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Verbal and nonverbal processing among left- and right-handed good readers and reading-disabled children

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The University of Arizona, 1987
VERBAL AND NONVERBAL PROCESSING
AMONG LEFT- AND RIGHT-HANDED
GOOD READERS AND READING-DISABLED CHILDREN

by
Pamela Fankhauser Conrad

A Dissertation Submitted to the Faculty of the
DIVISION OF EDUCATIONAL FOUNDATIONS AND ADMINISTRATION
In Partial Fulfillment of the Requirements
For the Degree of
DOCTOR OF PHILOSOPHY
WITH A MAJOR IN EDUCATIONAL PSYCHOLOGY
In the Graduate College
THE UNIVERSITY OF ARIZONA

1987
As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Pamela Fankhauser Conrad entitled Verbal and Nonverbal Processing Among Left- and Right-Handed Good Readers and Reading Disabled Children and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

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Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

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SIGNED: Paula Counsel
I am very grateful for the encouragement and support of my research advisor, Dr. John Obrzut. His interest and expertise in the field of neuropsychology and the learning-disabled child were invaluable in the conception, development, and completion of this study. I am very appreciative of the support and suggestions of my other doctoral committee members, Dr. Glen Nicholson and Dr. Shitala Mishra.

This study could not have been completed without the cooperation of the children, teachers, and administrators of the schools selected for this investigation. Appreciation is also extended to Jo Ann Hurley for her assistance in typing the manuscript in its many forms.

I am especially grateful for the love and support of my parents, sister, grandmother, and daughters, Erin and Abigail, throughout my doctoral program.

Finally, my husband Clifton has given me the encouragement, support, and freedom to explore my intellectual possibilities without judgment or impatience. He has been role model and friend throughout this long and rewarding journey.
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Differences in cerebral lateralization of verbal and nonverbal stimuli between left- and right-handed good readers and left- and right-handed reading-disabled children were examined. The study utilized the dichotic listening paradigm and examined the effects of directed attention on the processing of consonant-vowel (CV) and tonal stimuli by the four groups. The sixty subjects included fifteen right-handed good readers (eleven females and four males, mean age 10-3), fifteen left-handed good readers (eight females and seven males, mean age 10-5), fifteen right-handed reading-disabled children (six females and nine males, mean age 10-5), and fifteen left-handed reading-disabled children (four females and eleven males, mean age 10-8). All left-handed subjects had sinistral relatives.

A three-factorial analysis of variance resulted in a significant left ear advantage (LEA) for tonal stimuli across all directed attention conditions for all groups. When presented with CV stimuli, the right-handed good readers produced a significant right ear advantage (REA) across all attentional conditions. The left-handed good readers and left-handed reading-disabled children were left ear (LE) dominant in the free recall and directed left conditions but
produced a shift toward the right ear (RE) during the directed right condition. Right-handed reading-disabled children demonstrated a REA during free recall and directed right but were able to direct attention to the LE in the directed left condition.

The study provided initial findings on the auditory processing of simple tonal stimuli among anomalous groups of children and documented the strong LEA found in previous studies of adult subjects. Verbal processing results for right-handed good readers and reading-disabled children confirmed previous findings with these populations. Reversed verbal processing (right hemisphere) was documented in both left-handed groups in two of the experimental conditions.

The results provide additional support for the structural theory of lateralization and suggest reversed or bilateralized processing abilities for language in strongly left-handed good reader children. Components of the attentional bias model are necessary to explain the effects of directed attention on the auditory perceptual asymmetry found in the reading-disabled groups.
CHAPTER 1
INTRODUCTION AND REVIEW OF THE LITERATURE

This chapter will present a general introduction to the study of human laterality followed by a Statement of the Problem, Need for the Study, Purpose of the Study, Research Questions, and Definition of Terms. The chapter will provide a literature review on the theories of cerebral lateralization and the measurement techniques associated with laterality research. Although functional and structural brain asymmetry is acknowledged, the review will concentrate broadly on behavioral indices of laterality and specifically on auditory measures of cerebral asymmetry. The dichotic listening literature will be discussed in some depth, especially its utility in studying learning-disabled1 and left-handed populations and its usefulness in assessing nonverbal auditory processing.

Introduction

There is now a large body of research evidence which supports the notion that the left and right cerebral

1. The terms learning disabled and reading disabled will be used interchangeably in this dissertation.
hemispheres in humans process information differently. Evidence for such ideas has a long history and has been studied in a variety of populations, such as patients with brain damage or surgically severed corpus callosums, neurologically normal adults, and children with varieties of learning problems (Hellige, 1983). As a result of these studies, the notion of hemispheric differentiation has been generally accepted for some time, although the specific details and extent of these differences continue to be studied. The popularity of this line of research has been such that cerebral asymmetry has been linked to learning problems, schizophrenia, autism, and sex differences in intellectual abilities (Bryden, 1982). Through the use of modern electrophysiological and behavioral methods, many behavioral functions have been demonstrated to be primarily mediated by the left or right hemisphere.

