as there are loci of cerebral lesions in this circuit and its contiguous brain tissue." (p. 242) The subtype literature further describes differences in the cognitive profiles of dyslexics.

Motor abnormalities have been found to frequently accompany dyslexia, hyperactivity, poor concentration and behavior disorders. However, they were conspicuously absent in a Pure Dyslexia subtype identified by screening for all other abnormalities (Symmes and Rapoport, 1972). Subjects were screened for all other contributing deficits such as sensory impairment, history of chronic illness or serious accident, seizures or any of the prenatal or perinatal conditions relating to fetal anoxia and thus to neurological high risk. Subjects were likewise screened for psychiatric, socioeconomic and educational contributing factors.

Although the distinction between specific subtypes among dyslexics has been well established (Kinsbourne, 1963; Mattis, 1975; Denckla, 1977; Boder, 1973) little research is available on further describing the distinct characteristics of these subtypes, particularly in relation to motor function. However, two studies do address this issue. The absence of motor abnormalities in Pure Dyslexia was first established by Symmes and Rappaport (1972). One study (Denckla, 1985), examining motor function of Pure Dyslexics screened for ADD and other contributing abnormalities, found dyslexics to be superior to normals in speed of repetitive and alternating movements. The distinguishing characteristics of the dyslexic subjects in this study was a tendency toward a large right-left difference. That is, the tendency of dyslexics was for movements on the left side to be excessively slow compared to controls.

Another study (Leslie, 1985) examining the unimanual and bimanual motor function of dyslexics on sequential fine motor movements on the Purdue Pegboard used a dyslexic subtype (Mattis, 1975) with naming difficulty. A finding of particularly poor left hand performance differentiates dyslexics (9 to 12 yrs old) from controls. Leslie found a difference only in the unimanual condition and argues that this suggests problems in interhemispheric collaboration to the extent that the left hemisphere controls fine manual dexterity and planned sequential action (Geschwind, 1975; Heilman, 1979; Kimura, 1977; Kimura, 1974). In other words, poor left hand performance might be due to inadequate transfer of left hemisphere motor programs to the right hemisphere for execution with the left hand. Alternative explanations like faulty right hemisphere functioning or faulty motor learning were ruled out.

This finding is consistent with Denckla's (1985) report of greater slowing in the left hand of a Pure Dyslexic group executing sequential finger movements (although the tasks differ in the type of muscle groups engaged, they both employ repetitive, sequential movements thought to be generated by the left hemisphere). Leslie further reports a difference between the groups on the pattern of correlations between the unimanual and bimanual tasks. From this she argues that the groups employed different strategies in executing the tasks. Thus, her argument for differences in interhemispheric collaboration is based on defining the particular task demands, here being sequential motor movement, citing the literature indicating left hemisphere specialization for planned sequential fine motor action and the evidence of differences in performance and strategy in the dyslexic and control subjects.

Findings of such variability in the cognitive abilities and deficits of dyslexics support a multiple-antecedent, multiple consequent model (Wiener and Cromer, 1967) which assumes that different antecedents or cognitive deficits will have different consequences such as unique error patterns. This study examines one model of reading failure and argues for the necessity of efficient transmission through neural connections between and within hemispheres in the brain in order to employ compensatory skills and integrate all the complex cognitive functions engaged in skilled reading.

Left Hemisphere Model of Reading Failure

Two prominent models of developmental reading failure, the Left Hemisphere Model and the Interhemispheric Collaboration Model, differ in what each regards as the hypothesized underlying neural dysfunction. The first, the Left Hemisphere Model, is based on evidence that both language processes and skilled hand movements are preferentially programed in the left cerebral hemisphere (Hammond, 1982; Kimura, 1977; Levy, 1973). Thus, this model relates reading failure to language disorders (Vellutino, 1978; Liberman, 1976; Vogel, 1974; Rudel, 1985; Denckla, 1976) and motor defecits (Annett, 1973; Corkin, 1974; Rudel, 1985) attributed to the left hemisphere.

Poor readers have been found to have receptive and expressive language delays (Orton, 1937), impaired word finding (Wolf, 1980; Rudel, 1985) slowed automatized naming (Denckla, 1976), poor learning of verbal absurdities, phonic structure, syntax and semantic processing (Vellutino, 1978; Liberman, 1976; Vogel, 1974; Voller, 1976). Deficits in temporal order perception (Senf, 1969; Bakker, 1972: and slower rate of phonological discrimination (Tallal, 1974) have also been related to the language impairment observed in dyslexic children.

Motor anomalies associated with language disorders have been demonstrated in Annett's finding (1973) of speed of foot movement being correlated with vocabulary and the poor performance of dyslexics on movement sequences (Corkin, 1974). Similarly, the findings from studies suggesting poorer left hand performance in dyslexics (Leslie, 1985) and greater right-left differences in dyslexics (Rudel, 1985) demonstrate the importance of obtaining precise measures of speed and accuracy in assessing the single hand motor function of dyslexic subjects and will be the focus of Experiment I in this study. The findings from these studies which demonstrate differences in unimanual motor function in pure dyslexic subjects have been influential in the design of the first experiment testing unimanual motor coordination with visual feedback.

Interhemispheric Collaboration Model of Reading Failure

The second, or Interhemispheric Collaboration Model, suggests that reading is not strictly a left hemisphere function but requires collaboration of both hemispheres (Gazzaniga, 1973; Myklebust, 1975). Other researches have speculated that delays in myelination of the cerebral commissures (specifically the corpus callosum), may limit the ability of the hemispheres to integrate information necessary for reading, and may account for one subtype of dyslexia (Evans, 1978; Blau, 1977; Valett, 1980; Pirozzolo, 1979; Cermak, 1981). At present, not enough research data has been replicated to support or rule out interhemispheric integration as a contributor to dyslexia.

Best (1985) reviews the related literature supporting this view and proposes a theoretical argument. She argues against the alexia-dyslexia analogy and criticizes the logic underlying interpretations of findings of left hemisphere differences in dyslexia. Quoting Orton (1937) and Geshwind (1962), Gladstone and Best (1985) address the limits of the analogy between the adult alexic and the developmentally dyslexic child.

"The primary difficulty with the analogy is that it ignores the word developmental in developmental dyslexia. It assumes an equivalence between the mature performance of an acquired skill and acquisition of that skill. This violates two important neuropsychological concepts: developmental plasticity and the dynamic nature of neural activity."

Presenting evidence for the Interhemispheric Collaboration Model, they focus primarily on the cognitive and neurological differences between the acquisition of a skill and the performance of the skill once it is acquired as the essential argument for considering interhemispheric collaboration to be a prominent factor in dyslexia. They use Goldberg and Costa's (1981) model as one possible explanation for how complex cognitive skills are acquired and eventually lateralized. In this model, complex novel stimuli are initially encoded in the right hemisphere with a shift of knowledge acquisition to the left hemisphere while building a linguistically coded descriptive system.

"Within this model, reading acquisition, which may be viewed as the imposition of a novel visual code on an established auditory-linguistic code, would be predicted to show this right-to left-hemisphere shift. Goldberg and Costa (1981) propose that a general right to left shift occurs during the acquisition of any skill. To make the argument specific to reading acquisition, written letters (orthography) would constitute abstract, intrinsically meaningless visuospatial forms to a beginning reader. Perception of meaningless visuospatial figures typically shows a right-hemisphere advantage (e.g., Kimura, 1966), whereas perception of the auditory-linguistic components in spoken and written language (phonics) shows a left-hemisphere bias (Kimura, 1961). If Goldberg and Costa's general argument is correct, then the early acquisition of reading skill would be expected to rely heavily on communication between the hemispheres, with decreased amounts of collaboration necessary as the skill developed. For the adult, reading would be expected to show a left-hemisphere advantage because the visual units have become familiar symbols that are linguistically coded. Consistent with these notions, Gordon and Carmon (1976) have demonstrated a shift from right-to left-hemisphere advantage for a task that required learning names for unfamiliar visual symbols."

Further support for the importance of interhemispheric collaboration in reading exists throughout the neuropsychological literature. Gazzaniga (1973) stated that reading is a process that requires the transfer of information between the cerebral hemispheres and has suggested that some aspects of minimal brain dysfunction reflect problems in the shuttling of information between various specialized processing centers in the brain. Myklebust (1975) also has suggested that the primary deficit of some dyslexic children is impairment of the ability of one hemisphere to communicate with the other, reflected cognitively by the child's inabilty to convert verbal learning (left hemisphere) into nonverbal form. Gazzaniga (1973) posits that when there is inadequate inhibition between the hemispheres, cerebral dominance and specialization fail to develop and the response of one half of the brain interferes with the responding of the other, preventing the overall efficiency of the collaboration process.

Given the many linguistic abilities that the right hemisphere is capable of displaying (Coltheart, 1983), including the perception and production of spoken language and specific reading skills (Zaidel, 1982; Groves, 1981; Lassen, 1978), the Interhemispheric Collaboration Model holds that the collaboration of the two hemispheres through the corpus callosum plays an essential role in the reading process.

To date this model is based on theoretical reasoning and nonreplicated experimental studies. Research studies focusing specifically on interhemispheric function related to reading have employed a variety of methods in examining this model and the role of the corpus callosum in cognitive function.

One series of experiments focuses on interhemispheric transfer in dyslexic subjects and is based on Geschwind's concept of connection-disconnection. They were designed to investigate the hypothesis that developmental dyslexia could be attributed to interhemispheric transfer deficits (Rudel, 1974; Rudel, 1977; Vellutino, 1978; Vellutino, 1983; Broman, 1985). Rudel (1974) looked at the discrimination and learning of Braille configurations and found that performance, responding "same/different" while palpating the Braille configuration, was better using the left hand of right handed normal children over 10 years of age. Vellutino (1978) presented poor and normal readers with Chinese ideographs through tachistoscopic images to one visual field. The ideographs were paired with common English words for the children to learn. It was predicted that presentation to the right hemisphere should discriminate between poor and normal readers if interhemispheric transfer was inhibiting the reading process. This was not the case. Normal readers were better at learning the word/symbol association in both conditions of right and left hemisphere presentation. Similarly, there was no indication of an interhemispheric transfer deficit in poor readers with detection of simple dots presented to right and left visual fields (Vellutino, 1983).

Four experiments by Rudel (Broman, et. al., 1985) looked at manual reaction times to the simple stimuli of tones and dots. When presented to both hemispheres simultaneously, to individual hemispheres and to the opposite hemisphere of the responding hand of normal and poor readers, bilateral presentation yielded faster reaction times. However, there was no consistent right-left difference or consistent superiority of the intra-vs. inter-hemispheric reaction times of either of the groups.

Subsequent experiments, stemming from this finding, were based on the possibility that simple tone and dot stimuli may be processed subcortically, and may be bypassing the cortical association areas involved in reading. A similar study, using tachistoscopic presentation of single letters, measured reaction times and errors to stimuli presented on the same side as the responding hand or the opposite side. Reaction times were not significantly longer for the poor readers group, nor did they make more errors in the crossed condition. However, poor readers were selectively faster and made more errors in the right hand condition. Thus, this series of experiments did not find evidence of interhemispheric transfer deficits in dyslexics.

In an interhemispheric collaboration study by Neff (1986), she argues that "Studies are needed to focus on an age range that spans a period of years when interhemispheric communication ability is supposedly developing, and that examines the three known components of the communication process (transfer, inhibition and ability to screen out interference)." (p. 5) She utilizes a cross sectional comparison of normal and poor readers with five tasks requiring no language but engaging within hemisphere and between hemisphere processing of perceptual, motor and visuospatial stimuli. The tasks included texture matching (Galin, 1974), motor control of finger movements (Rey, 1941; Kinsbourne, 1973), finger localization (Galin, 1974) and maze learning. The expected performance increment with increasing age was found in the normal readers, age 3 to 11, looking at a ratio of crossed vs. uncrossed errors. The dyslexic children, age 11 to 15, resembled younger normal children in overall level of correct response and in the ratio of crossed to uncrossed errors. Performance of the poor readers approximated that of the normal readers who were 4 to 6 years younger than themselves and showed improvement with age within the dyslexic group.

Since the dyslexic deficencies observed in nonverbal tasks were based on delayed interhemispheric collaboration ability in execution of motor function, she argues for the importance of further study in determining the role of this function in dyslexia. In addition, she argues for the necessity of using a research design with broader age range and tasks specific to interhemispheric transfer, classical inhibition and ability to screen out interference which may be more readily observed in simple nonverbal tasks. The findings in this study point to the difference between simple interhemispheric transfer of information in simple verbal tasks and the more complex functions required in interhemispheric collaboration for execution of motor tasks where greater shielding and sharing of information is required.

Such findings on interhemispheric function in dyslexia have also led to examination of the literature on the role of the corpus callosum in cognitive function. The similarity of motor deficiencies in bimanual synchronization reported among adults with surgical separation of the corpus callosum or callosal agenesis (Dennis, 1976; Kreuter, 1972; Ferriss, 1975; Zaidel, 1977) and subjects with reading failure (Klicpera, 1981) further supports this model. This literature suggests that, under normal conditions, the callosal pathways may serve to regulate the motor outflow necessary for bimanual synchronization while inhibiting overflow movements from the opposite hemisphere which would interfere with bimanual coordination. Similarly, the callosal pathways may facilitate the integration of the many complex cognitive functions required in reading.

Another series of experiments focuses specifically on the bimanual coordination skills of dyslexics (Badian, 1977; Klicpera, 1981; Wolff, 1985). On a bimanual, sequential tapping task (Wolff, 1985), dyslexics were unable to maintain a rhythmic movement pattern when the auditory feedback of a metronome was removed. At high speeds of movement, adolescent, male dyslexics exhibited greater overall variability in performance and strayed further from the expected 2:1 intermanual ratio of movements which was paced by the metronome. Like the callostomy patients, they were unable to sustain independence in limb movements without feedback. Difficulty in preventing the momentarily inactive, non-leading hand (either right or left) from moving in unison with the active, leading hand suggests deficient inhibition of overflow movement through the corpus callosum. Since the dyslexic subjects compared to normal controls were unable to sustain this bimanual synchronized movement, the finding supports the hypothesis of poor interhemispheric collaboration among dyslexics.

Application of the Interhemispheric Collaboration Model findings from partial callostomy and acallosal subjects to the bimanual difficulties observed in dyslexics is limited by the differences in the nature of the tasks performed and the type of feedback available in each. In other words, both the task of bimanual tapping to a metronome and bimanual manipulation of a crank pen plotter with visual feedback require synchronization of the two hands and thus the two hemispheres based on sensory feedback. However, the differences between auditory and visual sensory feedback and the two distinct motor manipulations in the tasks also means differences in which neural pathways are engaged through the corpus callosum. Consequently, these differences limit inferences which can be drawn regarding comparable neurophysiological function.

Bimanual Skill Acquisition in Acallosal, Commissurotomy Subjects and Normal Controls

The findings from four studies that analyze the acquisition of bimanual motor skills (Preilowski, 1972; Fagard, 1985; Gladstone, 1985; Jeeves, 1988) have been influential in the design of the second experiment in this study testing bimanual skill and the formulation of these hypotheses. Three of these studies (Preilowski, 1972; Fagard, 1985; Jeeves, 1988) differ from this design in two ways. First, they analyze improvement in bimanual skills over repeated sessions of training where this study looks at performance on single trials. Second, they employ a bimanual task requiring movement of the limbs in turning a crank with each hand and arm rather than turning knobs with the fingers. This difference in the type of task for acquisition of a bimanual motor skill is of particular significance because engagement of the entire limb and hand using gross motor coordination have been found to be regulated by ipsilateral pathways of the pyramidal tract (Brinkman, 1972; Sperry, 1968; Geshwind, 1970) where fine motor movements of the distal musculature of the fingers is facilitated by contralateral pathways. All four of these studies tested subjects at different age ranges and no mention is made in any of these studies of screening subjects for ADD-Hyperactivity. Since children with ADD have been found to have increased overflow movements (Denckla 1978), this would be an important variable to control in matched samples on studies where precision of bimanual motor movement is measured.

Preilowski's (1978) results from testing adult partial callosal patients and adult normal controls on bimanual coordination skills indicate that initial phases of skill acquisition contain a variety of errors for all subjects, (i.e., turning in the wrong direction, with the wrong hand or at the wrong time). This initial inconsistency in performance led Preilowski (1977) to suggest that "from the beginner's first few trials no information can be gained about specific sensory motor mechanisms underlying the learning of a motor skill". However, once the basic movement pattern was mastered, the primary difficulty consisted in coordinating the movement of the 2 limbs at the correct rate for the angle being traced or "angular velocity". Alternation of action of the hands producing a stair step effect in the pathway being traced was typical of the partial callosal patients but not of normal control subjects. Progress in the acquisition of skill was more rapid in controls. All subjects performed better with visual feedback. With 500 trials of training, partial callosal subjects never reached the same level of performance as controls despite no differences in initial performance and equally extended practice.

Without visual feedback, partial callosals drifted toward equivalent rate of movement of the 2 hands on angles requiring different rates of movement. The greatest difficulty was observed in tracing an angle at 112.5' which required greater suppression of the action of the right hand in relation to faster action of the left hand. Conversely, performance improved at 157' under the reversed conditions where suppression of the left hand was necessary in relation to the greater action of the right hand. Preilowski reasoned that if the left hemisphere is dominant for motor programming, the predominant flow of inhibitory impulses through the commissures must be from the right hemisphere to the left. When the right hand must be slowed to coordinate with the faster movement of the left hand, the effects of the partial commissurotomy can be seen in less inhibition of movement and this explains the difference in performance on angles requiring different ratios of hand movement. (Note: Although the use of the term inhibition in this interpretation departs from the common neurological use of the concept of inhibition, it suggests that separation of the corpus callosum does not allow for suppression of irradiations from the right hemisphere and independent regulation of movement in the right hand.)

This shift toward equivalent rate of movement which occurs when visual feedback is withdrawn was interpreted by Preilowski (1977) as reflecting the absence of motor corollary outflow in subjects without intact interhemispheric pathways through the corpus callosum. He contrasts the execution of the task with and without visual feedback by arguing that with visual feedback immediate information to regulate the hands is available to both hemispheres. In contrast, without the visual feedback, he states, "In finely skilled coordination, however, they are handicapped since no direct exchange of information is possible between the hemispheres," because "...immediate information from the movements of one hand is not available to the other hand." Consequently, Preilowski posits that the difference in performance of partial callosal subjects and normals on this task suggests that the anterior commissures facilitate the interhemispheric interaction of motor corollary outflow. With this control mechanism eliminated, the partial callosal subjects were forced to rely on slower visual and proprioceptive feedback systems.

Fagard (1985), following the model used by Preilowski, tested normal children (7 year olds) and adults in the acquisition of bimanual motor skills. Initial performance revealed a similar pattern in the steps for learning described by Preilowski with an initial difficulty in establishing the motor sequence and then a tendency toward the equivalent rate of movement when inappropriate to the task. Establishing a correct, consistent movement pattern or mastering the angular velocity, which eliminated alternating hand movement and directional errors, took longer for children than adults. Fagard described errors related to angular velocity where the 2 hands must move at different rates. He described these errors as differing in kind from "true mirror movements" but suggests they are caused by motor irradiations affecting the fine tuning of movement necessary for precise angular velocity in the children. This argument implicates the immature corpus callosum in the childrens' inferior mastery of this interhemispheric task.

Equivalent rate movement demands (1:1 ratio), where the hands move in unison, characterized the condition which produced the most accurate performance in both groups. Movement of the hands at different rates produced errors or drift in the direction toward equivalent movement. Further, mastery of tracing an angle at 22' with greater movement of the right hand than left proved more difficult than the reverse at 67' for the children but not adult subjects. This finding is the reverse of Prielowski's results where the greatest difficulty occurred on angles requiring greater movement of the left hand and inhibition of the right hand.

Based on the findings of Preilowski and Fagard, Jeeves (1988) questioned the interhemispheric capacity of 6 year olds to perform a similar task in comparison to 10 year olds and adults because of their incomplete myelinization of the corpus callosum. Subjects also received training beyond that given in Fagard's study with 9 sessions of practice as compared to 4 sessions of practice given by Fagard.

For adults and 10 year olds with visual feedback, the angles requiring coordinated activity of the two hands did not produce significant differences in performance based on equivalent or different movement constraints. However, the 6 year olds showed significantly greater deviation on angles that required different ratios of simultaneous hand movements but did not differ from the others when the hands moved alternately or in exact unison. There was no difference in performance based on greater activity of one hand in relation to the other. In contrast, Jeeves reports that acallosals also tested (Jeeves, in press) exhibited significantly greater difficulty suppressing the right hand to coordinate with the greater activity of the left hand, replicating Preilowski's finding with partial commissurotomy subjects. For the 6 year olds, the data suggests the reverse. The mean deviation when suppressing the left hand is greater than when suppressing the right hand, but the difference is not statistically significant due to wide variability in the sample.

Bimanual Skill Acquisition in Dyslexics

Following the reasoning of Preilowski and Fagard, Gladstone (1985) utilized this model for interhemispheric collaboration in a study examining the interhemispheric skills of dyslexic boys, questioning the role of interhemispheric integration in reading. All dyslexic subjects were selected to meet the criterion of an anomic subtype of dyslexia (Mattis, 1975). Gladstone's design differed in several ways from the other studies. He compared age matched dyslexic and normal readers at 9 to 14 years of age on a task similar to that of Preilowski and Fagard. However, his apparatus only required use of the fingers to turn a knob rather than using the entire limb to turn a crank. In addition, Gladstone controlled for the possible influence of manual preference in skill acquisition by varying the control of horizontal and vertical movement of the pen. That is, "The position of the potentiometer controls were counterbalanced so that the left hand controlled the x axis for half of the subjects in each group, and the left hand controlled the y axis for the other half." Angles were traced in both the upper right and upper left spatial quadrants which included the angles used in both Preilowski's and Fagard's designs. Data was collected on single session performance rather than repeated training sessions.

No differences were found in comparing the performance of groups using one hand at a time on unimanual trials. However, when the two hands moved in unison, dyslexics were slower and/or less accurate in bimanual trials. These differences were found only on angles in the upper left quadrant where the two hands were required to turn in opposite directions (bidirectional) and were not exhibited on angles in the upper right quadrant where tracing required that the two hands turned in the same direction (unidirectional). This finding was present under both visual and no visual feedback conditions.

Gladstone further found that the poorer performance among the dyslexics was primarily due to the function of the left hand. Specifically, he reports group differences where the control subjects exhibit better left hand performance on the bidirectional angles as compared to unidirectional angles. However, dyslexics displayed poorer left as compared to their own right hand performance on bidirectional angles. Also, when visual feedback was removed, the dyslexics differed from controls by frequently reversing the direction which the left hand had been turning. This error was never observed in the age matched normal controls and persisted across trials despite knowledge of results.

The interpretation of this unique tendency of the dyslexics to reverse the direction of the left hand remains unclear. In contrast to Preilowski's statement that no information can be gained from the subjects first few trials of practice, Gladstone posits that the quality of errors on initial trials of bimanual motor skill acquisition discriminates between dyslexic and normal readers. From this finding, Gladstone suggests that "a strong movement preference for unidirectional coaction of the two hands existed among the impaired readers, and they had difficulty inhibiting this tendency" without the use of visual feedback. This difference between dyslexic and normal controls in bimanual coordination skills was interpreted as a manifestation of deficient interhemispheric communication. It is also consistent with the findings of Preilowski when partial commissurotomy subjects showed the greatest deficits on trials which preferentially relied on the input of the left hand.

Before interpretations of this finding based on neuroanatomical similarities or differences in the groups can be discussed, the influence of methodological characteristics of the study must be considered. Gladstone does not report whether the method of controlling for manual preference by having half of the subjects manipulating the horizontal and vertical with opposite hands also meant that only half of the subjects used the left hand to turn in a counterclockwise direction in the upper left quadrant. If this were the methodology employed, it would represent another variable for consideration in interpreting the finding that nearly half of the dyslexic subjects reversed the direction of movement of their left hand compared to no loss of direction among the controls. In other words, it raises the question of which group is making most of the errors. Were the nearly half of the dyslexic sample who made reversal errors all initially turning the left hand in the same direction before the visual feedback was removed? Similarly, there is no report of possible age effects in the sample. Since the age of this population includes boys during the years when myelinization of the corpus callosum is completing (Yakolev, 1967), these reversals in direction of movement may be attributable to the chronologically or maturationally younger dyslexic subjects. There is also no indication that subjects were screened for ADD/Hyperactivity which may account for greater overflow movement in some of the dyslexic subjects.

The similarity between the bimanual performance of callostomy patients and dyslexic boys is striking, but these and other differences in the procedures used in these studies limit inferences regarding comparable underlying neuropathology. Gladstone's study, for example, required subjects to manipulate 1.5 mm knobs, engaging the use of distal musculature only. In contrast, Preilowski's callostomy patients were required to use gross motor function engaging neural pathways for both distal and proximal muscles when turning the 6 mm crank handles. Such problems with research methods used to assess motor function are a source of concern, particularly in relation to sensitivity of instruments and reliability of findings (Shaffer, 1983; Szatmari, 1984). In addition, none of these studies (Preilowski, 1972; Fagard, 1985; Gladstone, 1985; Jeeves, 1988) screened the subjects for the presence of Attention Deficit Disorder with Hyperactivity (ADD-H) which has been found to be associated with a high incidence of motor anomalies involving slowed repetitive, sequential movements and excessive overflow movement (Denckla, 1978). These motor anomalies have been found to discriminate dyslexic groups with and without ADD-H (Denckla, 1985). Since the neural substrates responsible for these motor anomalies have not as yet been identified, it is possible that the findings of these studies may be, in part attributable to the presence of ADD-H rather than dyslexia.

In order to address these concerns and further explore the developmental differences between dyslexic and normal readers in motor skill acquisition and the relationship between interhemispheric collaboration and reading skill, the proposed study will utilize highly sensitive, computerized, bimanual and unimanual motor tasks which compare performances of poor readers to two control groups of normal readers. One group will be age-matched to the dyslexic subjects in order to test the developmental lag theory and one group will be younger and hence have limited interhemispheric collaboration ability. Having two normal reader control groups of different ages will help tease out effects of chronological age and actual maturational level of the brain and just where dyslexics fit on this continuum in order to assess bimanual coordination skills both qualitatively and quantitatively. All subjects will be screened for ADD-H.

Development of Interhemispheric Collaboration in Normal Children

The use of a younger group of normal readers to demonstrate limited cooperation of the two hemispheres is supported by the developmental literature which suggests that increases in such parallel processing ability is correlated with Piagetian stages of cognitive development (Pascual-Leone, 1970). The work of Merola and Liederman (1985) demonstrates an increase in hemispheric independence between 10 and 12 years of age, the time of completion of myelinization of callosal fibers (Yakolev, 1967). Liederman (1986) reasons that hemispheric collaboration requires the ability of the hemispheres to "share" or transfer information for coordination of simultaneous processing of tasks while hemispheric independence allows the hemispheres to "shield" or suppress unwanted information from the opposite hemisphere for independent processing. A marked decrease of overflow movements in children during this age has been well documented (Denckla, 1973; Wolff, 1983; Haggerty, 1985) and suggests that normal physical maturation allows for such hemispheric cooperation.

Liederman's concept of independent work stations in the two hemispheres allowing for shielding and sharing represents a higher order cognitive function beyond simple transfer and inhibition. As used by Liederman (1986) shielding and sharing suggest that the two hemispheres have a capacity to divide attention between two tasks. This maturational cognitive achievement has a neurological basis which is as yet unclear and remains to be explored (Denckla, 1986).

The model suggests that the two sides of the brain could serve as independent centers for information processing. But the developmental mechanisms for how they simultaneously cooperate and yet perform distingtly different tasks is also largely unknown. From a series of experiments Liederman has proposed that interhemispheric cooperation develops in three stages. In stage 1, from birth to age 3, there is a relative lack of communication between hemispheres. The second stage, 3 to 10 years, is characterized by excessive or imprecise communication between the hemispheres. The third stage, during adolescence and early adulthood, flexible shifts from sharing to shielding allows for accurate and independent parallel processing in the two hemispheres. In stage 3, the relatively unique and independent capacities of the hemispheres begin to emerge and result in overall higher efficiency.

Kinsbourne (1988) applies such a model to the interpretation of Neff's (1986) finding that dyslexics exhibit interhemispheric collaboration difficulties. Since the dyslexics also had greater errors on within hemisphere tasks, Kinsbourne argues for an interpretation of immaturity in the specificity of independent work stations both within and between hemispheres.

"Neurologically, perhaps both within and between cerebral representations of the hands, dyslexics have more difficulty in maintaining comparable levels of activation for separate central loci for purposes of a successive match, and more difficulty selectively activating a single effector while leaving others within the same category in their activation base state. Rather than thinking in terms of a selective callosal deficit, we should bear in mind that the corpus callosum is simply the largest of an extensive set of cortico-cortical connections. Maybe these connections contribute to rendering cognition specific and differentiated and perhaps it is in this rather general function that the reading-disabled children are in retard."

