TASK-DEPENDENT HEMISPHERE LATERALIZATION IN EEG AS A FUNCTION OF RELATIVE ACHIEVEMENT AND READING STRATEGY

By

DONAL EUGENE BRANTLEY

Bachelor of Science

University of Texas at Arlington

Arlington, Texas

1978

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 1982

TASK-DEPENDENT HEMISPHERE LATERALIZATION
IN EEG AS A FUNCTION OF RELATIVE
ACHIEVEMENT AND READING STRATEGY

Thesis Approved:

Thesis Adviser

Dean of Graduate College

PREFACE

This study examines the relationship between task-related cerebral hemisphere functioning and relative academic achievement levels in young males. Relative achievement is defined as the extent to which a child is achieving at levels expected for him on the basis of IQ scores. The primary objective is to demonstrate differences in hemispheric specialization that are related to academic patterns frequently seen in learning disabled children. Cerebral functions are assessed through electroencephalographic measurement techniques.

The completion of this study was dependent upon the contributions of numerous individuals. The author would like to express special appreciation to his major advisor, Dr Philip J. Murphy, for his expertise, patient guidance, and generous investment of time. Appreciation is also expressed to the other committee members, Dr. James Price and Dr. Robert S. Schlottmann, for their efforts and assistance in smoothing out the final manuscript.

Thanks are also expressed to the fellow students who were of great help during the data collection phase, especially Anne Campbell, Launa Houston, and Kelly O'Neil. They were an invaluable asset in completing this study.

Appreciation must also be expressed to Ron Koehn, a special friend who provided assistance in various ways throughout the study. As liason to the University while the author was away, Ron averted crises many times.

Finally, the greatest debt of gratitude to be acknowledged is to my family. My wife, Debbie, and son, Christopher, were a constant source of encouragement and support. Without them by my side, this study might never have been completed. There is no way to measure their sacrifices or the importance of the special motivation they provided.

TABLE OF CONTENTS

Chapter | Page

LIST OF TABLES

Table | Page

CHAPTER I

INTRODUCTION

The higher cognitive processes in man are commonly associated with the functioning of the cerebral cortex. This brain structure is bilaterally represented as the right and left cerebral hemispheres. Despite a considerable overlap in function between the two hemispheres, there are some cognitive operations which, for optimal performance, seem to require more involvement from one hemisphere than the other. The left cerebral hemisphere appears to be dominant for the functions of language, logical thinking, and analytic-sequential processing while the right hemisphere is described as dominant for nonverbal reasoning, musical ability, and holistic-simultaneous (gestalt) perception (Milner, 1971; Galin and Ornstein, 1972; Levy, 1974; Piazza, 1977; Gazzaniga, Steen, and Volpe, 1979).

The nature of this functional cerebral asymmetry follows the same general pattern for most individuals. There is a small percentage of people however, in whom cerebral dominance differs from the usual pattern. In these individuals, processes which are usually best served by the right hemisphere may rely more upon the left hemisphere and vice versa. In addition, some individuals also differ from the norm by failing to show any measurable cerebral asymmetry for functions which are commonly thought of as lateralized (Hecaen and Ajuriaguerra, 1964).

The presence of cerebral lateralization in the human brain has been described as an adaptive phenomenon which effectively increases information processing capabilities (Levy, 1969; Galin and Ornstein, 1972). Given this idea, theorists in the area of learning disorders have increasingly suggested that some forms of learning disabilities might be characterized by faulty or incomplete cerebral lateralization for crucial mental processes (Dearborn, 1933; Orton, 1939; Gesell and Amatruda, 1941; Zangwill, 1962; Gazzaniga, 1973). Conceivably, a defect in cerebral lateralization could produce difficulties in specific academic tasks like reading, writing, or arithmetic while leaving global intelligence essentially intact and within normal limits. This is just the type of disability pattern often seen in learning disabled (LD) children as they attempt to progress in school (Kinsbourne, 1975).

The variety of experimental procedures which have been used to investigate the functional asymmetry between the right and left cerebral hemispheres is impressive. Many of these procedures, first used with normal populations, have since been applied to learning disabled populations. When similar procedures are used to compare LD children with their non-LD peers, the LD children frequently exhibit different patterns of hemispheric dominance. The most prevalent finding has been that the left cerebral hemisphere appears less dominant for the processing of verbal tasks in LD children (Connors, 1971; Preston, Guthrie, and Childs, 1974; Guyer and Friedman, 1975; Pettit and Helms, 1979).

Techniques for assessing cerebral dominance can be broadly classified into two types: (a) methods which directly measure or manipulate cerebral activity and (b) methods which indirectly infer cerebral activity on the basis of a special functional relationship that each hemisphere has with the contralateral motor and sensory periphery (Harris, 1979). An indirect method of determining cerebral dominance would be one that relies upon some measure of hand, ear, or visual half-field lateral dominance for a certain task as an indicator of contralateral cerebral dominance for that same task. Harris' (1979) concern over the conceptual leap from peripheral to central functioning that is required in these indirect methods is pertinent. The frequent finding that various measures of peripheral laterality do not always concur for the same individual on analogous tasks casts some doubt on the validity of peripheral dominance as a reliable indicator of cerebral dominance (Zangwill, 1962; Porac and Coren, 1976; Satz, 1976).

The major difficulty encountered in attempts to indirectly assess cerebral dominance is circumvented by several techniques which directly assess or alter some aspect of cerebral functioning. These procedures include the study of cognitive changes associated with: (a) hemisphere specific lesions, (b) electrical stimulation of selected cerebral areas, (c) injection of sodium amobarbitol into one hemisphere, and (d) changes in cortically generated electrical potentials (electroencephalography). The "split-brain" studies began by Sperry (1961) and his students might also be considered one of the paradigms for the direct study of hemispheric function. In the absence of corpus callosum mediated interhemispheric communication, the abilities of the cerebral hemispheres are directly reflected in the skills of the contralateral motor and sensory systems (Sperry, Gazzaniga, and Bogen, 1969).

The more direct methods of examining cerebral dominance and hemispheric functioning have problems as well. The most prevalent of these is a limited range of applicability. Studies involving hemisphere-specific lesions or surgical severing of the corpus callosum are limited to pre-existing populations and observations obtained from these traumatized brains are of questionable generalization to the functioning of an intact individual. Likewise, direct electrical stimulation of the cerebral hemispheres requires opening the cranium in order to gain access to cortical tissue or applying external electroconvulsive shock to one side of the skull. The use of either of these procedures on normal or LD children for purely research purposes is hard to justify practically or ethically. Another direct measure of cerebral dominance which suffers from limited applicability is the Wada test (Wada and Rasmussen, 1960). This procedure involves the chemical disruption of functioning in one cerebral hemisphere at a time by injecting sodium amobarbital into the carotid artery on the same side of the neck. If the cerebral hemisphere on that side is dominant for speech, the patient will become temporarily mute. This is such a crude measure, suitable to only a narrow range of tasks, that it has not found use in a wide range of conditions or populations.

One direct technique exists for assessing cerebral hemispheric activity which is both non-intrusive and applicable to a variety of different populations. This technique, electroencephalography, involves the recording of moment to moment changes in electrical potentials which occur on the scalp. When properly recorded, these scalp potentials can be reliable indicators of electrical changes occurring in underlying areas of cerebral cortex. Several variations of the electroencephalographic (EEG) technique have been developed and each one provides a somewhat different way of viewing cortical activity.

The clinical EEG, recorded while the subject is at rest, has been of little value in cerebral dominance research since it is not task specific and typically reveals little if any lateral asymmetry (Aird and Gastaut, 1956; Margerison, St. John-Loe, and Binnie, 1967; Hughes, 1971).

In comparison, bilateral EEG recorded while the subject is presented brief stimuli or performing a cognitive task frequently does demonstrate a task-dependent hemispheric asymmetry. In normal populations, the left hemisphere exhibits greater changes in electrical activity in response to verbal stimuli or verbal tasks whereas the right hemisphere exhibits greater changes following the presentation of spacial stimuli or tasks (Galin and Ornstein, 1972; Butler and Glass, 1974; Doyle, Ornstein, and Galin, 1974; Morgan, Mcdonald, and Hilgard, 1974; Dumas and Morgan, 1975; McLeod and Peacock, 1977).

The momentary changes in cortical electrical activity seen in response to a briefly presented stimulus such as a flash of light, a click, or a tachistoscopically shown word or figure is known as an evoked potential. Several investigators have studied evoked potentials and found differences between LD and non-LD populations in their hemisphere specific responses to verbal and spatial stimuli (Ertl and Douglas, 1970; Connors, 1971; Preston, Guthrie, and Childs, 1974; Shields, 1973). The nature of the differences cited in these studies varies considerably however, and prompted Harris (1979) to comment:

> It is possible that new refinements of EEG technique will give us very important information for reading diagnosis in the future, but this promise is at present unfulfilled . . . EEG techniques using evoked responses and computorized analysis of records seem promising but need further development and replication of findings (pp. 340-341).

One promising EEG paradigm for the study of hemispheric asymmetry involves the recording of ongoing cortical activity while the subject is in the process of performing a mental task. Rather than recording the brain's momentary response to a discrete environmental event as in evoked potential research, a longer period of continuous bilateral EEG is recorded while the subject is actively seeking the answer or solution to various problems and tasks. Little work has been done with LD children using this technique, but the general notion of left hemisphere dominance for verbal tasks and right hemisphere dominance for spatial and musical tasks has been supported when such an approach is used with normal individuals (Galin and Ornstein, 1972; Doyle, Ornstein, and Galin, 1974; Morgan, Mcdonald, and Hilgard, 1974; Dumas and Morgan, 1975; Davidson and Schwartz, 1977; McLeod and Peacock, 1977; Ehrlichman and Weiner, 1979; Trotman and Hammond, 1979).

The few studies which have recorded bilateral EEG from LD children while they perform various cognitive tasks have provided tentative support for the hypothesis of atypical cerebral lateralization in this population. Sklar, Hanley, and Simmons (1972) found greater coherence (synchrony) between different areas within the right hemisphere during text reading for LD (dyslexic) children than for a group of normal controls. More recently, Murphy, Darwin, and Murphy (1977) found that LD students with a Performance IQ 15 points greater than their Verbal IQ showed less hemisphere specific arousal during verbal and spatial task performance than did another group of LD students who did not show a Verbal-Performance IQ discrepancy. Since all of the subjects in their experiment were considered learning disabled, comparisons to non-LD populations could not be made.

The purpose of the present investigation is to extend the use of in-task bilateral EEG with students who show academic patterns commonly associated with learning disabilities, such as having achievement scores which are considerably beneath their expected levels based upon IQ data. Students who do not show this "relative under-achievement" pattern will also be included in order to provide a wide range for contrast. Ongoing EEG activity, recorded during the performance of a variety of verbal and non-verbal tasks, will be examined in relationship to a group of intellectual and educational variables, including the relative achievement measure.

CHAPTER II

LITERATURE REVIEW

Normal Hemisphere Lateralization

The first awareness of a functional asymmetry in the human brain probably came from observations of people who had suffered injury to one side of the head. These observations may well antedate recorded history. One of the first to publish findings of this type was Pierre-Paul Broca in 1861. Broca studied behavioral changes in patients suffering from brain damage as the result of stroke or injury. He then made comparisons between his behavioral findings and autopsy results after a patient died. Broca noted that difficulty in the use of expressive language was frequently associated with trauma to the posterior inferior aspect of the cerebral cortex, especially in the left hemisphere. Similarly, Wernicke (1886) localized an area in the posterior association cortex of the left hemisphere presumably involved in the understanding of language. Damage to what became known as Wernicke's area often produces a profound form of receptive language deficit. Studies of brain damage and resulting behavioral changes continued, but the importance of the left hemisphere of the cerebral cortex for language functions was already becoming well established. More recently, Milner (1954) examined patients who had portions of their right or left hemisphere surgically removed in an attempt to control severe epilepsy. She found that verbal abilities were predominantly disrupted by removal of portions of the left hemisphere while removal of comparable regions from the right hemisphere produced deficits in spatial, musical, and complex perceptual abilities.

In the middle of this century two new techniques for studying hemisphere functioning were introduced. Brain surgeons made use of the Wada test in order to determine which hemisphere was dominant for language in prospective candidates for surgery. By injecting sodium amobarbital into the carotid artery on one side of the neck, it was possible to assess how important the hemisphere on that side was to the patient's language abilities. If it was the hemisphere dominant for language, then the injection would produce temporary loss of speech (Wada and Rasmussen, 1960). From the Wada test it has been shown that over 95 percent of right handed patients are left hemisphere dominant for language functions. In left handed patients, the left hemisphere is still language dominant 70 percent of the time, the right hemisphere is dominant in another 15 percent, and the final 15 percent seem to have no dominant hemisphere for language at all. This latter group shows no speech loss when sodium amobarbital is injected on either side (Rasmussen and Milner, 1975).

The second technique for studying hemisphere functioning that appeared in the 1950's was also developed to assist in brain surgery. Penfield established a procedure of opening the cranium and electrically stimulating small areas on the surface of the cerebral cortex (Penfield and Jasper, 1954). The behavioral concomitants of such stimulation were used as an index of the effects that surgical removal of specific areas of cortex might produce. In the course of his investigations, Penfield reported that stimulation of areas in the left hemisphere produced relatively greater disruption of ongoing speech and generated the most vocalization responses (Penfield and Roberts, 1959).

In the 1960's a new surgical procedure was developed by Sperry and his colleagues which provided a unique method for the study of hemisphere specialization (Sperry, 1961). In an effort to limit the spread of seizures in patients with intractable epilepsy, they surgically severed the forebrain commissures (corpus callosum and anterior commissure) which serve to interconnect the two hemispheres. This prevented seizures which originated in one hemisphere from involving the hemisphere on the other side. Another result of the surgery was that transfer of information between the hemispheres was effectively abolished. Thus perceptual stimulation received in one hemisphere remained in that hemisphere alone. This formed the basis for a program of experimentation designed to examine the independent capabilities of each hemisphere.

Micheal Gazzaniga (1970), in The Bisected Brain, discusses a number of experimental procedures for making information available to individual hemispheres in "split-brain" patients. The most reliable of these methods involves the presentation of visual stimuli to either the right or the left of the patient's point of fixation. If this presentation is brief enough, the stimulus will be registered only in the visual half-field on the side to which it was presented. In split-brain patients who have a severed optic chiasm, stimulation that is limited to a single visual half-field will be received in the contralateral hemisphere only.

In using this procedure Gazzaniga found that the right hemisphere had severly retarded language skills. This is in contrast to the verbally proficient left hemisphere. Patients were unable to name or describe words and pictures received solely in the isolated right hemisphere. This appeared to be an expressive language deficit because limited receptive language abilities were present in the right hemisphere. For instance, common nouns (but not verbs) could frequently be matched with the appropriate item from a group of objects or pictures placed in front of the patient. While verbs were not comprehended by the right hemisphere, pictoral representation of the desired action quickly received a matching response. This suggested that the right hemisphere was fully capable of producing the activity described by the verbs when it could understand what was being requested. In addition, mathmatical calculations were severly limited in the right hemisphere. For both verbal and mathmatical abilities, the left hemisphere was able to perform at levels comparable with the patient's pre-surgery functioning.