With regard to left hemisphere functioning, evidence from all sources confirms that for most right-handed people speech and other language skills depend mainly on the left cerebral hemisphere. As language is involved in many aspects of human cognition, lesions in the left hemisphere give rise to many disabilities. Among the symptoms associated more often with left- than right-sided lesions in right handers are disorders of speech production and comprehension, reading, writing, and calculation
(Hécaen and Sauguet, 1971). Electrical mapping studies have shown that different aspects of language function, such as naming, short-term verbal memory, reading, and phoneme discrimination may depend on discrete locations in the left hemisphere (Annett, 1985).

Studies reporting language dysfunction involving the right hemisphere in left-handed subjects have drawn many researchers to conclude that there is a higher incidence of right hemisphere speech in this population, although this conclusion is not generalizable to all left-handed individuals (Herron, 1980). Lesions of the right hemisphere are not associated with the dramatic losses often reported in left hemisphere lesions, but most evidence indicates that it has an important role in the processing of nonverbal tasks, including music (Gates and Bradshaw, 1977b), spatial abilities (Benton, 1979), face recognition (Warrington, 1982), and emotional recognition (Ley and Bryden, 1981). It should be noted that the advantages of the right hemisphere for such tasks have been more difficult to identify and substantiate than the advantages of the left hemisphere for verbal tasks. That is, analysis is impeded by the fact that most right hemispheres cannot talk and also by the rudimentary state of psychological theories of nonverbal cognition (Annett, 1985). However, the characterization of the right
hemisphere as primarily serving visuo-spatial functions is now firmly based on a wealth of neuropsychological evidence (DeRenzi, 1982).

In general, the research described above all assume separate functioning for each hemisphere. However, arguments have evolved which question the necessity of differentiating cerebral functioning. Milner (1971) posited that while the two hemispheres are functionally different, they may both be capable of the same functions. For example, Sperry (1974) observed in split-brain patients that the right hemisphere was capable of assuming language functioning. Annett (1985) proposes that

the differentiation of cerebral function could depend solely on the single nudge that induces the left hemisphere to serve speech. Both hemispheres are probably capable of serving visuo-spatial processes, but the right is led to take the major role as the left becomes specialized for language (p. 121).

This disparity between theories of specialization remains today, and research continues into the role of the two hemispheres in cognitive functioning.

Statement of the Problem

Many investigators have sought to establish an association between learning disabilities and cerebral dominance. Major theories of lateralization have provided the groundwork for various hypotheses about the
relationship between cognitive deficits in learning-disabled children and cerebral organization. However, systematic study of this relationship has only taken place since the 1960s. Early interest in footedness, eyedness, and handedness has been replaced with vigorous research into perceptual asymmetries. The study of listening asymmetries, in particular, has become a viable method for assessing the manner in which speech perception is lateralized in normal and learning-disabled populations.

Although laterality research with children has been derived from a variety of visual, manual, and auditory techniques, dichotic listening procedures have provided researchers with some of the most useful results. Comparative studies with right-handed normal and learning-disabled children have indicated that both groups appear to have left hemispheric specialization for language but that learning-disabled children are not as strongly lateralized (Obrzut, Hynd, and Boliek, 1986c). Although differences in performance are consistently reported, the research fails to clarify whether these discrepancies are the result of neurological deficits, developmental delays in lateralization, incomplete cerebral dominance, or attentional shifting. Bryden (1982) contends that it is likely that a more general, nonspecific deficit is characteristic of learning disabilities.
One of the major concerns of this study is to attempt to control for factors which might affect results obtained from dichotic listening procedures. The study will use a precuing paradigm to address the possible effects of attentional biasing in subjects and will attempt to control for heterogeneity in grouping and lack of sophistication in measurement. Through the use of a verbal cuing procedure, it will be possible to determine whether directed attention strategies affect either the direction or degree of laterality for any of the groups. If responses to stimuli are affected by the directed attention conditions, then support will be provided for the attentional bias hypotheses. If shifting in attention does not occur, then structural models of cerebral lateralization may be addressed.

In the past decade, a number of investigators have also reported robust and reproducible right-left asymmetries in the perception of dichotically presented tonal stimuli among normal adults (e.g., Efron, Koss, and Yund, 1983b). Gregory (1981) reports that ear dominance for pitch in a sample of 222 subjects showed that 75 percent were left ear dominant. While most studies accept the hypothesis that the right hemisphere is involved in the perception and processing of complex pitch information, the studies have utilized significantly different methods and
stimulus parameters. Additionally, research utilizing child populations and learning-disabled children have been virtually nonexistent.

Another major purpose of this study will be to investigate cerebral organization for simple tonal information between normal and reading-disabled children. The dichotic presentation of tone sequences, which have been studied and revised by Efron et al. (1983b), will provide a context for evaluating right hemisphere auditory functioning in these groups. It will additionally provide new information on the structural and attentional bias models of cerebral lateralization.