Following the reasoning of Liederman and Kinsbourne, it is expected in this study that 1) younger normal readers would not produce coordinated, simultaneous movements because of a more limited capacity for sharing information between the two hemispheres due to age. 2) despite intact fine motor control, this qualitative difference in performance is expected with and without visual feedback. 3) because of the interference of overflow movements due to the inability to fully suppress unnecessary information from the opposite hemisphere, the younger children are expected to exhibit quantitative differences in their performance seen in the presence of reversals and disproportionate execution of different hand movements. Thus, the fine tuning of shielding and sharing of information between the hemispheres is expected in the older group of normal readers, but not the younger group.

It is further expected that older, poor readers, like the younger normal readers, will exhibit signs of deficient interhemispheric cooperation. Specifically, it is predicted that: 1) Older poor readers will execute a disproportionate ratio of equivalent rate and unidirectional hand movements on angles which require different rate and bidirectional movement patterns. 2) Despite having intact fine motor control, this qualitative difference in performance is expected with and without visual feedback. 3) Older poor readers are expected to reverse the direction of hand movements on trials where visual feedback is unavailable for monitoring. Thus, the interhemispheric skills of dyslexic boys are predicted to be similar to the younger normal readers. Such a finding would further establish a relationship between reading failure and limited interhemispheric cooperation seen in bimanual motor skills. Should there be no difference between the poor readers and the age-matched control group, it would suggest that previous research findings of deficient bimanual motor coordination in poor readers may be attributable to methodological considerations or other factors found to correlate with these motor anomalies such as ADD-H and behavioral disorders.

III. THESIS STATEMENT

The purposes of this study are to:

1) Demonstrate the validity of a computerized task capable of assessing unimanual and bimanual fine motor and
visuospatial skills.

2) Examine the development of unimanual and bimanual motor skills of normal children from 7 to 8 yrs of age and 12 to 16 yrs of age. Specifically, hypotheses were generated to examine the development of motor function as it relates to right/left differences, use of visual feedback or knowledge of results, effects of direction of overflow in bimanual tasks and effects of direction of hand movement in bimanual coordination.

3) Examine the development of unimanual and bimanual motor skills of dyslexic children and compare their abilities with age matched and younger normal readers. The aim in testing dyslexic subjects is to focus on the development of the cooperative interaction of the right and left hemispheres through the corpus callosum and the relationship of interhemispheric cooperation to the

acquisition of reading skills. The study will investigate hypotheses suggesting that adolescents with poor reading ability will be characterized by bimanual motor skills below age expectancy and perform similarly to young children who have not as yet developed these skills due to incomplete neuronal development such as myelinization of the corpus callosum.

IV. PRELIMINARY STUDIES

In order to address these concerns and further explore the relationship between interhemispheric collaboration and reading skill, a pilot study was undertaken, utilizing a highly sensitive, computerized apparatus to assess subjects' performance on unimanual and bimanual motor tasks discussed in detail in the Methodology Section. Pilot data was collected on two groups of children, both of whom had age appropriate reading skills. The first group consisted of seven children between the ages of 7:11 and 8:10, while the second was made up of four children between the ages of 12:0 and 14:11.

The pilot data was found to be highly consistent with the observations made by (Preilowski, 1972; Fagard, 1985; Jeeves, 1988; Liederman, 1985). While no quantitative analysis of the data was done due to the small number of subjects performing on single trials, the younger children, like the callostomy patients, were found to be limited in their ability to execute simultaneous movements of the two hands. They tended to alternate between the right and left hands, producing a stairstep effect (Figure 3) despite accurate fine motor control as exhibited by normal range performance on the Purdue Pegboard. On the basis of Fagard's and Liederman's research, this finding suggests immature interhemispheric collaboration for the sharing of information in a simultaneous processing task.

Frequent reversals in hand movements were also observed among the younger children on tasks requiring simultaneous but asymmetrical movements of the right and left hands (i.e., movements requiring a 2:1 or 1:2 ratio of left to right hand movement rather than 1:1). This suggests immature interhemispheric independence or the inability to inhibit overflow. When visual feedback was provided, the younger children were frequently able to monitor their initial reversals (Figure 4). When visual feedback was removed at the midpoint, however, they continued the reversal of the right hand (Figure 5), the left hand (Figure 6) or both hands (Figure 7). The older children who were tested exhibited no difficulty in these skills (Figure 8). Based on the current literature and these findings the following specific hypotheses have been formulated regarding the performance of the three subject groups under each of the conditions in the two experiments assessing unimanual and bimanual skills.

CHAPTER V

HYPOTHESES FOR EXPERIMENTAL ASSESSMENT OF UNIMANUAL (EXPERIMENT I) AND BIMANUAL (EXPERIMENT II) FINE MOTOR SKILLS

Hypotheses addressing questions raised in the literature and defined by the thesis of this study will be addressed here in relation to Experiment I evaluating the independent right and left hand fine motor skills of the subjects (unimanual skills) and the ability to coordinate the fine motor skills of both hands simultaneously (bimanual skills) in Experiment II.

Normal Developmental Effect for Experiment I Unimanual Motor Skill

Hypotheses predicting performance on execution of unimanual, fine motor skills of normal readers are based on the influence of lateralization (right and left differences) and age.

Within Group Contrasts

H1: Since all subjects are right handed, it is predicted that both groups will perform significantly better in accuracy with the use of the right hand when compared to the left hand.

Between Group Contrasts

H2: Since fine motor skills have been found to improve with age (Gardner, 1979), it is predicted that an improvement in accuracy when using the right or left hand will be seen with age among the normal reading groups.

Normal Developmental Effect for Experiment II

Bimanual Motor Skill

Hypotheses predicting performance on acquisition of bimanual motor skill are based on the results from similar studies by Fagard (1985) and Jeeves (1988). Hypotheses concerning acquisition of skill influenced by age, availability of visual feedback, and complexity of task in symmetrical and asymmetrical hand movements are tested.

Within Group Contrast

H3: Within each reading group it is expected that accuracy will be better in the unguided, visual feedback condition than the memory, no visual feedback condition.

Between Group Contrast

H4: Because of the need for interhemispheric collaboration in the bimanual task (Fagard, 1985) it is expected that the older reading group will perform more accurately than the younger reading group on the unguided, visual feedback condition and the memory, no visual feedback condition.

Normal and Dyslexic Performance on Experiment I
Unimanual Motor Skill

Within Group Contrast

H5: Since all subjects are right handed, it is predicted that dyslexic subjects will perform significantly better in accuracy with the use of the right hand when compared to the left hand.

Between Group Contrast

H6: There will be no difference between the dyslexic and age-matched normal readers on the performance of the right and left hand seperately.

H7: The dyslexics will perform more accurately with their right and left hand than the children.

Normal and Dyslexic Performance on Experiment II
Bimanual Motor Skill

Within Group Contrast

H8: Within the dyslexic group, it is expected that accuracy will be better in the unguided, visual feedback condition than the memory condition.

H9: Within the dyslexic and younger reading groups it is expected that some subjects will loose the correct direction of hand movement when visual feedback is removed (Gladstone, 1985).

H10: It is expected that loss of direction of hand movement among dyslexic and younger readers will be attributable to bidirectional movement of the left hand (Gladstone, 1985).

Between Group Contrast

Because of the need for interhemispheric collaboration in the bimanual task (Fagard, 1985) and the evidence for difficulty in bimanual tasks in dyslexics (Klicpera, 1981), it is expected that:

H11: The age-matched reading group will perform more accurately than the dyslexic group on the unguided visuall feedback condition and memory condition.

H12: There will be no difference between the performance of the dyslexics and the children on the unguided visual feedback condition and the memory, no visual feedback condition.

CHAPTER III

METHODOLOGY

Subjects

Three groups of right-handed, middle class males with normal intelligence were tested. The three subject groups consisted of: 1) 14 normal readers between the ages of 7:0 and 8:11; 2) 19 normal readers between the ages of 12:0 and 16:11; and 3) 23 poor readers between the ages of 12:0 and 16:11. Normal readers were students in the White Plains Public School System. Poor readers were students attending the Kildonan School in Amenia, N.Y., which is a private school for dyslexic boys. Parental consent for participation in this study was obtained for each subject (Appendix A, B) with the assistance of the school administration. The schools screened files in order to identify students who met the sample criteria. They then forwarded to the parents of these students, letters requesting their son's participation with a permission form for the parents to sign and return. From the 1/3 of the consent forms returned, the study sample was selected.

Sample Criterion:

Dyslexic Subjects

Age - 12 to 16

IQ - Full Scale above 90

Block Design - 7 or above

Reading - Myklebust Quotient Below 85

Attention - Hyperactivity Index below 1.5

Laterality - Right Handed, 7 out of 11 on the RNESS

History - No relevant medical, neurological or psychiatric history with ample social and educational opportunity.

Visual Acuity - No uncorrected visual acuity deficits (through school and parent report).

Spatial Perception and Memory - Benton Judgement of Line Orientation score within 1 SD of normal and Benton Spatial Memory score average or above.

No adopted children.

Older Normal Reading Subjects

Age - 12 to 16

IQ - Cognitive Ability Test above 95 on verbal & nonverbal subtests

Block Design - 7 or above

Reading - Myklebust Quotient above 95

Attention - Hyperactivity Index below 1.5

Laterality - Right Handed, 7 out of 11 items on the RNESS

History - No relevant medical, neurological or psychiatric history with ample social and educational opportunity.

Visual Acuity - No uncorrected visual acuity deficits.

Spatial Perception and Memory - Benton Judgement of Line Orientation score within 1 SD of normal and Benton Spatial Memory average range or above.

No adopted children.

Younger Normal Reading Subjects

Age - 7 to 8

IQ - WISC-R, Vocabulary 10 or above

Block Design - 7 or above

Reading - Myklebust Quotient above 95

Attention - Hyperactivity Index below 1.5

Laterality - Right Handed, 7 out of 11 items on the RNESS

History - No relevant medical, neurological or psychiatric history with ample social and educational opportunity.

Visual Acuity - No uncorrected visual acuity deficits.

Spatial Perception and Memory - Benton Judgement of Line Orientation within 1 SD of Normal and Benton Spatial Memory score average or above.

No adopted children.

Exclusion criteria for all three subject groups are listed above. In addition, children with a history of neurological impairment, such as head trauma, seizure activity, etc., psychiatric illness, use of psychotropic medication, medical illness which limits motor coordination, lack of educational opportunity or uncorrected visual acuity deficits were excluded. Adequate visual-spatial perception was determined by scores within 1 standard deviation on the Judgement of Line Orientation Test while adequate spatial memory was established by average or above scores on Benton Spatial Memory Test. Poor vs. normal reading ability was established using the Myklebust quotient [(2 x reading age)/mental age plus chronological age)] using the reading age from the Piat Word Recognition Test. Children whose Myklebust quotients were below 85 are considered to be poor readers while normal readers achieve scores greater than 95.

For the purposes of this study, dyslexics are defined as boys who have adequate educational opportunity with no known neurological, intellectual, psychiatric or perceptual disorders, yet demonstrate a significant deficit in their ability to identify words when compared to age and IQ- matched control subjects. This definition is taken from the World Federation of Neurology (Federal Register, 1976).

Screening Battery and Ancillary Battery:

The following tests were used for sample selection and descriptive characteristics of the sample:

Intelligence: Dyslexics - WISC-R
Older Normal Controls - Cognitive Abilities Test, WISC-R Vocabulary and Block Design
Younger Normal Controls - Cognitive Abilities Test, WISC-R Vocabulary and Block Design.

Reading: Piat Word Recognition, Piat Reading Comprehension, Woodcock/Johnson Word Attack, Myklebust Quotient.

Motor: Revised Neurological Examination of Subtle Signs (RNESS), Purdue Pegboard.

Graphomotor: Beery, Maze Speed, Pencil Excursion.

Attention: Conners Parent Ratings, Conners Teacher Ratings.

Language: Rapid Automatized Naming Test, Boston Naming Test, Token Test.

Spatial: Benton Spatial Memory, Benton Judgement of Line Orientation Test.

History: Parents were asked to complete a questionnaire on their child's medical, neurological and psychiatric history (see Appendix C for test forms).

Apparatus

A standard Apple IIe computer was used to collect the experimental data. For Experiment I, a Kraft 829-001 joystick controls the movement of the cursor in the unimanual condition to obtain separate measures of skill for the right and left hand. For Experiment II, the computer was controlled by two, three-turn potentiometers, which are 3/4 inch in diameter and provide the apparatus for moving the cursor in the bimanual condition, requiring the use of both hands. An electrical switch device allows for alternating between the two apparatuses. For bimanual testing, turning of the left potentiometer regulates vertical movements of the cursor while turning of the right potentiometer regulates horizontal movements of the cursor. Consequently, simultaneous movement of the two knobs allowed the subject to also steer the cursor through diagonal pathways displayed on the screen. A computer program, capable of sampling movement of the cursor 60 times per second, tracks and records the cursor's movement. Designing and building the equipment, writing the computer program and conducting validity/reliability studies to regulate 1) the timing and accuracy of the stimuli presentation 2) precision in recording and storing of responses were completed over a two year period in conjunction with the Graduate Computer Science Department of the City University of New York.

Stimuli

Visual stimuli are the same for Experiment I and Experiment II. Testing consists of tracing a series of single pathways which are randomly presented by the computer program. In each experiment the subject is presented with the same 12 angles (Figure 1). Three of the 12 angles are traced starting in each of the four spatial quadrants. The orientation of these pathways was selected in order to require a ratio of left to right hand movements of 2:1, 1:1, 1:2 when performed in the bimanual condition as subjects are turning the potentiometers. Thus, all possible combinations of clockwise and counterclockwise hand movements are tested.

In Experiment II, tracing of one of the four 1:1 ratio angles will be randomly selected to be traced as a practice trial. The practice trial contains a guiding line at the center of the path (Guided Condition) and is used to train the subjects in the use of the equipment (Figure 2). Then the 12 paths are presented in the unguided condition of visual feedback, which consists of the same pathways without the guiding line identifying the exact center of the pathway. Finally, tracing of the angles is repeated with decreasing visual feedback (Memory Condition). The no visual feedback condition is also without the guiding center line and after completing 1/2 of tracing the path, the cursor automatically disappears, requiring the subject to trace the pathway totally from memory.

Procedure

Subjects were tested individually in a quiet, closed room in their schools. In all cases, no other person was present during testing. They were seated at the computer in a chair which is adjusted for height and viewing of the computer screen. The control equipment was beneath a covering which prevented subjects from viewing their hands and limited visual feedback to movement of the cursor on the computer screen.

All subjects were given the following instructions in both Experiment I and Experiment II. "The object of the task is for you to move the cursor from one end of the pathway to the other staying as close to the center of the pathway as you can. It is important to go as quickly as you can, but it is more important to stay as close to the center of the pathway as you can."

Trials from Experiment I and Experiment II were alternated in order to provide diversity in the tasks and to maintain the highest possible level of attention, interest and motivation. Testing was begun with the execution of the practice trial which was followed by tracing the 12 angles in the bimanual, unguided condition. Subjects were then asked to trace the same unguided angles by using one hand with the joystick. All subjects were required to manipulate the joystick with a pencil-like grip using the thumb and first two fingers. Subjects were alternated in terms of which hand was tested first in Experiment I in order to counterbalance any advantages that might accrue from primacy of usage.

After completing the unimanual testing, the subjects returned to using both hands to complete the memory condition. All subjects were given the following instructions: "You are now going to trace the same angles which you completed earlier but this time something different is going to happen. When the cursor reaches the halfway point (demonstrated by identifying the spot on the screen), it will disappear. When it does, I want you to stop until I dim the screen (demonstrated) and then continue turning the knobs to finish tracing the pathway from memory."

When the subjects stop at the midpoint, the examiner lowered the brightness of the screen so all visual stimuli disappeared. This precaution was taken to avoid having the subjects obtain any further visual feedback. A source of feedback is possible since individual pixels which outline the pathway on the screen disappear when the cursor crosses over them. Consequently, if the cursor were to go out of the pathway, a pixel would disappear at that point, identifying the location of the unseen cursor. Subjects were instructed to begin tracing again as soon as the screen was dark. The entire experimental task took approximately 50 minutes.

CHAPTER IV

RESULTS

The purposes of this study were to 1) Demonstrate the validity of a computerized task capable of assessing unimanual and bimanual fine motor and visuospatial skills 2) Examine the development of unimanual and bimanual motor skills by comparing the performance of normal children from 7 to 8 yrs of age and 12 to 16 yrs of age 3) Examine the development of unimanual and bimanual motor skills of dyslexic children and compare their abilities with age matched and younger normal readers.

This chapter presents the results of statistical analyses conducted to satisfy the above purposes. A general discussion of the results and their implications is found in Chapter V.

Chapter IV is organized into the following sections:

A. Method for Scoring Raw Data: Creation of Experimental Measures

B. Total Experimental Data

C. Sequence of Data Analysis

D. Group Differences on Screening Battery and Ancillary Battery

E. Reliability/Validity Studies of Experimental Measures

F. Normal Developmental Effect for Experiment I - Unimanual Motor Skill

G. Normal Developmental Effect for Experiment II - Bimanual Motor Skill

H. Normal and Dyslexic Performance in Experiment I - Unimanual Motor Skills

I. Normal and Dyslexic Performance in Experiment II - Bimanual Motor Skills

J. Normal and Dyslexic Performance on Acquisition of Angular Velocity.

Method for Scoring Raw Data: Creation of Experimental Measures

Experimental data for each subject was stored on an individual floppy disk. The original data consisted of recording a sampling of the movement of the cursor on the screen 60 times every second and saving those locations on the disk. Computer programs were written in order to reproduce on the screen the original line produced by the subject and in order to quantitatively score the tracing according to accuracy and time. Scoring of the tracing begins at the entry of the pathway and ends upon exiting the pathway. If the cursor goes outside the pathway prior to the end point, scoring is completed when the cursor passes beyond the perimeter of the circle formed by connecting the outermost points of each of the 12 angles (see Figure 1). In the interest of obtaining the most accurate measure of time and in order to correct for the variability among subjects, the program subtracts the amount of time for pausing at the midpoint on each of the 12 memory condition trials from the total time for the trial. Similarly, since the subjects only have visual feedback during the last half of each trial in the memory condition, scores are generated for the first and last half of each trial separately as well as a score for the total of each trial.

The following experimental measures are calculated for each of the individual trials:

1. DEVIATION SUM (DS) - The amount, in pixels and direction of deviation in accuracy of the plotted line compared to the target line computed relative to point 0.0 (upper left quadrant).

2. AVERAGE ABSOLUTE DEVIATION (AAD) - The amount of deviation in accuracy of the plotted line compared to the target line without regard for the sign. This is the absolute of the overall deviation in both directions - a measure of accuracy.

3. PATH LENGTH (PL) - Total path length in pixels/ total path length of target line (180 pixels) - a measure of accuracy.

4. TIME - Number of data points sampled in the trial - represents real time to complete the trial.

Total Experimental Data

Experiment I	Trials
Unimanual, Left Hand	12
Unimanual, Right Hand	12
Experiment II	
Bimanual, Practice Trial	1
Bimanual, Unguided Condition	12
Bimanual, Memory Condition	12
Total Number of Trials per Subject	49
Total Number of Subjects	56
Total Number of Trials	2744

Sequence of Data Analysis

Data collected in both the screening and ancillary batteries of tests and on the experimental tasks were analyzed using the Statistical Package for the Social Sciences. All experimental data collected and scored on the Apple IIe using Basic language were converted for IBM compatibility using the computer program Quad Link and then entered into the CUNY mainframe. This additional manipulation of the data was necessary in order to make it compatible with SPSS analysis.

In order to establish the reliability of the measures, Chronbach Alpha's were computed for each experimental measure. Similarly, Pearson-R correlations were used to determine whether the experimental measures of accuracy (absolute deviation and path length) are independent of each other for each of the groups. Pearson-R correlations were also used to determine whether time and accuracy are independent functions for each of the groups.

The statistical analysis used to test predictions primarily uses the Students t Test to test each of the hypotheses previously discussed. Since the two control groups of normal readers differ so greatly in age, skill acquisition and cognitive functioning, they were compared to the dyslexic group and to each other using separate t Tests to examine each of the hypotheses. For each experiment, group contrasts were made to test the within-group hypothesis for dyslexics and normal readers as well as between-group contrasts for all three groups. Although it might appear that this is a three-group design necessitating Analysis of Variance to test all hypotheses, in actuality there is a single experimental group and two control groups - one matched for age and the other for reading level, and necessarily younger. In addition, the two control groups are compared separately to establish the effects of age on this task. None-the-less, to protect against the risks of multiple t tests, all contrasts among the three groups will be reported in terms of critical values subjected to Dunn's Procedure, commonly referred to as Bonferroni Corrections.

Group Differences
on Screening Battery and Ancillary Battery

All subjects were tested on the Screening Battery and the Ancillary Battery for purposes of establishing that subjects met sample criterion for the study and to obtain descriptive characteristics of the subjects' cognitive abilities.

Table 1 contains the Means and Standard Deviations for the dyslexic group and age-matched readers, with t values and probabilities when the groups are compared to each other. Reading tests which discriminate dyslexics and normal readers (Piat Word Recognition, Piat Comprehension, Woodcock Johnson Word Attack, Myklebust Quotient) as well as scores on WISC-R, Vocabulary, reflect a significant difference between the age matched groups. In contrast, there was no difference between the age-matched groups on perceptual, spatial, constructional skills required for Judgement of Line Orientation, WISC-R Block Design and Benton Spatial Memory. Surprisingly, on measures of laterality, the two groups differ significantly on hand measures. Although all subjects met the criteria of 7 out of 11 right handed items on the Revised Neurological Examination of Soft Signs, the dyslexic group proved to be significantly more extreme in lateralization. All subjects met criteria for the study and none exhibited indicators of ADD-H by either parent or teacher report on the Conners Rating Scale.

Table 2 reflects the similarities and differences between dyslexics and younger readers. On the screening battery of tests, the groups strongly differ on WISC-R Vocabulary and Block Design with younger readers scoring higher than dyslexics. This difference may reflect a sample bias in the selection of the younger readers. Parental consent is a strong factor in obtaining research participation and was more difficult to obtain with the younger subjects, given the amount of time required from subjects.

On reading scores the younger readers met criteria for the Myklebust Quotient, scoring significantly higher than dyslexics. Similarly, younger readers scored higher than dyslexics on decoding of nonsense syllables. However, on individual reading tests, there was no difference between the groups on word recognition (they were matched on this variable), reflecting the dyslexics reading lag. Dyslexics were significantly better on readiag comprehension despite poor decoding. All subjects met crition for laterality but the dyslexic group was more strongly right handed than the younger readers.

Table 3 compares performance of older readers and younger readers on screening battery tests reflecting the similarities between the reading groups on the Myklebust Quotient, Hyperactivity Index and Laterality Measure.

The age in months of the three groups is presented in Table 4, while Table 5 gives the comparison of the age-matched dyslexic and normal readers in the age groupings used for statistical comparisons in the data analysis on age effects. There is no age difference between these groups.

Table 6 contains comparisons of dyslexic and age-matched readers on the ancillary battery of tests which assess naming ability and syntax, motor function, constructional skills, spatial memory and frequency of using video games. Likewise, Table 7 compares dyslexic and younger readers on the same measures while Table 8 compares older and younger readers. There was no difference between the age matched groups on visual and spatial tasks. Similarly, all groups scored below criterion for inclusion in the sample on the Conners Hyperactivity Index. From the subject's report there is no evidence of greater practice for eye-hand coordination skill from use of video games in any of the groups.

Reliability/Validity Studies of Experimental Measures

In order to create robust estimators of the subjects performance, averages over all 12 angles under each condition were taken. Reliability was addressed by computing a Cronbach Alpha for each angle separately and then taking the mean of all 12 coefficients for each measure. Reliability checks using Cronbach's Alpha on the commonality of the 12 angles revealed Alphas ranging from .79 to .98 as seen in Table 9.

In order to address the validity of the accuracy measures used to assess the subjects' performance, Pearson-R correlations were obtained for the two measures of accuracy, Average Absolute Deviation and Path Length, to determine the degree of independence of these measures. Table 10 lists the Pearsons-R correlations and Probabilities for Average Absolute Deviation and Path Length for all three groups under both unimanual and bimanual conditions. The two measures of accuracy are positively correlated for all groups under all conditions except for the older readers in the memory condition. Consequently, they both are considered measures of accuracy for the purposes of this study.

To further establish the construct validity of the experimental measures, Pearson-R correlations were obtained between relevant standardized measures and the experimental measures. Table 11 lists the correlations between accuracy and time and the standardized measures of motor function, visuospatial and graphomotor skills. The language tests which so strongly differentiate the groups do not correlate with the experimental measures.

In order to address the relationship between time and accuracy in the performance of the subjects, Pearsons-R correlations were obtained to determine whether accuracy and time are independent of each other or correlated measures. Table 12 lists the Pearsons-R correlations and Probabilities for Average Absolute Deviation and Time for all three groups under both unimanual and bimanual conditions. Similarly, Table 12 lists the Pearsons-R Correlations and probabilities for Path Length and Time. The Pearson-R correlations for the two measures indicate that time and both measures of accuracy are positively correlated measures for the age-matched normal readers after tracing 12 trials of angles in the unimanual and bimanual conditions and under each of the visual feedback conditions. However, for the dyslexics and younger readers, time and accuracy are positively correlated in the unimanual condition and in the bimanual condition when no visual feedback is available. When visual feedback is available, there is no correlation between time and accuracy for dyslexics and children. In other words, time and accuracy function differently in the age-matched normal reading group than the dyslexic group. In addition, the pattern of correlations for dyslexics is similar to the pattern of correlations of the younger readers in the unguided condition where the use of interhemispheric collaboration and visual feedback is engaged.

Concern about practice effects, particularly in learning the bimanual coordination task was addressed in two ways. Presentation of all angles under all conditions was randomly assigned. Similarly, half of the sample first engaged the use of the right hand on unimanual testing and half of the sample first engaged the left hand. The question of whether the order of right and left affected performance was addressed with a comparison of subjects, within each group, who started with right and left hands and no significant differences in accuracy or time were found.

RESULTS OF EXPERIMENTAL ASSESSMENT METHOD
FOR UNIMANUAL (EXPERIMENT I)
AND
BIMANUAL (EXPERIMENT II)
FINE MOTOR SKILLS

Hypotheses addressing questions raised in the literature and defined by the thesis of this study will be addressed here in relation to Experiment I evaluating the independent right and left hand fine motor skills of the subjects (unimanual skills) and the ability to coordinate the fine motor skills of both hands simultaneously (bimanual skills) in Experiment II. Within each experiment, data analysis will address comparison of the subject differences within each of the three groups and the differences between the groups. Performance of the normal reading groups on the experimental assessment method will be presented first with data comparing performance of the dyslexic and normal readers following.

Normal Developmental Effect for Experiment I
Unimanual Motor Skill

Hypotheses predicting performance on execution of unimanual, fine motor skills of normal readers are based on the influence of lateralization (right and left differences) and age.

Within-Group Contrasts

H1: Since all subjects are right handed, it is predicted that both groups will perform significantly better in accuracy with the use of the right hand when compared to the left hand.

The hypothesis is partially supported: When performance of the right and left hands of the normal reading subjects was compared, older readers were significantly more accurate using their right hand (AAD: t=3.71, df=18, p.<.01) but showed no right/left difference in rate of performance (Table 12). In contrast, younger normal readers showed neither a right hand superiority in accuracy or rate of performance. This suggests that despite a right hand preference in all subjects, 7 and 8 year old subjects have not yet developed a greater precision in fine motor skills of the preferred hand.

Between-Group Contrasts

H2: Since fine motor skills have been found to improve with age (Gardner, 1979), it is predicted that an improvement in accuracy when using the right or left hand will be seen with age among the normal reading groups.

The hypothesis is partially supported: When older and younger normal readers were compared on right hand performance, older readers were significantly more accurate (AAD: t=3.00, df=31, p.<.05) as well as significantly faster (t=3.11, df= 31, p.<.05) in performance (Table 13). There was no difference in left hand accuracy, however, younger readers were significantly faster (t= 3.47, df=31, p. <.01).

Normal Developmental Effect for Experiment II
Bimanual Motor Skill

Hypotheses predicting performance on acquisition of bimanual motor skills are based on the results from similar studies by Fagard (1985) and Jeeves (1988). Hypotheses concerning acquisition of skill influenced by age, availability of visual feedback, and complexity of task in symmetrical and asymmetrical hand movements are tested.

Within-Group Contrasts

H3: Within each reading group it is expected that accuracy will be better in the unguided, visual feedback condition than the memory, no visual feedback condition.