This focus on language and language related abilities makes the right hemisphere appear virtually useless in split-brain patients. This is not the case at all however, as Gazzaniga, Steen, and Volpe (1979) relate:

> The right hemisphere, while lacking verbal sophistication, has proved to be superior on certain tasks, such as drawing and copying figures, arranging blocks to form geometric designs, and performing descriminations involving complex tactual patterns . . . The right hemisphere excels in tasks requiring spatial skills (p. 386).

Thus each separated hemisphere seems to have its own special functions. Of course, these findings were obtained from patients who had not only undergone a radical form of brain surgery, but had also suffered severe epilepsy much of their lives. How adequately they represent the functioning of individuals with healthy, intact brains is uncertain. Still, the agreement between these and previous findings on hemisphere-specific functioning is suggestive.

In another area of work with a clinical population, this time psychiatric inpatients, Gottlieb and Wilson (1965) observed that unilateral electroconvulsive shock treatment (ECS) to the left hemisphere produced a longer disruption of verbal functioning than ECS given to the right hemisphere. Expanding on this observation, Cohen, Noblen, Silverman, and Penick (1968) tested affectively depressed psychiatric inpatients on a verbal paired-association learning task and a visuographic design learning task before and after ECS to either or both cerebral hemispheres. As expected, task performance decrements following ECS depended on the type of ECS delivered. Patients receiving shock to both hemispheres demonstrated the greatest decrement on both types of tasks. For single hemisphere ECS, verbal paired-associates learning was most disrupted following treatment of the left hemisphere while visuographic design learning showed a larger deficit from treatment of the right hemisphere.

The examination of hemisphere specialization in normal individuals was made possible by Kimura's (1961, 1967) adaptation of Broadbent's (1954) dichotic listening techniques. In this procedure different auditory stimuli are presented simultaneously to the right and left ears. The ear from which the most accurate recall is obtained is then considered dominant for that type of stimulus. Since contralateral auditory projection fibers take precedence over ipsilateral ones (Rosenweig, 1951), it has been inferred that the observed ear dominance results from a corresponding dominance of the contralateral hemisphere. Kimura, using different spoken messages, found that material delivered to the right ear was generally reported more accurately in right-handed subjects. Although Kimura's findings of a right ear advantage and hence left hemisphere advantage for verbal stimuli has been replicated numerous times (Kimura, 1973; McGlone and Davidson, 1973; Zurif, 1974), there are critics who question the reliability of this approach in determining hemisphere dominance (Satz, 1976). For instance, dichotic listening studies of children in Holland do not show a right ear superiority for verbal stimuli until the age of nine, while several studies of American children report a right ear advantage in preschool populations (Piazza, 1977). The difficulties of dichotic listening paradigms is further illustrated by their tendency to underestimate the frequency of left hemisphere dominance for language as measured by more direct procedures such as Wada's test (Kinsbourne and Hiscock, 1978).

Another procedure conceptually similar to the dichotic paradigm is available for the visual modality. In this case different stimuli are projected simultaneously to the right and left of a focused reference point. When the two tachistoscopic stimuli are presented for no more than 150 milliseconds, each will be registered on neural paths leading only to the contralateral hemisphere (Hardick and Haapanen, 1979). Using this procedure, several investigators have reported a right visual half-field and presumably left hemisphere advantage for stimuli such as letters and words (Bryden, 1965; Mckeever and Huling, 1971; Kershner, 1977). A similar advantage has been reported in the left visual half-field for the recognition of faces (Geffen, Bradshaw, and Wallace, 1971). As with the dichotic listening paradigm, visual half-field studies are also subject to reliability problems (Harris, 1979). Detailed discussions of methodological issues in visual half-field studies are available (White, 1969; Hardyck, Tzing, and Wang, 1978; Hardyck and Haapanen, 1979).

Recent improvements in electroencephlographic (EEG) technology, including the use of computor analysis, have provided two major techniques for assessing hemisphere-specific cortical activity. The first of these techniques looks at short-term changes in brain generated electrical potentials in response to briefly presented auditory and visual stimuli. These brain responses are usually obscured by ongoing electrical activity and must be averaged across fifty or more presentations so that random background variations are cancelled out. This electrical cortical response, less than one second in duration, is termed an average evoked response (AER) and can be recorded separately for each hemisphere (Gresham and Evans, 1979).

AERs, though brief, are fairly complex waveforms which may show variations in a number of ways. The most frequently studied aspects of AERs are the latencies (time since stimulus onset) for the occurance of certain peaks in the waveform and the amplitude of peaks occurring at various times following stimulus presentation. Using light flashes to produce AERs which were recorded from both hemispheres, Rhodes, Dustman, and Beck (1969) found a moderate amplitude superiority for the right hemisphere. In children, this amplitude asymmetry increases with age and may be correlated with the normal lateralization of hemisphere functioning. Evidence of task-related AER asymmetry comes from the work of Buchsbaum and Fedio (1969). They noted that left hemisphere AERs show greater changes between verbal and non-verbal stimuli relative to right hemisphere AERs.

Undoubtedly the most sophisticated procedure for the study of cortical evoked responses is that devised by E. Roy John et al. (1977) at New York University Medical Center. John and a large number of fellow researchers constructed a "neurometric battery" which consists of recording ongoing EEG with the subjects eyes open and closed as well as eliciting AERs with a diverse set of stimuli. The presentation of the neurometric battery and the analysis of EEG data collected from nineteen scalp electrodes are completely computer controlled. Due to the large number of variables involved in this procedure, the amount of data generated is enormous. Since John's major interest is in using the neurometric battery as a diagnostic device, most of their analysis have been designed to determine factors which allow the greatest discrimination between the groups they have studied. Such factor-analytic discriminators are often difficult to relate to specific variations in EEG recordings. For a description which does justice to the complexity of this research, the reader is referred to John's (1977) book, Functional Neuroscience, Volume II. For the purpose of this review, it is noteworthy that the overall neurometric battery does not demonstrate a hemisphere asymmetry in normal children to whom it has been applied. Marked hemisphere asymmetry is considered indicative of neural pathology in any age group according to John et al. (1977).

A second new EEG procedure, in contrast to the AER approach, requires bilateral recording of ongoing EEG while subjects are actively engaged in cognitive tasks. In this technique, EEG is recorded for up to one minute continuously. The variables of greatest interest are the dominant (highest amplitude) frequency in the EEG waveform as well as the amplitude or power characteristic of certain frequency ranges. In this case power is the inverse of EEG arousal.

McLeod and Peacock (1977), in a replication of a classic study by Galin and Ornstein (1972), recorded EEG independently from the right and left hemispheres while normal right-handed college students performed verbal and spatial tasks. The verbal task required the subject to compose either a letter or a poem silently while the spatial task involved solving six items from the Minnesota Paper Form Board test (MPFB) without reporting their answers. They found a task-related hemisphere asymmetry for the EEG alpha band (7.5 - 13 Hz) but not for the whole band

(1 to 60 Hz). Alpha amplitude in the right hemisphere was higher than in the left hemisphere during both the verbal and spatial tasks for most subjects. The magnitude of this difference however, was significantly larger during the verbal task. Since McLeod and Peacock only report ratios of right to left parietal EEG amplitude, it is not possible to determine where this task-specific variation occurred. Considering that they describe their findings as similar to those of previous researchers (Galin and Ornstein, 1972; Doyle, Ornstein, and Galin, 1974; Morgan, Macdonald, and Hilgard, 1974; Dumas and Morgan, 1975), it seems most likely that their results were produced by a decrease in left hemisphere alpha amplitude during the verbal task or a decrease in right hemisphere alpha amplitude during the spatial task. All of the previous researchers had reported EEG alpha amplitude reduction over the hemisphere presumed to be dominant for each type of task. Interestingly, McLeod and Peacock found no relationship between the degree of alpha amplitude asymmetry during spatial task performance and the subjects earlier performance on a different portion of the MPFB test. This lack of correlation between extent of in-task hemisphere asymmetry and the ability to perform a task is in agreement with the findings of Dumas and Morgan (1975). McLeod and Peacock did find an age effect in their experiment. The degree of task related alpha amplitude asymmetry increased with age in their group of 17 to 35 year olds.

Ehrlichman and Wiener (1979) obtained a task related EEG asymmetry similar to that of McLeod and Peacock using different verbal and spatial tasks and employing a mixed sex group. In this study however, overall alpha amplitude was higher in the left hemisphere than the right hemisphere. This main effect for hemisphere was apparently not examined separately for the verbal and spatial tasks. There is the suggestion that it was produced by a considerable increase in alpha amplitude over the left hemisphere during the spatial tasks.

The major importance of Ehrlichman and Weiner's study is that their subjects were re-tested on different tasks of the same type within one week of the initial data collection. They found a high degree of consistency in the differences between subjects and within-subject correlations were significant for 8 of their 11 subjects. This suggests that task related hemisphere asymmetries represent stable characteristics of individuals and should be valuable in distinguishing those who have differing degrees of cerebral lateralization of functions.

Hemisphere Lateralization and Learning Disabilities

One of the earliest theories relating learning disabilities to incomplete lateralization of hemisphere functioning was that of Orton (1937, 1939). Orton proposed that the dominant hemisphere for language took perceptual precedence over the "minor" hemisphere and was in control of perception during reading and writing. In the absence of a clearly dominant hemisphere, he suggested that inter-hemispheric competition for perceptual control would result. This was thought to produce unstable, shifting perception during reading and writing, thereby accounting for the frequently seen letter reversal errors of dyslexic children.

In essence, Orton was suggesting a causal relationship between atypical hemisphere dominance patterns and disorders of written language processing. There was still no explanation for how atypical hemisphere dominance occurred. Gesell and Amatruda (1941) argued that perhaps this relationship was more coincidental than causal in nature. They considered that both mixed cerebral dominance and language disabilities might be the result of some form of damage or defect associated with the cerebral hemisphere that is usually dominant for language and related linguistic skills. Gesell and Amatruda's hypothesis gained some support from later findings that mixed hemisphere dominance can sometimes be seen in individuals who show no language deficits at all (Rasmussin and Milner, 1975).

Many present day researchers still ascribe to Orton's view that atypical hemisphere dominance is directly capable of contributing to reading and learning disabilities. They frequently differ with his entirely perceptual explanation however. For instance, Levy (1969) has concluded that the reading difficulties seen in some children are more central in nature, reflecting a failure of the cerebral hemispheres to optimize their linguistic functioning through the process of specialization. A growing body of literature has been produced in the attempt to gain support for these ideas.

Dichotic listening procedures, so popular in the study of normal hemisphere specialization, have been applied to the hypothesis of atypical hemisphere specialization in LD children. Considering the difficulties with this procedure that were described earlier, it is not surprising that the results from studies with LD children have been contradictory. In a comprehensive review of this literature, Naylor (1980) notes 15 relevant studies, seven of which report no difference in ear dominance for digits, letters, or words between reading disabled and normal children. Of the remaining eight studies, two describe a greater than normal right ear advantage for disabled readers, five found a less than normal right ear advantage among disabled readers, and one study found no ear advantage at all for reading disabled subjects. Naylor found visual half-field studies to be equally ambiguous regarding reading disability and concluded:

> Dichotic and dichaptic studies, like visual half-field studies, do not support the hypothesis that reading disability is related to incomplete or inconsistent cerebral asymmetry. The conclusion from this review is that these studies have not shed much light on the problem of learning disability. They merely highlight the conceptual

> and methodological problems that beset this area of research (p. 537).

Until the problems with studies of peripheral laterality are resolved, there are not likely to be any definitive results from this area relating to hemisphere specialization in any of the learning disorders.

Electroencephalographic procedures have been somewhat more consistant than peripheral measures in providing evidence of a difference in hemisphere specialization between LD and non-LD children. One of the first reports of such a distinction was made by Ertl and Douglas (1970) using their "Neural Efficiency Analyzer". This device was described as measuring the efficiency of processing within the brain by calculating the time (latency) between consecutive changes in EEG polarity. Reading disabled children tested by Ertl and Douglas were found to have greater right to left absolute latencies than normal readers (Ertl, 1975). Evans, Martin, and Hatchette (1976) attempted to replicate Ertl's findings. They were unable to distinguish between LD, normal, and gifted children using a purchased version of the Neural Efficiency Analyzer.

Connors (1971) employed a more conventional visual evoked response procedure and was able to demonstrate a decreased amplitude for the negative component of the AER waveform which occurred 200 milliseconds after a light stimulus was presented. This amplitude attenuation was seen over the parietal area of the left hemisphere for five poor readers from the same family. In addition, the amplitude of this same negative component over the left parietal area was significantly correlated with reading achievement in 27 LD children ($r = -.61$) and also in ten matched pairs of good and poor readers ($r = -.64$).

In a similar procedure, Preston, Guthrie, and Childs (1974) elicited AERs from three groups of nine-year-olds by presenting light flashes and words as stimuli. The three groups consisted of poor readers and two control groups, one matched to the poor readers on age and IQ and the other matched on reading ability and IQ. The poor readers were found to have smaller amplitudes in the AER component occurring at 180 milliseconds over the left parietal area when the light flash stimuli were used. The word stimuli however, did not discriminate between the three groups.

Shields (1973) studied AERs obtained from ten children who were experiencing visual processing difficulties and ten normal controls matched for age, sex, handedness, verbal IQ, and socioeconomic status. In order to produce the AERs, she used light flashes, words, geometric designs, and pictures. After examining the amplitude and latency for each of five AER components, Shields found that seven of the ten resulting variables distinguished between the two groups. Unfortunately, Shields does not discuss any right and left hemisphere differences in her results despite having recorded AERs bilaterally.

John et al. (1977) have applied their neurometric battery to the classification of a large number of LD children. The result was that a great many of the measures included in the battery were able to discriminate between the LD children and normal controls. The LD children usually demonstrated abnormalities on more than one of their measures. Using just five patterns of dysfunction, John and his associates were able to correctly identify 82 percent of the LD children without inappropiately classifying any of the normal children. It is noteworthy that one of these five discriminators was related to hemisphere asymmetry in the AERs. 71 percent of the LD children were found to have this asymmetry while none of the normal children exhibited such a pattern.

The ability of researchers to demonstrate hemisphere-specific differences in AERs between LD and non-LD children is encouraging. Yet for those interested in task related hemisphere asymmetries, the relative absence of stimulus specific effects (words versus pictures) makes this approach less than ideal.

There have been studies which recorded continuous EEG during task performance by LD children. Generally, they are supportive of the hypothesis of atypical hemisphere specialization in this population. Three published reports were found which utilized this technique and employed both LD and non-LD subjects.