The manner in which mental functions are represented in the cerebral cortex may vary among people in two distinct ways (Kinsbourne, 1975a). First, people may differ in the degree or strength of specialization of function. Second, mental functions may be represented in the usual cortical locations or they may be elsewhere, for example, right hemisphere lateralization of language. Right handers with speech represented in the right hemisphere may be a good source of data concerning the effects of anomalous functioning, but they are rare in the general population. However, left handers are a group with diverse cerebral representation of language. While clinical evidence indicates that most left handers are left
lateralized for language, many studies show that one-quarter to one-third of left handers have right hemispheric speech (e.g., Rasmussen and Milner, 1975; Annett, 1975). Additionally, it has been reported that left handers are overrepresented in learning-disabled children (e.g., Zangwill, 1960; Morley, 1965).

Left handers as a distinct group have not been studied systematically in the recent dichotic listening literature because of their presumed confounding effects (Obrzut, personal communication). Additionally, researchers have argued that there should be distinctions made between "natural" and "pathological" left handedness. Pathological left handers are viewed as having received early left hemispheric brain insult and whose handedness was physiologically induced. However, despite the lack of dichotic research on this anomalous group, data gathered on left handers are relevant to the question of cerebral lateralization and brain function. Indeed, Bryden (1978) argues that an examination of differences between left and right handers is crucial if researchers are to verify that auditory asymmetries are in fact related to cerebral organization.

Therefore, another major concern of this study will be to investigate the significance of unusual representation of verbal and nonverbal processing in left-handed
normal and left-handed reading-disabled populations, with particular attention to the incidence of reversed hemispheric functioning. The study will attempt to control for familial sinistrality which is associated with a genetic predisposition for left handedness. Comparisons between left-handed groups and their responses to verbal and nonverbal stimuli will provide new and important data on the effects of handedness on information processing and cerebral lateralization.

Need for the Study

The cause of reading disabilities continues to elude researchers in neuropsychology, experimental, and educational psychology despite almost three-quarters of a century of research. The measurement of hemispheric asymmetries in children with these disorders stems from hypotheses long held by these researchers that cognitive tasks, such as reading problems in children and adults, may be the result of faulty cerebral dominance. While children with reading problems consistently perform differently from their normal counterparts on neuropsychological tasks, the research to date remains inconclusive as to the reasons for these differences.

Although there continue to be design and measurement problems with the techniques used to assess laterality, dichotic listening is widely accepted as a useful
approach in describing the important neuropsychological deficits that reading-disabled children experience. This study represents an attempt to investigate further the neuropsychological mechanisms that affect information processing in reading-disabled and good readers through the presentation of verbal and nonverbal stimuli in a dichotic listening experiment.

Many dichotic studies have replicated the initial findings of Kimura (1961a) which found a right ear advantage for verbal material in normal subjects. Other investigators have compared responses to verbal material by normal and learning-disabled children (e.g., Leong, 1976; Obrzut, Obrzut, Bryden, and Bartels, 1985) and have reported that disabled readers performed less accurately than normal readers in terms of their right ear superiority. While dichotic studies have been prolific in terms of reporting results from verbal stimuli, the literature is much less conclusive in reporting results from dichotically presented nonverbal stimuli. There is some evidence for a left-ear effect obtained for pitch, music, and environmental sounds among right-handed adults (e.g., Gregory, 1982; Spreen, Spellacy, and Reid, 1970). However, efforts to compare processing differences for pitch perception between groups of normal and reading-disabled children have been noticeably absent from the literature. This study
represents an attempt to understand the auditory processing differences of the left and right hemispheres for both verbal and nonverbal stimuli among good readers and reading-disabled children, with the additional factor of handedness also considered. It is crucial for researchers to address these differences in processing of nonverbal stimuli if hypotheses are to be forwarded as to the etiology of reading disabilities and the importance of lateralization in cognitive functioning.

Also noticeably absent from the dichotic listening literature on cerebral lateralization of normal and learning-disabled children is the question of the influence of handedness on ear preference. Most researchers have restricted their investigations to right-handed children because the adult literature on handedness has been inconclusive. Obrzut, Conrad, Bryden, and Boliek (1986b) report a left ear advantage (LEA) for consonant-vowel-consonant (CVC) stimuli in 15 left-handed, normal children, but there have been no reports of studies utilizing left-handed reading-disabled populations. This study examines differences between left- and right-handed good readers and reading-disabled children in an effort to further delineate cognitive processing differences which might affect a child's ability to learn.
Finally, the research evidence to date has proposed that the auditory perceptual processing of learning-disabled children is influenced by attentional biasing. By refining the dichotic listening task using a precuing paradigm, researchers have been able to study the attentional strategies of normal and learning-disabled populations (e.g., Hiscock and Kinsbourne, 1980a; Obrzet, Hynd, and Obrzet, 1983). Several studies have found that the directed attention conditions affect the degree of laterality in these populations (Obrzet, Hynd, Obrzet, and Pirozzolo, 1981; Obrzet et al., 1985). Therefore, this study further isolates and explains the effects of attentional biasing on information processing of both hemispheres. Results from this experiment will help clarify and expand current theoretical models and hypotheses of cerebral lateralization in these four groups.