The hypothesis is supported: When performance on the unguided condition is compared to the memory condition, both groups perform more accurately with visual feedback (AAD: Younger readers: $t=3.36$, $df=13$, $p.<.01$; Older readers: $t=5.60$, $df=18$, $p.< .001$) (Table 14) and demonstrate no difference in rate of performance.

Between-Group Contrasts

Unguided and Memory Condition

H4: Because of the need for interhemispheric collaboration in the bimanual task (Fagard, 1985) it is expected that the older reading group will perform more accurately than the younger reading group on the unguided, visual feedback condition and the memory, no visual feedback condition.

The hypothesis is partially supported: Readers 12 to 15 yrs of age are significantly more accurate than readers 7 to 8 yrs of age (AAD: $t=3.75$, $df=14.78$, $p.<.01$) and readers 15 to 16 yrs of age are significantly more accurate (AAD: t=3.49, df=17, p.<.01) and faster (t=2.28, df=17,p.<.05) than readers 12 to 15 yrs of age (Table 15) in the visual feedback condition.

Comparison of older and younger readers on the memory, no visual feedback condition does not support the hypothesis. Readers 7-8 years of age do not perform significantly different from older readers.

Normal and Dyslexic Performance in Experiment I
Unimanual Motor Skill

Within-Group Contrasts

H5: Since all subjects are right handed, it is predicted that dyslexic subjects will perform significantly better in accuracy with the use of the right hand when compared to the left hand.

The hypothesis is supported: When performance of the right and left hands of the dyslexic subjects was compared, dyslexics were significantly better using their right hand in both accuracy (AAD: t=3.63, df=22, p.<.001; Path Length: t= 5.67, df=22, p.<.000) and rate of performance (t=4.98. df=22, p.<.000) (Table 16).

Between-Group Contrasts

H6: There will be no difference between the dyslexic and age matched normal readers on the performance of the right and left hands separately.

The hypothesis is not supported: In their left hand performance, dyslexics are significantly more accurate (Path Length: t= 4.22, df= 40, p.<.01) and faster (t=4.35, df=40, p.<.01) than age matched readers (Table 17).

The right hand performance of dyslexics is also significantly more accurate (ADD: t=4.47, df=40. p.<.01; Path Length: t= 5.12, df=40, p.<.001) and faster (t=4.62, df=40. p.<.001) than age-matched readers (Table 18).

H7: The dyslexics and age-matched readers will perform more accurately with their right and left hands than the children.

The hypothesis is supported: On right hand performance, dyslexics are significantly more accurate (AAD: t= 5.76, df=35, p.<.001; Path Length: t=2.42, df=35, p.<.05) but are no faster than the younger readers (Table 19). On left hand performance, dyslexics are no more accurate or faster than younger readers.

Normal and Dyslexic Performance in Experiment II

Bimanual Motor Skill

Withi-Group Contrasts

H8: Within the dyslexic group, it is expected that accuracy will be better in the unguided, visual feedback condition than the memory condition.

The hypothesis is supported: Dyslexics are significantly more accurate (AAD: t=6.40, df=22, p.<.000) and faster (t=7.28, df=22, p.<.000) when visual feedback is available (Table 20).

H9: Within the dyslexic and younger reading groups it is expected that some subjects will lose the correct direction of hand movement when visual feedback is removed (Gladstone, 1985).

The hypothesis is supported: Reversal of the direction of hand movement occured in both the dyslexic and younger reading groups. When the frequency of reversals in the dyslexic group was compared to the younger reading group, the younger readers had significantly more reversals (Table 21).

H10: It is expected that loss of direction of hand movement among dyslexic and younger readers will be attributable to bidirectional movement of the left hand.

The hypothesis is partially supported: When the proportion of the reversals made by the left hand of dyslexic and younger subjects is examined (Table 22), it is the right hand which is primarily responsible for loss of direction without visual feedback. However, on trials requiring the hands to move in opposite directions (bidirectional) or the same direction (unidirectional) (Table 23), both groups have significantly more reversals in bidirectional quadrants.

Between-Group Contrasts

Because of the need for interhemispheric collaboration in the bimanual task (Fagard, 1985) and the evidence for difficulty in bimanual tasks in dyslexics (Klicpera, 1981), it is expected that:

H11: The age-matched reading group will perform more accurately than the dyslexic group on the unguided visual feedback condition and memory condition.

The hypothesis is not supported: There is no difference in accuracy of the dyslexic and age-matched reading groups. However, on the visual feedback condition, dyslexics are significantly faster (t=4.70, df=40, p.<.001) while they maintain equal accuracy (Table 24). There is no discriminating difference in accuracy or time between dyslexic and older readers on the memory condition.

H12: There will be no difference between the performance of the dyslexics and the younger readers on the unguided visual feedback condition and the memory, no visual feedback condition.

The hypothesis is not supported: Dyslexics are significantly more accurate (AAD: t= 3.73, df=35, p.<.01; PL: t=3.85, df=35, p.<.01) and faster (Time: t=4.96, df=35, p.<.001) than the younger readers on the unguided, visual feedback condition (Table 25). Similarly, on the memory, no visual feedback condition, dyslexics are significantly more accurate (P.L.: t=2.89, df=35, p.<.05) but no faster than the younger readers.

Normal and Dyslexic Performance on Acquisition of Angular Velocity

Research examining acquisition of bimanual motor skills has primarily focused on learning over repeated trials of practice (Preilowski, 1972; Fagard, 1985, Jeeves, 1988). Reports of performance affected by variation in the ratio of hand movement required to trace a particular angle are based on skills achieved after multiple practice sessions. Consequently, it was not possible to generate hypotheses for performance of these groups based upon the single trial performed for this study. Data addressing the acquisition of "angular velocity" will therefore be used as a basis for hypothesis generation.

Analysis of the data to examine group performance for bilateral coactivation of hand movement, and thus collaboration of the two hemispheres is presented by examining two issues: 1) the tendency toward dynamic coupling of the limbs in each group 2) amount of variation in accuracy and speed according to ratio of hand movement for each group.

In an attempt to examine the data for acquisition of precision in angular velocity and a tendency toward unintended coactivation or dynamic coupling of the limbs, the measure Directional Deviation Sum was used since it indicates by its + or - sign the direction of error (Figure 9). In other words, when the subjects' tracing of the pathway midline deviates primarily in one direction, the direction of that deviation is identified by the + or - sign of the accuracy score.

Fagard (1985) observed that the direction of errors demonstrated a tendency to drift from the angles requiring asymmetrical ratio of hand movement (1:2 or 2:1 ratio) toward a symmetrical ratio of hand movement (1:1). He argues that this represented dynamic coupling or unintended coactivation of the limbs.

Table 26 shows in the first column the "drift sign" or sign of the measure Directional Deviation Sum when performance is drifting toward 1:1 ratio of hand movement on the asymmetrical angles when visual feedback is available. When the direction of error of the older reading group is compared to drift sign, it is apparent that this group consistently errs in the direction of symmetrical movement. Although not as consistently, the dyslexic group also shows a tendency toward erring in the direction of symmetrical movement (Table 27). In contrast, the younger reading group shows no consistent pattern in direction of errors (Table 28). When visual feedback is removed, all groups consistently err in the direction of symmetrical movement (Table 29,30,31).

The second issue of variation in accuracy due to differences in ratio of hand movement is addressed by the question: Can a difference in level of difficulty between angles requiring symmetrical (1:1 ratio of hand movement) and asymmetrical movement (2:1 or 1:2 ratio of hand movement) be demonstrated, and if so, is there any difference between groups? Following the reasoning of Preilowski (1972), Fagard (1985) and Jeeves (1988), greater precision in interhemispheric collaboration (shielding and sharing of information) should be necessary on the asymmetrical (1:2 and 2:1 ratio) angles and should result in less precise performance.

On the first 12 angles traced with visual feedback, the performance of the older reading group on 1:1 ratio angles is compared to 1:2 and 2:1 angles (Table 32). Older readers are significantly less accurate and execute the task significantly more slowly on the 1:2 ratio angles. In contrast, there is a very slight difference in accuracy between 1:1 and 2:1 ratio and no difference in rate of performance.

Similarly, the dyslexic group performance demonstrates greatest difficulty on 1:2 ratio angles (Table 33) in both accuracy and speed when compared to 1:1 ratio angles, but no difference between 1:1 and 2:1

ratio angles. The younger normal readers demonstrate the same pattern of results (Table 34) with a significant difference in both accuracy and speed when comparing 1:1 and 1:2 ratio angles. There was no difference between 1:1 and 2:1 ratio angles.

When the same 12 angles are repeated without visual feedback (Table 35), the older reading group again performs most poorly in both accuracy and speed on angles requiring 1:2 ratio of hand movement compared to 1:1 and 2:1 ratio angles. In contrast, the dyslexic group has greater difficulty on all asymmetrical angles (1:2 and 2:1 ratio) without visual feedback (Table 36). For the younger reading group, when visual feedback was removed, there was no difference in performance based on ratio of hand movement.

Chapter V

DISCUSSION

The findings will be discussed in the following order: 1) General discussion of the problem addressed in the study, design and results of the experiment 2) Discussion of the specific hypotheses 3) Discussion of the implications and limitations of the findings 3) Applications of basic research to educational practice 4) Direction for future research.

General Discussion

Assessment of the development of motor skill in dyslexic children has been an aspect of extensive research. Historically, this is one of many attempts to define a neurological basis for reading failure. Many motor abnormalities or neurological soft signs such as choreiform movements, synkinesis, slow-rate of movement, mirror movements and dyspraxia have been examined and found prevalent in learning disabled and hyperactive populations. However, such soft signs have not been found to be specific to dyslexia or observed in dyslexic populations screened for other abnormalities.

One neurologically-based explanation for developmental reading failure is a deficit in interhemispheric interaction (Best, 1985; Kinsbourne, 1988) which may be attributed to either delayed maturation of the corpus callosum or the underlying neural systems which transmit information between the hemispheres through the corpus callosum. Whatever the etiology, faulty hemispheric integration or cooperation has been identified as a possible risk factor or correlate of developmental reading failure (Neff, 1986) and is a function accessible to examination through unimanual and bimanual motor tasks. These motor skills have been examined in a number of different paradigms and populations, most notably in split-brain samples. The approach used in this study involved the comparison of performance on unimanual and bimanual motor tasks, a paradigm that has been successfully employed by Gladstone (1985) in a dyslexic population and by Preilowski (1972) in a split-brain sample.

In an attempt to address the need for assessment of visuomotor, unimanual and bimanual skill engaging fine motor function, a computerized system similar to currently popular videogames was developed. This perceptuomotor assessment method provide measures of both speed and accuracy of fine motor movement in manipulating a joystick or two potentiometers in order to guide the cursor on the computer monitor by tracing a series of 12 angles.

The present study consists of two experiments conducted to examine the unimanual and bimanual motor skills of dyslexic children and to compare their performance with age (12 to 16 years of age) and IQ-matched normal readers as well as chronologically younger normal readers (7 to 8 years of age) who were matched with the dyslexics' reading level. Groups were of comparable intellectual and SES levels. All subjects were right handed. They were likewise screened for other neurologically based deficits including Attention Deficit Disorder, perceptual-spatial impairment and for psychiatric disturbance. All subjects have had ample social and educational opportunities. In addition, they were tested for language, graphomotor and fine motor function on standardized tests and assessed for frequency of prior use of video games in order to rule out a practice effect from these results.

Reliability of the assessment measures was statistically confirmed. Preliminary evidence for concurrent validity of the experimental measures was likewise established. The relationship between time and accuracy was tested for each group to determine whether these were independent or related measures. Accuracy and time were found to be positively correlated measures for the older reading group in both the unimanual and bimanual conditions. In addition, the dyslexic and younger readers only showed a similar positive correlation between time and accuracy in the unimanual condition and in the bimanual condition when no visual feedback was available. When visual feedback was available, there was no significant correlation between these measures for the dyslexics and younger readers.

Experiment I measured accuracy and speed of unimanual fine motor skill on the computerized visuomotor tracking task where the right and left hands independently manipulated a joystick in order to trace a pathway on the computer monitor. It was expected that all groups would perform better with the right hand than the left hand and that improvement would be observed with increasing age.

Experiment II measured accuracy and speed of bimanual fine motor skill on the same computerized visuomotor tracking task. The left and right hands, respectively, controlled the vertical and horizontal movement of the cursor on the screen while tracing the same series of pathways. Experiment II further examined the use of visual feedback in the execution of the tracking task by assessing performance on the same trials when visual feedback was removed. It was expected that the interhemispheric collaboration skill necessary to perform this task would demonstrate a difference between dyslexic and age-matched readers with the dyslexic subjects performing similarly to the younger readers.

It was further expected that dyslexic and younger readers would have greater difficulty maintaining the movement timing, direction and appropriate inhibition of one hand in relation to the other to produce a tracing of the desired angle when unable to monitor their movements with visual feedback. The greatest difficulty in these skills was expected to occur in the performance of the left hand and under conditions where the two hands were moving in opposite (clockwise and counterclockwise) rather than the same (both clockwise or counterclockwise) direction.

Experimental results were analyzed for both within and between group comparisons. In Experiment I, older readers and dyslexics demonstrated better unimanual performance with the right hand than the left hand. Younger readers demonstrated no difference between right and left hand performance. Dyslexics were found to be significantly faster and more accurate than age-matched readers with both the right and left hands.

Both older groups were found to excel beyond the performance of the younger readers.

In Experiment II on bimanual motor coordination, all subjects performed better with visual feedback available than they did when feedback was removed. With visual feedback, older readers were more accurate than younger readers and contrary to expectation, dyslexics were comparably accurate while faster than age-matched readers. When visual feedback was removed, dyslexics did not demonstrate the expected deficit, but rather lost the superior performance demonstrated on both the unimanual and bimanual tasks with visual feedback, performing equally in both accuracy and speed to the age-matched readers and significantly better than the younger readers.

However, when the quality of errors observed on the bimanual, memory condition was analyzed, dyslexics and younger readers demonstrated similar patterns of immaturity in their execution of the task which were never observed in the older reading group. When visual feedback was removed, both dyslexic and younger reading subjects lost the direction of the movement of one or both hands, completely reversing the direction of the tracing. Qualitative inspection of the errors showed that the greater proportion of reversals was not executed by the left hand, but was primarily a function of the right hand for the dyslexic subjects and was equally distributed between the right and left hands for the younger readers. When frequency of occurrence of reversals in unidirectional and bidirectional quadrants was examined, both groups had significantly more reversals in the bidirectional quadrants.

On examination of the subjects' mastery of angular velocity, two issues for analysis were formulated. First, the direction of drift or direction of deviation from the desired angle was examined for each group. Second, a comparison of performance was made on angles requiring the hands to move in unison (1:1 ratio of hand movement) to angles requiring asymmetrical movement (1:2 or 2:1 ratio of hand movement).

When direction of drift was analyzed for each of the three groups, the older readers consistently erred in the direction of 1:1 ratio of hand movement on all angles under both the visual feedback and memory conditions, suggesting a natural tendency toward dynamic coupling of the two hands in the initial phase of acquisition of bimanual motor coordination. In contrast, when visual feedback was available, the younger readers demonstrated no consistent pattern of performance, erring equally in the direction of symmetrical movement of the hands and in the opposite direction. However, when younger readers executed the task without visual feedback, their performance was similar to the older readers, erring most consistently in the direction of 1:1 ratio of hand movement. Dyslexic group performance was similar to, but not as consistent as that of the older readers'. Dyslexics most frequently erred in the direction of symmetrical movement when visual feedback was available. Like the older readers, when visual feedback was removed, dyslexics consistently erred in the direction of symmetrical movement of the two hands. Consequently, all three groups spontaneously reverted to dynamic coupling of the two hands without the assistance of visual feedback.

On a comparison of performance of tracing angles with different ratio of hand movement with visual feedback, all groups were significantly less accurate on angles requiring 1:2 ratio of hand movement (i.e. right hand moving twice as fast as left). All groups demonstrated comparable acccuracy when comparing angles with 1:1 and 2:1 ratio of movement. This finding demonstrates that on 1:2 ratio angles, when the right hand must restrain its natural tendency toward dynamic coupling or slowing down to move in unison with the left hand, significantly less accurate performance is observed in all groups.

Discussion of Specific Hypotheses

Three questions were formulated from the thesis of this study and will now be ad discussing each of the hypothesis which were developed to answer them.

Question #1

Can the developmental acquisition of fine motor unimanual and bimanual skills be measured on a computerized task utilizing visual feedback and differentiate between normal children between 7 and 16 years of age?

Part of this question was addressed in H1 and H2 in Experiment I on unimanual motor function.

H1: Since all subjects are right handed, it is predicted that both groups will perform significantly better in accuracy with the use of the right hand when compared to the left hand.

H2: Since fine motor skills have been found to improve with age (Gardner, 1979), it is predicted that an improvement in accuracy when using the right or left hands will be seen with age among the normal reading groups.

Results displayed in Figure 10 demonstrate the difference in unimanual accuracy of the right and left hands for both the older and younger normal reading group. Similarly, Figure 11 displays the difference in speed of performance for the right and left hands for both the older and younger normal readers.

Apparent from these figures is a significant difference between the two groups in the manual execution of the task. The older readers have significantly more accuracy with their right hands than with their left, which is not the case for the younger readers. However, the younger readers are faster, sacrificing accuracy in their performance.

This finding suggests that despite all subjects being right handed, the younger readers have not as yet developed greater precision in fine motor function with their preferred hand and have not as yet developed an ability to regulate speed in order to increase accuracy.

The question of differentiating between the developmental acquisition of bimanual skills with visual feedback in normal children between 7 and 16 years of age is addressed in H3 and H4.

H3: Within each reading group it is expected that accuracy will be better in the unguided, visual feedback condition than the memory, no visual feedback condition.

H4: Because of the need for interhemispheric collaboration in the bimanual task (Fagard, 1985), it is expected that the older reading group will perform more accurately than the younger reading group on the unguided, visual feedback condition and the memory, no visual feedback condition.

Results displayed in Figure 12 demonstrate the significant difference in bimanual accuracy for older and younger reading groups when visual feedback is available for monitoring performance. Similarly, Figure 13 displays the difference in speed of bimanual performance for the older and younger readers with visual feedback. When executing the task without visual feedback, Figure 14 displays the accuracy performance results for older and younger normal readers while Figure 15 gives the contrast in speed between the two groups. The data indicate that an increase in accuracy on bimanual coordination occurs with age.

The subsequent two questions derived from the thesis of this study apply these results to comparisons with dyslexic subjects. Specifically, the study asked:

Question #2

Do reading disabled children differ from age-matched normal readers in either fine motor control engaging the hands separately or in bimanual coordination?

Question #3.

Do the bimanual coordination skills of dyslexic children resemble those of younger, normal readers?

Comparison of dyslexic and normal readers' performance on unimanual skill were made using H5, H6 and H7.

H5: Since all subjects are right handed, it is predicted that dyslexic subjects will perform significantly better in accuracy with the use of the right hand when compared to the left hand.

H6: There will be no difference between the dyslexic and age-matched normal readers on the performance of the right and left hands separately.

H7: The dyslexics will perform more accurately with their right and left hands than the children.

The performance of dyslexic subjects on this unimanual visuomotor task demonstrates two important characterstics. First, the dyslexics are superior to both groups in accuracy (Figure 16) and speed (Figure 17), contrary to the hypothesis. Second, the dyslexics exhibit a greater difference between the accuracy of their right and left hands than the two control groups (Figure 16).

The second important characteristic of this unimanual data is the differenc[illegible]en right and left hand performance of each group which varies considerably. Figure 18 presents a bar graph illustrating the 20% difference between accuracy of the two hands in dyslexics, while the older readers had only a 9% difference between the hands and the younger readers had a 7% difference, which was not statistically significant. This large difference between the right and left hand performance of dyslexics has been previously observed (Denckla, 1985; Annett, 1985)

Comparisons of dyslexic and normal readers performance on bimanual skill acquisition were made using H8, H9, H10, H11 and H12.

H8: Within the dyslexic group, it is expected that accuracy will be better in the unguided, visual feedback condition than the memory condition.

H9: Within the dyslexic and younger reading groups it is expected that some subjects will lose the correct direction of hand movement when visual feedback is removed (Gladstone, 1985).

H10: It is expected that loss of direction of hand movement among dyslexic and younger readers will be attributable to bidirectional movement of the left hand (Gladstone, 1985).

Because of the need for interhemispheric collaboration in the bimanual task (Fagard, 1985) and the evidence for difficulty in bimanual tasks in dyslexics (Klicpera, 1981), it is expected that:

H11: The age-matched reading group will perform more accurately than the dyslexic group on the unguided visual feedback condition and memory condition.

H12: There will be no difference between the performance of the dyslexics and the children on the unguided visual feedback condition and the memory, no visual feedback condition.

In the execution of the bimanual motor task, the significant superiority in visuomotor skill among the dyslexics is no longer apparent in their accuracy (Figure 19). However, the dyslexics execute the task at a significantly faster rate (Figure 20), while maintaining accuracy equal to the older readers.

When visual feedback is removed, there is no evidence of superiority in visuomotor tracking ability among the dyslexic subjects for either accuracy (Figure 21) or speed (Figure 22). Although the dyslexic subjects remain somewhat faster (Figure 22), this finding is no longer significant. Figure 23 illustrates the findings for all three groups on both visual feedback and memory condition for accuracy and demonstrates the similarity between the age matched groups and the greater difficulty for all groups when visual feedback is removed. Similarly, Figure 24 illustrates the findings for all three groups on both visual feedback and memory condition for speed. Here there is no significant difference between any of the groups without visual feedback.

No hypotheses were generated to examine the differences and similarities of performance in relation to ratio of hand movement. Since the designs of studies previously assessing bimanual skill acquisition employed multiple trials of training rather than the single trial performance in this study, there was no basis for hypotheses generation. Consequently, the performance of these subject groups will be used to propose hypotheses regarding what can be learned from a single trial of bimanual skill acquisition.

These findings indicate the following observations: 1) Normal subjects beyond the age of maturation of the corpus callosum (Yakolev, 1967) exhibit a tendency toward dynamic coupling of the hands on initial trials of bimanual skill acquisition with and without visual feedback. (Tables 26 & 29) Normal childern before the age of maturation of the corpus callosum exhibit more primitive errors of loss of direction and inability to produce simultaneous movements and therefore do not initially demonstrate dynamic coupling of the two hands (Tables 28 & 31). 3) Dyslexic children beyond the age of maturation of the corpus callosum show a trend toward dynamic coupling of the two hands (Tables 27 & 30). However, some dyslexic children exhibit motor immaturities of loss of direction and an inability to produce simultaneous movements which is similar to younger readers.

Figure 25 illustrates each groups accuracy in performance in relation to the condition of varying ratios of hand movement. All groups are less accurate and slower (Figure 26) on angles requiring 1:2 ratio of hand movement. This is also the case when visual feedback is removed (Figure 27).

Implications and Limitations of Findings

In order to explain these findings, a discussion of the relationship between the cognitive demands of this task, the literature on right hemisphere functions in normals and right hemisphere function in dyslexics and the mechanisms of interhemispheric collaboration is applicable.

The focus of interest in this investigation involves assessing and comparing the perceptuo-motor skills of normal and dyslexic children. Because of the complexity of the neurological structures which are engaged in performing this task, interpretation of the findings requires discussion of these cognitive functions separately. That is, this computerized task requires very precise visuospatial perception, effective guidance of accurate fine motor control and integration or coordination of motor systems controlling left and right distal musculature of the hands. Each of these will be discussed in relation to the cognitive characteristics of the sample.

First, a description of the relevant cognitive skills of the dyslexic and age-matched subject groups on standardized tests is a starting point. The performance of the dyslexics on various measures of language and reading indicate that the dyslexic subjects have deficiencies in left hemisphere functions. This conclusion is derived from an extensive literature relating specific deficits in naming and syntax to compromise of left hemisphere perisylvian areas. The linguistic deficiencies are not observed in the two control groups. The dyslexic and age-matched readers appear to have equivalent visuospatial abilities on block design, judgement of line orientation and spatial memory, however, there was a ceiling effect evident for both groups on the latter two tests. When the groups were compared on spatial-graphomotor skill they were likewise equivalent, except for the dyslexics excelling on more frequently replicating the most difficult items on the test (Beery). Consequently, there is evidence of normal range ability and the possibility of superior right hemisphere skill as well as left hemisphere dysfunction in the dyslexic subjects. In addition, the groups were not distinguished on a battery of motor tests (R-NESS). Thus, all groups were screened for any deficiency in visuospatial perception and fine motor control necessary to execute the experimental task.

Evidence of deficiency in left hemisphere functions with intact or superior right hemisphere skills has been described previously in dyslexic populations

(Symmes, 1972; Owen, 1971; Denckla et al., 1980; Gordon, 1980). Geschwind (1982) points out studies that have documented superior talent in certain areas of nonverbal skill, such as art, architecture, engineering and athletics.

Geschwind and Galaburda (1985) have further proposed the concept "pathology of superiority" in understanding the extremely discrepant skills observed in dyslexics. In an elegant theory drawing on neurology, endocrinology, immunology and neuropsychology, they propose that testosterone during fetal life affects the development of the left and right hemispheres of the brain differentially. They hypothesize that a fetal sensitivity to testosterone, or an excessively high amount of the hormone, can cause retarded development in the language areas of the left hemisphere which may also disturb cytoarchitectural development in the right hemisphere as well. They argue that the lack of cell death in the right hemisphere and the observed symmetrical rather than the usual asymmetrical shape of the hemispheres may be responsible for superior right hemisphere skills described in dyslexic populations.

Interpretation of these experimental results of this study will be made in view of the cognitive characteristics of the dyslexic sample (left hemisphere dysfunction with normal or possibly superior right hemisphere skill). This profile is consistent with the initial experimental finding of superior performance by the dyslexic subjects in unimanual, visuomotor skill. This finding is interpreted as being due to superior visuospatial ability on the part of the dyslexic sample in comparison to age-and IQ-matched controls. The interpretation is partly based upon the finding of normal fine motor control in the dyslexic sample and the emphasis on visuospatial perception in this task.

The association of visuospatial abilities with right hemisphere function has long been established (Kimura, 1969; Levy, 1976; Robertshaw, 1976). However, conflicting findings supporting this association and those showing no hemisphere difference (Bryden, 1976; Birkett, 1977) suggest that the right hemisphere advantage is more readily observable with increasing complexity of the task. This has been true for research methodology employing perception of line orientation (Fontenot, 1972; Kimura, 1974; Phippard, 1977; Sasanuma, 1978), a motor response to perception such as placing a rod to match the position of a standard (De Renzi, 1971) and methods using a greater memory component (Oscar-Berman, 1978). Evidence of right hemisphere superiority with respect to learning tactile configurations, such as raised dots of the type used in Braille reading, also suggest a right hemisphere advantage for spatial configurations (Hermelin, 1971; Rudel et al., 1974, 1977; Harriman, 1979).

The literature focusing specifically on 'manipulo-spatial skills' (Young, 1983) further supports the interpretation of superior right hemisphere ability for the dyslexic unimanual performance. In summarizing the literature, Le Doux (1983) argues,

> "Early studies of split-brain humans found the left hemisphere performing poorly on tasks involving spatial processing (Bogen and Gazzaniga, 1965; Gazzaniga, 1965; Levy-Agresti and Sperry, 1968; Levy, 1972; Nebes, 1971, 1972, 1973). These data were consistent with the well-known clinical observation that right hemisphere, particularly right inferior parietal damage, produces disturbances in visuo-spatial perception. More recent observations in both split-brain (Le Doux, 1977; Gazzaniga, 1978; Le Doux, 1979) and brain-damaged (Le Doux, 1980) patients have suggested that the left hemisphere's difficulty with spatial tasks is not so much in visuo-spatial

perception, per se, but in guiding complex behavior in space.

For example, many of the tasks used to demonstrate profound differences in spatial ability between the hemispheres of split-brain patients required, in addition to visual perception, the use of the hands in perceiving or constructing spatial stimuli. When the manipulo-spatial demands were relaxed, turning the tasks into pure visuo-spatial tasks, both hemispheres could perform well (Le Doux, 1977; Gazzaniga, 1978). The left hemisphere inability is thus not so much in perception as in guiding behavioral interactions with the spatial environment."

Le Doux's distinction between pure visuospatial perception and execution of complex motor function in visuomotor tasks is the primary distinction demonstrated in the results of this study. In other words, this computerized task requires very precise visuospatial perception, effective guidance of accurate fine motor control and integration or coordination of motor systems controlling left and right distal musculature of the hands. Given the level of complexity of this task, the task characteristics and the literature on guiding motor movement in a spatial environment argue for predominantly right hemisphere control in the execution of these tasks.