Sklar, Hanley, and Simmons (1972) recorded bilateral EEG from both dyslexic and normal children during each of five conditions: eyes closed resting, eyes open resting, performing mental arithmetic, reading word lists, and reading text. The best discrimination between their two groups was obtained with the eyes closed resting and reading text conditions. With their eyes closed, normal children displayed greater EEG power (integrated amplitude) in the 9 to 14 Hz (alpha) band. Dyslexic children, in the same eyes closed condition, had less power in the alpha band and relatively more power in the 3 to 7 Hz (theta) and 16 to 32 Hz (beta) bands. During the reading text condition, coherence (EEG synchrony) was greater across the two hemispheres for the normal subjects than for the LD subjects. The dyslexic children did have more coherence between points within the right hemisphere however, which may indicate more involvement of the right hemisphere in verbal processing. There are a few problems in interpreing these findings which must be considered. First, Sklar, Hanley, and Simmons do not discuss the hand preference composition of their groups. It has been shown that left-handed individuals have a higher probability of atypical hemisphere dominance for language irrespective of any dysfunction in linguistic abilities (Rasmussin and Milner, 1975). Additionally, it is not clear from their discussion whether these researchers obtained the hemisphere specificity that has been well documented in later studies (Galin and Ornstein, 1972; Doyle, Ornstein, and Galin, 1974; Morgan, Macdonald, and Hilgard, 1974; Dumas and Morgan, 1975). If they failed to obtain such a pattern, then the comparability of their results would be rather suspect.

Another study which must be interpreted with caution is that of Grunau, Purves, McBunney, and Low (1981). These investigators recorded in-task EEG from a group of low birth weight children between the ages of 12 and 15. Some of these children had been diagnosed as showing minimal cerebral dysfunction (MCD) while the rest were neurologically normal. Grunau et al. found that those children higher in visuospatial reasoning ability showed more of a decrease in alpha and theta power from the parietal areas during both verbal and perceptual task performance. They failed however, to find the expected task-specific EEG asymmetries that would indicate hemisphere specialization in their subjects.

Two additional studies have been reported which recorded bilateral EEG during task performance by "learning disabled" children. These studies are limited by their absence of normal control subjects with which to compare their findings. Murphy, Darwin, and Murphy (1977) found that LD children who had verbal and performance IQs that were no more than five points discrepant demonstrated the same pattern of task-specific hemisphere asymmetry as Galin and Ornstein (1972) found for normal subjects. They showed a decrease in right hemisphere power during spatial tasks and a decrease in left hemisphere power during verbal tasks. LD children who had a Verbal IQ at least 15 points below their Performance IQ showed a power decrease in the left hemisphere regardless of the task involved. In addition, the IQ discrepant group had significantly more power (less arousal) during the tasks than the IQ similar group.

Rebert, Wexler, and Sproul (1978) also employed two subgroups of severly reading disabled children in a similar in-task EEG procedure. These children, residents of a school for the neurologically handicapped, were classified according to whether their disability was primarily with written language (dyslexic) or with oral language (dysphasic). The dyslexic group had more power in the left hemisphere than in the right during a reading task. This discrepancy was reduced during a drawing task. The dysphasic group, by comparison, had slightly more power in the right hemisphere than in the left during the reading task and this pattern reversed during the drawing task. Thus in this study, the dysphasic group showed a more normal pattern of hemisphere specialization.

It is hard to draw conclusions from these studies of in-task EEG because of their methodological differences. What is lacking is a study which includes a normal or non-LD group and successfully demonstrates the normal hemisphere specialization (asymmetry) which should be present in this group. This would provide a procedural "check" which can give more meaning to the findings that are then obtained with LD children as well as increase comparability to previous research.

Hypotheses

This study proposed to examine task related cerebral hemisphere functioning, as indicated by EEG activity, in relation to degree of learning disability and type of reading strategy employed. Degree of learning disability will be quantified as the discrepancy between observed (achievement scores) and expected (IQ level) academic performance. The EEG measures employed will be the average alpha amplitude, which is considered inversely related to a hemisphere's dominance, and average dominant frequency which is directly related to a hemisphere's dominance. Reading strategy will be determined according to a modification of Boder's (1973) diagnostic reading procedure.

1. It was hypothesized that subjects who demonstrate no significant decrement in relative achievement would show an increase in EEG dominance in the left hemisphere relative to the right hemisphere during verbal task performance and an increase in EEG dominance in the right hemisphere relative to the left hemisphere during spatial task performance. The numeric tasks, which may involve both verbal and spatial elements, were not expected to demonstrate any significant right to left hemisphere asymmetries.

2. It is further hypothesized, for all subjects, that relative achievement would be directly related to left hemisphere dominance over the right hemisphere during verbal tasks and right hemisphere dominance over the left during spatial tasks. Reliance upon gestalt (sight) reading strategies is expected to be directly related to the dominance of the right hemisphere over the left during spatial task performance.

CHAPTER III

METHOD

Subject Selection

This study involved 18 males ranging in age from 7.8 to 15 years with a mean age of 11.4 years. Since a wide range of academic abilities was desired, subjects were obtained from two separate sources. No distinction was made in the study for a subject's referral source. All subject classification was based on psychological testing performed as part of the procedure or recent testing data obtained from reliable sources. Participation was limited to males due to recent debate over potential sex differences in hemisphere specialization (Trotman and Hammond, 1979; McGlone, 1980). Sufficient female subjects were not available to include sex as a factor in the present study.

Eleven of the children in this study were participants in a research clinic at a large midwestern University. Age range for this group was from 7.8 to 15 years with a mean of 11.2 years. The data collection for the present study constituted their first involvement in a program offering EEG biofeedback for learning disabled students. Children were obtained for the research clinic through referrals from parents, teachers, and related professionals. These referrals were solicited through information provided to local newspapers, schools, and child learning and health professionals. The services of the research clinic were available free of charge to students in Oklahoma public schools.

Although described for "learning disabled" students, participation in the research clinic did not require that a child meet any specific diagnostic criteria for being learning disabled. Essentially, all that was necessary for inclusion was that a parent and/or teacher consider the child learning disabled and that the parent and child agree to participate in the clinic after reviewing the eight to ten week program. Information and forms for the research clinic, as provided to parents, newspapers, and local agencies, are included in Appendix A.

In addition to the boys from the University research clinic, seven male volunteers were obtained from public schools in Oklahoma and Texas. These volunteers were all considered "normal" students by their parents and teachers. The mean age among this group was 11.7 years with a range from 9.6 years to 13.8 years.

Overview of Experimental Procedure

The experimental procedure was individually administered to all of the children. Two sessions were required to complete each subject's data collection. No more than ten days seperated these two sessions for any subject.

The first session required approximately one and one-half to two hours to complete. In this session the subject was introduced to the EEG recording equipment as well as the cognitive tasks he was to perform during the EEG recording. Next, the actual resting and in-task EEG measures were recorded. After disconnecting the subject from the EEG apparatus, he was then administered the Wide Range Achievement Test (WRAT).

The second session did not involve the EEG apparatus. This session consisted of approximately two hours of intellectual and performance testing. The child was administered a portion of Boder's (1973) diagnostic screening procedure for dyslexia, a selection of Harris' (1958) hand dominance tests, and finally the Weschler Intelligence Scale for Children-Revised (WISC-R).

Task-Related EEG Measures

Cognitive Tasks

The cognitive tasks presented to the children during periods of EEG recording were selected from a pool of 24 items equally divided into three catagories: verbal, spatial, and numeric. These items are presented in Appendix B. Two of the eight items from each catagory were used for demonstration purposes prior to the actual EEG recording.

This left six items of each type for the subject to attempt while the in-task EEG measures were collected.

The eight verbal items consisted of sentence completion problems with two words missing from each sentence. It was decided to have the subject choose among two-element responses as a means of increasing the processing time for the items without increasing the level of reading ability necessary to perform the task.

The eight numeric problems required the subject to select a pair of numbers which would complete an arithmetic series. For each series, the logic which determined the sequence involved adding or subtracting a constant amount to or from each consecutive element. An equal number of series requiring addition and subtraction were included. Each subject was presented an example series from each type.

The eight spatial items which were used came directly from the Minnesota Paper Form Board (MPFB) test. For these items, the subject's task was to select one of the five alternatives which, when assembled, would produce a figure most like the completed design in the upper left-hand corner of each problem. In selecting items from the MPFB, an attempt was made to obtain items which did not have obvious quick solutions while avoiding items which might appear overwhelming and thus inhibit solution attempts.

Apparatus

The equipment used in this study consisted of the following:

1. Two Autogenic Systems Inc. (ASI), Standard Electrode Assemblies. Each assembly consisted of two active electrodes which detected EEG impulses as differential measures from the scalp and one ground electrode which served as a common reference. The electrodes were metal wires embedded in sponge discs which were in turn housed in silicon rubber cups.
2. Two ASI, 120a Encephalograph Analyzers. These units received input from the electrode assemblies, clarified and consolidated the EEG signal, and produced an output signal for use with other equipment. A seperate unit was used for each hemisphere. The controls which required special settings for this study were:
   a. Instantaneous/Average Frequency Readout selector. This selected whether the frequency meter reflected instantaneous or averaged dominant frequency. For this study the instantaneous mode was selected.
   b. Auxiliary/Main Frequency Select Switch. This determined which of the two adjustable frequency ranges was displayed by the frequency

meter. This switch was set for the auxiliary range during data collection.

c. Auxiliary Range Parameter Threshold Controls. These established the frequency range over which the frequency meter was responsive. They were set to include frequencies between 8 and 13 Hz (EEG alpha). The use of this limited frequency range aided in the control of muscle tension artifacts.

d. Instantaneous/Average Amplitude Readout Selector. This determined whether the amplitude meter reflected instantaneous or average EEG amplitude. The averaged mode was used so that the meter always indicated EEG amplitude averaged over the immediately preceeding ten seconds.

e. Auxiliary/Main Amplitude Select Switch. Used to establish whether the amplitude meter reflected the main or auxiliary frequency range. Amplitude from the auxiliary range (8 to 13 Hz) was monitored during this study.

3. Two ASI, 5100 Digital Integrator/Wave Form Analyzers. One of these units was connected to each 120a Encephalograph Analyzer. They were used to obtain a digital readout of the average dominant frequency over a selected period of time. Relevant controls and settings for these units were:

a. Input Selector/Power Switch. This switch served to activate the unit as well as determine which functions would be performed on the input from the 120a Encephalograph Analyzers. During this study, the selector was placed in the $_1$ position and input was received in the $_1$ input jack on the back panel. This resulted in a time integral (area under the curve) function being performed on the EEG frequency data and displayed on the 5100's digital readout.

b. Compute Time Interval Selector. This control selected one of nine time periods for the computation of the time integral function on the frequency data. A 15 second compute time interval was chosen for this study.

c. Rest Time Interval Selector. This switch selected one of seven time intervals for the inter-trial (rest) period. This control was set to allow a 30 second pause between 15 second compute periods. No functions were calculated during the 30 second rest periods.

d. Display Switches. These consisted of five push-button switches which controlled the automatic cycling and the digital display readout. Three of these switches were utilized in this study.

(1) Start. This button, when depressed, cleared the digital display and when released, started the unit on a new compute/rest cycle.

(2) Auto. Depressing this switch placed the unit in the automatic operating mode in which it alternated between computing and resting intervals.

(3) E.O.P. When this button was depressed, the digital display would only function during the rest interval. During that time the display indicated functions performed over data from the immediately preceding compute period.

4. Elastic Electrode Retention Headband.

5. Singer Education Systems Inc., Model 8806 Caramate Projector. This automatic rear-projection slide viewing instrument had built-in slide storage as well as an audio cassette record and playback system. The audio cassette tape was used to provide automatic slide advancement.

Procedure

The subject and his guardian(s) were greeted outside the laboratory by two experimenters and escorted into the 3.6 meter by 3.2 meter by 2.4 meter experimentation room. This room housed the apparatus for EEG recording and slide presentation as well as seating for the subject, his escorts, and the experimenters. If so desired, the child's guardians were allowed to remain in the room while the subject was next given the introductory instructions. These included a description of the procedure planned for the session and an introduction to the EEG recording equipment. The basic instructions, found in Appendix C, were repeated, elaborated and individualized until each subject appeared comfortable with the procedure and apparatus.

The subject was next seated in a large padded recliner placed in the upright position. The EEG electrode sponges were briefly soaked in a salt water and soap solution, positioned on the subject's scalp, and held in place by one elastic headband. Right and left ground electrodes were placed one-half inch above each eyebrow. The active electrodes were positioned approximately one-half inch above the T_3 and T_4 coordinates and approximately one-half inch below the P_3 and P_4 coordinates of the 10-20 electrode reference system set forth by the International Federation of Societies for Electroencephalography and Clinical Neurophysiology (Jasper, 1958). The small deviations from standard placements were necessitated by the use of a single headband to secure the electrodes.

Following attachment of the electrodes, the EEG apparatus and slide projector were turned on. After a brief warm-up period, battery voltage, electrode contact, and interference checks were completed. Electrode adjustments were made until a clear EEG signal was received for each hemisphere. At this time parents or guardians who had remained were asked to leave so that the actual recordings could be made with as few distractions as possible. They were provided an estimate of one and one-half hours to complete the session.

The instructions to the subject were continued with a demonstration of the three types of cognitive tasks that he would be asked to perform. Once an understanding of the sample items was indicated, the subject was asked to sit back and relax. The experimenter returned to the EEG apparatus, corrected any new difficulties in signal reception, and initiated the actual data collection.

Once data collection began, the subject was asked to rest with his eyes closed (85 seconds) and then perform three sets of six cognitive tasks (45 seconds per task) separated by two 45 second rest periods. The recording session was concluded with another 85 second rest period. The 45 seconds alotted for each cognitive task consisted of 30 seconds during which the problem was viewed on the projector screen and a 15 second period during which the screen was blank and the subject was to report his answer. Participants were cautioned against speaking while the task presentation slide was still in view (and EEG recording was in progress).

The actual timetable for slide advancement and data collection are provided in appendix C along with the data recording form. Digital readings, reflecting dominant EEG frequency averaged over 15 second epochs, were taken from the display of the ASI 5100's. Frequency values for two such 15 second epochs were recorded during each eyes-closed resting condition. These epochs represented periods from 20 to 35 seconds and 65 to 80 seconds into the 85 second resting periods. One 15 second epoch was also recorded for each of the 18 cognitive tasks that the subject was asked to perform. These in-task epochs extended from 5 to 20 seconds into the 30 second presentation and processing period allowed for each task.

Measures of alpha amplitude, averaged over ten second epochs, were recorded from the amplitude meter of each ASI 120a. These averaging periods coincided with the final ten seconds of each dominant frequency recording period. Thus, the recording periods for amplitude extended from 25 to 35 seconds and 70 to 80 seconds into each eyes-closed resting phase and from 10 to 20 seconds into each slide (task) presentation period.

Intellectual and Performance Measures

Wide Range Achievement Test (WRAT)

The WRAT was individually administered to each subject according to the guidelines set forth in the user's manual (Jastak and Jastak, 1978). This instrument provided an index of academic functioning in the general areas of reading, spelling, and arithmetic. For the purpose of this study, the results of this test were expressed in terms of standard scores for each of the three subtests plus an average standard score for the overall test.