Although this study is at the "theory-generating" level of investigation, it will further explain the characteristics and variables which may play a role in the manifestation of reading disabilities in children. The goal of studies such as this is to help promote a more thorough understanding of the neuropsychological mechanisms underlying information processing in the human species and to help medical and school personnel in more effective
diagnoses and intervention planning for the reading disabled.

**Purpose of the Study**

The primary purpose of this study was to investigate the differences in cerebral lateralization of verbal and nonverbal stimuli between left- and right-handed good readers and left- and right-handed reading-disabled children. The study utilized the dichotic listening paradigm and examined the effects of directed attention on the processing of consonant-vowel (CV) and tonal stimuli by the four groups with particular attention given to the most effective combination of stimulus type and directed attention condition on cerebral laterality.

**Research Questions**

The following questions guided the study.

1. Is there a difference in laterality effect in free recall and directed attention conditions between left- and right-handed good readers and left- and right-handed reading-disabled children?

2. Is there a difference in overall accuracy of lateralized performance when presented either CV or tonal stimuli between left- and right-handed good readers and left- and right-handed reading-disabled children?
3. Does directed attention affect the processing of CV or tonal stimuli differently in the four groups?

4. What combination of stimulus type and directed attention conditions demonstrates the most pronounced effect on cerebral laterality?

**Definition of Terms**

**Asymmetry.** This term refers to properties which are not symmetrical. Structural asymmetries in the human body include structures which are not anatomically symmetrical, such as the brain, heart, and liver. Functional asymmetries refer to the functions or roles of a particular physiological structure. For example, in the auditory modality there are ear preferences for receiving certain types of information.

**Lateralization.** This term is defined as the dominance or superior development of one side of the body. In the human cerebral cortex, the right and left cerebral hemispheres process information somewhat differently from each other.

**Cerebral Dominance.** Although this term is often used interchangeably with cerebral lateralization, it implies that one cerebral hemisphere exerts a mastery or control over the other (Kinsbourne and Hiscock, 1978).

**Dichotic Listening.** This term refers to a non-invasive technique for simultaneously stimulating both ears
of a subject with different stimuli. The procedure is used to study auditory perception and cerebral dominance for verbal or nonverbal stimuli (Hynd and Obrzut, 1981). As employed by Kimura (1961a), the right ear advantages for dichotically presented verbal stimuli were attributed to left cerebral dominance for language and the functional prepotency of the contralateral pathways.

**Directed Attention.** This procedure involves directing a subject's attention to one side of space or the other. As used in the dichotic listening paradigm, the subject is asked to listen only to the left ear, although stimuli are presented simultaneously to both ears. Accuracy of directed ear report is then calculated. This precuing procedure enables researchers to study the attentional bias factor on observed ear reports. Studies generally report that normal subjects produce a right ear advantage (REA) for verbal information independent of cued instruction, while learning-disabled subjects are able to shift attention to the directed ear.

**CV Stimuli.** This refers to single pairs of stop-vowel nonsense syllables (ba, da, ga, pa, ta, ka) usually presented in synthesized phonetic pairs during a dichotic listening experiment. The CV stimuli appear to minimize the subject's reliance on memory or semantic processes while highlighting the central auditory mechanisms for
processing language-based information (Porter and Hughes, 1983).

**Tonal Stimuli.** This refers to the dichotic tone task involving the serial presentation of two tones, one at 1650 Hz (low) and the other at 1750 Hz (high). The subject is asked to indicate whether the sequence heard was HL or LH. The tonal stimuli highlight the central auditory mechanisms for processing simple acoustical sounds. Normal right-handed subjects should report hearing the left ear sequence more often than the right ear sequence (Efron et al., 1983b).

**Sinistrality.** This term implies left handedness. Familial sinistrality refers to left handedness found in one or more family members.

**Dextrality.** This term implies right handedness. Familial dextrality refers to right handedness found in all family members.

**Cerebral Lateralization**

The following review of the literature begins with an overview of the major theoretical approaches to human laterality, with particular attention to hypotheses about the relationship between cerebral lateralization and learning disabilities. Behavioral indices and measurement techniques associated with laterality studies are discussed, including motor, visual, and auditory research.
findings. The chapter will conclude with a review of research utilizing the dichotic listening paradigm with learning-disabled and left-handed populations. It will also examine recent findings concerning right hemispheric functioning through the use of nonverbal dichotic stimuli.

Theories of Cerebral Lateralization

A number of theories have been proposed to explain the cerebral asymmetries found in humans. A verbal-nonverbal or structural theory was proposed by Kimura (1967) which stresses the anatomical differences between the hemispheres at birth from which functional differences can be measured. According to this model, information presented to the left and right sides of the body travels contralaterally through nerve fibers to the left and right hemispheres. Because the left hemisphere is specialized for linguistic functions, it will process verbal stimuli, while the right hemisphere will process nonverbal input. Kimura explains that verbal stimuli presented to the left side (e.g., the left ear) or the left hemisphere will initially project to the right hemisphere, but because this side is incompetent to process the information, it will be transferred to the left hemisphere. Kimura's use of dichotic listening procedures to investigate cerebral lateralization has provided compelling evidence for her
theories and the resulting right ear, right visual field, right hand advantage for verbal material and left ear, left visual field, left hand advantage for nonverbal stimuli.