The findings in Experiment II, employing an even more complex perceptual motor task demonstrate some loss of superiority in the dyslexic groups' bimanual performance compared to unimanual performance when visual feedback is available. That is, in the bimanual condition, the dyslexics are not only able to maintain an equal accuracy with the age-matched readers but are also able to execute the task with greater efficiency in speed. When the perceptual half of this perceptual-motor task is removed, in the bimanual memory condition where visual feedback is not available, the dyslexic performance is indistinguishable from controls. Thus, the findings from these three experimental tasks indicate that this dyslexic group is not equal to, nor deficient in perceptual motor skill, but is superior in the perceptual ability guiding their fine motor function. This conclusion argues that the hypothesized differences between the dyslexic and age-matched readers are in a <u>perceptual superiority</u> rather than a <u>perceptual-motor deficiency.</u>

What of the hypothesized dyslexic difficulty with interhemispheric collabotation and expected similarities in bimanual perceptuomotor skill with the younger, reading matched control group? As the data indicates, and contrary to the hypotheses, overall performance on accuracy and speed distinguishes these two groups instead of demonstrating their similarities. However, examination of the quality of motor function reveals some similarities.

Both dyslexic and younger readers demonstrated a pattern of immaturity in acquisition of the bimanual motor task which is similar to that reported for commisurotomy patients (Preilowski, 1972) and younger normal children (Fagard, 1985; Jeeves, 1988). On initial trials with visual feedback, subjects in those two groups were reported to alternate hand movements creating a stair-step effect rather than producing simultaneous movements which trace a smooth line. This was likewise observed in the dyslexic and younger subjects of this study on initial trials with visual feedback. In addition, when visual feedback was removed, dyslexic and younger reading subjects also lost the direction of the movement of one or both of the hands, completely reversing the direction of the tracing. These motor characteristics which constitute the most primative errors described in bimanual motor skill acquisition studies have also been observed in commisurotomy patients (Preilowski, 1972), 6 and 7 year olds (Fagard, 1985; Jeeves, 1988) but were never observed in the age-matched normal readers of this study or normal adults (Fagard, 1985; Jeeves, 1988).

Although Preilowski (1972) argued that "from the beginners first few trials no information can be gained about specific sensory motor mechanisms underlying the learning of a motor skill", the results reported by Gladstone (1985) and the findings of this study suggest that this is not the case. Examination of the performance from a developmental perspective indicates that younger children and some dyslexic subjects exhibit specific immaturities in style of motor execution not observed in chronologically- older or age-matched normal reading subjects. Thus, the ability of subjects to execute simultaneous hand movements and sustain the correct direction of the hand movements for a desired angle appear to be maturational markers despite chronological age.

The greater proportion of reversals by the dyslexic group was attributed to loss of direction in the right hand. This finding could be interpreted as supporting the interpretation of inefficient control from the left hemisphere. Since the dyslexic group was found to have deficient left hemisphere ability related to language function, this conclusion has some merit. However, since the nature of the difficulty is related to performance in the bimanual condition only and there is no other evidence of right hand motor dysfunction on the standardized test results or the unimanual performance on the experimental task, further consideration of an interpretation of interhemispheric collaboration difficulty is warranted.

Since the poor right hand performance was only seen in the bimanual condition without visual feedback, an interpretation based on interhemispheric collaboration will be explored. It has been proposed that this task is most highly influenced by the visuospatial skills of the right hemisphere. Based on the importance of right hemisphere influence on this task, the finding would support the hypotheses of difficulty in interhemispheric collaboration when transferring spatial information from the right to the left hemisphere to guide the right hand is necessary. In other words, following Fagard's reasoning, the inability of the dyslexic subjects to suppress motor irradiations causing a reversal of the direction of hand movement argues for an interpretation of poor interhemispheric shielding of information being the source of the dyslexic immaturity on this task.

A similar tendency to lose the direction of hand movement by the younger readers who were expected to have difficulty with interhemispheric collaboration supports this interpretation. Consequently, these qualitative similarities between some of the dyslexics and younger readers suggests a delay in development of cerebral maturation among some of the dyslexics. Alternative interpretations of the dyslexic performance cannot be ruled out, as limitations in the research design do not allow for discrimination between these alternatives. Rather, what is needed is a design which would represents the actual speed or timing contribution of each hand to the overall performance in order to discuss further the specific implications of this finding. Although the interpretation of a developmental lag in cerebral maturation based on the dyslexic bimanual performance in this study may seem contradictory to the finding of superior unimanual skill, the qualitative similarities to younger readers is warrants a discussion of this interpretation .

Given the qualitative findings presented, the performance style of the dyslexic subjects contains many characteristics which resemble the younger readers and suggests a developmental lag in cerebral maturation even at the ages of 12 to 16. Application of the work of Liederman (1986), Neff (1986) and Kinsbourne (1988) may be helpful in further entertaining interpretations of this finding. The concept of hemispheric independence is relevant to the literature on bimanual skill acquisition in adults (Fagard, 1985; Jeeves,

1988) which has demonstrated a shift from initial dynamic coupling of the limbs to independent and precise movements of the hands (and thus independent functioning of the two hemispheres).

The qualitative performance deficits in bimanual skill acquisition by some dyslexics in this study are indicative of a lack of hemispheric independence. Although precision in such bimanual skills is remote from the problems in language and learning to read, Kinsbourne (1988) proposes a possible relationship between the two. He argues, "....a general function does conceivably link differential finger movement and differential word recognition: the ability to inhibit highly probable (compatible, familiar) responses in favor of less favorable but more specifically adaptive alternatives."

Kinsbourne elaborates on this proposed general differentiating function in his discussion of reading acquisition:

"The phonological referent of any letter grouping depends critically on other letters coexisting in the word. No sooner does the child learn how to pronounce a syllable than, in the context of a new word, he is told that it is pronounced differently. The impaired reader persists, for variable periods of time, with responses to letter groupings within a word that might be correct were these groupings present in isolation, but are incorrect or at least inadequate in the new context. The ability to override familiar in favor of more adaptive responses calls for neural inhibitory interactions generically related to those that enable one finger to be moved while the others are restrained from moving."

The immaturity observed in the execution of the bimanual task by some of the dyslexics lends itself to Kinsbourne's (1988) interpretation of interhemispheric difficulties in dyslexics. He further proposes:

"The disorder may, at least in the majority of cases, reflect an immature state of cerebral neuronal circuitry, making for neuromotor immaturity and generating other signs of the type that used to be attributed to "minimal cerebral dysfunction," as well as the more specific and consequential cognitive deficits that preempt the educator's attention. The difficulty experienced by the older, reading-disabled child is then comparable to that experienced by any younger, normal child (although the assumption is not justified that therefore the dyslexic will ultimately mature sufficiently to "catch up"). In any case it would be easy to see why neuronal circuitry with a degree of underdifferentiation might lend itself only with difficulty to the higher levels of automatization."

Such "higher level automatization" is essential to Liedermans concept of hemispheric independence which would allow for independent information processing to guide the two hands. Since the tendency to reverse the direction of hand movement was only observed in a subgroup of the dyslexic sample (8/23), any further discussion of this finding necessitates a discussion of dyslexic subtyping which would go far beyond the goals of this study. Additional statistical analysis of the characteristics of those dyslexics in this study who reversed the direction of hand movement without visual feedback, has not as yet been undertaken. Similarly, Gladstone (1985) gives no report of such differentiation for those among his dyslexic sample who reversed direction of hand movement.

In summary, the findings indicate that the sample of Pure Dyslexic subjects exhibit superior perceptual-motor ability in both unimanual and bimanual motor function but lose that superiority when unable to rely on the perceptual feedback. This finding supports an argument made by Geschwind (personal communication from Denckla) that "vision is the great equalizer for balance between the hemispheres." When vision is removed, the dyslexics must depend solely on the precision of visual memory rather than visual perception to guide underlying motor structures in the two hemispheres. Difficulty on this task may tap into the ability of the two hemispheres to interact with each other to share information and be able to suppress overflow when unable to monitor errors through knowledge of results. It is only under these unusually complex and constrained conditions that an immaturity in the dyslexics' interhemispheric collaboration skills is observed. This finding suggests that the use of visual feedback not only allows the dyslexics to excel beyond the age-matched readers, but also masks the presence of an immaturity in some dyslexics' skills necessary for this interhemispheric task.

Applications of Basic Research to Educational Practice

A question frequently raised in relation to basic research in brain organization in dyslexia asks how this information is relevant to the lives and learning of dyslexic children and adults. Since none of the experimental tasks performed in the study were designed to directly measure reading mastery, direct inferences about learning to read cannot be made. However, as Samuel Orton and those who continued his work believed, the key to "the treatment and prevention of many disorders have advanced only when the structural foundations of that disorder have been elucidated" (Geschwind, 1982). The degree to which individual differences in cognitive skills and the rate or course of their development influences learning is a significant basis for approaching the remediation of dyslexia.

It is not necessarily the case that any deficiency in hemispheric interaction directly results in specific reading disability and may, in fact, be a correlate or risk factor. Dyslexic children do not read like split-brain subjects. In addition, younger children in this study showing immaturity in interhemispheric collaboration in motor skills are able to read at an age appropriate or above level. Consequently, any evidence of interhemispheric collaboration difficulties should not be used to justify training in motor interhemispheric transfer skills. Unfortunately, teaching approaches have often been based on correcting the deficiencies of inferred disorders (Denckla, 1978; Vellutino, 1979). Training students in skills correlated with reading difficulty may have no relation to reading itself. What then is the educational value of a study such as discussed here?

Several applications of these findings are relevant for remediation of dyslexia. The first and most significant issue is the emphasis these findings place on the individual difference which is observed among dyslexics and between dyslexics and normal readers. Children with dyslexia show broad diversity in cognitive strengths and weaknesses demonstrated in the dyslexia subtype literature. Understanding this variability is essential for defining a successful approach to teaching. In other words, the approach to teaching children with specific reading disability needs to be developmentally based on the functional level of the individual child's skills rather than what is expected from age or IQ level.

Dyslexic children often exhibit extreme discrepancies in strengths and weaknesses which cause them and adults working with them considerable confusion and misinterpretation of their academic performance. Consequently, children who are seriously delayed in reading need more help than normal children to master skills in their deficit areas and to establish a positive sense of self esteem and confidence in academic ability. These children often develop expectations of failure and resistance to the hard work necessary for acquiring academic skills. It is particularly a problem for children like those described in this study who excel beyond their peers in some cognitive abilities yet suffer the embarrassment of failure in others. Such children derive great benefit from understanding the nature of their cognitive difficulties and association with peers who have similar problems.

One recent approach to the understanding of learning and cognitive abilities (Gardner, 1985) proposes that the concept of intelligence actually masks multiple intelligences. Gardner (1987) argues that "intelligence is basically a pluralistic concept", and he delineates seven types of intelligence or "cognitive modules" which are related to discrete regions of the brain and require independent learning with limited transfer from one module to another. Gardners argument is in keeping with the developmental theories discussed in this study, particularly that of Geshwind's (1982) concept of "pathology of superiority". The work of Geshwind and Galaburda (1985) provides a neuroanatomical basis for the argument of discrepant skills or multiple intelligences, all of which can be tremendously useful to educators and counsellors who are helping children understand why they are "smart" at some things and "dumb" at other things.

Appropriate expectations for academic success in the classroom are essential for all children, particularly for the child with discrepant or delayed skills. Dealing with learning problems directly related to the cognitive disability itself requires both specific diagnostic understanding of the cognitive strengths and weaknesses (or level of intelligences) of the child and an appropriate teaching method which challenges growth in strengths and remediates areas of learning disability. When dyslexic children are expected to read as well as normal children but not at the same rate or age, motivation to learn is fostered and the debilitating experiences of failure are avoided. Consequently, the two main problems faced by educators working with learning disabled students are the problems of identifying and remediating the cognitive disability and the problems owing to psychological factors (emotional adjustment, motivation, self concept) that are directly and/or indirectly related to being learning disabled.

Minimal research is available for insight into the effect a learning disability has on personality development. However, the work of Cohen (1986) identifies some of the key emotional issues which these children with such discrepant skill levels must face. In his study, Cohen discusses the emotional conflicts encountered in learning disabled students. He observed,

"The learning-disabled children and adolescents studied evidenced two major emotional configurations: 1) a low level, chronic depression; and 2) an unusually high propensity to experience distress, anxiety and panic anxiety. These emotional characteristics were uniquely interwoven into the larger fabric of each youngster's personality.

Virtually all of the learning-disabled children over the age of seven evidenced a chronic, low-level depression. These depressive feelings were not related to internalized frustration, anger due to frustration, as Silver (1974) has described, but rather to the sad feelings of having lost a valued part of self. Often (but not always), this sense of loss was related to part of the "head/brain".

The sad feeling that there is a discrepancy between what one "is" and what one "ought" to be, and the ensuing frustration characterized both groups of youngsters studied. However, only the learning-disabled youngsters showed a low-level, chronic depression and the fantasy that they had lost a valued part of themselves."

The unexpected findings of both superior perceptual motor skills among the dyslexics as well as signs of immaturity in cerebral maturation in the group emphasizes the importance of an educational approach which accounts for individual difference. Special remedial methods such as the multisensory approach to teaching are available for remediation. Similarly, research on teaching methods geared to different subtypes of dyslexia (Doehring, 1984) and the gifted dyslexic (Jones, 1986) has begun.

Research findings which demonstrate extreme differential abilities and a delayed course of skill development can be most useful to educators by helping them to see a unique course and pattern of learning in a learning disabled student, rather than a child who cannot keep up with peers. Denckla (1985) discusses a study showing younger dyslexics having the worst performance on a map-walking test, while older dyslexics (after maturation of the corpus callosum) showed performance superior to normals. She uses this finding as support for the argument that the unique developmental course of dyslexics must be considered in view of their ultimate potential. In other words, "what must be considered 'money in the bank' during early years may later be withdrawn and usefully applied for successful academic achievement".

Future Research

This research study demonstrates a perceptual-motor superiority in the dyslexic subjects unimanual performance as well as indications of immaturity in cerebral maturation in bimanual skill acquisition in a third of the dyslexic group. Additional research is needed in order to further ascertain the implications of these findings. Specifically, further analysis of the existing data as well as improvements in the design and apparatus would be helpful.

Continued analysis of the data from this study could address several significant questions:

1.) Are there factors on either the experimental measures or the standardized tests which identify the dyslexic subgroup who reversed the direction of their hands or executed the bimanual task with alternating rather than simultaneous movements?

2.) Are there additional scoring measures which could be developed that would more precisely represent the different styles of execution of the task. Specifically, measures which would determine the respective contributions of the two hands when alternating, rather than performing simultaneous movements?

3.) Does controlling for, or matching dyslexic and older reading subjects on unimanual performance affect the comparison of the groups on bimanual performance?

Improvements in the methodology focus on expanding the capabilities of the apparatus in order to better address the issue of the respective contributions of the two hands to bimanual performance and obtaining a broader examination of the dyslexic population. Possible alternatives include:

1.) Connecting a device to the potentiometers which will measure the exact contribution of each hand, giving a count of total turning of each hand.

2.) Videotape the movement of the two hands in order to evaluate the timing relationship between the two hands as the task is executed. This method would reflect the issue of dominance, revealing which hand is doing the leading and which hand is doing the following.

3.) Examine bimanual skill acquisition in dyslexics over a broader age range, including performance of left handers, females and specific subtypes of dyslexics.

4.) Look at learning of bimanual skill over multiple trials to examine rate and style of learning.

5.) Administer additional tests which have been shown to assess interhemispheric transfer (Neff, 1986) to further establish concurrent validity.

APPENDIX A

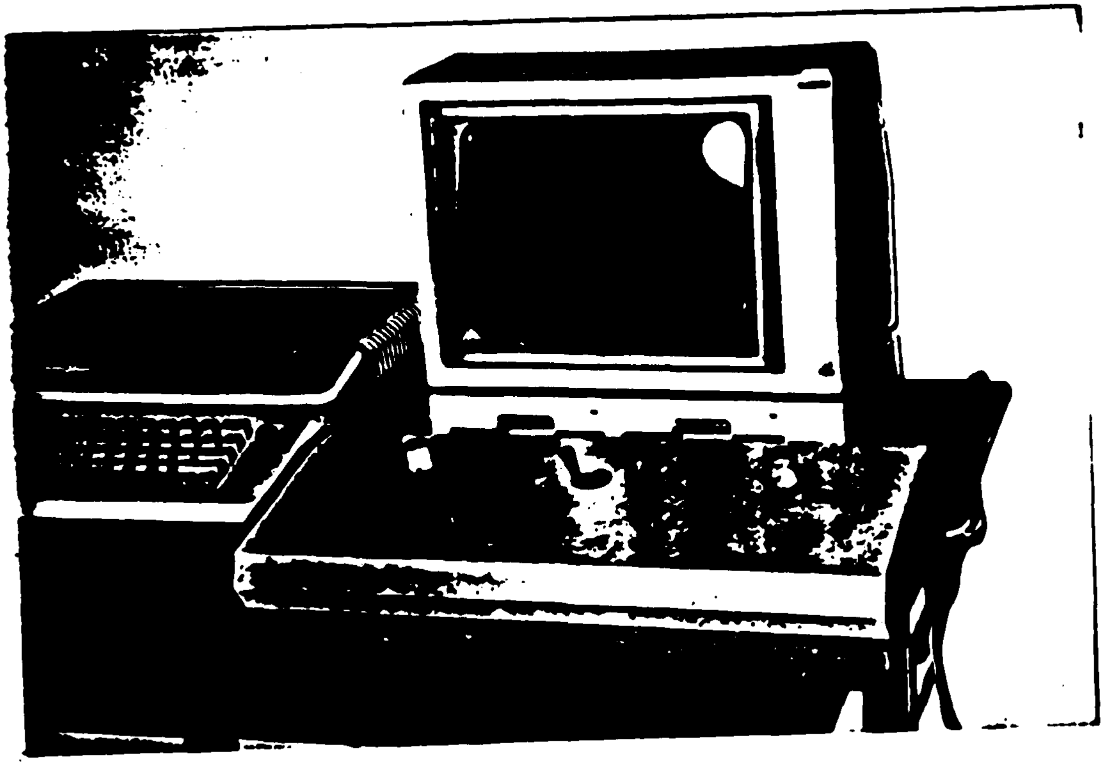


ILLUSTRATION OF APPARATUS

APPENDIX B

GLOSSERY OF TERMS

Dynamic Coupling - A natural tendency for the two hands to perform at equivalent rates (Fagard, 1985) in bimanual motor skill acquisition which affects accuracy in angular velocity.

Angular Velocity - Term used in bimanual motor skill acquisition (Fagard, 1985) to designate the ability to manipulate the two knobs simultaneously at the desired rate which will trace a target line.

Symmetrical Movement - Entrained movement pattern in execution of the bimanual experiment where the two hands move the knobs at equivalent rates and amounts (1:1 ratio of movement).

Asymmetrical Movement - Entrained movement pattern in the execution of the bimanual experiment where the two hands move the knobs at different rates and amounts (2:1 ratio or 1:2 ratio) according to the target line.

Reversal - Term used to describe performance observed in dyslexic and younger readers where the direction of an entrained bimanual movement of the hands (clockwise or counter clockwise) is changed to movement opposite to the intended path and direction when visual feedback is removed.

Correction - Adaptation in the turning of the knob which was made by all subjects whereby they changed the movement of the cursor on the screen to return to the center of the pathway after observing deviation away from the target line.

APPENDIX C

Charlotte A. Tomaino, M.A. M.Phil.
White Plains, New York 10606

Dear Parent,

Your son has been invited to participate in an exciting research study being conducted in the Kildonan School. The study is on the acquisition of reading skills. It addresses such questions as:

"Why do some children develop normal reading skills while others fail to learn to read when they have had ample educational opportunity and come from supportive family environments?"

This study is being conducted by Charlotte Tomaino from the City University of New York, with the cooperation of the Kildonan School. The research participants will be asked to play a video game much like a child's etch-a-sketch game where they will trace a maze pathway and single pathways at varying angles. Youngsters participating in the pilot study have enjoyed the "game-like" computer experiment and learned some new computer skills at the same time.

The first session involves the administration of standardized neuropsychological tests lasting approximately an hour. Unnecessary testing will be avoided by using test scores currently on file at the school. During the second session the youngsters will play a computer game on an Apple IIe. This session lasts approximately 35 minutes. All information derived from the testing will be kept strictly confidential.

If you agree to have your son participate in this research study, please sign below and return the form in the enclosed envelope. <u>Your son's participation and the subsequent findings may benefit other children in the future.</u> If you have any questions please call me at the above number (or Dr. King at the school) and I will be happy to explain the study in greater detail.

Sincerely,

____

I consent to have my son, ______________________, participate in the research study described above and have his prior test scores made available.

_______________________ Signature

_______________________ Date

_______________________ Printed Name

_______________________ Home or Business Phone

____ Home address

APPENDIX D

Charlotte A. Tomaino, M.A. M.Phil.
White Plains, New York 10606

Dear Parent,

Your son has been invited to participate in a research study being conducted in the White Plains Schools. The study is on the acquisition of reading skills. It addresses such questions as:
"Why do some children develop normal reading skills while others fail to learn to read when they have had ample educational opportunity and come from supportive family environments?"

This study is being conducted by Charlotte Tomaino from the City University of New York, with the cooperation of the White Plains School System. The research participants will be asked to play a video game much like a child's etch-a-sketch game where they will trace a maze pathway and single pathways at varying angles. Youngsters participating in the pilot study have enjoyed the "game-like" computer experiment and learned some new computer skills at the same time.

The first session involves the administration of standardized neuropsychological tests lasting approximately an hour. During the second session the youngsters will play a computer game on an Apple IIe. This session lasts approximately 35 minutes. All testing will be done in your child's school. All information derived from the testing will be kept strictly confidential.

If you agree to have your son participate in this research study, please sign below and return the form in the enclosed envelope. Your son's participation and the subsequent findings may benefit other children in the future. If you have any questions please call me at the above number (or Mr. Walters at the school) and I will be happy to explain the study in greater detail.

Sincerely,

I consent to have my son participate in the research study described above and have his school testing scores made available.

Signature

Date

Printed Name

Home or Business Phone

Home address

APPENDIX E

Screening Battery and Ancillary Battery of Tests Administered

Intelligence: Dyslexics - WISC-R

Older Normal Controls - Cognitive Abilities Test, WISC-R Vocabulary and Block Design

Younger Normal Controls - Cognitive Abilities Test, WISC-R Vocabulary and Block Design.

Reading: Piat Word Recognition, Piat Reading Comprehension, Woodcock/Johnson Word Attack, Myklebust Quotient.

Motor: Revised Neurological Examination of Subtle Signs (RNESS), Purdue Pegboard.

Graphomotor: Beery, Maze Speed, Pencil Excursion.

Attention: Conners Parent Ratings, Conners Teacher Ratings.

Language: Rapid Automatized Naming Test, Boston Naming Test, Token Test.

Spatial: Benton Spatial Memory, Benton Judgement of Line Orientation Test.

APPENDIX F

CHILDREN'S HISTORY FORM

INSTRUCTIONS TO PARENTS: Please fill out the form to the best of your knowledge. If some questions are not applicable to your child, write in N.A. If you need more space or wish to make an additional comment, please attach a separate sheet.

Child's Name:______________________ Birthdate:______________

Home Address:____

____

Home Phone: (   )______________

Mother's Name:__________________ Father's Name:__________________

Business Address (Father/Mother):______________________________

____

School Currently Attending:____________________ Grade:__________

Address:____

____

Telephone: (   )________________

Name of person filling out this form:__________________________

Date:________________

Relationship to Child:______________________________

PREGNANCIES:

Was this child adopted?   Yes______   No________

Did you have any of the following complications during this pregnancy?
If so, indicate which month:

Anemia_______ High Blood Pressure________ Swollen Ankles________

Kidney Disease________ Heart Disease________

German Measles________ Toxemia____________ Staining____________

Bleeding____________ RH or other blood incompatibility________

Vomiting____________ Virus____________

Threatened miscarriage or early contractions:____________________

Chronic illness(s) such as diabetes, kidney infection, thyroid, etc.

____

Other illnesses during pregnancy:____________________

____

Hospitalization during pregnancy other than during delivery__________

When____________________Why____________________

Operation____________________

Injury____________________

Which medications, if any, did you take during this pregnancy?

____

How much weight did you gain during this pregnancy?__________

Did you have any other complications?__________If so, what?

____

List all of your pregnancies in order, including the child to be seen. If a pregnancy ended in miscarriage, state at which month. If you have had more than six pregnancies, continue on the back of this page.

Year	Name	Length of Pregnancy (in mos.)	Birth Weight	Sex	Complications

BIRTH HISTORY:

Name of Hospital:____________________

How many hours from first contraction to birth?____________________

Were you given medication? Yes______ No_______ What kind?____________________

Why was it given?____

Were you under anesthesia during childbirth? Yes__________ No________________

What kind?____

Was labor induced? Yes_________ No____________ Why?____________________

How?____

Was the baby born head first? Yes____________ No______________ Don't know______

Were forceps used? Yes________ No________ Why?____________________________

Did you have a Caesarian Section? Yes__________ No________ Why________________

Did the baby have any bruises? Yes__________ No____________ Where?______________

Was this a multiple birth? Yes_____________ No____________ How many?__________

Did this baby have breathing problems? Yes__________ No_________ Don't know______

Was the cord around the neck Yes__________ No__________ Don't know______________

Did the baby cry quickly? Yes_______ No_______________ Don't know______________

Was the baby's color normal? Yes__________ No__________ Don't know______________

Blue?________ Yellow?_____________

If the baby was yellow (jaundiced), did he receive:

Oxygen?	Yes_____	No_____	How long?____________________
Transfusions?	Yes_____	No_____	How many?____________________
Phototherapy (lights)?	Yes_____	No_____	How many days?________________

Were there any other complications before you took the baby home?

Yes________ No______ What?______________________________________

Was the baby placed in an incubator or special crib?

Yes______ No______ How long?______________________________________

How long after birth did you take the baby home?______________________

EARLY HISTORY:

General:

Did this baby have feeding problems? Yes__________ No__________

Describe them____

Was the baby colicky? Yes__________No__________How long?____________________

Did the baby require formula changes? Yes__________No__________

Describe them____

Difficulty sucking as an infant? Yes__________No__________

Difficulty chewing? Yes__________No__________

Drooling past 2 1/2? Yes__________No__________

Was the baby normally active? Yes__________No__________

Describe____

Was the baby limp? Yes__________No__________

Was the baby stiff? Yes__________No__________

Did the baby show unusual trembling? Yes__________No__________

Did the baby fail to grow normally? Yes__________No__________

Did the baby fail to gain weight? Yes__________No__________

Was this baby different in any way from brothers or sisters, or from other children his/her age?

Yes__________No__________Describe how______________________________

<u>Motor Milestones?</u>

Age sat alone______________Age tied shoes______________

Age walked without holding on______________Age pedaled tricycle______________

Age fed self______________Age rode bicycle______________

Age dressed self____________________

<u>Language Milestones:</u>

Age spoke first words____________________

Age put 2-3 words together______________

Age good sentence structure______________

Speech problems? Yes________No________Describe______________________________

Toileting:

Age trained for urine?________________For bowels______________________

Bed wetting? Yes________No______Age Started?________How often?________

Age controlled?______________

Did (s)he have urine accidents during the day? Yes__________No__________

Did (s)he have soiling? Yes__________No____________

MEDICAL HISTORY

Has your child had meningitis or encephalitis? Yes_______No________

What age?____________

Has your child had a head injury? Yes________No____________

Loss of consciousness?___________

Did your child have any significant injuries? Yes__________No__________

Has your child ever had high or prolonged fevers? Yes________No__________

Did (s)he have frequent ear infections? Yes_______No_________

Does (s)he have any visual defects? Yes_______No___________

Did (s)he have any hearing defects? Yes_______No___________

Does (s)he suffer from heart disease? Yes________No________

Does (s)he have asthma? Yes___________No__________

Has your child had seizures? Yes______No_______Age at first seizure__________

Has your child had episodes of unconsciousness? Yes__________No_____________

Has your child been hospitalized? Yes____________No________________

Age_______Reason____

Age_______Reason____

List any other uncommon childhood illnesses your child has had:_______________

____

____

Does your child frequently complain of:

Headache? Yes___ No___ Nausea? Yes______ No________

Weakness? Yes___ No___ Stomachaches? Yes______ No________

Dizziness? Yes___ No___ Chronic Constipation? Yes________ No________

Trouble with vision? Yes___ No___ Chronic Diarrhea? Yes______ No________

Trouble with hearing? Yes_________ No________

Other? Yes________ No______ What?_______________________________________

____

____

List any medications that your child has taken in the past for more than a month (include dosage given and reason it was taken):

____

____

List any medications your child is currently taking (include dosage and reason for taking it):____

____

Has your child had:

Eye exam? Yes_______ No_______ Age________ Results_______________________

Hearing exam? Yes________ No________ Age_________ Results__________________

EEG? Yes_________ No__________ Results_________________________________

Other special medical tests? Name______________________________________

Results____

Have you consulted any medical specialists for the child?