Boder's Diagnostic Reading Procedure

Boder (1973) described a technique for assessing a child's reliance upon holistic word recognition versus sequential phonic analysis during word recognition tasks. Children who show a selective deficit in holistic word recognition are referred to as dyseidetic and those with a specific phonic analysis deficit have been labeled dysphonetic. In some respects, the deficient processes in these two types of disabilities are parallel to the processes typically associated with the right and left cerebral hemispheres respectively. Rather than a strict classification into one of the two types of disability, the subjects in this study were rated on a continuum from exclusive reliance on holistic word recognition to exclusive reliance upon sequential phonic analysis as a word reading strategy.

The word reading list was taken directly from Boder (1973). It consisted of 160 words grouped into eight sets of 20 words each. These sets represented eight reading levels extending from pre-primer through sixth grade. Each word was typed in the center of an unruled, white, 7.6 centimeter by 12.7 centimeter index card in lower-case letters using black ink. The graded word lists are included in

Appendix D, p. 88. Within each list, the words are presented in the order of their presentation to the subjects.

Beginning with the 20-word list closest to the child's WRAT reading level (excluding the pre-primer and sixth grade lists), the experimenter presented the 20 words individually for approximately ten seconds. For each word, it was noted whether the child read the word immediately (within two seconds), within three to ten seconds, or not at all. If the subject correctly read ten or more of the 20 words from the first list presented, he was presented the next higher word list followed by the next lower level word list. If fewer than ten of the words from the first word list are correctly read, the lower level word list was presented before the higher level word list.

The score on this procedure was determined by the percentage of correctly read words which were recognized immediately (within two seconds). This was used to represent the subject's relative utilization of holistic gestalt word recognition strategies as opposed to sequential phonic-analytic strategies. Boder's (1973) findings support the idea that words correctly read within one to two seconds are recognized as whole gestalts while words requiring up to ten seconds to recognize are more likely being processed by sequentially sounding-out parts of the word.

Five of the participants in this study were found to be reading beyond the sixth grade level. These subjects could only be presented the three highest level word lists even though this simplified the reading task for them. The effect of this simplification for these five subjects was probably to increase the proportion of words which they were able to recognize immediately.

Harris' Tests of Hand Dominance

Three tests were administered from the 1958 edition of the Harris' Tests of Lateral Dominance in order to determine each subject's degree of right or left hand dominance. The three tests selected were the Hand Preference Test, in which the subject is asked to pantomime which hand he would use to perform a variety of tasks, the Simultaneous Writing Test, in which the subject must simultaneously write digits with both hands without looking, and the Handwriting Test, which requires the subject to write his full name with his preferred hand and then with the other hand. Each test was administered and scored according to Harris' (1958) testing manual.

Numeric values from negative two through positive two were assigned to the five points along the left-right continuum used in scoring each test. The subject's hand dominance was represented by the sum of the scores obtained on the three individual tests. This produced a possible range of scores from negative to positive six. The negative values represent greater left hand dominance while the positive values represent greater right hand dominance. The absolute value of this total score provided a measure of the strength of a child's laterality independent of right or left handedness.

Weschler Intelligence Scale for Children-Revised (WISC-R)

All ten standard subtests of the WISC-R were administered in accordance with the procedures outlined in the testing manual (Weschler, 1974). From these ten scores, the verbal, performance, and full-scale IQs were calculted for each subject.

A measure of "relative achievement" was obtained by subtracting the full-scale IQ from a child's average scaled score on the three subtests of the WRAT. This relative achievement variable was used to reflect the extent to which a child was achieving at his expected level academically. A positive score on this variable indicated high achievement while a negative score indicated under-achievement. A value of -15 or lower was used to indicate that a child was achieving significantly below his expected level.

Coding of EEG Variables

Due to the large number of EEG variables generated by this procedure, a three letter identification system was devised. The first letter of this code represents the hemisphere being measured (r̲ight or l̲eft). The second code letter represents the condition under which the measure was taken (b̲aseline, v̲erbal, s̲patial, or n̲umeric). The final letter indicates the type of EEG measure involved (*f*requency or *a*mplitude). Thus, RVA indicates right hemisphere verbal task average amplitude or more simply, right verbal amplitude. All capital letters in the code indicates that baseline values have not been adjusted for. Lower case letters refer to in-task measures as deviations from corresponding hemisphere baseline measures. Therefore, lsf indicates the difference between LSF and LBF. This might be termed the left spatial frequency increase from baseline.

In order to indicate the difference between the right and left hemispheres for a specific condition and EEG measure, the letter designating hemisphere was removed from the three letter coding system. This two letter code is only used for baseline adjusted scores and therefore is always in lower case. For instance, na will represent the hemispheric difference in numeric amplitude.

For each of the various EEG measures used in this study, a single value was calculated for each subject. Thus, each baseline score was actually the average of four seperate EEG recording segments and each in-task score represented the average of six seperate recording segments, one for each of the six different verbal, spatial, and numeric tasks.

CHAPTER IV

RESULTS

By the definition used in this study, 9 of the 18 participants were found to be significant under-achievers, that is, their average achievement score on the WRAT was at least 15 standard score points below their Full-Scale IQ. Eight of these under-achievers were from among the 11 subjects who had been referred to the research clinic as learning disabled by either a teacher or parent. The remaining under-achiever came from among the seven "normal" volunteers who were also included in the study. Means and standard deviations for the subject variables are given in Table 1, Appendix E. There were no significant differences between the under-achieving and normal-achieving subjects on any of these variables.

Examination of Table 1 suggests that the "relative achievement" distinctions in this study were more attributable to IQ differences than to achievement score differences. The relative under-achievers demonstrated average WRAT standard scores only slightly lower than the more normal achieving children (the means were 89.78 and 95.33 respectively, $\underline{t} = .33$, $\underline{p} > .50$) while their Full-Scale IQ scores tended to be higher than the normal group (mean of

117.0 compared to 98.89, $t = 1.13$, $p > .30$). This pattern means that the relative under-achievers in this study were considered so due to their generally above average intelligence but only average academic performance. There is another type of under-achiever, not well represented in this study, which may be more commonly associated with learning disabilities. This would be the children of average intelligence who are unable to perform at academic levels appropriate for their age. The results of the present study may have been different if more children of this type had been included.

An important part of this study was the attempt to demonstrate a task-specific hemispheric difference for normal subjects such as previous researchers have shown. This was assessed through a two by three (hemisphere by task) analysis of variance for each of four EEG measures, recorded average alpha amplitude, baseline adjusted average alpha amamplitude, recorded dominant frequency, and baseline adjusted dominant frequency. Only the nine relatively normal academic achievers were included in these analyses which are given in Tables 2 and 3, Appendix E. The hemisphere by task interaction, needed to replicate earlier findings, did not reach significance for any of the four dependent measures. The main effect for hemisphere however, was significant for two of the EEG variables, recorded average alpha amplitude ($F(1,48) = 11.14$, $p < .005$) and recorded dominant frequency ($F(1,48) = 4.52$, $p < .05$).

The means and standard deviations relevant to the preceding analyses can be found in Tables 4 through 7 of the Appendix E (pp. 94-97). For the significant hemisphere effects, these tables show that both the amplitude and frequency measures were higher for the left hemisphere than for the right hemisphere. The failure of the hemisphere effects to persist after adjustments were made for relevant baseline values indicates that hemispheric differences already present at baseline were crucial to the findings. These baseline differences may have resulted from the use of seperate recording channels (and equipment) for the two hemispheres. For this reason, the EEG measures which have been adjusted for baseline values were deemed to be more valid indicators of hemispheric differences resulting from task involvement.

The hand dominance measure, initially intended for use as a covariate in many of these analyses, was not included due to its failure to provide sufficient discrimination between subjects. Of the 17 subjects that this variable was measured on, all but one were determined to be strongly right hand dominant. The small differences obtained between subjects were considered neither meaningful nor reliable.

In addition to the analyses of variance, Pearson product-moment correlation coefficients were calculated for all subject variables with the different EEG measures, between the subject variables, and between the baseline adjusted EEG measures. Appendix F includes all of the correlation coefficients that were calculated (Tables 8 through 11, pp. 99-106). Multiple correlation coefficients were also calculated for the baseline adjusted EEG measures using both relative achievement and reading strategy as predictor variables (Table 13, Appendix F).

The correlations and multiple correlations involving the relative achievement and reading strategy measures were of particular interest. Contrary to expectation, the relative achievement variable was not significantly related to any of the EEG measures. It did however, demonstrate reliable relationships with Performance IQ ($r = -.64$, $p < .01$), Full-Scale IQ ($r = -.50$, $p < .05$), and the WRAT spelling subtest ($r = .48$, $p < .05$). Higher relative achievement was associated with lower Performance and Full-Scale IQ scores as well as higher spelling achievement. These findings are not surprising since relative achievement was defined as the average standard score on the WRAT minus the Full-Scale IQ score for each child.

Reading strategy was found to correlate significantly with two EEG measures, rnf ($r = -.49$, $p < .05$) and rsf ($r = -.48$, p .05). Greater reliance upon sight reading strategies relative to phonetic reading strategies was associated with smaller increases from baseline in dominant frequency for the right hemisphere during both numeric and spatial task performance. Reading strategy did not correlate highly with any measure of hemispheric difference.

Among the subject variables, reading strategy was significantly correlated with Verbal IQ (r = .56, p < .05) and all of the subtest scores from the WRAT (reading, r = .53; spelling, r = .52; arithmetic, r = .49; average, r = .54; in each case p < .05). In general, the children who had higher verbal intelligence or were high academic achievers tended to rely more upon sight reading strategies relative to phonic-analytic (phonetic) strategies.

When both relative achievement and reading strategy measures were employed in multiple correlation with the EEG variables, little was gained in accounting for EEG variability (Table 13, Appendix F). Only the multiple correlation with rsf was significant (R^2 = .37, p < .05). Examination of the corresponding simple correlations (Table 8, Appendix F) showa that this multiple correlation was produced by the association of increased right hemisphere frequency (baseline adjusted) during spatial tasks with higher relative achievement (r = .31, p < .25) and decreased reliance upon sight reading strategies (r = -.48, p < .05). The two predictor variables, relative achievement and reading strategy were unrelated (r = -.02).

The correlation coefficients in Table 9, Appendix F, show that the various measures of hemispheric differences in adjusted alpha amplitude were consistently related to WRAT achievement scores. Out of 12 correlations, 11 were significant at the .05 level or better. In each, greater right hemisphere amplitude relative to left hemisphere amplitude was associated with higher achievement scores. Hemispheric differences in amplitude were also frequently related to subject's IQ scores (5 of 9 correlations were significant at the .05 level or better). During verbal tasks, greater amplitude in the right hemisphere relative to the left hemisphere was associated with higher Verbal, Performance, and Full-Scale IQ scores (r = .63, $p < .01$, r = .56, $p < .05$, and r = .63, $p < .01$, respectively). For the spatial tasks, a similar pattern was seen for Verbal and Full-Scale IQ scores (r = .55, $p < .05$ and r = .54, $p < .05$). Hemispheric differences in adjusted alpha amplitude during numeric tasks did not correlate significantly with any of the IQ measures.

In contrast to the amplitude measures, none of the measures of hemispheric differences in baseline adjusted dominant frequency were significantly related to either the achievement or IQ variables. The Chi-square analyses of these correlation patterns (Table 12, Appendix F) show that hemispheric differences in adjusted alpha amplitude were significantly better than hemispheric differences in adjusted dominant frequency as predictors of achievement scores ($\chi^2 = 20.3$, $df = 1$, $p < .001$) and IQ scores ($\chi^2 = 6.97$, $df = 1$, $p < .01$).

Although no specific hypotheses were associated with the intercorrelations among the various EEG measures, examination of Table 11 of Appendix F reveals interesting patterns. For each task condition, hemispheric differences in adjusted dominant frequency are more strongly associated with changes occurring in the left hemisphere than in the right hemisphere. The correlation coefficients between left hemisphere adjusted frequency and hemispheric differences in adjusted frequency for the verbal, spatial, and numeric tasks were -.72, -.78, and -.72 respectively. All three of these correlations were significant at better than the .001 level. By comparison, only one of the corresponding correlations for the right hemisphere reached significance at the .05 level (rvf with vf, $\underline{r}$ = .49).

The adjusted alpha amplitude measure did not exhibit the same pattern as the adjusted dominant frequency measure. Hemispheric differences in adjusted alpha amplitude were not strongly related to variations occurring in either individual hemisphere. The difference between the adjusted dominant frequency and adjusted alpha amplitude measures in this respect may have been due to the greater coherence between the right and left hemisphere demonstrated by the adjusted amplitude measure. The correlation coefficients between right and left hemisphere adjusted alpha amplitude were significant at the .0001 level for all three task conditions ($\underline{r}$ = .92 for the verbal tasks, .94 for the spatial tasks, and .95 for the numeric tasks). Correlation coefficients between the two hemispheres using the adjusted dominant frequency measure were only .26 for the verbal tasks, .65 for the spatial tasks, and .51 for the numeric tasks. The latter two correlations were significant at the .01 and .05

levels respectively. This suggests that the adjusted alpha amplitude measure demonstrated less hemispheric specificity than the adjusted dominant frequency measure.

CHAPTER V

DISCUSSION

This study was not successful in replicating the task-dependent hemisphere asymmetries that many previous researchers have found in the EEGs of normal subjects. In attempting this replication, the verbal and spatial task conditions were of primary importance. The means presented in Tables 4 through 7 (Appendix E) for the nine highest relative achievers indicate that the right hemisphere EEG measures came the closest to differentiating the verbal and spatial tasks. Although the differences were not statistically reliable, both right hemisphere dominant frequency and alpha amplitude tended to be lower during verbal task performance as compared to spatial task performance.

Given that there was very little change across conditions for the left hemisphere EEG measures, the tendency toward lower right hemisphere dominant frequency during the verbal tasks is consistent with the hypothesis of left hemisphere dominance for verbal tasks. The decrease in right hemisphere alpha amplitude during the verbal tasks however, is actually more suggestive of right hemisphere dominance for verbal tasks. This tendency toward contradiction between the dominant frequency and alpha amplitude measures suggests that EEG arousal commonly associated with increases in dominant EEG frequency is not as directly comparable to EEG arousal associated with decreases in alpha amplitude as had been expected. None of the correlation coefficients calculated between dominant frequency and alpha amplitude measures for a given hemisphere and task reached significance (Table 11, Appendix F). In other studies, it has been measures of alpha amplitude rather than dominant frequency which have been the most successful in demonstrating task-specific hemisphere asymmetries (McLeod and Peacock, 1977).

As predicted, the numeric tasks displayed no evidence of hemisphere specialization. Of course, the absence of specialization for either the verbal or spatial tasks in this study makes the results for the numeric tasks rather ambiguous. The numeric tasks were not expected to demonstrate hemisphere specialization because they were felt to call upon both verbal and spatial processing skills. The mean adjusted alpha amplitude values for the three task conditions (Table 5, Appendix E) show that each one of the tasks had greater amplitude decreases in the right hemisphere than the left hemisphere. For the numeric tasks however, the actual right-left hemisphere difference was less than for the other two tasks (1.26 compared to 2.48 for the verbal tasks and 2.36 for the spatial tasks, $\underline{t}(16) = 3.44$ ($\underline{p} < .01$) and 2.69 ($\underline{p} < .05$) for the respective two-tailed tests). This is the type of result that would be expected if the numeric tasks did indeed involve cognitive processes which represent a blend of verbal and spatial skills.