Another model of cerebral lateralization is the attentional-bias or cerebral activation explanation proposed by Kinsbourne (1973, 1975b). Kinsbourne offers no explanation of the origins of left or right specialization but premises his theories on these previously established cerebral asymmetries. This body of work suggests that asymmetries of perception and performance depend on relative levels of arousal in the two hemispheres such that one or the other dominates processing. Holding to this view, visual field and auditory asymmetries (often tested using the dichotic-listening procedure) depend on the priming of the hemisphere better able to deal with the verbal or nonverbal stimuli presented. Thus, verbal activity should prime the left hemisphere and lead to better performance in the right visual field or the right ear. While a directional bias of attention is perhaps necessary to facilitate information processing in the left or right hemisphere, researchers generally agree that perceptual asymmetries cannot be completely explained by Kinsbourne's notion of attentional factors (Rourke, Bakker, Fisk, and Strang, 1983).
In recent years it has become increasingly common to discuss lateralization in terms of information processing theory. Moscovitch (1979) proposes that lateralization does not occur at the early sensory input stages of information processing but does occur at later or deeper stages of processing. For example, he reports that there were no laterality effects for rapidly presented faces where the subject had little time to process the target face to any depth. When a time lag was introduced, a laterality effect was recorded for face recognition (Moscovitch, Scullion, and Christie, 1976). Bever and Chiarello (1974) found that skilled musicians exhibited a right ear advantage (REA) for music, while a control group showed a LEA for the same stimuli. An explanation for these results proposes that musicians process more analytically in their left hemispheres, and nonmusicians rely on a more holistic, right hemisphere strategy. Information processing theory, then, tends to equate "analytic" and "sequential" with left hemisphere control and "holistic" and "simultaneous" with right hemisphere functioning. While research is relatively recent and inconclusive in this area, Moscovitch's points, which stress the importance of the speed of the stimulus presentation and the necessity of doing a detailed task analysis of the procedures used to generate a laterality effect, are well taken (Bryden, 1982).
A final theory of cerebral laterality proposes a developmental or maturational element in the functional asymmetries found in the human brain. Lenneberg (1967) originally proposed that the functions of the left hemisphere gradually develop and are well established by puberty. A modification of this theory was presented by Krashen (1973), who found that this specialization for language is actually completed by the age of five. In general, the model proposes that the left hemisphere develops its capacity to process language earlier than the right hemisphere, and, therefore, laterality is not necessarily predetermined. If the left hemisphere were damaged before a critical developmental time in a child's life, the right hemisphere might assume responsibility for language functioning (Corballis, 1983). Further, Moscovitch (1977) and other researchers propose that during the period of language development, the corpus callosum actually exerts an inhibitory influence on the right hemisphere so that it does not compete with the left in language processing. Conflicting results from recent studies indicate that cerebral dominance may not be a developmental phenomena and that unilateral speech representation is probably present at birth (Hiscock and Kinsbourne, 1978; Hynd, Obrzut, Weed, and Hynd, 1979).
The present investigation draws its theoretical underpinnings from the structural model first proposed by Kimura which utilized the dichotic listening paradigm to investigate ear advantage for verbal and nonverbal stimuli. The study also relies on the attentional-bias theories of Kinsbourne in its refinement of the dichotic listening methodology. Directed attention procedures were utilized in an attempt to study the role of attentional bias in children's lateralized performance on dichotically presented stimuli.

Cerebral Lateralization and the Learning-Disabled Child

The four major models previously presented have provided the theoretical foundations for a majority of the laterality research in both adult and child populations. A more recent focus has been directed at observing cerebral asymmetries in learning-disabled children. Despite the numerous methodological problems and inconsistent pattern of findings, several hypotheses have evolved concerning the relationship between cerebral laterality and learning disabilities. Because the present study addresses some of these hypotheses in its conclusion, a brief overview of the positions is warranted.

During the 1920s and 1930s, Samuel Orton (1937) forwarded his theory relating learning disabilities with a
failure of the dominant hemisphere to achieve functional superiority. Orton hypothesized that physiological representations of a stimulus were initially established in both hemispheres, that is, they were thought to be mirror images of each other. If the image was not suppressed in the nondominant hemisphere, usually the right hemisphere for verbal stimuli, then the result was interhemispheric rivalry which led to confusion and poor performance. Thus, for decades special education has viewed language disabilities as linked to incomplete hemispheric dominance.

Although extreme views regarding this model have diminished, the literature still promotes a strong link between cerebral lateralization and cognitive performance (e.g., Knights and Bakker, 1976).