Yes_______ No_________ Why?____

Age__________ Reason____

____

Results____

____

BEHAVIOR AND SOCIAL HISTORY:

Who lives in the home?______________________________

Are there significant marital conflicts? Yes________No__________

Are there significant conflicts between child and parent? Yes__________No_________

Do parents agree on how to discipline child? Yes_________No__________

Who disciplines and how?______________________________

____

How does your child respond to discipline?______________________________

Does your child have difficulty getting along with children his own age?

yes_________No_________

Does your child have difficulty getting along with adults?

Yes_________No__________

How does (s)he occupy himself?______________________________

____

How does your child perform athletically?______________________________

Check the ones that describe your child:

Shy?____________________

Well behaved?____________________

Impulsive?____________________

Clumsy using his hands?____________

Immature?____________________

Stubborn?____________________

More active than other children?__________

Clumsy in walking?____________________

Does your child or did your child ever have:

Temper tantrums?____________________

Sleep problems?____________________

Nightmares?____________________

Blank spells?____________________

Falling spells?____________________

Average intelligence?____________

Poor handwriting?____________

Head banging?____________

Toe walking?____________

Thumb sucking?____________

Tics or twitching?__________

Difficulty staying with one activity for a reasonable length of time?____________

Did you child ever eat paint, paper, etc.? Yes______________No________________

Which hand does your child use most often? Right________________Left___________

Age established?_____________

Does your child switch hands? Yes_________No___________

Has your child had emotional, adjustment or behavioral problems?

Yes_______No________

Has your child received any psychological or psychiatric treatment?

yes________No_____By Whom?_______________When____________________________

Place?____

SCHOOL HISTORY: (if applicable)

Did your child attend nursery school or a preschool program?

Yes_______No_______Age started__________________

Were there problems? Yes______No_______If yes, describe:_______________

____

Did your child attend first grade? Yes_________No________Age started_____________

Were there problems? Yes__________No__________If yes, describe:_________________

____

Has the school currently reported problems with:

Reading?	Yes_____No______	Behavior?	Yes_______No_____
Spelling?	Yes_____ No______	Social adjustment?	Yes_______No_____
Writing?	Yes____No_______	Attention span?	Yes_______No_____
Arithmetic?	Yes_____No_______	Following directions?	Yes_______No_____

Does your child like school? Yes_______No___________

Has any psychological testing been done? Yes_________No___________

By whom?______________________________When?___________________________

Where?____

What recommendations were made?____

____

Is your child in a special education class? Yes__________ No__________

What kind?__________

When was (s)he placed there?__________

Does your child receive any special services in school (resource room, tutoring, remedial reading, speech, etc.)?

Yes__________ No__________ What services?__________

For how long?__________

Have you gotten any help privately for your child? Yes__________ No__________

What sort?__________

By whom?__________

When?__________ How often?__________

FAMILY HISTORY:

(UNDER PARENTS LIST NAMES OF CHILDREN IN ORDER OF BIRTH)

	Age	Education (grade)	Occupation	Health	School or Behavior Problem
Father					
Mother					

Did anyone in your immediate family or other relative have any of the following? (If so, who?)

Neurological disease? Yes__________ No__________

Seizures (epilepsy)? Yes__________ No__________

Hearing problems? Yes__________ No__________

Visual problems? Yes__________ No__________

Emotional problems? Yes__________ No__________

Mental retardation? Yes__________ No__________

Slowness in talking? Yes__________ No__________

Slowness in walking? Yes__________ No__________

Hyperactivity? Yes__________ No__________

Learning problems? Yes__________ No__________

Similar problems to child? Yes__________ No__________

Does any disease run in the family? Yes__________ No__________

What?____

____

••••••••••••

Additional Comments:

TABLE 1

Comparison of Dyslexic and Age Matched and Older Reading Groups On Screening Battery Tests

	Dyslexic		Older			
	Mean	SD	Mean	SD	t	Prob
Vocabulary	10.13	1.49	11.95	2.27	3.12	**
Block Design	10.96	1.85	11.79	2.94	1.07	
ATTENTION						
Hyperactivity Index-Teacher	.3652	.321	.2632	.329	1.01	
Hyperactivity Index-Parent	1.70	3.26	.3579	.209	1.98	
READING						
Myklebust Quotient	.6952	.09	1.14	.140	12.16	***
Piat Word Recognition Grade Level	5.78	1.95	12.90	0.00	15.90	***
Piat Word Comprehension Grade Level	6.79	2.29	11.06	1.83	6.56	***
W/J Word Attack	4.10	1.44	12.90	0.00	26.57	***
LATERALITY						
Laterality Hand (Max = 11)	10.96	.21	9.95	.97	4.45	**
Laterality Foot (Max = 2)	1.78	.52	1.73	.56	.27	
Laterality Eye 0 or 1	.826	.39	.89	.32	.62	
PERCEPTUAL/SPATIAL						
Benton Spatial Memory	13.78	1.63	13.53	1.35	.51	
Judge of Line Orientation	25.83	3.26	25.63	2.91	.20	

* p. < .05 ** p. < .01 *** p. < .001, two-tailed, connected.

TABLE 2

Comparison of Dyslexic and Younger Reading Groups On Screening Battery Tests

	Dyslexic		Younger			
	Mean	SD	Mean	SD	t	Prob
Vocabulary	10.13	1.49	15.5	2.31	8.62	***
Block Design	10.96	1.85	14.14	2.14	4.79	***
ATTENTION						
Hyperactivity Index-Teacher	.3652	.321	.4357	.337	0.64	
Hyperactivity Index-Parent	1.70	3.26	.5143	.266	1.74	
READING						
Myklebust Quotient	.6952	.094	1.14	.099	13.84	***
Piat Word Recognition Grade Level	5.78	1.95	5.20	1.01	1.20	
Piat Word Comprehension Grade Level	6.79	2.29	5.06	.913	3.22	**
W/J Word Attack	4.10	1.44	8.92	3.22	5.28	***
LATERALITY						
Laterality Hand (Max = 11)	10.96	.21	9.64	1.55	3.15	**
Laterality Foot (Max = 2)	1.78	.52	1.5	.760	1.35	
Laterality Eye 0 or 1	.826	.39	.5714	.514	1.71	
PERCEPTUAL/SPATIAL						
Benton Spatial Memory	13.78	1.63	11.29	1.68	4.23	**
Judge of Line Orientation	25.83	3.26	20.14	4.61	4.09	**

TABLE 3

Comparison of Older and Younger Reading Groups On Screening Battery Tests

	Older		Younger			
	Mean	SD	Mean	SD	t	Prob
Vocabulary	11.95	2.27	15.5	2.31	4.41	**
Block Design	11.79	2.94	14.14	2.14	2.54	*
ATTENTION						
Hyperactivity Index-Teacher	.2632	.33	.4357	.337	1.48	
Hyperactivity Index-Parent	.3579	.21	.5143	.266	1.89	
READING						
Myklebust Quotient	1.14	.14	1.14	.099	.01	
Piat Word Recognition Grade Level	12.90	0.00	5.2	1.01	33.43	***
Piat Word Comprehension Grade Level	11.06	1.83	5.06	.913	12.34	***
W/J Word Attack	12.90	0.00	8.92	3.22	5.41	***
LATERALITY						
Laterality Hand (Max = 11)	9.95	.97	9.64	1.55	.69	
Laterality Foot (Max = 2)	1.74	.562	1.5	.760	1.03	
Laterality Eye 0 or 1	.8947	.315	.5714	.514	2.24	
PERCEPTUAL/SPATIAL						
Benton Spatial Memory	13.53	1.35	11.29	1.68	4.25	**
Judge of Line Orientation	25.63	2.91	20.14	4.61	4.19	**

TABLE 6

Breakdown by Mean Age in Months for all Subject Groups

	N	Mean	SD
Dyslexics	23	181.56	17.06
Older	19	180.00	15.88
Younger	14	92.93	5.6

TABLE 5

Comparison of Dyslexic and Reading Groups for Age Match

	Dyslexic			Older				
Age Range	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**t**	**Prob**
12 to 16	23	181.56	17.06	19	180.00	15.88	0.31	
12. to 15.5	10	165.30	12.90	10	165.20	14.79	0.63	
15.5 to 16.11	13	194.08	6.29	9	192.00	3.61	1.19	

TABLE 6

Comparison of Dyslexic and Age Matched Readers on Ancillary Battery Tests

	Dyslexic		Older			
	Mean	SD	Mean	SD	t	Prob
READING						
RAN color	38.87	6.30	30.21	4.66	4.97	***
RAN number	24.48	5.48	18.84	3.32	4.11	**
RAN objects	46.74	7.29	38.00	6.52	4.05	**
RAN letters	26.52	7.57	18.63	3.52	4.45	**
MOTOR						
Purdue Pegboard R	14.13	1.69	14.33	1.41	0.41	
Purdue Pegboard R	14.91	1.88	14.94	1.39	0.06	
Purdue Pegboard L	13.09	1.31	12.22	1.17	2.20	
Purdue Pegboard L	14.22	1.38	13.78	1.22	1.07	
Purdue Pegboard B	10.87	1.25	10.78	1.26	0.23	
Purdue Pegboard B	11.26	1.42	11.00	1.495	0.57	
RNESS						
L foot tap time	51.52	11.64	49.53	8.95	0.61	
L foot tap mirror	.0435	.209	0.0	0.0	0.91	
L foot tap overflow	0.0	0.0	.1053	.315	1.61	
L foot tap dysrythmia	.6087	.499	.1579	.375	3.25	**
L foot tap sequence	0.0	0.0	0.0	0.0	0.0	
L heel/toe time	79.74	14.11	66.84	12.45	3.11	*
L heel/toe mirror	.0435	.209	.0526	.229	0.14	
L heel/toe overflow	.2174	.422	.1579	.375	0.48	
L heel/toe dysrythmia	.8696	.344	.7368	.452	1.08	
L heel/toe sequence	.3913	.499	.3158	.478	0.50	
L hand pat time	38.87	4.61	40.89	7.55	1.02	
L hand pat mirror	.087	.288	0.0	0.0	1.31	
L hand pat overflow	.1739	.388	0.0	0.0	1.95	
L hand pat dysrythmia	.1739	.388	.1053	.315	0.62	
L hand pat sequence	0.0	0.0	.0526	.229	1.10	
L hand p/s time	63.65	13.77	56.05	9.73	2.02	
L hand p/s mirror	0.0	0.0	0.0	0.0	0.0	
L hand p/s overflow	.087	.288	0.0	0.0	1.31	
L hand p/s dysrythmia	.2609	.45	.1053	.315	1.27	
L hand p/s sequence	.087	.288	.0526	.229	0.42	

TABLE 6
(Continued)

L finger tap time	55.30	6.67	56.74	9.08	0.59	
L finger tap mirror	.0435	.209	0.0	0.0	0.91	
L finger tap overflow	.3043	.470	.1053	.315	1.57	
L finger tap dysrythmia	0.0	0.0	.1053	.315	1.61	
L finger tap sequence	0.0	0.0	0.0	0.0	0.0	
L finger seq time	80.57	16.54	73.26	17.01	1.41	
L finger seq mirror	.1739	.388	.1579	.375	0.14	
L finger seq overflow	.6522	.487	.4737	.513	1.15	
L finger seq dysrythmia	.6522	.487	.4737	.513	1.15	
L finger seq sequence	.3913	.499	.3684	.496	0.15	
R foot tap time	48.30	10.73	50.00	8.88	0.55	
R foot tap mirror	0.0	0.0	0.0	0.0	0.0	
R foot tap overflow	.0435	.209	0.0	0.0	0.91	
R foot tap dysrythmia	.4348	.507	.2105	.419	1.54	
R foot tap sequence	0.0	0.0	0.0	0.0	0.0	
R heel/toe time	76.74	20.24	65.53	13.73	1.69	
R heel/toe mirror	.0435	.209	0.0	0.0	0.91	
R heel/toe overflow	.087	.288	.0526	.229	0.42	
R heel/toe dysrythmia	.8696	.344	.6316	.496	1.83	
R heel/toe sequence	.2609	.449	.3684	.496	0.74	
R hand pat time	36.13	4.18	37.16	6.41	0.63	
R hand pat mirror	.0435	.209	0.0	0.0	0.91	
R hand pat overflow	.1739	.388	0.0	0.0	1.95	
R hand pat dysrythmia	.0435	.209	.0526	.229	0.14	
R hand pat sequence	0.0	0.0	0.0	0.0	0.0	
R hand p/s time	57.83	12.52	53.74	9.53	1.17	
R hand p/s mirror	0.0	0.0	0.0	0.0	0.0	
R hand p/s overflow	0.0	0.0	0.0	0.0	0.0	
R hand p/s dysrythmia	.0435	.209	0.0	0.0	0.91	
R hand p/s sequence	0.0	0.0	0.0	0.0	0.0	
R finger tap time	53.09	4.46	54.53	9.22	0.62	
R finger tap mirror	.0435	.209	0.0	0.0	0.91	
R finger tap overflow	.5217	.511	.0526	.229	3.95	**
R finger tap dysrythmia	.0435	.209	.1053	.315	0.76	
R finger tap sequence	0.0	0.0	0.0	0.0	0.0	

TABLE 6
(Continued)

R finger seq time	77.68	16.36	68.95	15.98	1.70	
R finger seq mirror	.1304	.344	.0526	.229	0.84	
R finger seq overflow	.6957	.470	.5789	.507	0.77	
R finger seq dysrythmia	.6522	.487	.3684	.496	1.86	
R finger seq sequence	.3043	.470	.2105	.419	0.68	
Heel walk errors	2.09	.90	1.26	.991	2.82	*
Heel walk overflow R	.5642	.507	.2632	.452	2.02	
Heel walk overflow L	.5217	.511	.3684	.496	0.98	
Toe walk Errors	.5217	.898	.1053	.459	1.94	
Toe walk overflow R	.087	.288	.1053	.315	0.20	
Toe walk overflow L	.1304	.344	.1053	.315	0.24	
Side foot walk Errors	1.57	.945	1.00	1.00	1.88	
Side foot walk overflow R	.5217	.511	.1579	.375	2.58	*
Side foot walk overflow L	.6087	.499	.4211	.507	1.20	
Tandem walk forward Errors	.3478	.885	.0526	.229	1.54	
Tandem walk backwards	1.57	1.08	.5263	.905	3.33	**
sustination posture time	1.74	1.39	1.42	1.22	0.78	
sustination posture fall	.8696	.344	.8421	.375	0.25	
sustination posture arms	.4348	.507	.1579	.375	1.98	
sustination steadiness time	0.0	0.0	.1579	.688	1.10	
sustination steadiness overflo	.4783	.511	.3158	.478	1.06	
sustination steadiness time	.1304	.344	.1579	.501	0.21	
CONSTRUCTIONAL						
Beery	20.67	2.20	20.68	1.77	0.03	
Beery-top	171.71	3.23	166.11	6.05	3.55	**
LANGUAGE						
Token Test	16.39	1.69	18.58	1.39	4.33	**
Boston Naming Test	47.72	5.73	51.83	4.50	2.25	
PRACTICE EFFECT						
Video Game	1.27	1.16	1.42	.902	0.45	

TABLE 7

Comparison of Dyslexic and Younger Readers on Ancillary Battery Tests

	Dyslexic		Younger			
	Mean	SD	Mean	SD	t	Prob
READING						
RAN color	38.87	6.30	46.92	10.14	2.95	*
RAN number	24.48	5.48	29.43	6.57	2.47	
RAN objects	46.74	7.29	58.29	15.87	2.56	*
RAN letters	26.52	7.57	29.93	7.45	1.34	
MOTOR						
Purdue Pegboard R	14.13	1.69	11.71	1.82	4.11	**
Purdue Pegboard R	14.91	1.88	12.92	2.10	2.92	*
Purdue Pegboard L	13.09	1.31	10.64	1.28	5.55	***
Purdue Pegboard L	14.22	1.38	11.54	1.27	5.76	***
Purdue Pegboard B	10.87	1.25	8.86	1.03	5.05	***
Purdue Pegboard B	11.26	1.42	9.54	1.9	3.09	*
RNESS						
L foot tap time	51.52	11.64	71.0	14.14	4.55	***
L foot tap mirror	.0435	.209	0.0	0.0	0.78	
L foot tap overflow	0.0	0.0	.1429	.363	1.90	
L foot tap dysrythmia	.6087	.499	.50	.519	0.63	
L foot tap sequence	0.0	0.0	.2143	.426	2.44	
L heel/toe time	79.74	14.11	111.14	34.34	3.26	**
L heel/toe mirror	.0435	.209	.0714	.267	0.36	
L heel/toe overflow	.2174	.422	.5714	.514	2.28	
L heel/toe dysrythmia	.8696	.344	.9286	.267	0.55	
L heel/toe sequence	.3913	.499	.3571	.497	0.20	
L hand pat time	38.87	4.61	53.21	12.16	4.23	**
L hand pat mirror	.087	.288	.0714	.267	0.16	
L hand pat overflow	.1739	.388	.2143	.426	0.30	
L hand pat dysrythmia	.1739	.388	.3571	.497	1.25	
L hand pat sequence	0.0	0.0	0.0	0.0	0.00	
L hand p/s time	63.65	13.77	71.71	19.53	1.47	
L hand p/s mirror	0.0	0.0	0.0	0.0	0.00	
L hand p/s overflow	.087	.288	.2143	.426	1.09	
L hand p/s dysrythmia	.2609	.45	.4286	.514	1.04	
L hand p/s sequence	.087	.288	.0714	.267	0.16	

TABLE 7
(Continued)

L finger tap time	55.30	6.67	77.57	9.12	8.56	***
L finger tap mirror	.0435	.209	0.0	0.0	0.78	
L finger tap overflow	.3043	.470	.7857	.426	3.13	*
L finger tap dysrythmia	0.0	0.0	.50	.519	4.66	***
L finger tap sequence	0.0	0.0	0.0	0.0	0.00	
L finger seq time	80.57	16.54	140.0	44.69	4.62	***
L finger seq mirror	.1739	.388	.4286	.514	1.71	
L finger seq overflow	.6522	.487	.8571	.363	1.36	
L finger seq dysrythmia	.6522	.487	.7857	.426	0.85	
L finger seq sequence	.3913	.499	.2143	.426	1.10	
R foot tap time	48.30	10.73	63.36	9.997	4.24	**
R foot tap mirror	0.0	0.0	0.0	0.0	0.00	
R foot tap overflow	.0435	.209	0.0	0.0	0.78	
R foot tap dysrythmia	.4348	.507	.2143	.426	1.36	
R foot tap sequence	0.0	0.0	.1429	.363	1.90	
R heel/toe time	74.74	20.24	104.23	30.87	3.47	**
R heel/toe mirror	.0435	.209	0.0	0.0	0.78	
R heel/toe overflow	.087	.288	.50	.519	2.73	*
R heel/toe dysrythmia	.8696	.344	.9286	.267	0.55	
R heel/toe sequence	.2609	.449	.2857	.469	0.16	
R hand pat time	36.13	4.18	48.43	6.01	7.34	***
R hand pat mirror	.0435	.209	0.0	0.0	0.78	
R hand pat overflow	.1739	.388	.2143	.426	0.30	
R hand pat dysrythmia	.0435	.209	.2857	.469	1.83	
R hand pat sequence	0.0	0.0	0.0	0.0	0.00	
R hand p/s time	57.83	12.52	64.15	14.06	1.39	
R hand p/s mirror	0.0	0.0	0.0	0.0	0.00	
R hand p/s overflow	0.0	0.0	.3571	.497	3.48	**
R hand p/s dysrythmia	.0435	.209	.2857	.469	1.83	
R hand p/s sequence	0.0	0.0	0.0	0.0	0.00	
R finger tap time	53.09	4.46	70.00	8.18	7.12	***
R finger tap mirror	.0435	.209	0.0	0.0	0.78	
R finger tap overflow	.5217	.511	.50	.519	0.12	
R finger tap dysrythmia	.0435	.209	.3571	.497	2.24	
R finger tap sequence	0.0	0.0	0.0	0.0	0.00	

TABLE 7
(Continued)

R finger seq time	77.48	16.36	137.0	15.50	10.6	***
R finger seq mirror	.1304	.344	.3571	.497	1.64	
R finger seq overflow	.6957	.470	1.0	0.0	2.41	
R finger seq dysrythmia	.6522	.487	.9286	.267	2.23	
R finger seq sequence	.3043	.470	.50	.519	1.18	
Heel walk errors	2.09	.90	2.93	.267	4.19	**
Heel walk overflow R	.5642	.507	.8571	.363	1.88	
Heel walk overflow L	.5217	.511	.8571	.363	2.14	
Toe walk Errors	.5217	.898	1.86	1.03	4.16	**
Toe walk overflow R	.087	.288	.4286	.514	2.28	
Toe walk overflow L	.1304	.344	.3571	.497	1.64	
Side foot walk Errors	1.57	.945	2.57	.756	3.37	**
Side foot walk overflow R	.5217	.511	1.0	0.0	3.48	**
Side foot walk overflow L	.6087	.499	.9286	.267	2.53	*
Tandem walk forward Errors	.3478	.885	1.14	1.29	2.22	
Tandem walk backwards	1.57	1.08	2.0	.784	1.31	
Sustination posture time	1.74	1.39	1.36	1.34	0.82	
Sustination posture fall	.8696	.344	.7857	.426	0.66	
Sustination posture arms	.4348	.507	.1429	.363	1.88	
Sustination steadiness time	0.0	0.0	.0714	.267	1.29	
Sustination steadiness overflo	.4783	.511	.8571	.363	2.42	
Sustination steadiness time	.1304	.344	.2143	.426	0.66	
CONSTRUCTIONAL						
Beery	20.67	2.20	15.14	2.83	6.23	***
Beery-top	171.72	3.23	121.36	17.47	10.65	***
LANGUAGE						
Token Test	16.39	1.69	16.36	2.37	0.04	
Boston Naming Test	47.72	5.73	40.86	3.74	3.88	**
PRACTICE EFFECT						
Video Game	1.27	1.16	1.93	1.07	1.70	

TABLE 8

Comparison of Older and Younger Readers on Ancillary Battery Tests

	Older		Younger			
	Mean	SD	Mean	SD	t	Prob
READING						
RAN color	30.21	4.66	46.92	10.14	5.55	***
RAN number	18.84	3.32	29.43	6.57	5.53	***
RAN objects	38.00	6.52	58.29	15.87	4.51	**
RAN letters	18.63	3.52	29.93	7.45	5.26	***
MOTOR						
Purdue Pegboard R	14.33	1.41	11.71	1.82	4.59	***
Purdue Pegboard R	14.94	1.39	12.92	2.10	3.23	**
Purdue Pegboard L	12.22	1.17	10.64	1.28	3.65	**
Purdue Pegboard L	13.78	1.22	11.54	1.27	4.98	***
Purdue Pegboard B	10.78	1.26	8.86	1.03	4.62	***
Purdue Pegboard B	11.00	1.695	9.54	1.9	2.40	
RNESS						
L foot tap time	49.53	8.95	71.00	14.14	5.34	***
L foot tap mirror	0.0	0.0	0.0	0.0	0.00	
L foot tap overflow	.1053	.315	.1429	.363	0.32	
L foot tap dysrythmia	.1579	.375	.50	.519	2.20	
L foot tap sequence	0.0	0.0	.2143	.426	2.21	
L heel/toe time	66.84	12.45	111.14	34.34	4.61	***
L heel/toe mirror	.0526	.229	.0714	.267	0.22	
L heel/toe overflow	.1579	.375	.5714	.514	2.68	*
L heel/toe dysrythmia	.7368	.452	.9286	.267	1.41	
L heel/toe sequence	.3158	.478	.3571	.497	0.24	
L hand pat time	40.89	7.55	53.21	12.16	3.59	**
L hand pat mirror	0.0	0.0	.0714	.267	1.17	
L hand pat overflow	0.0	0.0	.2143	.426	2.21	
L hand pat dysrythmia	.1053	.315	.3571	.497	1.78	
L hand pat sequence	.0526	.229	0.0	0.0	0.85	
L hand p/s time	56.05	9.73	71.71	19.53	2.76	*
L hand p/s mirror	0.0	0.0	0.0	0.0	0.00	
L hand p/s overflow	0.0	0.0	.2143	.426	2.21	
L hand p/s dysrythmia	.1053	.315	.4286	.514	2.24	
L hand p/s sequence	.0526	.229	.0714	.267	0.22	

TABLE 8
(Continued)

L finger tap time	56.74	9.08	77.57	9.12	6.50	***
L finger tap mirror	0.0	0.0	0.0	0.0	0.00	
L finger tap overflow	.1053	.315	.7857	.426	5.28	***
L finger tap dysrythmia	.1053	.315	.50	.519	2.71	*
L finger tap sequence	0.0	0.0	0.0	0.0	0.00	
L finger seq time	73.26	17.01	140.0	44.69	5.14	***
L finger seq mirror	.1579	0.375	.4286	.514	1.75	
L finger seq overflow	.4737	.513	.8571	.363	2.39	
L finger seq dysrythmia	.4737	.513	.7857	.426	1.85	
L finger seq sequence	.3684	.496	.2143	.426	0.94	
R foot tap time	50.00	8.88	63.36	9.997	4.05	**
R foot tap mirror	0.0	0.0	0.0	0.0	0.00	
R foot tap overflow	0.0	0.0	0.0	0.0	0.00	
R foot tap dysrythmia	.2105	.419	.2143	.426	0.03	
R foot tap sequence	0.0	0.0	.1429	.363	1.72	
R heel/toe time	65.53	13.73	104.23	30.87	4.24	**
R heel/toe mirror	0.0	0.0	0.0	0.0	0.00	
R heel/toe overflow	.0526	.229	.50	.519	3.02	*
R heel/toe dysrythmia	.6316	.496	.9286	.267	2.21	
R heel/toe sequence	.3684	.496	.2857	.469	0.48	
R hand pat time	37.16	6.41	68.43	6.01	5.13	***
R hand pat mirror	0.0	0.0	0.0	0.0	0.00	
R hand pat overflow	0.0	0.0	.2143	.426	2.21	
R hand pat dysrythmia	.0526	.229	.2857	.469	1.72	
R hand pat sequence	0.0	0.0	0.0	0.0	0.00	
R hand p/s time	53.74	9.53	64.15	14.06	2.50	
R hand p/s mirror	0.0	0.0	0.0	0.0	0.00	
R hand p/s overflow	0.0	0.0	.3571	.497	3.15	*
R hand p/s dysrythmia	0.0	0.0	.2857	.469	2.67	*
R hand p/s sequence	0.0	0.0	0.0	0.0	0.00	
R finger tap time	54.53	9.22	70.00	8.18	4.99	***
R finger tap mirror	0.0	0.0	0.0	0.0	0.00	
R finger tap overflow	.0526	.229	.50	.519	3.02	*
R finger tap dysrythmia	.1053	.315	.3571	.497	1.78	
R finger tap sequence	0.0	0.0	0.0	0.0	0.00	

TABLE 8
(Continued)

R finger seq time	68.95	15.98	137.0	15.50	11.68	***
R finger seq mirror	.0526	.229	.3571	.497	2.13	
R finger seq overflow	.5789	.507	1.0	0.0	3.09	*
R finger seq dysrythmia	.3684	.496	.9286	.267	4.17	**
R finger seq sequence	.2105	.419	.50	.519	1.77	
Heel walk errors	1.26	.991	2.93	.267	6.99	***
Heel walk overflow R	.2632	.452	.8571	.363	4.04	**
Heel walk overflow L	.3684	.496	.8571	.363	3.12	*
Toe walk Errors	.1053	.459	1.86	1.03	5.96	***
Toe walk overflow R	.1053	.315	.4286	.514	2.24	
Toe walk overflow L	.1053	.315	.3571	.497	1.78	
Side foot walk Errors	1.00	1.00	2.57	.756	4.93	***
Side foot walk overflow R	.1579	.375	1.0	0.0	8.38	***
Side foot walk overflow L	.4211	.507	.9286	.267	3.72	**
Tandem walk forward Errors	.0526	.229	1.14	1.29	3.12	*
Tandem walk backwards	.5263	.905	2.0	.784	4.89	***
sustination posture time	1.42	1.22	1.36	1.34	0.14	
sustination posture fall	.8421	.375	.7857	.426	0.40	
sustination posture arms	.1579	.375	.1429	.363	0.12	
sustination steadiness time	.1579	.688	.0714	.267	0.50	
sustination steadiness overflo	.3158	.478	.8571	.363	3.55	**
sustination steadiness time	.1579	.501	.2143	.426	0.34	
CONSTRUCTIONAL						
Beery	20.68	1.77	15.14	2.83	6.93	***
Beery-top	166.11	6.05	121.36	17.47	9.19	***
LANGUAGE						
Token Test	18.58	1.39	16.36	2.37	3.13	*
Boston Naming Test	51.83	4.50	40.86	3.74	7.35	***
PRACTICE EFFECT						
Video Game	1.42	.902	1.93	1.07	1.48	