Despite the suggestive findings for the numeric tasks, the failure to obtain a significant task by hemisphere effect overall for the higher achieving subjects indicates that the present EEG measures should be interpreted with caution. If the relevant means had been in the expected direction and less contradictory in nature, then the small number of subjects involved in these particular analyses might offer an explanation for the negative findings. However, other researchers have obtained the expected task-specific hemisphere dominance with as few as 10 or 11 subjects (Ehrlichman and Wiener, 1977; Trotman and Hammond, 1979).

One factor which may have contributed to the lack of task-specific hemisphere asymmetries in this study was the relatively young age of the participants. All of the research discussed earlier which did find evidence of hemisphere specificity in continuously recorded EEG had used older, adult subjects. There is considereble evidence from other techniques however, such as dichotic listening tasks (Piazza, 1977) and average evoked response studies (Buchsbaum and Fedio, 1969; Rhodes, Dustman, and Beck, 1969 1969), to suggest that task-specific hemisphere asymmetries should be demonstrable in children even younger than those included in this study.

The particular verbal tasks used in this study represent another deviation from previous research. Although items from the MPFB have been successfully employed as spatial tasks by other researchers (McLeod and Peacock, 1977), the verbal items used in this study have not been validated in such a manner. Many of the verbal tasks used by other investigators have required that the subjects be more creative. McLeod and Peacock (1977) had their subjects compose letters or poems and Ehrlichman and Wiener (1979) had subjects find synonyms for selected words or create as many sentences as possible from the same set of words. Still, some very non-creative tasks have also been successfully employed as verbal items. Trotman and Hammond (1979) required their subjects to count backwards and to count the letters in a sentence. Considering the wide range of items that have successfully served as verbal tasks in these experiments, the items employed in this study would seem to have been satisfactory as well.

In EEG research there must always be the concern that extraneous variability in the records, especially that resulting from motor activity, might overshadow the desired brain-wave effects. The present study attempted to minimize such contamination through the use of band-pass filters which allowed only 8 to 13 Hz activity to be recorded. The majority of motor artifacts are well above or below this range. Some investigators have used more sophisticated means of controlling artifacts. One method has been to record muscle tension and eye movements simultaneous with EEG recordings (McLeod and Peacock, 1977). Artifacts are then either adjusted for visually or by computor. While Trotman and Hammond (1979) were able to demonstrate task-related hemisphere effects reporting only the controls used in this study, it may be that more precise artifact controls are important for reliable production of such effects.

Examination of the data collected on all 18 subjects provided little basis for conclusions. The relative achievement variable accounted for far less of the EEG variability than had been anticipated. This may have been the result of extraneous variation in the EEG measures as just discussed or it may indicate that the relative achievement variable, as a measure of learning disability, is not associated with any physical reality related to the EEG measures used in this study. The descrepancy between a child's expected and obtained levels of academic achievement may be too heavily influenced by motivational factors and experience with remedial training to permit ready detection of underlying physiological components.

It may have been possible to demonstrate more of a relationship between EEG measures and the relative achievement variable if there had been greater representation in the subject group of children in the average intellectual range whose achievement was well below normal. This group might be expected to evidence a higher percentage of EEG abnormalities than the typical relative under-achievers seen in this study, who were of superior intellectual ability but only average in terms of academic achievement.

It had been predicted that the reading strategy variable, for which higher values indicated greater reliance upon sight reading strategies, would be positively correlated with the extent of right hemisphere dominance during spatial task performance. There was no evidence of such a relationship among any of the hemispheric difference measures obtained from the EEGs. The only significant relationship the reading strategy variable exhibited with any of the spatial task EEG measures was a negative one. As reliance upon sight reading strategies increased, the increase in right hemisphere frequency relative to baseline tended to decrease ($r = -.48$, $p < .05$). This is suggestive of decreasing right hemisphere spatial dominance as the use of sight reading tactics increased.

Reading strategy was found to be remarkably unrelated to a child's relative level of achievement ($r = -.02$, $p > .90$). Children achieving at or above their expected academic levels demonstrated no reliably greater use of sight reading strategies than did children whose achievement fell below their expected abilities. It was found however, that the children with higher verbal intelligence and/or higher absolute achievement scores relied upon sight reading tactics to a greater extent than the lower achieving, less verbally intelligent children. It is unlikely that this effect resulted from the reading task simply being easier for the more advanced readers since word lists of graded difficulty were employed in an effort to adjust for the varying levels of reading ability among the children. The five children who were reading at levels beyond which full adjustment could be made for did have a large impact upon the correlation between reading strategy and verbal IQ. Removing them from the analysis dropped the correlation from .56 to .42 which was no longer significant. It was not felt that this indicated these subject's scores were invalid however, since removing them from the correlation between reading strategy and the average WRAT achievement score resulted in an increase in the statistic from .54 to .62 ($p < .05$).

It therefore appears that, for material of equal difficulty, academically superior children make greater use of sight reading strategies relative to phonetic strategies. This suggests that poor readers may be relying upon less effective phonetic reading strategies even in situations in which they would be expected to be able to utilize sight reading strategies. Phonetic reading strategies can be very useful in helping to auditorily reproduce unfamiliar written words. However, meanings are associated with entire words and groups of words. An excessive focus upon the parts which make up a word may actually interfere with overall understanding when reading for comprehension.

In conclusion, neither of the hypotheses set forth in this study were substantiated. The higher ("normal") relative achieving subjects did not demonstrate hemisphere lateralization, i.e., left hemisphere dominance for verbal tasks and right hemisphere dominance for spatial tasks. There was also no significant evidence of any direct relationship between the relative achievement measure and the extent of left hemisphere dominance for verbal tasks or right hemisphere dominance for spatial tasks. Indeed, neither relative achievement nor reading strategy was found to be significantly related to any of the EEG measures of hemisphere difference or dominance.

The one finding in this study which would most seem to warrant further investigation was the tendency for the less verbally intelligent, lower achieving children to be overly dependent upon phonetic reading strategies relative to the more successful children. Excessive reliance upon this sometimes less efficient reading tactic may be partially responsible for some of these children's poorer academic skills. It remains to be seen whether this reading pattern is a learned response or a consequence of lower verbal intelligence.

BIBLIOGRAPHY

Aird, R. and Gastaut, Y. Occipital and posterior EEG rhythms. Electroencephalography and Clinical Neurophysiology, 1959, 11, 637-656.

Boder, E. Developmental dyslexia: a diagnostic approach based on three atypical reading-spelling patterns. Developmental Medicine and Child Neurology, 1973, 15, 663-687.

Broadbent, D. The role of auditory localization and attention in memory span. Journal of Experimental Psychology, 1954, 47, 191-196.

Broca, P. Remarques sur le siege de la faculte du langage articule, suivi d'une observation d'apheme. Bulletin Societe Anthropologia, 1861, 6, 330-357. Cited in C. Hardyck and R. Haapanen, 1979.

Bryden, M. P. Tachistoscopic recognition, handedness and cerebral dominance. Neuropsychologia, 1965, 3, 1-8.

Buchsbaum, M. and Fedio, P. Visual information and evoked responses from the left and right hemispheres. Electroencephalograpy and Clinical Neurophysiology, 1969, 26, 266.

Butler, S. R. and Glass, A. Asymmetries in the electroencephalograph associated with cerebral dominance. Electroencephalography and Clinical Neurophysiology, 1974, 36, 481-491.

Cohen, B. D., Noblin, C. D., Silverman, A. J., and Penick, S. B. Functional asymmetry of the human brain. Science, 1968, 162, 475-477.

Conners, C. K. Cortical visual evoked responses in children with learning disorders. Psychophysiology, 1971, 7, 418-428.

Davidson, R, J. and Schwartz, G. E. The influence of musical training on patterns of EEG asymmetry during musical and non-musical self-generation tasks. Psychophysiology, 1977, 14, 58-63.

Dearborn, W. F. Structural factors which condition special disability in reading. Proceedings of the American Association for Mental Deficiency, 1933, 38, 266-283.

Doyle, J. C., Ornstein, R., and Galin, D. Lateral specialization of cognitive mode: II. EEG frequency analysis. Psychophysiology, 1974, 11, 567-578.

Dumas, R. and Morgan, A. EEG asymmetry as a function of occupation, task, and task difficulty. Neuropsychologia, 1975, 13, 219-228.

Ehrlichman, H. and Wiener, M. S. Consistency of task-related EEG asymmetries. Psychophysiology, 1979, 16, 247-252.

Ertl, J. Research News Letter No. 1. Toronto: Neural Models Ltd., 1975.

Ertl, J. and Douglas, V. Evoked Potentials and Dyslexia. Toronto: Neural Models Ltd., 1970.

Evans, J. R., Martin, D., and Hatchette, R. Neural efficiency analyzer scores of reading disabled, normally reading and academically superior children. Perceptual and Motor Skills, 1976, 43, 1248-1250.

Galin, D. and Ornstein, R. Lateral specialization of cognitive mode: an EEG study. Psychophysiology, 1972, 9, 412-418.

Gazzaniga, M. S. The Bisected Brain. New York: Appleton-Century-Crofts, 1970.

Gazzaniga, M. S. Brain theory and minimal brain dysfunction. Annals of New York Science, 1973, 205, 88-92.

Gazzaniga, M. S., Steen, D., and Volpe, B. T. Functional Neuroscience. New York: Harper and Row, 1979.

Geffen, G., Bradshaw, J. L., and Wallace, G. Interhemispheric effects on reaction time to verbal and nonverbal visual stimuli. Journal of Experimental Psychology, 1971, 87, 415-422.

Gesell, A. and Amatruda, C. S. Developmental Diagnosis: Normal and Abnormal Child Development. New York: Paul B. Hoeber, 1941.

Gottlieb, G. and Wilson, I. Cerebral dominance: temporary disruption of verbal memory by unilateral electroconvulsive shock treatment. Journal of Comparative and Physiological Psychology, 1965, 60, 368-372.

Gresham, F. and Evens, J. R. Recent developments in electrophysiological measurement: implications for school psychology. Psychology in the Schools, 1979, 9, 314-321.

Grunau, R. V. E., Purves, S. J., McBurney, A. K., and Low, M. D. Identifying academic aptitude in adolescent children by psychological testing and EEG spectral analysis. Neuropsychologia, 1981, 19, 79-86.

Guyer, B. L. and Friedman, M. P. Hemisphere processing and cognitive styles in learning-disabled and normal children. Child Development, 1975, 46, 658-668.

Hardyck, C. and Haapanen, R. Educating both halves of the brain: educational breakthrough or neuromythology? Journal of School Psychology, 1979, 17, 219-230.

Hardyck, C., Tzeng, O. Z. L., and Wang, W. S-Y. Lateralization of function and bilingual judgements: is thinking lateralized? Brain and Language, 1978, 5, 56-71.

Harris, A. J. Harris Tests of Lateral Dominance: Manual of Directions (3rd Ed.). New York: Psychological Corporation, 1958.

Harris, A. J. Lateral dominance and reading disability. Journal of Learning Disabilities, 1979, 12, 337-343.

Hecaen, H. and Ajuriaguerra, J. Left-handedness: manual superiority and cerebral dominance, translated by E. Ponder. New York: Grune and Stratton, 1964.

Hughes, J. R. Electroencephalography and learning disabilities. In H. R. Myklebust (Ed.), Progress in Learning Disabilities (Vol. III). New York: Grune and Stratton, 1971.

Jasper, H. H. The ten-twenty electrode system of the International Federation of Societies for Electroencephalography and Clinical Neurophysiology. Electroencephalography and Clinical Neurophysiology, 1958, 10, 371-375.

Jastak, J. F. and Jastak, S. The Wide Range Achievement Test: Manual of Instructions. Wilmington, Del.: Jastak Associates, 1978.

John, E. R., Kermel, B. Z., Cornig, W. C., Easton, P., Brown, D., Ahn, M., John, M., Harmony, T., Prichep, L., Toro, A., Gerson, I., Bartlett, F., Thatcher, R., Kaye, H., Valdes, P., and Schwartz, E. Neurometrics. Science, 1977, 196, 1393-1400.

John, E. R. Functional Neuroscience, Vol. II. Hillsdale, N. J.: Lawrence Erlbaum Associates, 1977.

Kershner, J. R. Cerebral dominance in disabled readers, good readers, and gifted readers: search for a valid model. Child Development, 1977, 48, 61-67.

Kimura, D. Cerebral dominance and the perception of verbal stimuli. Canadian Journal of Experimental Psychology, 1961, 15, 166-171.

Kimura, D. Functional asymmetry of the human brain in dichotic listening. Cortex, 1967, 3, 163-178.

Kimura, D. The asymmetry of the human brain. Scientific American, 1973, 228, 70-78.

Kinsbourne, M. Cerebral dominance, learning, and cognition. In H. R. Myklebust (Ed.), Progress in Learning Disabilities, Vol. III. New York: Grune and Stratton, 1975.

Kinsbourne, M. and Hiscock, M. Cerebral lateralization and cognitive development. In M. Grady and E. Luecke (Eds.), Education and the Brain. Chicago: University of Chicago Press, 1978.

Levy, J. Possible basis for the evolution of lateral specialization of the human brain. Nature, 1969, 224, 614-615.

Levy, J. Cerebral lateralization and spatial ability. Behavior Genetics, 1976, 6, 171-188.

Likert, R. and Quasha, W. H. Revised Minnesota Paper Form-Board, Series AA and BB. New York: Psychological Corporation, 1934.

Margerison, J. H., St. John-Loe, P., and Binnie, C. D. Electroencephalography. In P. A. Venables and I. Martin (Eds.), A Manual of Psychophysiological Methods. Amsterdam: North Holland Publishing Company, 1967.

McGlone, J. Sex differences in human brain asymmetry: a critical survey. The Behavioral and Brain Sciences, 1980, 3, 215-263.

McGlone, J. and Davidson, W. The relation between cerebral speech laterality and spatial ability with special reference to sex and hand preference. Neuropsychologia, 1973, 11, 105-113.

Mckeever, W. F. and Huling, M. D. Bilateral tachistoscopic word recognition as a function of hemisphere dominance and interhemispheric transfer time. Neuropsychologia, 1971, 9, 281-288.

McLeod, S. S. and Peacock, L. J. Task-related EEG asymmetry: effects of age and ability. Psychophysiology, 1977, 14, 308-311.

Milner, B. Intellectual function of the temporal lobes. Psychological Bulletin, 1954, 51, 42-62.

Milner, B. Interhemispheric differences in the localization of psychological processes in man. British Medical Bulletin, 1971, 27, 272-277.

Morgan, A. H., Macdonald, H., and Hilgard, E. R. EEG alpha: lateral asymmetry related to task and hypnotizability. Psychophysiology, 1974, 11, 275-282.