Another major hypothesis concerning learning disabilities was proposed by Lenneberg (1967), who contended that left hemisphere specialization for language is a developmental phenomenon in normal children. Learning-disabled children experience a lag or delay in hemispheric specialization which impacts on their ability to acquire and perform age-appropriate cognitive skills. Bakker and associates (e.g., Bakker, Teunissen, and Bosch, 1976) as well as Satz and his colleagues (e.g., Satz and Van Nostrand, 1972) propose that this maturational lag hypothesis helps to explain developmental dyslexia in older
children. While visual-motor and auditory-visual integration skill develop earlier and would be delayed in young dyslexics, linguistic skills which develop later in the maturational process would be more delayed in older dyslexic children. The theory assumes, of course, that speech processes become lateralized as the child becomes older. Although Lenneberg's original theories are still prevalent in the literature, recent studies have questioned the notion that cerebral lateralization increases with age (e.g., Hynd and Obrzut, 1981; Obrzut et al., 1981). These studies have found that lateraledized language capabilities exist in children ages six years and above, therefore putting into question the hypothesis that learning disabilities are somehow related to the developmental process.

Kinsbourne's attentional bias theory (1973, 1975b) serves as a third alternative hypothesis of functional asymmetry. He proposed that each hemisphere is dominant for particular kinds of stimuli and that the stimuli activates the appropriate hemisphere, thus shifting attention toward the contralateral side of space. Efforts to test this attentional hypothesis with normal and learning-disabled children through a precuing, dichotic listening paradigm have shown that normal children do not shift their ear effect for verbal stimuli and remain right ear dominant in all conditions. Learning-disabled children
consistently reversed their ear effect, showing a LEA for verbal stimuli in the directed left condition (Obrzut et al., 1981). Obrzut and his colleagues propose that learning-disabled children lack fully developed mechanisms for reciprocal inhibition of the nondominant hemisphere and thus are able to shift attention to stimuli presented in either perceptual field. They also suggest that there may be defects in the callosal functioning, therefore making it more difficult for them to process verbal information (Obrzut et al., 1981; Obrzut, Hynd, and Obrzut, 1983).

**Behavioral Indices of Laterality**

While empirical findings resulting from animal studies have contributed much to our understanding of human laterality, most of the evidence supports the fact that human cerebral lateralization is a unique phenomenon (Corballis, 1983). Human laterality has been observed and systematically studied for centuries, and numerous theories of specialization and function have emerged. Although in general most theories assume distinctly separate roles and functions for each hemisphere, many researchers argue that discrete and separate hemispheric functioning is not as polarized as previously thought (Milner, 1971; Sperry, 1974). Therefore, many questions still remain with regard to cerebral laterality and hemispheric functioning.
Through the application of modern anatomical, electrophysiological and behavioral techniques, many cerebral functions have been demonstrated to be primarily mediated by either the left or right hemispheres. A detailed description of all of the techniques and related research findings is beyond the scope of this chapter, but the reader is encouraged to consult Rourke et al. (1983) or Bryden (1982) for reviews of anatomical and physiological indices of lateralization. Behavioral methods that are used to understand perceptual asymmetries include visual, haptic, auditory, and concurrent verbal-motor (time-sharing) stimulation. Lateral preference, including hand preference, hand performance, and time-sharing techniques have been used extensively to explore motoric asymmetry.

The following discussion briefly reviews results from studies investigating motor and visual asymmetries in child populations. A more detailed review of auditory asymmetries and auditory measures of lateralization will also be provided. Special attention will be directed to the dichotic listening paradigm and the influence of attentional mechanisms on subject performance.

Motor Asymmetry

There are several potential advantages in using output measures to study laterality. Kinsbourne and Hiscock (1983) note that output processes (handedness in
particular) appear to be more distinctly lateralized in humans than input processes. Secondly, it is easier to observe output tasks than perceptual tasks. However, there are major concerns with this line of research in understanding important laterality differences between the normal and learning-disabled child.

The motor performance literature itself is quite unlike the perceptual asymmetry research addressed in the present study, primarily owing to the wide diversity of methods and hypotheses being generated. Bryden (1982) categorizes three major lines of research, including handedness, dual-task performance, and tracking performance. Bryden points out that while perceptual research has shown excellent correspondence between performance deficits seen in brain-damaged subjects and performance asymmetries in normal subjects, there is a marked lack of this correspondence with motor tasks. For this reason, motor asymmetry research has not been as useful in studying the cognitive correlates of motor outputs in the learning-disabled child.

Witelson (1977) and Young (1977) have reviewed studies involving motoric asymmetries in children and have concluded that there is very little agreement in terms of handedness and its relationship to laterality. The only clear evidence suggests that the right hand is superior for
motor tasks (left hemisphere), while the left hand is more adept at performing spatial tasks. Studies examining handedness and learning disabilities have proposed that these children suffer from weak hand preference and that left handers are poor readers. However, Hardyck and Petrinovitch (1977) concluded from a survey of the handedness literature that there is little support for either position. Lateral preference for motor tasks and performance differences between hands provide little useful information on cognitive processing as it relates to cerebral organization.