TABLE 9

Reliability of Experimental Measures Expressed As the Mean for all 12 Angles*

Unimanual	Left Hand Mean	Right Hand Mean
Average Absolute Deviation	.81	.83
Path Length	.79	.84
Time	.97	.98

Bimanual	Mean
Average Absolute Deviation	.93
Path Length	.95
Time	.92

*Expressed as Values of Cronbach's alpha

TABLE 10

Pearson-R Correlations
For Average Absolute Deviation & Path Length
Under All Conditions for Each Group

	Dyslexic	Older	Younger
UNIMANUAL			
Left Hand	+ .67 ***	+ .84 ***	+ .91 ***
Right Hand	+ .88 ***	+ .93 ***	+ .76 ***
BIMANUAL			
Unguided	+ .78 ***	+ .69 ***	+ .62 **
Memory	+ .76 ***	+ .25	+ .89 ***

TABLE 11

Pearson-R Correlations
Between Experimental and Standardized Measures
for Normal Readers

	AAD	TIME
LEFT HAND		
L foot tap time	-.35 *	-.35 *
L heel/toe time	-.09	-.34 *
L hand pat time	-.37 **	-.26
L finger tap time	-.22	-.38 **
L finger sequence time	-.17	-.39 **
Beery	.23	.52 ***
Spatial memory	.22	.27
Judge of line orientation	.35 *	.39 **
Boston Naming	.11	.04
Token Test	.18	.15
RIGHT HAND		
R foot tap time	-.37 **	-.34 *
R heel/toe time	-.25	-.20
R hand pat time	-.40 **	-.35 *
R finger tap time	-.35 *	-.40 **
R finger sequence time	-.37 **	-.49 ***
Beery	.46 ***	.50 ***
Spatial memory	.37 **	.28
Judge of line orientation	.38 **	.48 ***
Boston Naming	.08	.00
Token Test	.18	.12
BIMANUAL/UNGUIDED		
L foot tap time	-.53 ***	-.19
L heel/toe time	-.68 ***	-.18
L hand pat time	-.69 ***	-.16
L finger tap time	-.49 ***	-.07
L finger sequence time	-.36 *	-.11
R foot tap time	-.41 ***	-.20
R heel/toe time	-.47 ***	-.09
R hand pat time	-.52 ***	-.20
R finger tap time	-.48 ***	-.15
R finger sequence time	-.57 ***	-.16
Beery	.70 ***	.40 **
Spatial memory	.46 ***	.30 *
Judge of line orientation	.39 **	.33*
Boston Naming	.34	.09
Token Test	.22	.04

TABLE 12

Pearson-R Correlations
For Average Absolute Deviation & Time
Under All Conditions for Each Group

	Dyslexic	Older	Younger
UNIMANUAL			
Left Hand	+ .58 **	+ .85 ***	+ .63 **
Right Hand	+ .83 ***	+ .84 ***	+ .35
BIMANUAL			
Unguided	+ .39	+ .60 **	+ .28
Memory	+ .73 ***	+ .91 ***	+ .88 ***

Pearson-R Correlations
For Path Length & Time
Under All Conditions for Each Group

	Dyslexic	Older	Younger
UNIMANUAL			
Left Hand	+ .79 ***	+ .93 ***	+ .62 **
Right Hand	+ .85 ***	+ .93 ***	+ .31
BIMANUAL			
Unguided	+ .15	+ .59 **	+ .20
Memory	+ .69 **	+ .22	+ .79 ***

TABLE 13

Comparison of Unimanual Left and Right Hand Performance Within Normal Reading Groups

OLDER SUBJECTS	Left		Right			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	785.59	193.33	655.81	156.84	3.71	***
Path Length	1.58	.101	1.55	.175	1.69	
Time	306.53	108.38	281.6	111.99	1.76	

YOUNGER SUBJECTS	Left		Right			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	935.25	303.94	867.88	249.32	0.81	
Path Length	1.51	.20	1.52	.30	0.11	
Time	188.47	72.07	174.76	72.99	0.96	

TABLE 14

Comparison of Older and Younger Normal Reading Groups on Left and Right Hand Performance

LEFT HAND	7/8		12/16			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	935.25	303.94	785.59	193.33	1.62	
Path Length	1.51	0.20	1.59	0.18	1.20	
Time	188.67	72.07	304.53	108.38	3.69	**

RIGHT HAND	7/8		12/16			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	867.88	249.32	655.81	156.84	3.00	*
Path Length	1.52	0.30	1.55	0.17	0.34	
Time	174.76	72.99	281.60	111.99	3.11	*

TABLE 15

Comparison of Bimanual Performance Under Visual Feedback and Memory Conditions Within Normal Reading Groups

YOUNGER SUBJECTS	Unguided		Memory			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	1714.56	1077.84	5089.66	3960.2	3.36	***
Path Length	2.23	0.742	2.29	1.08	0.23	
Time	379.55	125.01	350.90	130.49	0.57	

OLDER SUBJECTS	Unguided		Memory			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	613.28	204.98	2927.33	1757.59	5.60	***
Path Length	1.78	.824	1.7	.496	0.69	
Time	339.55	92.91	405.94	171.72	1.76	

TABLE 16

Comparison of Normal Reading Groups on Bimanual, Visual Feedback Conditions

	7/8 Year Olds		12/15 Year Olds			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	4117.16	2105.82	1936.44	470.45	3.75	**
Path Length	2.70	1.03	2.56	1.53	0.26	
Time	929.19	239.75	926.51	239.20	0.03	

	12/15 Year Olds		15/16 Year Olds			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	1936.44	470.45	1245.63	382.78	3.49	**
Path Length	2.56	1.53	1.47	.108	2.24	
Time	926.51	239.20	699.44	188.12	2.28	

TABLE 17

Comparison of Left & Right Hand Performance
For Dyslexic Subjects

	Left		Right			
	Mean	SD	Mean	SD	T	Prob
Average Absolute Deviation	675.41	348.66	445.43	147.26	3.63	***
Path Length	1.39	.131	1.31	.122	5.67	***
Time	175.31	84.25	145.41	69.49	4.98	***

TABLE 18

Comparison of Dyslexic and Age Matched Readers
On Left & Right Hand Performance

LEFT HAND

	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	675.41	348.66	785.59	193.33	1.29	
Path Length	1.39	.131	1.59	.181	4.22	**
Time	175.31	84.25	304.53	108.38	4.35	**

RIGHT HAND

	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	445.43	147.26	655.81	156.84	4.47	**
Path Length	1.31	.122	1.55	.175	5.12	***
Time	145.41	69.49	281.60	111.99	4.62	***

TABLE 19

Comparison of Dyslexic and Young Readers On Left & Right Hand Performance

LEFT HAND	Dyslexic		Younger			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	675.41	348.66	935.25	303.94	2.30	
Path Length	1.39	.131	1.51	.200	2.25	
Time	175.31	84.25	188.47	72.07	0.49	

RIGHT HAND	Dyslexic		Younger			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	465.43	147.26	867.88	249.32	5.76	***
Path Length	1.31	.122	1.52	.302	2.42	
Time	165.41	69.49	174.76	72.99	1.22	

TABLE 20

Comparison of Performance on Visual Feedback
And Memory Conditions for Dyslexic Subjects

	Unguided		Memory			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	627.96	213.27	2879.32	1687.1	6.60	***
Path Length	1.45	.166	1.44	0.247	0.18	
Time	200.35	65.95	362.70	110.55	7.28	***

TABLE 21

Comparison of Dyslexic and Younger Reading Groups On Reversing the Direction of Hand Movements During Memory Condition Trails

	Frequency of Reversals	
	Dyslexics	Youngers
0	15	4
1	3	1
2	2	0
3	2	1
4	0	2
5	0	0
6	0	1
7	0	2
8	0	1
9	1	0
10	0	0
11	0	0
12	0	1
13	0	1

Dyslexic			Younger				
N	Mean	SD	N	Mean	SD	t	Prob.
23	0.96	2.01	14	4.36	4.25	3.30	**

TABLE 22

Distribution of Subject According to the Pattern Of Their Reversals that Occured in Unidirectional Quadrants and Bidirectional Quadrants

DYSLEXIC SUBJECTS

Unidirectional Reversals	Bidirectional Reversals	N
0	1	3
0	2	2
0	3	1
1	2	1
5	4	1

YOUNGER SUBJECTS

Unidirectional Reversals	Bidirectional Reversals	N
0	3	1
0	4	2
1	5	1
2	3	1
2	4	1
2	5	1
5	7	1
6	7	1
1	0	1

	Unidirectional		Bidirectional			
	Mean	SD	Mean	SD	t	Prob
Dyslexics	0.75	1.75	2.00	1.07	3.03	*
Youngers	1.90	2.08	4.20	2.04	4.44	**

TABLE 23

Distribution of Subjects According to the Proportion of their Reversals that Were Made by Each Hand

Proportion	Proportion	Olders	Dyslexics	Youngers
Left	Right	N = 0	8	10
0	1.00	0	6	1
.25	.75	0	0	1
.31	.69	0	0	1
.50	.50	0	1	1
.58	.42	0	0	1
.60	.40	0	0	1
.67	.33	0	1	3
.71	.29	0	0	1

	DYSLEXICS		YOUNGERS			
	Mean	SD	Mean	SD	t	Prob
Left	0.15	0.28	0.50	0.24	2.92	**
Right	0.85	0.28	0.50	0.24	2.92	**

TABLE 24

Comparison of Dyslexic and Age Matched Readers On The Bimanual Visual Feedback & Memory Conditions

UNGUIDED	Dyslexic		Older			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	627.96	213.27	613.28	204.98	.23	
Path Length	1.65	.166	1.78	.824	1.72	
Time	200.35	65.95	339.55	92.91	5.49	***

MEMORY	Dyslexic		Older			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	2879.32	1687.10	2927.33	1757.59	0.09	
Path Length	1.44	.247	1.70	.496	2.05	
Time	342.70	110.55	405.94	171.72	1.39	

TABLE 25

Comparison of Dyslexic and Younger Readers On The Bimanual Visual Feedback & Memory Conditions

UNGUIDED	Dyslexic		Younger			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	627.96	213.27	1716.56	1077.86	3.73	**
Path Length	1.45	.166	2.23	.762	3.85	**
Time	200.35	65.95	379.55	125.01	6.96	***

MEMORY	Dyslexic		Younger			
	Mean	SD	Mean	SD	t	Prob
Average Absolute Deviation	2879.32	1687.10	5089.66	3940.20	1.99	
Path Length	1.44	.247	2.29	1.08	2.89	*
Time	342.70	110.55	350.90	130.49	0.20	

TABLE 26

The Mean Accuracy for Directional Deviation Sum On All Angles under Visual Feedback Conditions for the Older Reading Groups

	UNGUIDED	Drift Sign*	Drift	Older Mean	SD
1:1 Ratio Angles	2		+	67.13	1164.93
	5		-	270.25	1130.84
	8		-	423.57	1511.79
	11		+	568.54	512.93
1:2 Ratio Angles	3	-	-	472.42	885.30
	4	+	+	558.55	1233.81
	9	+	+	296.47	894.09
	10	-	-	160.97	576.06
2:1 Ratio Angles	1	+	+	553.99	1154.63
	6	-	-	428.61	938.91
	7	-	-	391.33	822.42
	12	+	+	679.98	458.73

*Sign of Deviation Sum when performance is drifting toward 1:1 ratio of hand movement.

TABLE 27

The Mean Accuracy for Directional Deviation Sum On All Angles under Visual Feedback Conditions for the Dyslexic

		Drift Sign*	Drift	Unguided Mean	SD
1:1 Ratio Angles	2		+	123.17	746.27
	5		-	69.89	1101.86
	8		-	567.31	980.62
	11		+	655.68	1268.66
1:2 Ratio Angles	3	-	-	595.32	1365.07
	4	+	+	126.76	950.81
	9	+	-	213.83	807.18
	10	-	+	262.81	1106.69
2:1 Ratio Angles	1	+	+	685.20	977.13
	6	-	-	20.09	1381.92
	7	-	-	898.98	826.63
	12	+	+	516.76	709.73

*Sign of Deviation Sum when performance is drifting toward 1:1 ratio of hand movement.

TABLE 28

The Mean Accuracy for Directional Deviation Sum On All Angles under Visual Feedback Conditions for the Younger Reading Groups

	UNGUIDED	Drift Sign*	Drift	Younger Mean	SD
1:1 Ratio Angles	2		-	84.18	1635.06
	5		+	68.73	2320.07
	8		-	686.80	1887.12
	11		+	854.32	3269.97
1:2 Ratio Angles	3	-	+	361.66	1292.31
	4	+	-	766.73	2020.48
	9	+	-	1.57	2630.28
	10	-	-	55.22	747.83
2:1 Ratio Angles	1	+	+	1804.24	2133.48
	6	-	+	1400.99	2576.07
	7	-	-	965.52	2921.52
	12	+	-	106.98	2289.65

*Sign of Deviation Sum when performance is drifting toward 1:1 ratio of hand movement

TABLE 29

The Mean Accuracy for Directional Deviation Sum On All Angles under Memory Conditions for the Older Reading Groups

	MEMORY	Drift Sign*	Drift	Older Mean	SD
1:1 Ratio Angles	2		+	605.82	1928.56
	5		-	369.37	2112.99
	8		-	1425.50	1520.30
	11		+	1052.47	2816.02
1:2 Ratio Angles	3	-	-	2158.98	2392.41
	4	+	+	2097.52	1691.97
	9	+	+	208.00	3793.91
	10	-	-	1261.06	4737.90
2:1 Ratio Angles	1	+	+	4724.92	4615.17
	6	-	-	3554.42	3611.44
	7	-	-	5015.58	4545.65
	12	+	+	2597.47	2127.81

*Sign of Deviation Sum when performance is drifting toward 1:1 ratio of hand movement.

TABLE 30

The Mean Accuracy for Directional Deviation Sum On All Angles under Memory Conditions For the Dyslexic

		Drift Sign*	Drift	Memory Mean	SD
1:1 Ratio Angles	2		+	489.52	5025.01
	5		+	89.55	2579.02
	8		-	797.77	1727.02
	11		+	640.08	1001.17
1:2 Ratio Angles	3	-	-	1588.50	2562.20
	4	+	+	2326.29	1874.38
	9	+	+	2315.42	4073.30
	10	-	-	3040.47	4327.22
2:1 Ratio Angles	1	+	+	1847.60	3556.72
	6	-	-	787.21	5330.32
	7	-	-	2917.20	3237.40
	12	+	+	1667.47	3250.75

*Sign of Deviation Sum when performance is drifting toward 1:1 ratio of hand movement.

TABLE 31

The Mean Accuracy for Directional Deviation Sum On All Angles under Memory Conditions for the Younger Reading Groups

	MEMORY	Drift Sign*	Drift	Younger Mean	SD
1:1 Ratio Angles	2		+	465.00	3679.57
	5		-	875.06	2614.73
	8		+	694.37	5759.97
	11		+	2183.39	20684.90
1:2 Ratio Angles	3	-	-	2386.31	6658.68
	4	+	+	203.52	4247.35
	9	+	+	4101.29	8870.55
	10	-	-	254.40	5623.47
2:1 Ratio Angles	1	+	+	3076.48	8095.27
	6	-	-	817.25	4279.87
	7	-	-	2077.38	6187.29
	12	+	-	438.80	6717.93

*Sign of Deviation Sum when performance is drifting toward 1:1 ratio of hand movement.

TABLE 32

Comparison of Older Reading Group Performance On Angles Requiring Different Ratios of Hand Movement With Visual Feedback

	1:1		1:2			
	Mean	SD	Mean	SD	T	Prob
Average Absolute Deviation	544.74	236.01	699.29	309.34	2.27	*
Path Length	1.77	0.67	1.93	1.32	0.93	
Time	311.49	90.87	375.21	135.37	3.05	***

	1:1		2:1			
	Mean	SD	Mean	SD	T	Prob
Average Absolute Deviation	544.74	236.01	570.99	163.64	0.45	
Path Length	1.77	0.67	1.64	0.63	2.23	*
Time	311.49	90.87	315.94	74.54	0.25	

TABLE 33

Comparison of Dyslexic Group Performance On Angles Requiring Different Ratios of Hand Movement With Visual Feedback

	1:1		1:2			
	Mean	SD	**Mean**	SD	T	Prob
Average Absolute Deviation	483.56	122.29	766.98	429.73	3.05	***
Path Length	1.38	0.15	1.53	0.36	2.00	
Time	178.38	75.39	211.21	73.45	2.11	*

	1:1		2:1			
	Mean	SD	**Mean**	SD	T	Prob
Average Absolute Deviation	483.56	122.29	584.18	293.72	1.55	
Path Length	1.38	0.15	1.39	0.21	0.28	
Time	178.38	75.39	198.99	77.34	1.50	

TABLE 36

Comparison of Younger Readers Performance On Angles Requiring Different Ratios of Hand Movement With Visual Feedback

	1:1		1:2			
	Mean	SD	Mean	SD	T	Prob
Average Absolute Deviation	1496.42	842.36	1844.17	1208.84	2.32	*
Path Length	2.11	0.60	2.23	0.84	0.84	
Time	351.28	151.05	401.18	127.91	2.38	*

	1:1		2:1			
	Mean	SD	Mean	SD	T	Prob
Average Absolute Deviation	1496.42	842.36	1690.23	1158.66	1.16	
Path Length	2.11	0.60	2.28	0.90	1.18	
Time	351.28	151.05	388.98	147.89	1.36	

TABLE 35

Comparison of Older Reading Group Performance On Angles Requiring Different Ratios of Hand Movement Without Visual Feedback

	1:1		1:2			
	Mean	SD	Mean	SD	T	Prob
Average Absolute Deviation	1608.25	1493.95	4167.36	2744.68	6.39	***
Path Length	1.65	0.53	1.77	0.65	2.25	*
Time	362.33	155.71	432.87	207.07	2.40	*

	1:1		2:1			
	Mean	SD	Mean	SD	T	Prob
Average Absolute Deviation	1608.25	1493.95	2689.60	1644.79	2.41	*
Path Length	1.65	0.53	1.64	0.48	0.16	
Time	362.33	155.71	400.30	202.25	1.17	

TABLE 36

Comparison of Dyslexic Group Performance On Angles Requiring Different Ratios of Hand Movement Without Visual Feedback

	1:1		1:2			
	Mean	SD	Mean	SD	T	Prob
Average Absolute Deviation	1892.18	1585.16	3539.89	2053.56	6.74	***
Path Length	1.39	0.18	1.46	0.31	1.30	
Time	327.79	112.49	360.82	145.91	1.77	

	1:1		2:1			
	Mean	SD	Mean	SD	T	Prob
Average Absolute Deviation	1892.18	1585.16	2923.75	1829.56	3.32	***
Path Length	1.39	0.18	1.46	0.29	1.31	
Time	327.79	112.49	348.35	120.71	1.45	

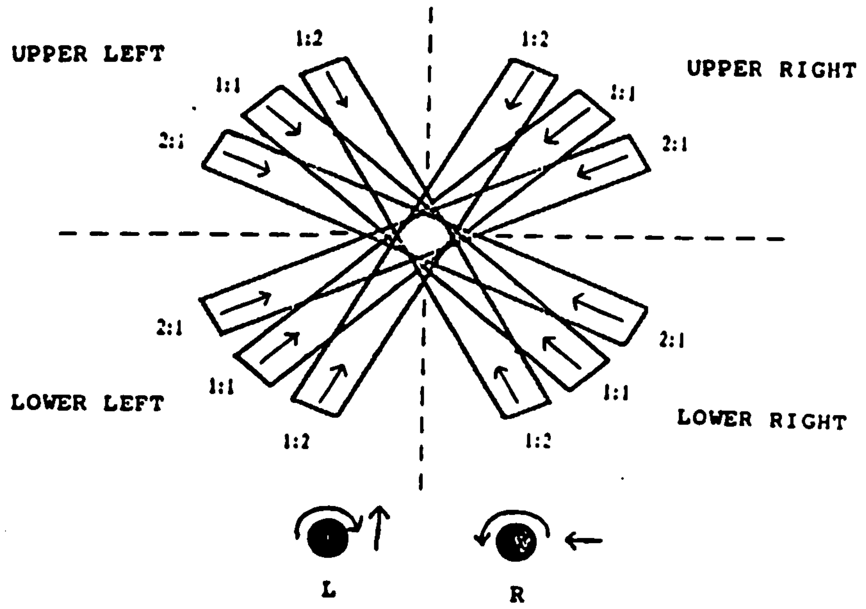
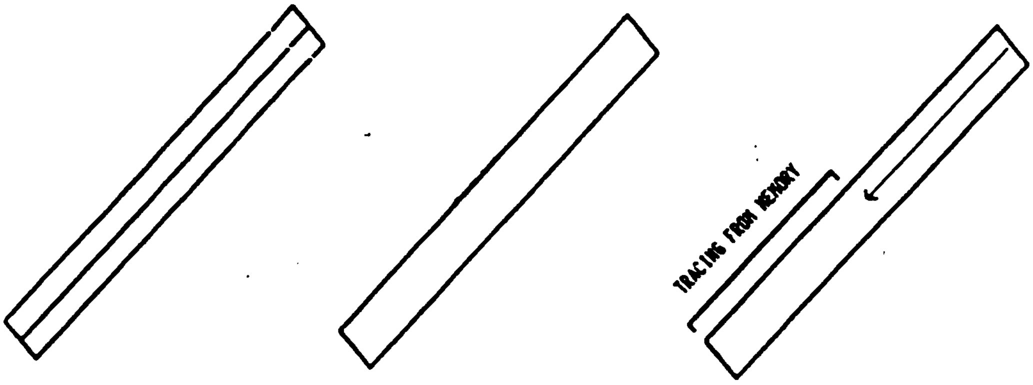


FIGURE 1
SCHEMATIC REPRESENTATION OF THE 12 ANGLES
REQUIRING 1:2, 1;1, 2:1 RATIO OF HAND MOVEMENT
STARTING IN EACH OF THE 4 SPATIAL QUADRANTS.