Murphy, P. J., Darwin, J., and Murphy, D. A. EEG feedback training for cerebral dysfunction: a research program with learning disabled adolescents. Biofeedback and Self-Regulation, 1977, 2, 288.

Naylor, H. Reading disability and lateral asymmetry: an information-processing analysis. Psychological Bulletin, 1980, 3, 531-545.

Orton, S. T. Reading, Writing, and Speech problems in Children. New York: W. W. Norton, 1937.

Orton, S. T. A neurological explanation of the reading disability. Educational Record, 1939, 20, 58-68.

Penfield, W. and Jasper, H. H. Epilepsy and the Functional Anatomy of the Human Brain. Boston: Little, Brown, 1954.

Penfield, W. and Roberts, L. Speech and Brain Mechanisms. Princeton: Princeton University Press, 1959.

Pettit, J. M. and Helms, S. B. Hemispheric language dominance of language-disordered, articulation-disordered, and normal children. Journal of Learning Disabilities, 1979, 12, 71-76.

Piazza, D. M. Cerebral lateralization in young children as measured by dichotic listening and finger tapping tests. Neuropsychologia, 1977, 15, 417-425.

Porac, C. and Cohen, S. The dominant eye. Psychological Bulletin, 1976, 83, 880-897.

Preston, M. Guthrie, J., and Childs, B. Visual evoked responses in normal and disabled readers. Psychophysiology, 1974, 11, 452-457.

Rasmussen, T. and Milner, B. Clinical and surgical studies of the cerebral speech areas in man. In K. J. Zulch, O. Creutzfeldt, and G. C. Galbraith (Eds.), Otfred Foerster Symposium on Cerebral Localization. Heidelberg: Springer-Verlag, 1975.

Rebert, C. S., Wexler, B. N., and Sproul, A. EEG asymmetry in educationally handicapped children. Electroencephalography and Clinical Neurophysiology, 1978, 45, 436-442.

Rhodes, L. E., Dustman, R. E., and Beck, E. C. The visual evoked response: a comparison of bright and dull children. Electroencephalography and Clinical Neurophysiology, 1969, 27, 364-372.

Rosenzweig, M. R. Representation of the two ears at the auditory cortex. American Journal of Physiology, 1951, 167, 147-158.

Satz, P. Cerebral dominance and reading disability: an old problem revisited. In R. M. Knight and D. J. Bakken (Eds.), The Neuropsychology of Learning Disorders: Theoretical Approaches. Baltimore: University Park Press, 1976.

Shields, D. I. Brain responses to stimuli in disorders of information processing. Journal of Learning Disabilities, 1973, 6, 501-505.

Sklar, B., Hanley, J., and Simmons, W. An EEG experiment aimed toward identifying dyslexic children. Nature, 1972, 240, 414-416.

Sperry, R. W. Cerebral organization and behavior. Science, 1961, 133, 1749.

Sperry, R. W., Gazzaniga, M. S., and Boren, J. E. Interhemispheric relationships: the neocortical commissures; syndromes of hemispheric disconnection. In P. J. Vinken and G. W. Bruyn (Eds.), Handbook of Clinical Neurology, Vol. 4. Amsterdam: North Holland Publishing Company, 1969.

Trotman, S. C. A. and Hammond, G. R. Sex differences in task-dependent EEG asymmetries. Psychophysiology, 1979, 16, 429-431.

Wada, J. and Rasmussen, T. Intracarotid injection of sodium amytol for the lateralization of cerebral speech dominance: experimental and clinical observations. Journal of Neurosurgery, 1960, 17, 266-282.

Wernicke, C., 1886. Cited in Pribram, K. H., Languages of the Brain: Experimental Paradoxes and Principles in Neuropsychology. Monterey, California: Brooks/Cole Publishing Company, 1971, p. 354.

Weschler, D. Weschler Intelligence Scale for Children-Revised. New York: The Psychological Corporation, 1974.

White, M. J. Laterality differences in perception: a review. Psychological Bulletin, 1969, 72, 387-405.

Zangwill, O. Dyslexia in relation to cerebral dominance in reading disability. In J. Money (Ed.), Reading Disability: Progress and Research Needs in Dyslexia. Baltimore: John Hopkins Press, 1962.

Zurif, E. B. Auditory lateralization: prosodic and syntactic factors. Brain and Language, 1974, 1, 391-404.

APPENDICES

APPENDIX A

RESEARCH CLINIC PRESS RELEASE

AND INFORMATION FORMS

PRESS RELEASE

Biofeedback Aid for the

Learning Disabled

Dr. Philip Murphy, Associate Professor in the Psychology Department at OSU, announced plans for the opening of a specialized research clinic providing intellectual evaluation, electroencephalographic assessment and biofeedback training for learning disabled students in grades 1 through 12. Biofeedback techniques, found useful in a variety of medical and psychological conditions, have been recently found increasingly helpful in the management of learning problems in hyperactive and other types of learning disabilities. Biofeedback is an innovative educational technology that has been shown to improve verbal IQ, performance IQ, attention span, reading and arithmetic, and decrease hyperactive behavior in appropriate cases. The purpose of the research clinic is to further understanding of the specific effectiveness of biofeedback in the treatment of learning problems. Biofeedback at this time must be considered an experimental technique for the remediation of learning disabilities. The services of BILD (Biofeedback Instruction for Learning Disabilities) Research Clinic include a cognitive evaluation, EEG assessment, and a biofeedback training program. These services are free of charge to the public. To qualify for these services, a student must be enrolled in the 1st through 12th grade in an Oklahoma school and be considered learning disabled. If you believe your student or your child qualifies and you are interested in BILD, call 405/624-6029 between 8 a.m. and noon or 1 to 5 p.m.

Biofeedback Instruction for Learning Disabilities (BILD)

Program Format:

1) Psycho-educational testing data will be collected on your child. If recent information is not available, we will do the testing ourselves. Testing may include: an intelligence test, achievement test, and a screening instrument for learning disabilities.

2) Your child will next be introduced to our biofeedback equipment and shown the hook-up procedure. When s/he is comfortable with this, a short baseline recording of brain-wave activity will be made while s/he woks some simple problems.

3) Following the baseline session will come 6 to 8 training sessions. Training sessions will require about one hour each and will be scheduled once or twice per week. During the training s/he will use the feedback tone to try to control brain-wave activity.

4) When the training sessions are completed there will be one or two final sessions in which the psycho-educational testing will be repeated. This will enable us to assess what changes have occurred due to the training.

This is an experimental technique and we cannot guarantee what benefit, if any, your child will receive. This form of biofeedback has been found helpful to other children on a variety of academic tasks.

In previous applications of this technique, we have encountered one undesirable side effect. The elastic band which is used to hold the monitoring electrodes in place may produce a headache if it is worn too tight. This can be easily alleviated by proper adjustment. Your child will be told about this so that s/he can assist us in avoiding the problem.

If after reading this program format, you would like for your child to participate in BILD, please sign the accompanying consent form and fill out the release of information form for the agency which you believe to have the most complete and up-to-date testing information on your child. Unless your child has been evaluated by a special agency or clinic recently, his/her school will probably have the best records and testing information. Return the two completed forms to the address provided. As soon as we receive the forms, we will send for the relevant testing information on your child. Once we know what testing remains to be completed, we will contact you to set up an appointment. This process usually takes a few weeks.

If you still have unanswered questions, please call us at the OSU Psychology Dept. (624-6025). Ask to speak with Dawn. She will get you in touch with someone who can answer your questions or have your call returned.

Thank you for your interest in our program.

CONSENT FOR UTILIZATION OF SERVICES

PROVIDED BY PROJECT B.I.L.D.

PROJECT B.I.L.D.
c/o Dr. Phil Murphy
Department of Psychology
North Murray Hall
Oklahoma State University
Stillwater, OK 74074

Date: ____________________

Name: ____________________

I hereby voluntarily consent to utilizing the services provided by PROJECT B.I.L.D. Possible services include: Psychoeducational assessment, biofeedback treatment, and consultations with parents/students. The nature of these services will be explained to me and through mutual consent they will not constitute a violation of my personal rights or welfare. However, I am aware that psychology is not an exact science and I acknowledge that no guarantees will be made to me as to the results of these services.

I understand that strict confidentiality will be observed of all information obtained as a result of my participation under the guidelines established by the Public Health Service and the American Psychological Association. Complete confidentiality will be preserved and information will be released only to qualified professionals and only with my explicit written permission.

This form has been fully read by me and I certify that I understand it's contents. (Please sign below.)

____
Parent or Guardian

APPENDIX B

VERBAL, SPATIAL, AND NUMERIC COGNITIVE TASKS

VERBAL ITEMS

The correct answers are underlined here for demonstration purposes. Otherwise, the items appear as they were presented to the subjects.

Sample items:

The ________ ran ________ town.

A) cat, at B) car,for <u>C</u>) boy, to

D) cat, out E) boy, on

Go ________ the store ________ me.

A) for, with <u>B</u>) to, for C) at, for

D) at, with E) in, at

Test items:

Hard ________ makes ________ tired.

A) times, all B) work, it C) times, few

<u>D</u>) work, us E) work, he

Boys and ________ are soon ________.

A) women, adults B) girls, men C) women, old

<u>D</u>) girls, adults E) girls, young

The ________ will ________ tonight.

A) sky, show B) sun, shine <u>C</u>) moon, shine

D) moon, show E) stars, show

Every ________ can ________ happy.

A) boy, have B) boys, be C) boy, has

D) boys, have <u>E</u>) boy, be

Verbal test items continued:

You and ________ are ________ home.

A) them, gone B) they, going C) they, get

D) them, going E) they, gone

Look ________ at ________ toy.

A) there, mine B) here, my C) over, mine

D) here, mine E) away, my

SPATIAL ITEMS

Since these items were adopted from the Minnesota Paper Form Board Test (MPFB), they cannot be presented here. The reader is referred to the test itself (Likert and Quasha, 1934) for illustrations of the following items.

Sample items: 3 and 8 (form AA).

Test items: 11, 14, 22, 29, 34, and 38 (form AA).

NUMERIC ITEMS

Sample item:

11 14 17 __ 23 __

A) 20, 25 B) 21, 26 C) 21, 27

D) 20, 26 E) 19, 25

14 12 10 __ 6 __

A) 8, 4 B) 9, 4 C) 9, 5

D) 8, 3 E) 9, 3

Test items:

3 7 11 __ 19 __

A) 13, 23 B) 13, 21 C) 15, 23

D) 14, 25 E) 15, 25

Numeric test items continued:

25 20 15 ___ 5 ___

A) 12, 2 B) 10, 1 C) 9, 0

D) 9, 1 E) 10, 0

4 7 10 ___ 16 ___

A) 12, 20 B) 13, 18 C) 14, 18

D) 13, 19 E) 14, 19

20 17 14 ___ 8 ___

A) 10, 5 B) 10, 4 C) 11, 5

D) 10, 6 E) 11, 4

2 8 14 ___ 26 ___

A) 22, 30 B) 20; 32 C) 21, 31

D) 20, 34 E) 22, 32

23 19 15 ___ 7 ___

A) 11, 4 B) 13, 3 C) 13, 5

D) 11, 3 E) 12, 4

APPENDIX C

EEG RECORDING SESSION: INSTRUCTIONS, FORMAT, AND DATA COLLECTION FORM

INSTRUCTIONS

TODAY WE ARE GOING TO USE THESE MACHINES TO LOOK AT WHAT YOUR BRAIN DOES WHILE YOU DO SOME DIFFERENT KINDS OF THINGS. THIS DOESN'T HAVE ANYTHING TO DO WITH HOW SMART YOU ARE, WE CAN'T TELL THAT. WE DO KNOW THAT PEOPLE'S BRAINS DO DIFFERENT THINGS, NOT NECESSARILY BETTER THINGS, JUST DIFFERENT THINGS. WE ARE TRYING TO FIND OUT WHAT THOSE DIFFERENCES MEAN. THAT'S WHERE YOU CAN HELP US.

THIS MACHINE IS CALLED AN ELECTROENCEPHALOGRAPH OR EEG FOR SHORT. IT RECORDS ELECTRICAL ACTIVITY FROM A PERSON'S BRAIN WHEN WE PUT THESE THINGS, CALLED ELECTRODES (show electrodes, place on experimenter's head), ON HIS HEAD. THESE DON'T HURT AT ALL. THEY WILL NOT SHOCK YOU. THIS IS ALL YOU WILL FEEL (place on child's head). WE WILL USE SIX OF THESE IN ALL. THEY DON'T DO ANYTHING TO YOU, THEY JUST RECORD WHAT HAPPENS INSIDE YOUR HEAD.

AFTER WE PUT THE ELECTRODES ON YOUR HEAD AND HOLD THEM IN PLACE WITH THIS HEADBAND (show headband), I WILL WATCH WHAT THIS MACHINE DOES WHILE YOU DO SOME THINGS THAT I WILL SHOW YOU LATER. (Turn on the EEG analyzers) THIS IS KIND OF WHAT I WILL BE SEEING ON THE MACHINE WHILE YOU ARE "HOOKED-UP" TO THE ELECTRODES (wriggle electrodes; point out the meters). DO YOU HAVE ANY QUESTIONS? ARE YOU READY FOR ME TO PUT THE ELECTRODES ON YOU NOW? (turn off analyzers; mount electrodes) TELL ME IF THIS IS TOO TIGHT. (Turn on all power; allow warm-up; test batteries, signal).

WE ARE ALMOST READY TO START THE ACTUAL RECORDING. (turn to any guardians who have stayed) WE WILL NEED FOR YOU TO LEAVE NOW SO THAT THERE WILL BE AS FEW DISTRACTIONS AS POSSIBLE. WE SHOULD BE THROUGH IN ABOUT ONE AND ONE-HALF HOURS.

SAMPLE TASK INSTRUCTIONS

I WOULD LIKE FOR YOU TO TRY THREE TYPES OF PROBLEMS AND PUZZLES FOR ME WHILE YOU ARE HOOKED UP TO THE EEG MACHINES. I WILL SHOW YOU EACH ONE ON THIS SCREEN (point out projector screen).

(Advance slide) THIS IS A FILL-IN-THE-BLANK KIND OF QUESTION. WHEN YOU SEE A SENTENCE LIKE THIS, I WANT YOU TO DECIDE WHICH PAIR OF WORDS AT THE BOTTOM WOULD MAKE THE SENTENCE SOUND BEST AND MAKE THE MOST SENSE. BE SURE AND LOOK AT ALL OF THE CHOICES BEFORE YOU MAKE YOUR DECISION. SOME OF THE CHOICES MAY SOUND OK BUT THEY MAY NOT BE THE BEST. (Read the sentence, alternately filling in word pairs) WHICH SENTENCE SOUNDS THE BEST? (If other than C, say, "how about C, the boy ran to town, does that sound better?" once the child understands, continue). WHEN YOU HAVE DECIDED WHICH ANSWER IS BEST, REMEMBER THE LETTER OF THAT ANSWER. WHEN THE SCREEN GOES BLANK, LIKE THIS (advance slide), THEN TELL ME THE LETTER OF THE ANSWER YOU THINK IS BEST. BE SURE NOT TO TALK WHILE THE PROBLEM IS STILL ON THE SCREEN. USE ALL OF THAT TIME TO WORK ON THE ANSWER. DO YOU UNDERSTAND? I'M GOING TO SHOW YOU ANOTHER

ONE JUST THE WAY THEY WILL BE SHOWN WHEN WE ACTUALLY RECORD YOUR EEG. ARE YOU READY? (advance slide; show for 30 seconds; advance again). WHICH WORDS MADE THE SENTENCE SOUND BEST? TELL ME THE LETTER OF THE ANSWER. (Go back to the slide; agree or correct answer; advance slide).