Another research paradigm which has been somewhat successful in examining hemispheric asymmetry of function is the time-sharing or dual-task paradigm. The tasks involve concurrent activities, such as motor-motor, motor-verbal, or motor-visual, where the interaction between the activities is lateralized. Kinsbourne and Hicks (1978) explain that if the interaction is lateralized, for example, if visual stimuli interfere with right-hand performance more than left-hand performance, then one may infer how these activities are represented in the cerebral cortex. The time-sharing procedure has a long and noble tradition in experimental psychology, where it has been used to study selective attention, fluctuations in attention on varieties of information processing tasks, the
psychological refractory period, and automaticity (Bryden, 1982). Examples of this research with children include the work of Hiscock and Kinsbourne (1978, 1980b), who found that verbal responses lowered right hand tapping rates. This is interpreted as evidence for left hemispheric processing for both speech and right-handed motor activities. The lowered tapping rates resulted from the inability of the left hemisphere to control two tasks simultaneously.

Obrzut, Hynd, Obrzut, and Leitgeb (1980) also used a time-sharing procedure with matched groups of learning-disabled and normal children. Results showed that both groups of children at all developmental levels were lateralized for language in the left hemisphere, although the learning-disabled group showed slower tapping rates and had significantly greater task interference problems.

Kinsbourne and Hiscock (1983) concluded that despite the mixed results from the time-sharing procedure with both child and adult populations, there are a few consistent findings which should be acknowledged. First, nearly all studies provide evidence that cognitive tasks may disrupt concurrent motor activity. Second, certain verbal tasks, such as reading aloud, disrupt right-hand performance more than left-hand performance. Third, dual-task studies confirm that certain verbal functions are
performed asymmetrically in the brain, but conclusions about nonverbal lateralization are inconsistent. Fourth, dual-task performance in children closely resembles that found in adults.

In conclusion, the motor asymmetry literature, especially the time-sharing paradigm, may provide additional information on hemispheric function and organization in anomalous groups of children, but the literature does not provide the robust findings often associated with visual or auditory modalities. Obrzut and Boliek (1986) emphasize that the procedure is potentially valuable only if experimental variables such as sample sizes and linguistic tasks are better controlled. In addition, they advise better experimental control over the verbal output measure, with or without the concurrent motor task.

Visual Asymmetry

Research in the area of visual lateralization has made dramatic advances, both in theory and experimentation, and is well on its way to becoming an integral part of the research on human cognition (Hardyck, 1983). This is not to say that the visual half-field paradigm used in this research is free of problems.

Reviewers are quick to note major concerns in terms of experimental control of information processing strategies used by the subjects and in selecting appropriate
stimuli for the task (Rourke et al., 1983). Nevertheless, vision has become one of the most popular modalities for laterality research with children.

The visual half-field paradigm involves the tachistoscopic presentation of verbal or nonverbal stimuli to the right or left visual field. In bilateral presentation, stimuli are presented to both visual fields simultaneously. As with auditory asymmetry techniques, the basic findings reveal a right visual field superiority for verbal information and a left visual field superiority for nonverbal, visuo-spatial tasks (Witelson, 1977).

Early studies with learning-disabled populations provided inconsistent results. McKeever and Huling (1970) reported significant right visual half-field (RVHF-left hemisphere) advantage for verbal stimuli in groups of normal and poor readers. Other studies in the 1970s revealed this same RVHF advantage with reading-disabled children but noted that they were lateralized less strongly than their normal counterparts (e.g., Marcel, Katz, and Smith, 1974; Bouma and Legein, 1977). McKeever and VanDeventer (1975) first proposed that this reduced RVHF found in older dyslexic readers might be a result of a left hemisphere dysfunction.

Kershner (1977) also used a visual half-procedure with groups of gifted, good, and dyslexic readers and found
significant RVHF advantage for all groups, but a lower score was reported for the dyslexic group. When the researcher controlled for reading abilities between groups, the cerebral dominance effect was eliminated. As a result of these findings, Kershner concluded that reading impairment is somehow related to hemispheric differences in the processing of reading stimuli.

Attempts to study right hemispheric superiority for spatial processing in learning-disabled children was attempted by Witelson (1976). Using unfamiliar figures of people, the author found that the dyslexic group showed a reduced LVHF (right hemisphere) superiority when compared to the good readers. She concluded that dyslexic readers either lack a clear right hemisphere processing function or that the function is bilaterally represented. Therefore, if reading-disabled children have bilateral representation of visuo-spatial information, this could interfere with normal linguistic processing. Although the study provided important information on the nature of right hemispheric functioning in reading-disabled children, Bryden (1982) points to procedural problems in the Witelson study, in particular the lack of any experimental controls over subject attention. He concludes that the results may be more indicative of different attentional strategies rather than providing clear lateralization evidence.
Attempts to control for attentional effects in visual half-field research have been conducted recently by Obrzut, Hynd, and Zellner (1983). Carefully matched learning-disabled and normal children were given a pre-stimulus cue to direct their attention to one visual field or both and then were presented with verbal stimuli. Control children demonstrated a RVHF superiority in all directed conditions, while the learning-disabled group showed the expected RVHF advantage only in the unilateral condition. In both unilateral and bilateral conditions, the learning-disabled children recognized more of the stimuli presented to the left visual field (right hemisphere) than to the left. Obrzut and his colleagues concluded that the differences in performance by the learning-disabled group were more a result of their ability to direct attention to stimuli in the experimental task than to functional asymmetry of verbal processing.