GUIDED CONDITION

UNGUIDED CONDITION

MEMORY CONDITION

FIGURE 2
VISUAL FEEDBACK CONDITIONS

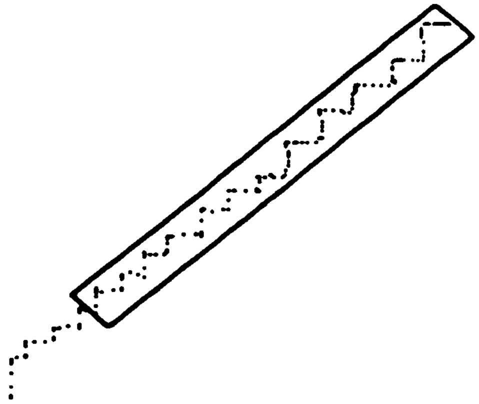


FIGURE 3
ANGLE #2, 8:10 YEAR OLD
ALTERNATING HAND MOVEMENTS

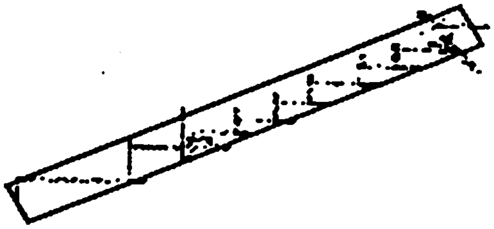


FIGURE 4
ANGLE #1, 7:11 YEAR OLD
CORRECTIONS WITH VISUAL MONITORING

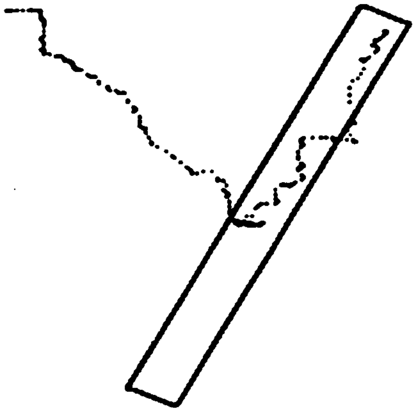


FIGURE 5
ANGLE #3, 8:6 YEAR OLD
REVERSAL OF LEFT HAND
WITH NO VISUAL FEEDBACK

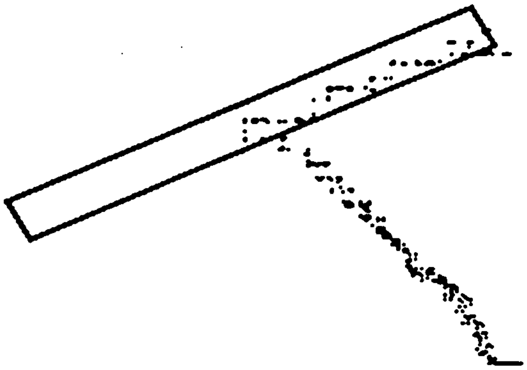


FIGURE 6
ANGLE #3, 8:7 YEAR OLD
REVERSAL OF RIGHT HAND
WITH NO VISUAL FEEDBACK

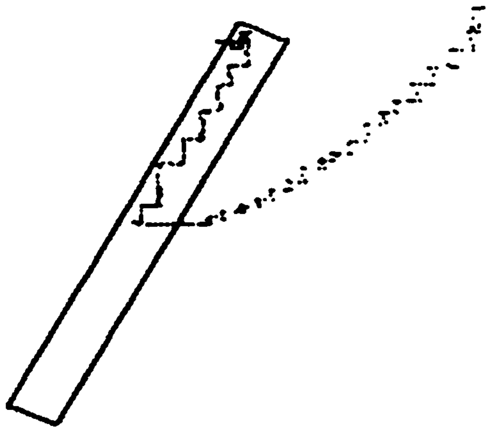


FIGURE 7
ANGLE #3, 8:10 YEAR OLD
REVERSAL OF BOTH HANDS
WITH NO VISUAL FEEDBACK

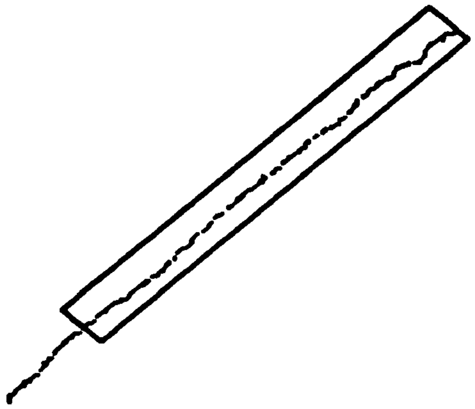


FIGURE 8
ANGLE #3, 12:0 YEAR OLD
SIMULTANIOUS HAND MOVEMENTS
WITH NO VISUAL FEEDBACK

FIGURE 9
DERIVATION OF + AND - SIGNS
FOR
DIRECTIONAL DEVIATION SUM

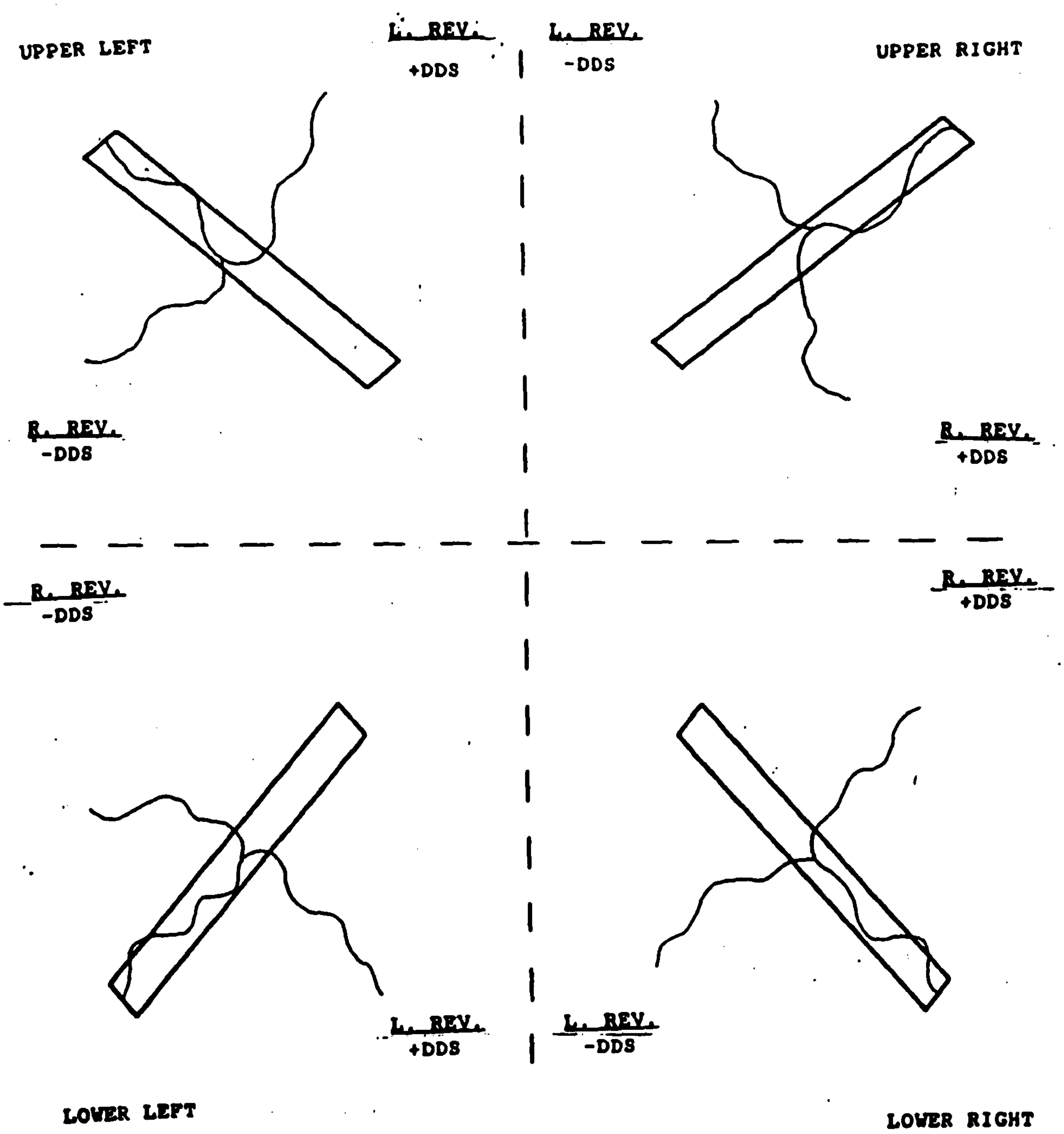


FIGURE 10 - NORMAL READERS

AGE EFFECT ON UNIMANUAL ACCURACY

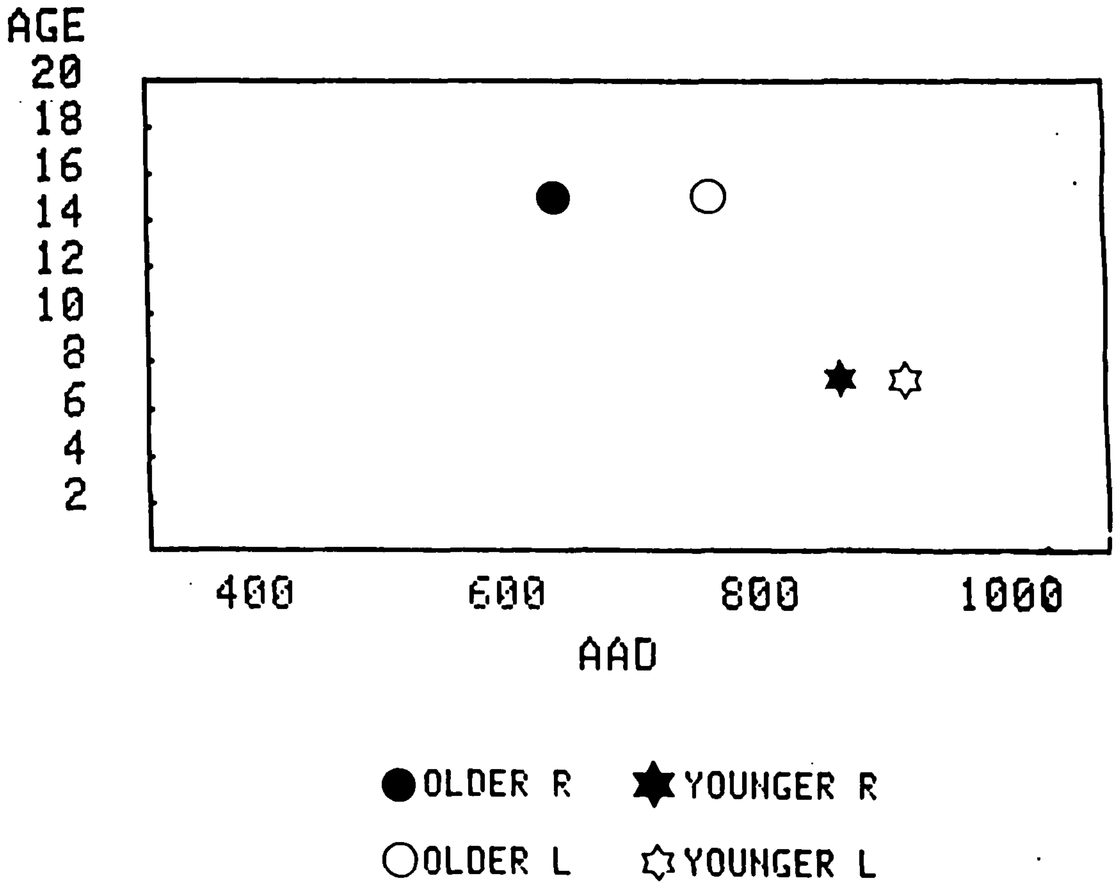


FIGURE 11 - NORMAL READERS

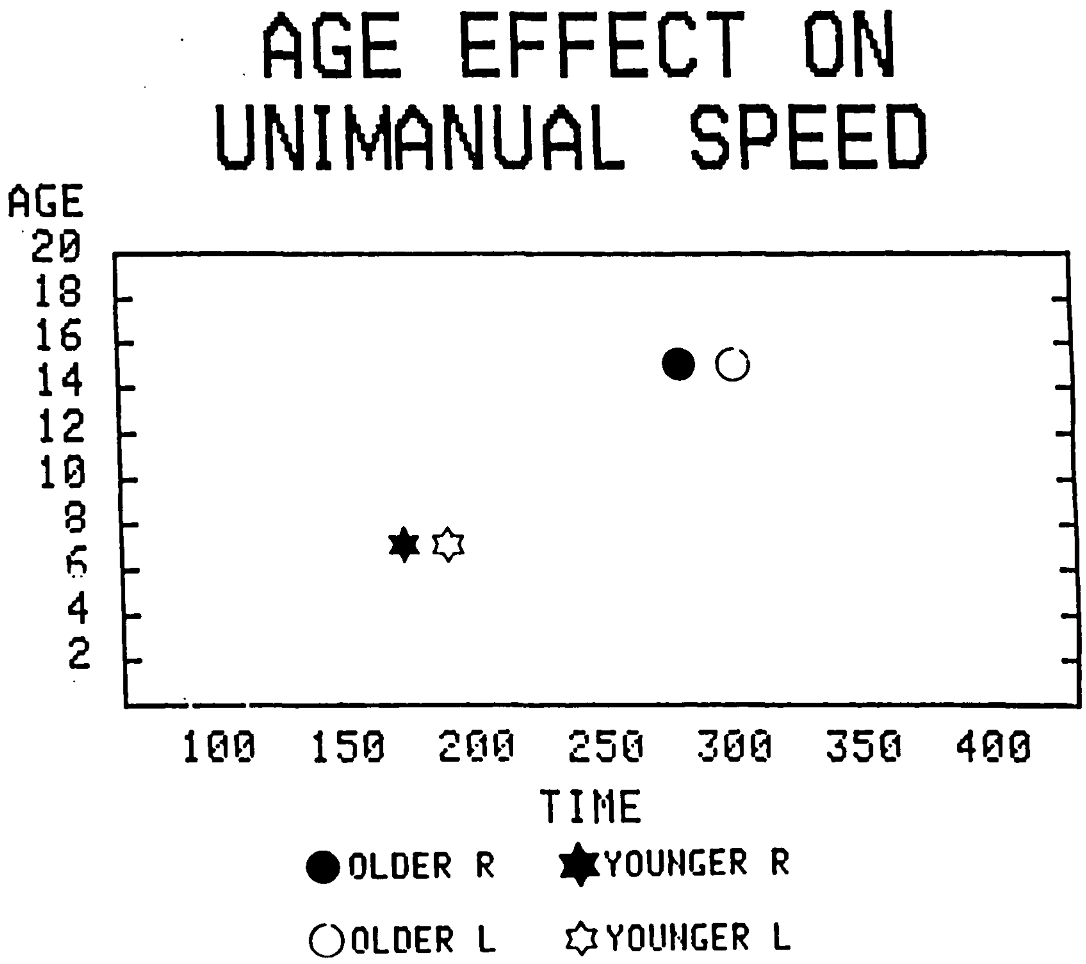


FIGURE 12 - NORMAL READERS

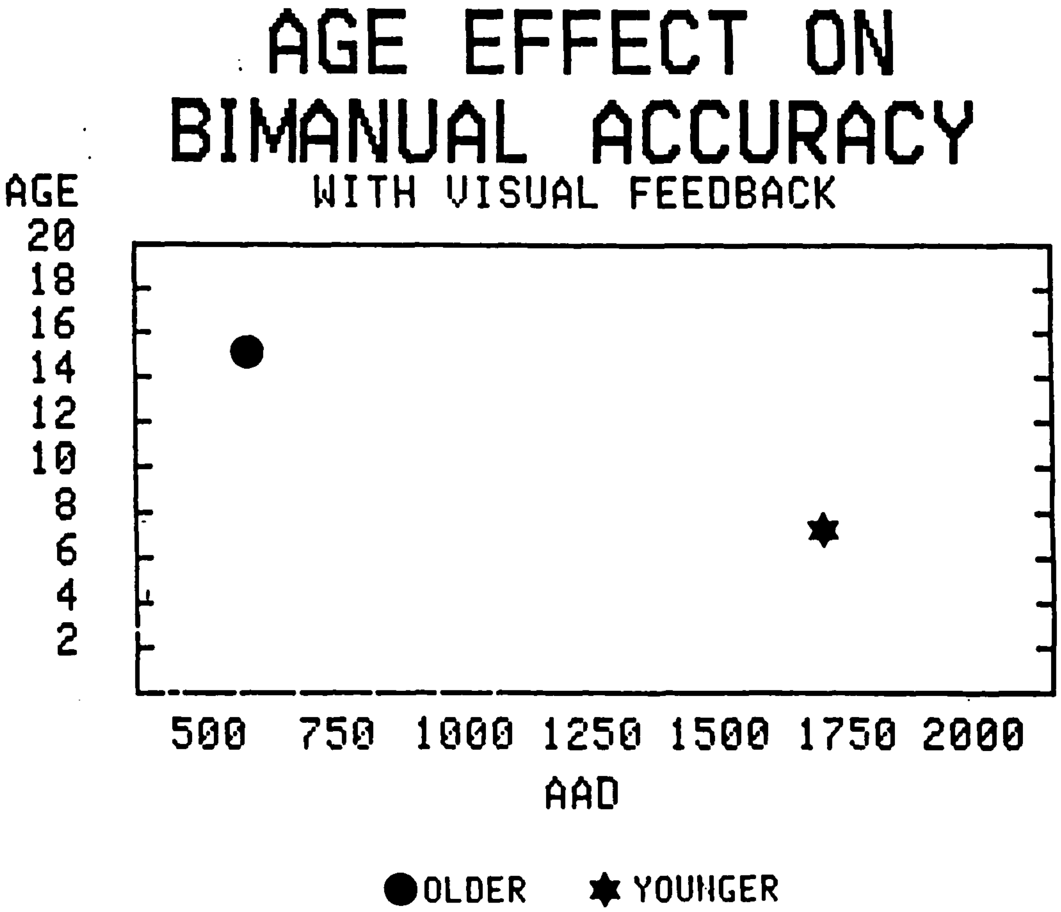


FIGURE 13 - NORMAL READERS

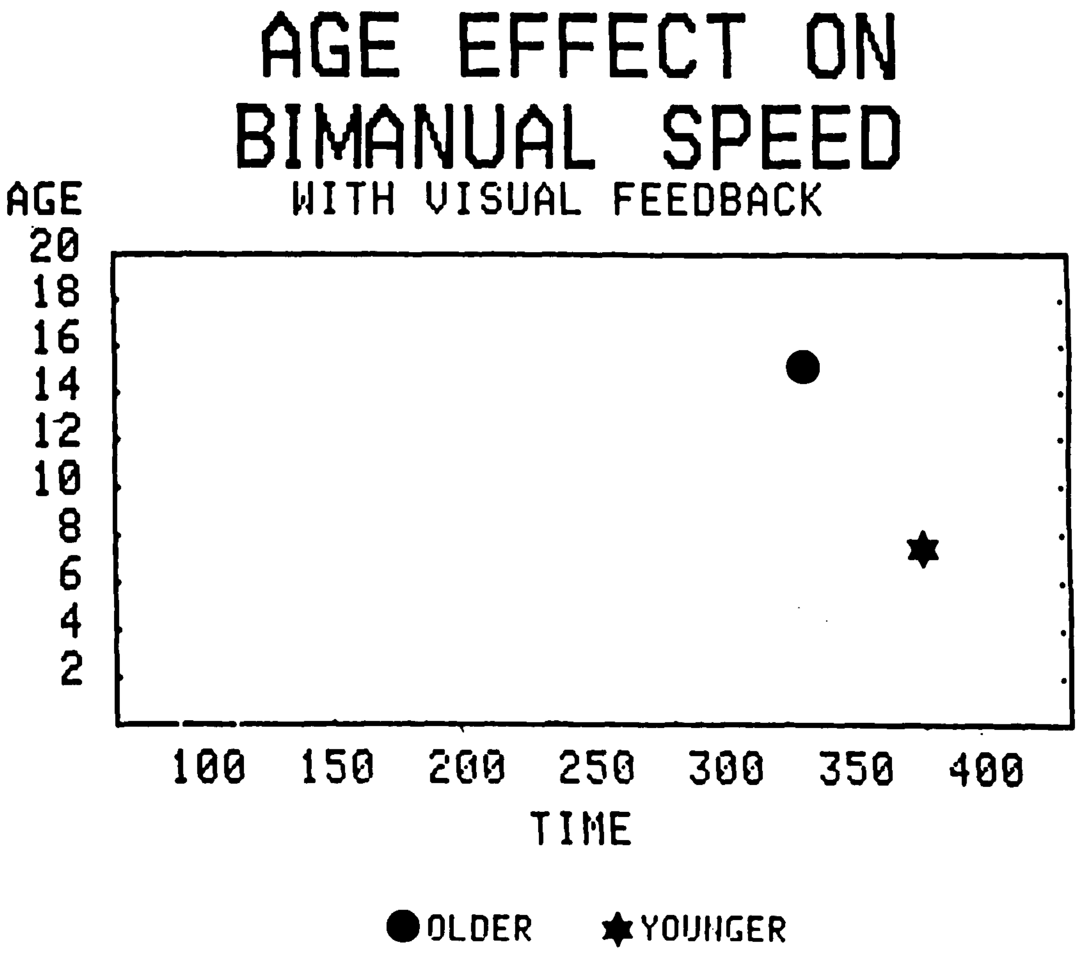
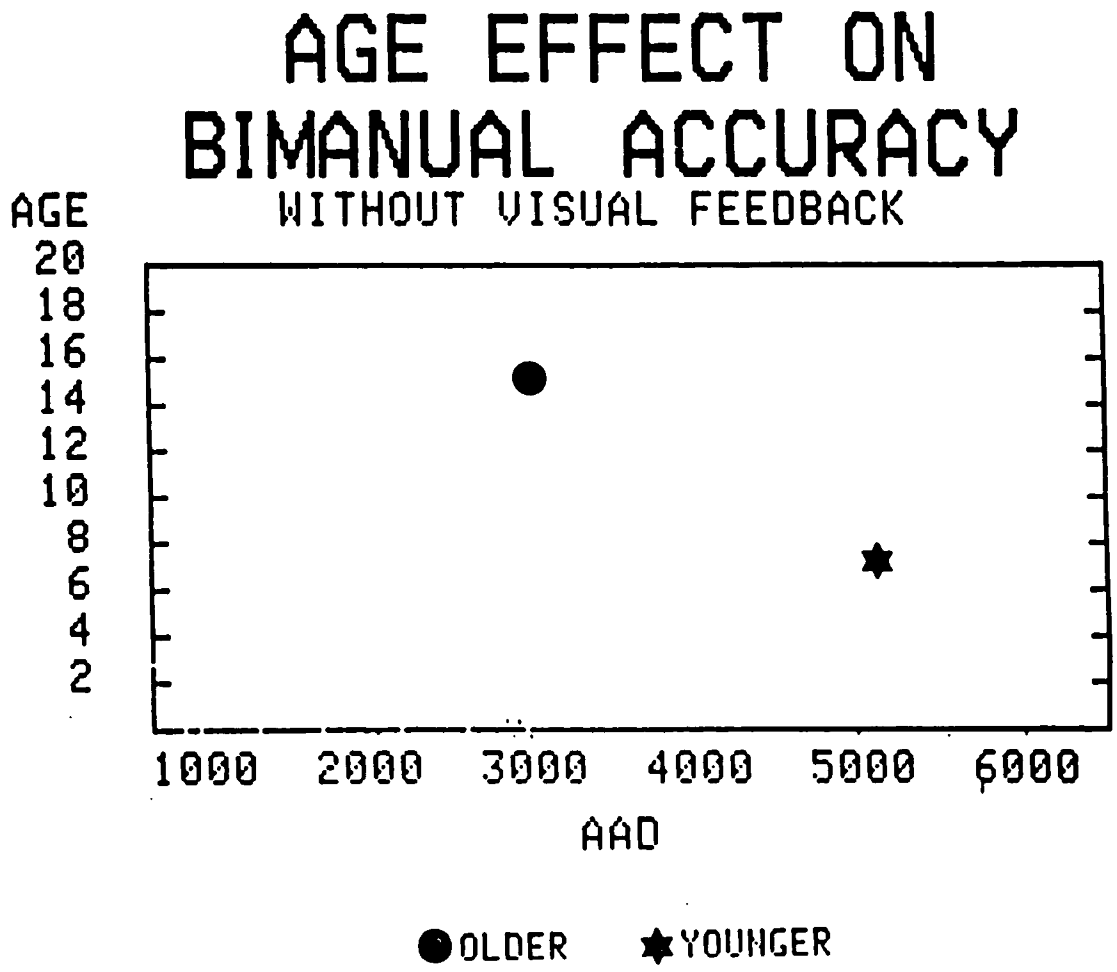