HERE IS ANOTHER KIND OF PROBLEM (advance slide). THIS IS A LIST OF NUMBERS WHICH HAS TWO NUMBERS MISSING. EACH NUMBER IN THE LIST DEPENDS UPON THE NUMBER THAT COMES BEFORE IT. IN THIS ONE THE NUMBERS INCREASE BY THREE EACH TIME. 11, 14, 17, WHAT WOULD COME NEXT? THE NEXT NUMBER WOULD BE 20 BECAUSE THAT IS THREE MORE THAN 17. AFTER 20 COMES 23 AND THEN COMES 26 BECAUSE 26 IS THREE MORE THAN 23 23. SO, FOR THIS PROBLEM THE ANSWER WOULD BE D) 20 AND 26. DO YOU SEE HOW THESE WORK? ON DIFFERENT LISTS OF NUMBERS, THE AMOUNT YOU HAVE TO ADD OR SUBTRACT WILL CHANGE. NOW YOU TRY ONE. I'LL GIVE YOU JUST AS LONG AS YOU WILL HAVE WHEN WE ARE ACTUALLY RECORDING. REMEMBER THE LETTER OF YOUR ANSWER AND GIVE IT TO ME WHEN THE SLIDE GOES BLANK. (Advance slide; wait 30 seconds; advance slide). WHAT WOULD BE YOUR ANSWER TO THIS ONE? (Correct if wrong). ANY QUESTIONS ABOUT THIS SECOND TYPE OF TASK?

THE LAST KIND OF PROBLEM IS DIFFERENT. (Advance slide) THESE ARE LIKE PUZZLES. YOUR JOB IS TO DECIDE WHICH OF THESE DIFFERENT SETS OF PIECES COULD BE PUT TOGETHER SO THAT THEY LOOK JUST LIKE THIS FIGURE UP HERE (point to model on slide). ONLY ONE OF THE SETS WILL MAKE ONE JUST LIKE THE MODEL. WHICH DO YOU THINK IT IS ON THIS ONE? (correct if wrong). HERE'S ONE THE WAY WE WILL DO THEM LATER (advance two slides; wait 30 seconds; advance slide). HOW WOULD YOU ANSWER THAT ONE? (correct if wrong, go back if needed). ANY QUESTIONS ABOUT THESE?

RECORDING INSTRUCTIONS

NOW THAT YOU KNOW HOW TO DO THE DIFFERENT KINDS OF PROBLEMS, I'M GOING TO SHOW YOU SEVERAL OF EACH TYPE. SELECT THE ANSWER YOU THINK IS BEST FOR EACH AND TELL ME YOUR ANSWER ONLY AFTER THE SCREEN GOES BLANK EACH TIME. REMEMBER NOT TO TALK WHILE THE PROBLEM OR PUZZLE IS STILL ON THE SCREEN. LET'S GET STARTED.

(Return to apparatus; check batteries, signal). JUST RELAX, THE FIRST FEW SLIDES WILL BE BLANK (start automatic slide control tape on projector; when the first slide advances, start the compute cycle of the ASI 5100s; wait for the next blank slide to advance). NOW CLOSE YOUR EYES AND RELAX UNTIL I TELL YOU TO OPEN THEM. (Wait for the next blank slide to advance) NOW OPEN YOUR EYES. THE NEXT SLIDE WILL SHOW YOU THE FIRST PROBLEM OR PUZZLE. REMEMBER THE LETTER OF YOUR ANSWER BUT DON'T TELL IT TO ME UNTIL THE SCREEN GOES BLANK. WE'LL DO SIX IN A ROW AND THEN TAKE A REST. (Record readings, after sixth answer, say) TAKE A SHORT BREAK HERE. YOU'RE DOING FINE. (After next blank slide advance) THE NEXT SLIDE STARTS THE SECOND SET OF SIX. (Repeat this after item 12; After the 18th item, say) CLOSE YOUR EYES NOW AND RELAX. (Take final readings) THAT'S ALL.

Time-table for EEG Recording

Time	Slide	Record	Time	Slide	Record
	turn on		555	"	in-task
0"	blank		565	blank	
30"	blank		580	item 10	
60	"	baseline	600	"	in-task
105	"	baseline	610	blank	
115	blank		625	item 11	
130	item 1		645	"	in-task
150	"	in-task	655	blank	
160	blank		670	item 12	
175	item 2		690	"	in-task
195	"	in-task	700	blank	
205	blank		745	blank	rest
220	item 3		760	item 13	
240	"	in-task	780	"	in-task
250	blank		790	blank	
265	item 4		805	item 14	
285	"	in-task	825	"	in-task
295	blank		835	blank	
310	item 5		850	item 15	
330	"	in-task	870	"	in-task
340	blank		880	blank	
355	item 6		895	item 16	
375	"	in-task	915	"	
385	blank		925	blank	
430	blank	rest	940	item 17	
445	item 7		960	"	in-task
465	"	in-task	970	blank	
475	blank		985	item 18	
490	item 8		1005	"	in-task
510	"	in-task	1015	blank	
520	blank		1050	"	baseline
535	item 9		1095	"	baseline

DATA COLLECTION FORM

Name ______________________ Date ______________

time	condition	EEG amplitude right/left	EEG frequency right/left	answer
60	baseline	____/____	____/____	
105	baseline	____/____	____/____	
150	item 1	____/____	____/____	___
195	item 2	____/____	____/____	___
240	item 3	____/____	____/____	___
285	item 4	____/____	____/____	___
330	item 5	____/____	____/____	___
375	item 6	____/____	____/____	___
465	item 7	____/____	____/____	___
510	item 8	____/____	____/____	___
555	item 9	____/____	____/____	___
600	item 10	____/____	____/____	___
645	item 11	____/____	____/____	___
690	item 12	____/____	____/____	___
780	item 13	____/____	____/____	___
825	item 14	____/____	____/____	___
870	item 15	____/____	____/____	___
915	item 16	____/____	____/____	___
960	item 17	____/____	____/____	___
1005	item 18	____/____	____/____	___
1050	baseline	____/____	____/____	
1095	baseline	____/____	____/____	

APPENDIX D

WORD LISTS AND RECORD FORM FOR DIAGNOSTIC READING PROCEDURE

WORD LISTS FOR DIAGNOSTIC

READING PROCEDURE

	Pre-Primer	Primer	1st Grade	2nd Grade
1.	and	are	after	across
2.	big	black	away	ask
3.	ball	came	blue	bird
4.	fast	did	call	city
5.	go	eat	dinner	does
6.	green	farm	faster	ever
7.	help	house	funny	five
8.	I	like	guess	girl
9.	little	now	here	happy
10.	mother	on	into	just
11.	not	paint	like	listen
12.	play	put	money	miss
13.	red	ready	nod	next
14.	ride	saw	pocket	over
15.	said	store	sat	pull
16.	stop	tree	stay	rolled
17.	the	your	then	step
18.	to	too	toy	talk
19.	we	white	was	uncle
20.	work	yes	with	wet

	3rd Grade	4th Grade	5th Grade	6th Grade
1.	almost	automobile	astronomy	apparatus
2.	awake	blindfolded	astonished	badge
3.	believe	characters	curious	burlap
4.	business	cottage	crocodiles	conceited
5.	chance	delight	doubt	decision
6.	deep	environment	equator	earthquake
7.	earth	flight	forge	foreign
8.	farther	goggles	genius	hibernation
9.	front	human	height	immense
10.	great	lame	inventor	knapsack
11.	heavy	marry	lizard	legendary
12.	important	natural	marmalade	marvelous
13.	laugh	pain	opposite	necessary
14.	minute	prisoners	position	persuade
15.	other	rough	recognized	quest
16.	promise	shallow	scrambled	substituted
17.	remember	soared	scholar	treacherous
18.	should	study	tomato	utter
19.	traffic	tourists	vowed	varnish
20.	wonderful	whisper	witness	wisdom

RECORD FORM FOR THE DIAGNOSTIC
READING PROCEDURE

Name ______________________________ Date ____________________

WRAT Reading Grade Level __________________

Set 1: ________				Set 2: ________				Set 3: ________		
2"	10"	10+		2"	10"	10+		2"	10"	10+
___	___	___	1	___	___	___	1	___	___	___
___	___	___	2	___	___	___	2	___	___	___
___	___	___	3	___	___	___	3	___	___	___
___	___	___	4	___	___	___	4	___	___	___
___	___	___	5	___	___	___	5	___	___	___
___	___	___	6	___	___	___	6	___	___	___
___	___	___	7	___	___	___	7	___	___	___
___	___	___	8	___	___	___	8	___	___	___
___	___	___	9	___	___	___	9	___	___	___
___	___	___	10	___	___	___	10	___	___	___
___	___	___	11	___	___	___	11	___	___	___
___	___	___	12	___	___	___	12	___	___	___
___	___	___	13	___	___	___	13	___	___	___
___	___	___	14	___	___	___	14	___	___	___
___	___	___	15	___	___	___	15	___	___	___
___	___	___	16	___	___	___	16	___	___	___
___	___	___	17	___	___	___	17	___	___	___
___	___	___	18	___	___	___	18	___	___	___
___	___	___	19	___	___	___	19	___	___	___
___	___	___	20	___	___	___	20	___	___	___
____	____	totals		____	____	totals		____	____	

Total read within 2" / Tot. read correct = reading score

_______ / _______ = _______

APPENDIX E

SUMMARY STATISTICS AND ANALYSIS OF VARIANCE TABLES

TABLE 1

MEANS AND STANDARD DEVIATIONS FOR SUBJECT VARIABLES

Variable	Total Sample (n = 18)	High Rel. Achievers (n = 9)	Low Rel. Achievers (n = 9)	Indep. t* Stat.
Age	11.36 (1.81)	11.06 (1.51)	11.66 (2.07)	.33
Verbal IQ	103.00 (18.64)	95.89 (20.98)	110.11 (13.57)	.80
Perform. IQ	111.78 (16.30)	102.22 (16.93)	121.33 (8.51)	1.43
Full Sc. IQ	107.94 (18.14)	98.89 (20.27)	117.00 (10.19)	1.13
Reading SS	97.67 (17.09)	99.33 (16.94)	96.00 (18.09)	.19
Spelling SS	89.06 (18.40)	94.56 (19.22)	83.56 (16.79)	.61
Arith. SS	91.00 (17.67)	92.56 (22.36)	89.44 (12.59)	.17
Read. Strat.†	73.53 (13.23)	70.44 (14.66)	77.00 (11.33)	.50
Handedness†	4.35 (2.67)	4.56 (2.55)	4.13 (2.95)	.16
Average SS	92.56 (16.78)	95.33 (19.21)	89.78 (14.56)	.33

* Student's t statistic for comparing independent means (high versus low relative achievers); d.f. = 16. No differences were significant at the .05 level.

† For these variables, n = 17 for the total sample and n = 8 for the low relative achievers; d.f. = 15 for relevant t statistics.

Note: Standard deviations are given in parentheses.

TABLE 2

ANALYSES OF VARIANCE FOR EEG
AMPLITUDE MEASURES*

Dependent Var. Independ. Var.	Degrees of Freedom	Mean Square	F Ratio	Prob. of > F
Recorded Amplitude:				
Task	2	52066.69	0.05	0.95
Hemisphere	1	11019763.63	11.36	0.002
Task by Hemi.	2	120734.68	0.12	0.88
Error	48	970167.57		
Adjusted Amplitude:				
Task	2	52066.69	0.07	0.93
Hemisphere	1	798863.41	1.05	0.31
Task by Hemi.	2	120734.68	0.16	0.84
Error	48	762444.31		

* Only the nine highest relative achievers were included in these analyses; relevant means and standard deviations are given in tables 4 and 5 of this appendix.

TABLE 3

ANALYSES OF VARIANCE FOR EEG FREQUENCY MEASURES*

Dependent Var. Independ. Var.	Degrees of Freedom	Mean Square	F Ratio	Prob. of > F
Recorded Frequency:				
Task	2	4261.56	0.17	0.84
Hemisphere	1	111975.57	4.57	0.04
Task by Hemi.	2	2905.41	0.12	0.89
Error	48	24518.44		
Adjusted Frequency:				
Task	2	4261.56	0.31	0.73
Hemisphere	1	23395.85	1.73	0.20
Task by Hemi.	2	2905.41	0.21	0.81
Error	48	13543.53		

* Only the nine highest relative achievers were included in these analyses; relevant means and standard deviations are given in tables 6 and 7 of this appendix.

TABLE 4

MEANS AND STANDARD DEVIATIONS FOR
EEG AVERAGE AMPLITUDE MEASURE

	EEG Recording Condition			
	Baseline	Verbal	Spatial	Numeric
Total Sample (n = 18):				
Right Hemi.	49.81 (14.80)	33.48 (10.76)	34.38 (9.72)	34.56 (10.18)
Left Hemi.	57.70 (16.00)	43.85 (10.40)	44.63 (11.10)	43.70 (8.99)
High Rel. Ach. (n = 9):				
Right Hemi.	53.98 (9.23)	36.55 (10.30)	38.04 (9.17)	39.23 (9.83)
Left Hemi.	60.58 (9.73)	47.17 (10.41)	47.18 (9.58)	46.58 (9.76)
Low Rel. Ach. (n = 9):				
Right Hemi.	45.64 (18.46)	30.41 (10.90)	30.73 (9.32)	29.88 (8.63)
Left Hemi.	54.82 (20.75)	40.52 (9.83)	42.09 (12.48)	40.82 (7.60)

Note: Standard deviations are given in parentheses.

TABLE 5

MEANS AND STANDARD DEVIATIONS
FOR EEG AVERAGE AMPLITUDE
INCREASE FROM BASELINE

	EEG Recording Condition		
	Verbal	Spatial	Numeric
Total Sample (n = 18):			
Right Hemi.	-16.33 (15.26)	-15.43 (15.26)	-15.26 (14.95)
Left Hemi.	-13.85 (15.18)	-13.07 (15.31)	-14.00 (14.89)
High Rel. Ach. (n = 9):			
Right Hemi.	-17.43 (10.66)	-15.94 (9.11)	-14.75 (9.11)
Left Hemi.	-13.41 (8.34)	-13.41 (7.35)	-14.00 (7.36)
Low Rel. Ach. (n = 9):			
Right Hemi.	-15.23 (19.45)	-14.91 (20.28)	-15.76 (19.79)
Left Hemi.	-14.30 (20.49)	-12.73 (21.06)	-14.00 (20.42)

Note: Standard deviations are given in parentheses.

TABLE 6

MEANS AND STANDARD DEVIATIONS
FOR EEG AVERAGE DOMINANT
FREQUENCY MEASURE

	EEG Recording Condition			
	Baseline	Verbal	Spatial	Numeric
Total Sample (n = 18):				
Right Hemi.	10.40 (0.91)	11.24 (1.09)	11.50 (0.97)	11.26 (1.08)
Left Hemi.	10.72 (0.97)	12.05 (1.78)	12.13 (1.62)	12.08 (1.58)
High Rel. Ach. (n = 9):				
Right Hemi.	10.10 (0.59)	10.93 (1.03)	11.34 (1.02)	11.02 (1.07)
Left Hemi.	10.59 (1.04)	12.13 (2.21)	12.09 (1.89)	11.80 (1.73)
Low Rel. Ach. (n = 9):				
Right Hemi.	10.71 (1.09)	11.55 (1.12)	11.66 (0.95)	11.50 (1.08)
Left Hemi.	10.85 (0.93)	11.97 (1.36)	12.18 (1.40)	12.36 (1.46)

Note: Standard deviations are given in parentheses.

TABLE 7

MEANS AND STANDARD DEVIATIONS FOR EEG AVERAGE DOMINANT FREQUENCY INCREASE FROM BASELINE

	EEG Recording Condition		
	Verbal	Spatial	Numeric
Total Sample (n = 18):			
Right Hemi.	0.84 (1.01)	1.10 (0.76)	0.86 (0.82)
Left Hemi.	1.33 (1.26)	1.41 (1.23)	1.36 (1.14)
High Rel. Ach. (n = 9):			
Right Hemi.	0.83 (0.65)	1.24 (0.81)	0.92 (0.82)
Left Hemi.	1.54 (1.66)	1.49 (1.43)	1.21 (1.26)
Low Rel. Ach. (n = 9):			
Right Hemi.	0.84 (1.32)	0.95 (0.74)	0.79 (0.86)
Left Hemi.	1.12 (0.73)	1.33 (1.08)	1.51 (1.07)

Note: Standard deviations are given in parentheses.

APPENDIX F

PEARSON PRODUCT-MOMENT AND MULTIPLE

CORRELATION COEFFICIENTS AND

CHI-SQUARE ANALYSES

TABLE 8

PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS BETWEEN SUBJECT VARIABLES AND EEG DOMINANT FREQUENCY MEASURES

Frequency Measure	Subject Variable				
	Rel. Ach.	Read. Strat.†	Verbal IQ	Perf. IQ	F. S. IQ
RBF	-.31	.04	-.20	.12	-.06
LBF	-.11	.00	-.28	.00	-.17
RVF	-.15	-.33	-.36	.19	-.32
LVF	.12	-.33	-.57*	-.29	-.48*
RSF	-.04	-.34	-.61**	-.34	-.52*
LSF	.11	-.34	-.54*	-.23	-.42
RNF	-.15	-.34	-.55*	-.23	-.44
LNF	-.10	-.35	-.51*	-.09	-.34
rvf	.11	-.39	-.21	-.31	-.28
lvf	.25	-.46	-.59**	-.40	-.54*
rsf	.31	-.48*	-.53*	-.57*	-.58*
lsf	.23	-.44	-.49*	-.30	-.42
rnf	.14	-.49*	-.50*	-.44	-.51*
lnf	-.05	-.48	-.47	-.12	-.33
vf	-.14	.15	.38	.14	.29
sf	-.04	.18	.20	-.08	.08
nf	.17	.14	.13	-.22	-.04

TABLE 8 (Continued)

Frequency Measure	Subject Variable				
	Age	WRAT Read.	WRAT Spell.	WRAT Arith.	WRAT Avg.
RBF	.46	-.35	-.37	-.29	-.34
LBF	.26	-.32	-.29	-.21	-.28
RVF	.46	-.38	-.49*	-.46	-.47*
LVF	.16	-.36	-.41	-.42	-.41
RSF	.40	-.51*	-.58*	-.61**	-.60**
LSF	.17	-.28	-.39	-.39	-.36
RNF	.44	-.55*	-.60**	-.59*	-.61**
LNF	.23	-.39	-.49*	-.46	-.46
rvf	.09	-.10	-.20	-.24	-.21
lvf	.03	-.26	-.36	-.43	-.37
rsf	-.03	-.24	-.30	-.44	-.35
lsf	.03	-.11	-.28	-.34	-.26
rnf	.07	-.33	-.38	-.46	-.43
lnf	.14	-.26	-.43	-.45	-.40
vf	.04	.17	.18	.21	.18
sf	-.06	-.05	.12	.09	.05
nf	-.10	.03	.18	.14	.11

* $p < .05$; ** $p < .01$.

† n = 17 for this variable; otherwise n = 18.

TABLE 9

PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS BETWEEN SUBJECT VARIABLES AND EEG AVERAGE AMPLITUDE MEASURES

Amplitude Measure	Subject Variable				
	Rel. Ach.	Read. Strat.†	Verbal IQ	Perf. IQ	F. S. IQ
RBA	.15	-.04	-.16	-.08	-.13
LBA	.04	-.08	-.17	-.08	-.14
RVA	.15	-.09	-.02	-.09	-.05
LVA	.14	-.27	-.41	-.43	-.45
RSA	.29	-.10	-.08	-.18	-.14
LSA	.05	-.33	-.37	-.38	-.42
RNA	.40	.00	-.17	-.32	-.24
LNA	.16	-.31	-.47*	-.45	-.49*
rva	-.03	-.02	.14	.01	.09
lva	.06	-.11	-.10	-.21	-.16
rsa	.05	-.02	.10	-.04	.04
lsa	.00	-.18	-.09	-.19	-.15
rna	.13	.04	.04	-.14	-.04
lna	.06	-.11	-.10	-.18	-.14
va	-.23	.20	.63**	.56*	.63**
sa	.13	.39	.55*	.43	.54*
na	.21	.44	.45	.13	.33

TABLE 9 (Continued)

Amplitude Measure	Subject Variable				
	Age	WRAT Read.	WRAT Spell.	WRAT Arith.	WRAT Avg.
RBA	-.32	-.01	-.02	.00	-.01
LBA	-.32	-.13	-.15	-.07	-.12
RVA	-.39	.05	.22	-.02	.08
LVA	-.33	-.41	-.22	-.40	-.37
RSA	-.33	.06	.27	.01	.11
LSA	-.33	-.46	-.26	-.42	-.41
RNA	-.42	.04	.26	-.03	.09
LNA	-.34	-.43	-.25	-.42	-.39
rva	.03	.04	.17	-.02	.07
lva	.11	-.15	.01	-.20	-.12
rsa	.10	.05	.19	.00	.08
lsa	.09	-.20	-.03	-.23	-.16
rna	.02	.04	.20	-.02	.07
lna	.13	-.12	.01	-.18	-.10
ra	-.21	.49*	.43	.48*	.48*
sa	.01	.71***	.64**	.66**	.70**
na	-.33	.50*	.58*	.47*	.54*

* $p < .05$; ** $p < .01$; *** $p < .001$.

+n = 17 for this variable; otherwise n = 18.

TABLE 10

PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS
AMONG SUBJECT VARIABLES

	Age	Rel. Ach.	Read. Strat.†	Verb. IQ	Perf. IQ	F. S. IQ	WRAT Read.	WRAT Spell.	WRAT Arith.	WRAT Avg.
Age	-	-.20	-.36	-.17	.00	-.11	-.30	-.37	-.19	-.30
Relative Ach.	-.20	-	-.02	-.34	-.64**	-.50*	.35	.48*	.17	.35
Reading Strat.	-.36	-.02	-	.56*	.42	.54*	.53*	.52*	.49*	.54*
Verbal IQ	-.17	-.34	.56*	-	.80***	.96***	.71***	.62**	.79***	.74***
Performance IQ	.00	-.64**	.42	.80***	-	.93***	.40	.27	.58*	.44
Full Scale IQ	-.11	-.50*	.54*	.96***	.93***	-	.61**	.49*	.73***	.64
WRAT Reading	-.30	.35	.53*	.71***	.40	.61**	-	.89***	.87***	.96***
WRAT Spelling	-.37	.48*	.52*	.62**	.27	.49*	.89***	-	.84***	.95***
WRAT Arithmetic	-.19	.17	.49*	.79***	.58*	.73***	.87***	.84***	-	.95***
WRAT Average	-.30	.35	.54*	.74***	.44	.64**	.96***	.95***	.95***	-

† n = 17 for this variable; otherwise n = 18.

* $p < .05$; ** $p < .01$; *** $p < .001$.

TABLE 11

PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS BETWEEN EEG DOMINANT FREQUENCY MEASURES AND AVERAGE AMPLITUDE MEASURES RELATIVE TO BASELINE†

	rvf	lvf	rsf	lsf	rnf	lnf
rvf	-	.26	.77***	.39	.86***	.28
lvf	.26	-	.62**	.88***	.51*	.84***
rsf	.77***	.62**	-	.65**	.80***	.55*
lsf	.39	.88***	.65**	-	.59**	.91***
rnf	.86***	.51*	.80***	.59**	-	.51*
lnf	.28	.84***	.55*	.91***	.51*	-
rva	.37	-.25	.23	-.12	.16	-.09
lva	.35	-.04	.37	-.02	.19	-.02
rsa	.33	-.21	.24	-.10	.14	-.09
lsa	.40	-.04	.35	.01	.25	.00
rna	.33	-.26	.25	-.16	.13	-.18
lna	.37	-.06	.39	.01	.19	.02
vf	.49*	-.72***	.00	-.50*	.16	-.55*
sf	.11	-.65**	-.04	-.78***	-.13	-.74***
nf	.38	-.54*	.02	-.55*	.23	-.72***
va	.05	-.55*	-.37	-.25	-.09	-.20
sa	-.20	-.50*	-.32	-.30	-.32	-.27
na	-.12	-.61**	-.43	-.53*	-.20	-.60**

TABLE 11 (Continued)

	rva	lva	rsa	lsa	rna	lna
rvf	.37	.35	.33	.40	.33	.37
lvf	-.25	-.04	-.21	-.04	-.26	-.06
rsf	.23	.37	.24	.35	.25	.39
lsf	-.12	-.02	-.10	.01	-.16	.01
rnf	.16	.19	.14	.25	.13	.19
lnf	-.09	-.02	-.09	.00	-.18	-.02
rva	-	.92***	.98***	.92***	.97***	.94***
lva	.92***	-	.94***	.97***	.93***	.99***
rsa	.98***	.94***	-	.94***	.98***	.95***
lsa	.92***	.97***	.94***	-	.92***	.95***
rna	.97***	.93***	.98***	.92***	-	.95***
lna	.94***	.99***	.95***	.95***	.95***	-
vf	.49 *	.29	.43	.32	.47	.32
sf	.34	.33	.33	.28	.42	.31
nf	.23	.17	.02	.20	.30	.14
va	.21	-.18	.13	-.10	.10	-.12
sa	.16	-.09	.17	-.19	.18	-.01
na	.11	-.15	.11	-.09	.18	-.15

TABLE 11 (Continued)

	vf	sf	nf	va	sa	na
rvf	.49*	.11	.38	.05	-.20	-.12
lvf	-.72***	-.65**	-.54*	-.55*	-.50*	-.61**
rsf	.00	-.04	.02	-.37	-.32	-.43
lsf	-.50*	-.78***	-.55*	-.25	-.30	-.53*
rnf	.16	-.13	.23	-.09	-.32	-.20
lnf	-.55*	-.74***	-.72***	-.20	-.27	-.60**
rva	.49*	.34	.23	.21	.16	.11
lva	.29	.33	.17	-.18	-.09	-.15
rsa	.43	.33	.02	.13	.17	.11
lsa	.32	.28	.20	-.10	-.19	-.09
rna	.47*	.42	.30	.10	.18	.18
lna	.32	.31	.14	-.12	-.01	-.15
vf	-	.66**	.76***	.53*	.30	.47*
sf	.66**	-	.73***	.02	.14	.34
nf	.76***	.73***	-	.16	.05	.52*
va	.53*	.02	.16	-	.65**	.66**
sa	.30	.14	.05	.65**	-	.58*
na	.47*	.34	.52*	.66**	.58*	-

* $p < .05$; ** $p < .01$; *** $p < .001$.

TABLE 12

FREQUENCY DATA FOR CHI-SQUARE ANALYSES OF CORRELATIONS BETWEEN EEG HEMISPHERE DIFFERENCES AND WRAT AND IQ SCORES

Correlations	Significant (p .05)	Not Significant (p .05)
	Observed (Expected)	Observed (Expected)
WRAT Scores with:*		
va, sa, na	11 (5.5)	1 (6.5)
vf, sf, nf	0 (5.5)	12 (6.5)
IQ Scores with:**		
va, sa, na	5 (2.5)	4 (6.5)
vf, sf, nf	0 (2.5)	9 (6.5)

* For this analysis, χ^2 = 20.3, d.f. = 1, $p < .001$.

** For this analysis, χ^2 = 6.92, d.f. = 1, $p < .01$.

TABLE 13

MULTIPLE CORRELATION COEFFICIENTS FOR EEG MEASURES RELATIVE TO BASELINE USING READING STRATEGY AND RELATIVE ACHIEVEMENT AS PREDICTOR VARIABLES

EEG Measure	R^2	EEG Measure	R^2
rvf	.19	rva	.01
lvf	.27	lva	.05
rsf	.37*	rsa	.03
lsf	.26	lsa	.05
rnf	.26	rna	.06
lnf	.23	lna	.06
vf	.03	va	.08
sf	.04	sa	.16
nf	.04	na	.22

* $p < .05$

Note: n = 17 for all R^2.

VITA 2

Donal Eugene Brantley

Candidate for the Degree of

Master of Science

Thesis: TASK-DEPENDENT HEMISPHERE LATERALIZATION IN EEG AS A FUNCTION OF RELATIVE ACHIEVEMENT AND READING STRATEGY

Major Field: Psychology

Biographical:

Personal Data: Born in Gatesville, Texas, June 5, 1958, the son of Mr. and Mrs. D. E. Brantley.

Education: Graduated from Temple High School, Temple, Texas, in May, 1976; attended Temple Junior College, 1975-76; received Bachelor of Science degree in Psychology from the University of Texas at Arlington in 1978; enrolled in graduate program at the University of Texas at Arlington, 1978-79; completed requirements for the Master of Science degree at Oklahoma State University in December, 1982.

Professional Experience: Residential Training Specialist, Trinity Valley Mental Health and Mental Retardation, 1978-79; graduate teaching assistant, the University of Texas at Arlington, 1978-79; graduate teaching assistant, Oklahoma State University, 1979-82; Trainee Psychologist, Veterans Administration Hospital, Oklahoma City, Oklahoma, 1980; Psychological Associate, Psychological Services Center, Oklahoma State University, 1980-82; Psychotherapist, Edgemeade of Texas, 1982.