FIGURE 14 - NORMAL READERS



FIRURE 15 - NORMAL READERS

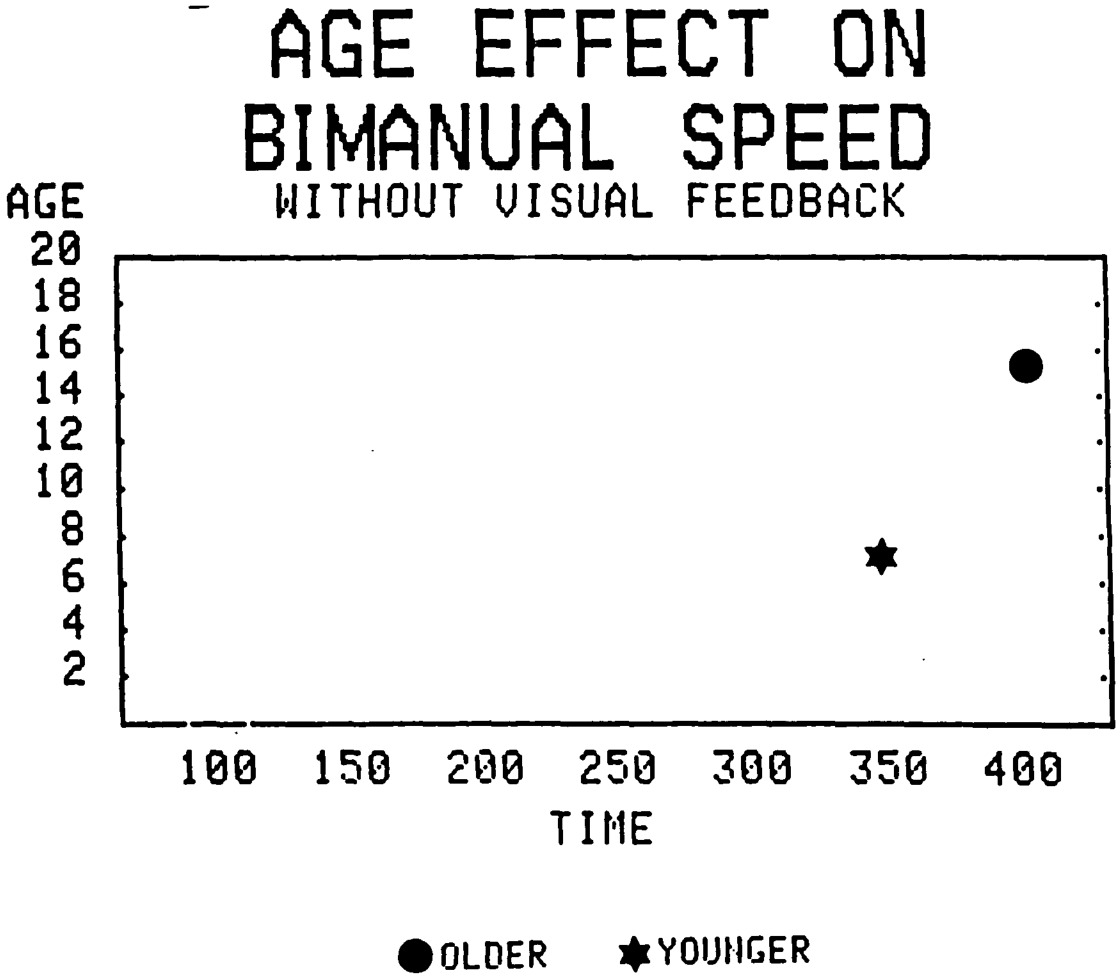


FIGURE 16 - DYSLEXICS & CONTROLS

AGE EFFECT ON UNIMANUAL ACCURACY

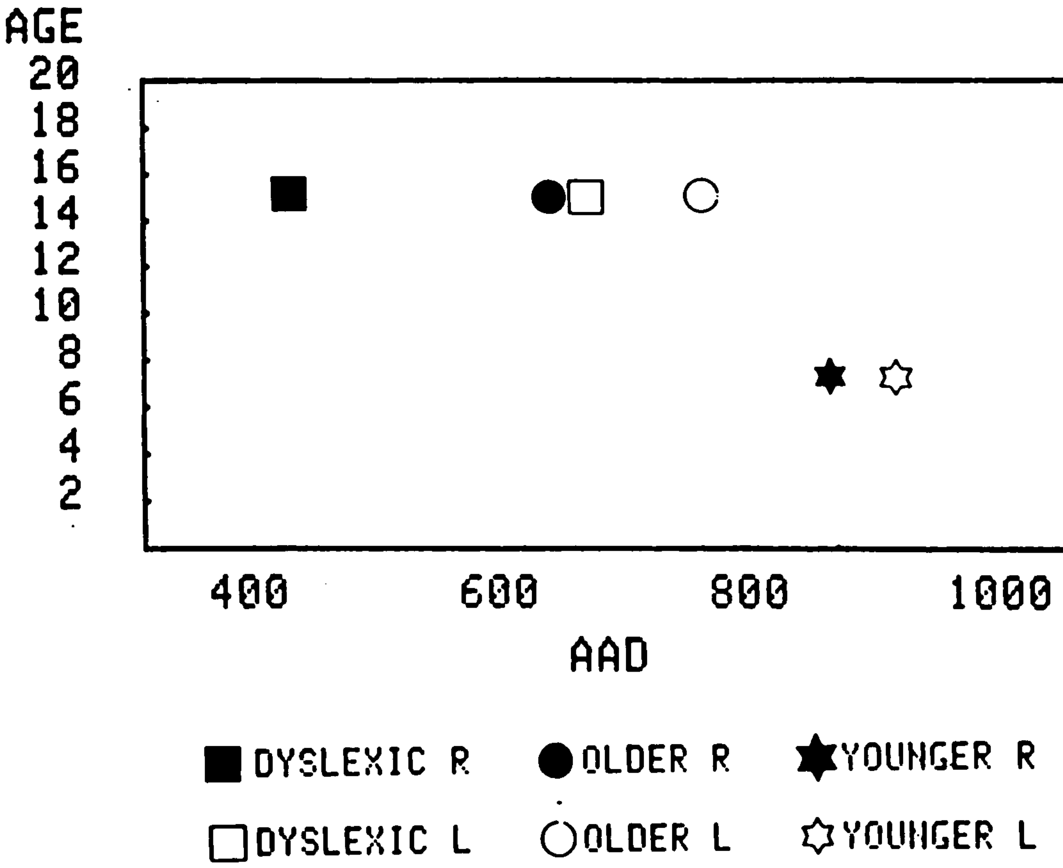


FIGURE 17 - DYSLEXICS & CONTROLS

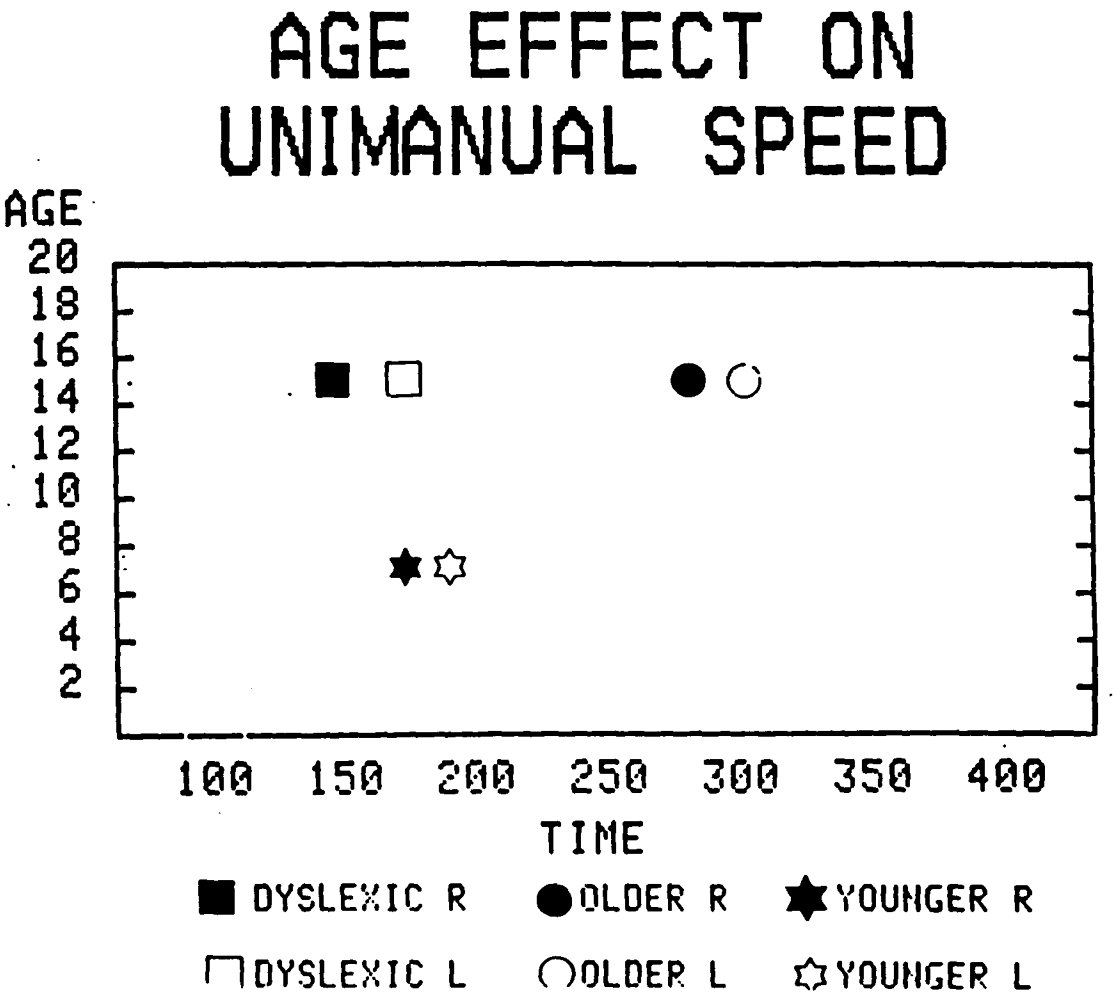


FIGURE 18 - DYSLEXICS & CONTROLS

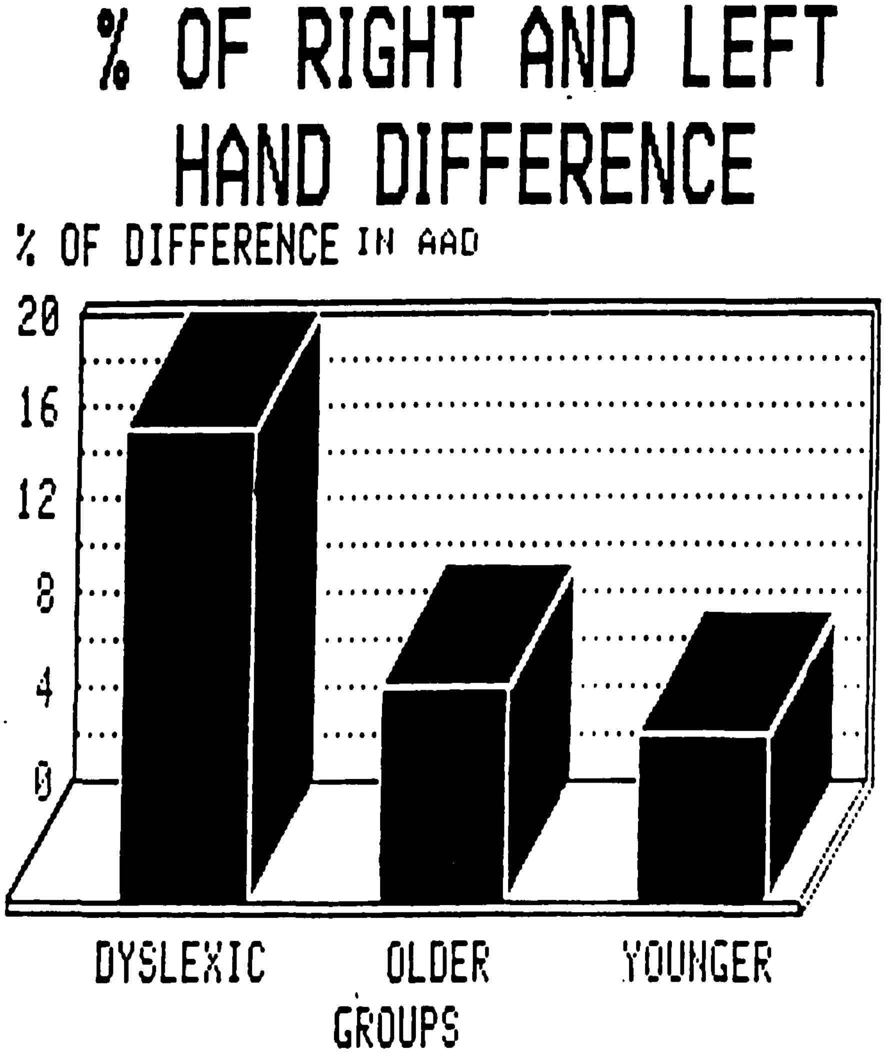
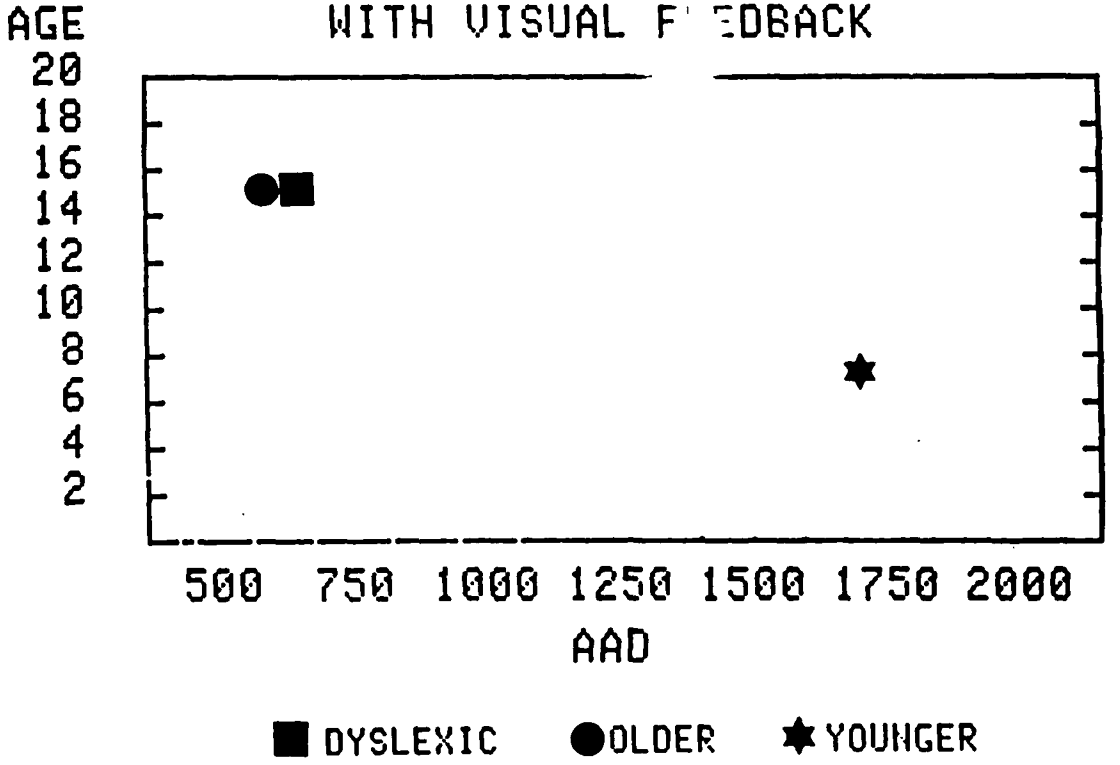


FIGURE 19 - DYSLEXICS & CONTROLS



AGE EFFECT ON BIMANUAL ACCURACY

WITH VISUAL FEEDBACK

FIGURE 20 - DYSLEXICS & CONTROLS

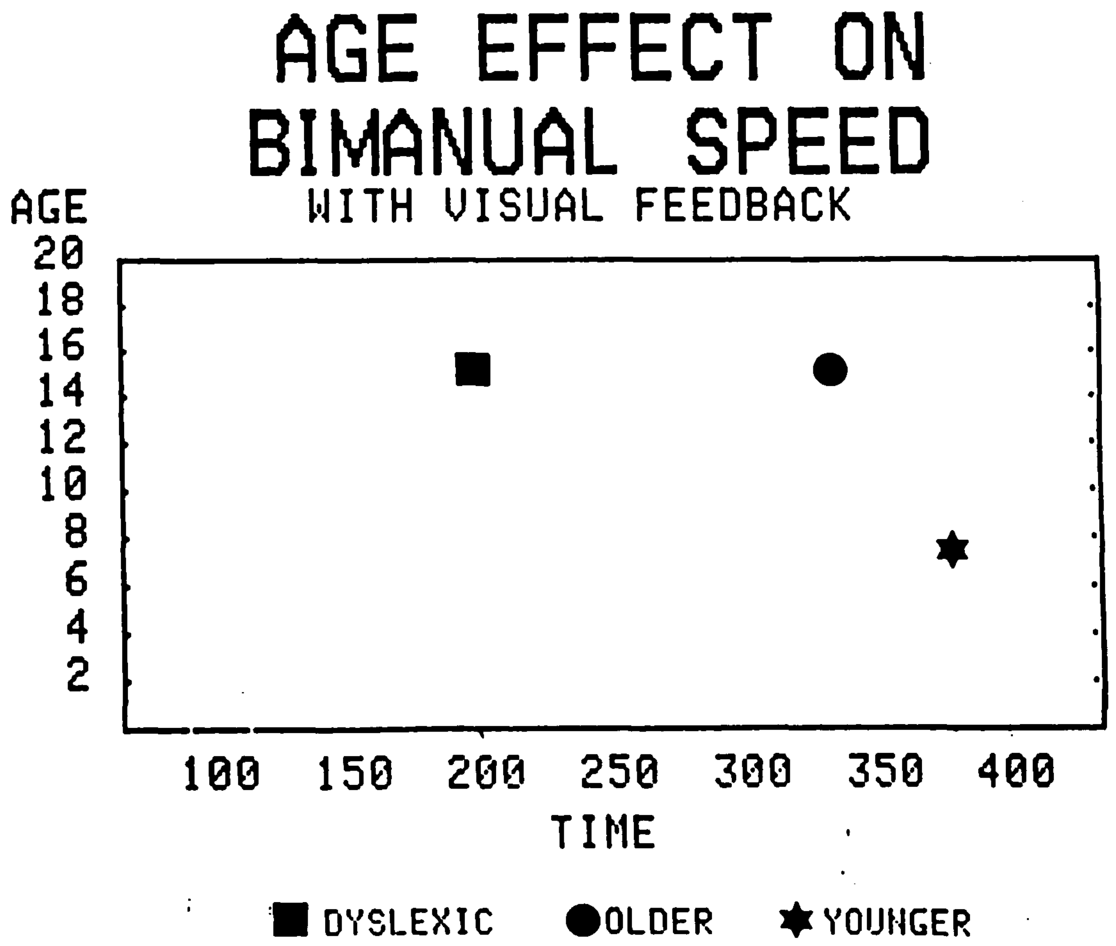


FIGURE 21 - DYSLEXICS & CONTROLS

AGE EFFECT ON BIMANUAL ACCURACY

WITHOUT VISUAL FEEDBACK

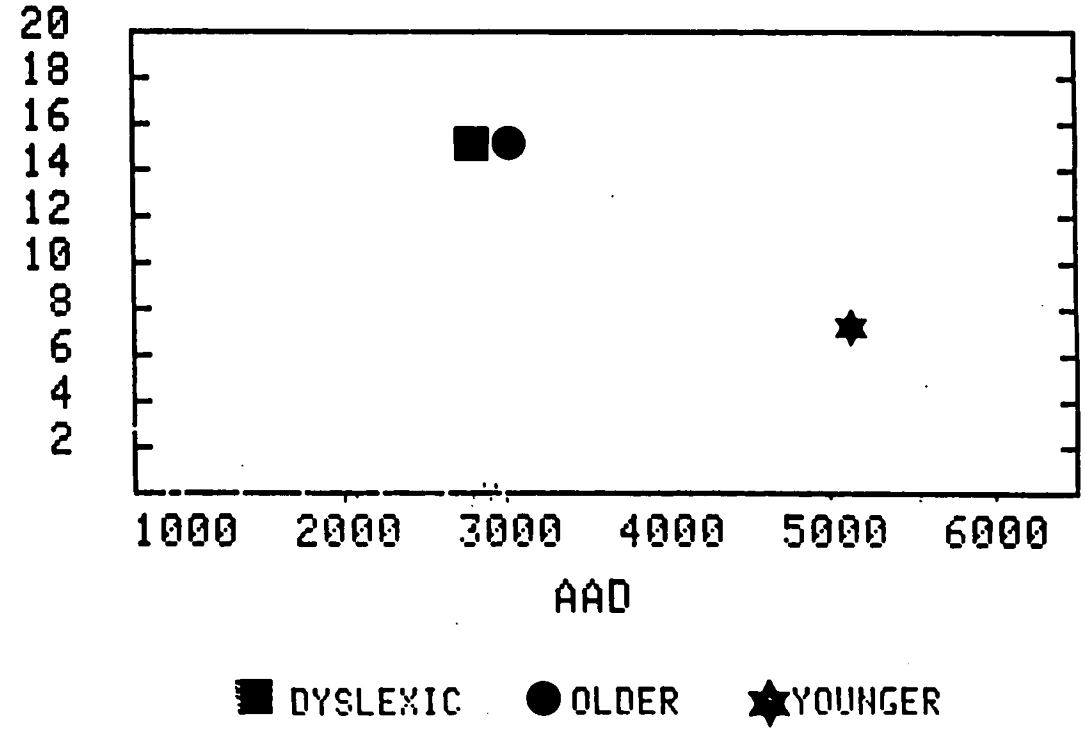


FIGURE 22 - DYSLEXICS & CONTROLS

AGE EFFECT ON BIMANUAL SPEED

WITHOUT VISUAL FEEDBACK

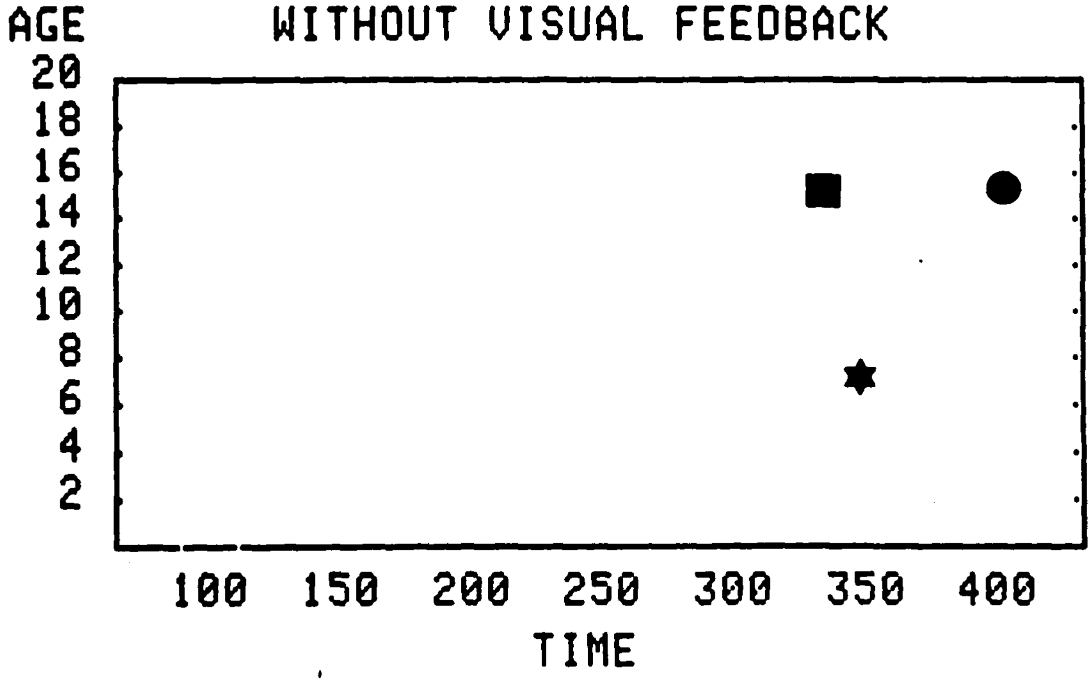
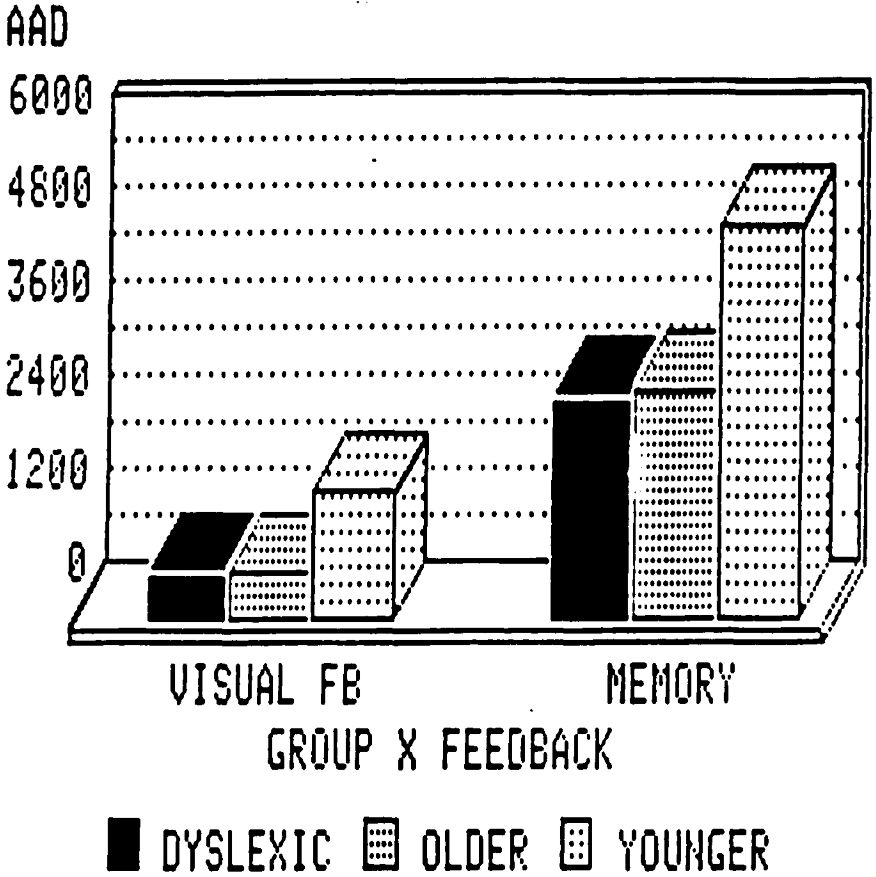


FIGURE 23 - DYSLEXICS & CONTROLS

EFFECT OF VISUAL FEEDBACK ON ACCURACY



FIRURE 24 - DYSLEXICS & CONTROLS

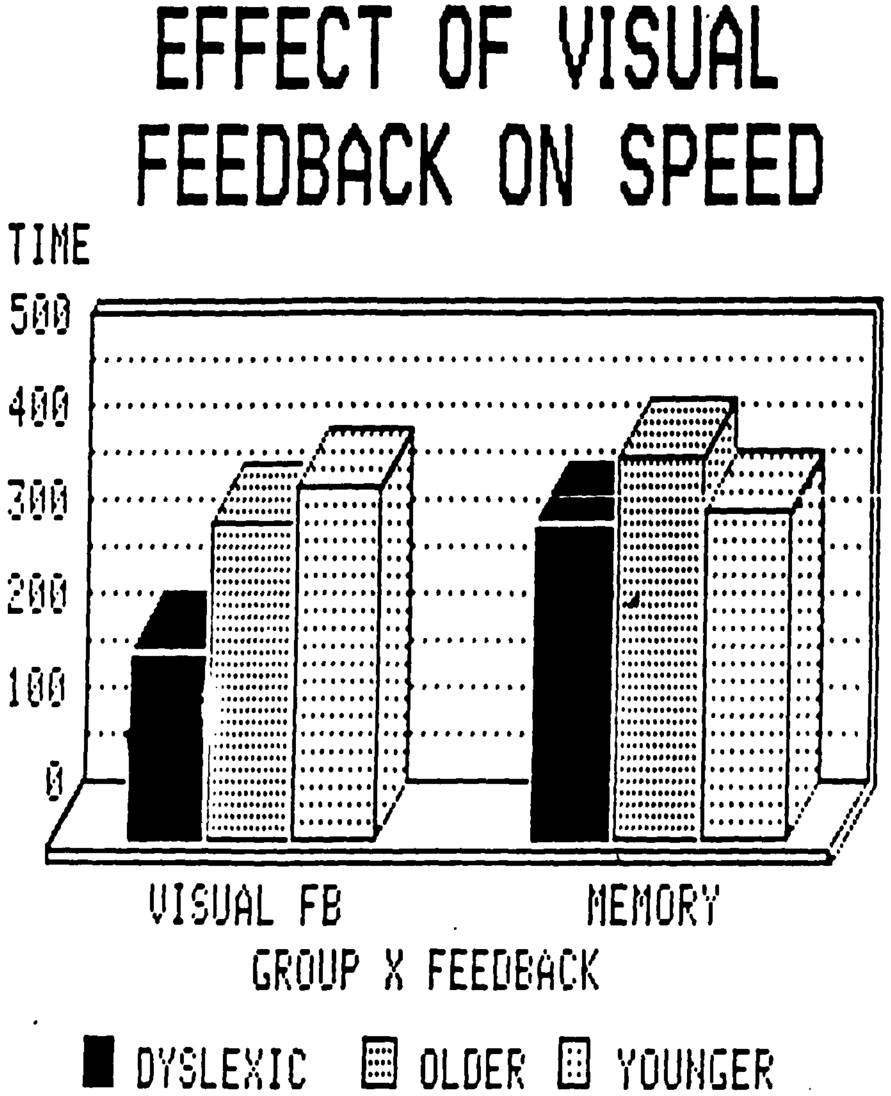


FIGURE 25 - DYSLEXICS & CONTROLS

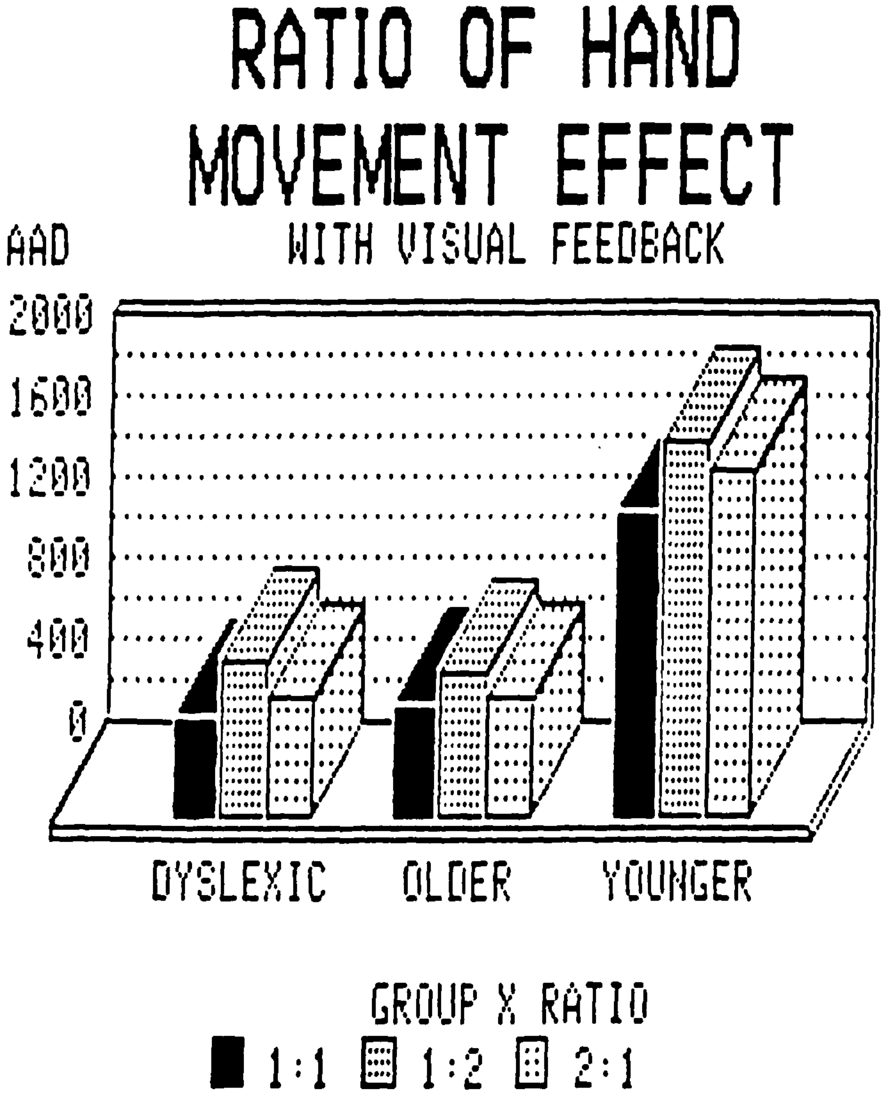


FIGURE 26 - DYSLEXICS & CONTROLS

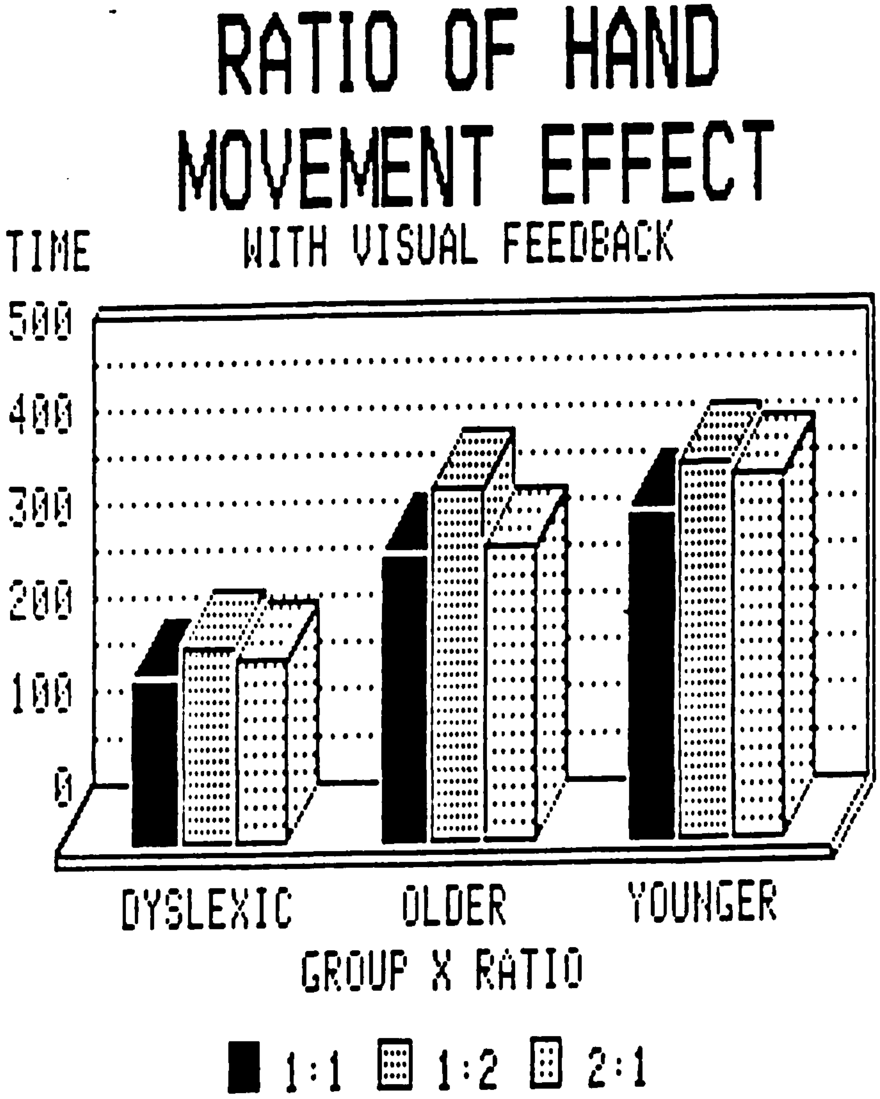
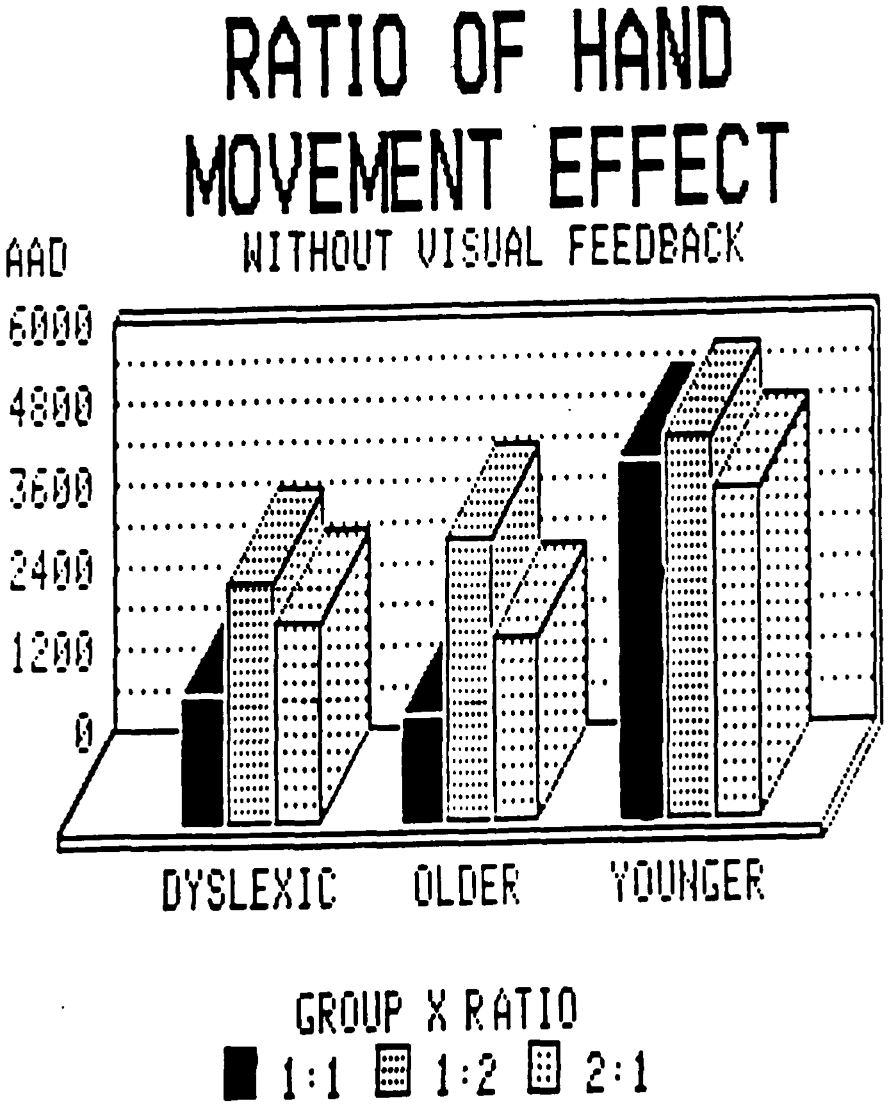


FIGURE 27 - DYSLEXICS & CONTROLS



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