Similar shifts in perceptual asymmetries are shown in dichotic listening studies employing the directed attention paradigm (e.g., Obrzut et al., 1981; Obrzut et al., 1983). Obrzut and Boliek (1986) conclude that the recent literature utilizing either the dichotic listening or visual half-field procedures has hypothesized that "learning disabled children may have brain activation patterns that are susceptible to attentional effects that
are not found in normal children" (p. 312). This hypothe­sis will be explored in more detail in the next section.

Auditory Asymmetry

Although research results demonstrating visual and motoric asymmetries have provided valuable data on the between-hemisphere differences of function in the normal and learning-disabled child, auditory asymmetries have proved to be one of the most important areas of concern in exploring cerebral lateralization. Additionally, the dichotic listening paradigm is generally accepted as a reliable and stable measure of cerebral dominance for central auditory functions (Bryden, 1982). Because a great percentage of learning-disabled children show deficits in auditory/linguistic functioning, auditory measures of these children are particularly important in contributing to our understanding of their lateralized functioning. Therefore, a more complete review of the dichotic listening literature will be provided in this section. Special attention will be given to results from dichotic studies with learning-disabled children and left-handed subjects. Additionally, pertinent results from dichotic presentation of nonverbal, tonal stimuli will be reviewed.

Verbal and nonverbal information presented audi­torily to a subject travels through the auditory pathways from each ear to both the ipsilateral and contralateral
auditory cortices (Bryden, 1982). Structurally, there is evidence that the contralateral pathways have greater numbers of fibers and can transmit information faster than the ipsilateral channels (Majkowski, Bochenck, Bochenck, Knapik-Fijalkowska, and Kopec, 1971). Although medical research indicates that there are more nerve fibers in the contralateral pathways, Ferraro and Minckler (1977) note individual variation in the degree of asymmetry in these pathways. These findings directly relate to individual differences reported in auditory lateralization studies. However, in spite of these individual differences, researchers generally agree that information from the right ear reaches the contralateral left hemisphere first with the opposite being true for the left ear (Bryden, 1982).

The pioneering work on auditory asymmetry using a dichotic listening procedure was provided by Kimura (1961a, b) where she initially discovered through a dichotic listening procedure that normal adults were more accurate in reporting verbal stimuli presented to the right ear. The dichotic listening paradigm will be discussed in some depth in the next section but, briefly, involves the simultaneous presentation of a series of paired stimuli to the subject's left and right ears. Reports of which stimuli are heard are interpreted as an "ear effect" for that particular pair of sounds.
Subsequent studies with clinical subjects revealed the importance of the temporal lobes in dichotic performance, especially the left temporal area, for the processing of verbal stimuli. Using subjects with epileptogenic lesions and known speech lateralization, as determined by sodium amytal testing, Kimura solidified her position that the dichotic procedure was an effective method of measuring lateralization for auditory information. She concluded that subjects with left hemispheric speech representation reported a right ear advantage (REA) for verbal stimuli, while those with right hemispheric speech produced a left ear advantage (LEA). As a result of these early experiments, the dichotic listening technique has become the most widely used noninvasive procedure in studies of auditory lateralization. Stimuli used in this research include words, word lists, sentences, nonsense syllables, digits and nonverbal stimuli, such as melodies or tones.

The early work exploring the function of the right hemisphere was also largely begun by Kimura (1964). Using melodic patterns, the initial experiment found a LEA in normal subjects. Subsequent findings with patients having had a right temporal lobectomy (removal of the right temporal lobe) showed a dramatic reduction in left ear report for melodies (Shankweiler, 1966). A large body of dichotic research now demonstrates that there is a left ear
superiority in normal, right-handed subjects for a wide range of nonverbal stimuli, including melodies, chords, and environmental sounds such as laughing, crying, and sighing (Bryden, 1982). However, some studies indicate a right ear effect for musical stimuli involving complex tonal sequences and rhythm (Halperin, Nachshon, and Carmon, 1973; Robinson and Solomon, 1974). Although the REA for verbal material has been replicated in countless studies, the LEA for music and environmental sounds is less conclusive because of procedural differences and problems in achieving an appropriate level of difficulty in tasks (Bryden, 1982).

In conclusion, the dichotic listening procedure has been used extensively in the assessment of auditory asymmetries in normal and brain-damaged adults. According to many researchers, these experimental results have provided us with important neuropsychological information from which a better understanding of human cognition has resulted.

A more recent focus of dichotic listening studies has been directed at learning-disabled and normal children, where researchers have observed ear advantages for a wide diversity of stimuli. Research employing the dichotic procedure with right- and left-handed subjects is less prolific in the literature, nevertheless, tentative hypotheses about functional differences between these
groups have been proposed. The following review examines the dichotic listening procedure in more depth and presents current research findings involving learning-disabled children, left-handed subjects, and results from studies employing nonverbal stimuli.

Dichotic Listening Paradigm

The dichotic listening procedure involves the simultaneous presentation of stimuli to a subject's right and left ear such that each ear is hearing similar information. For example, a subject might hear "ba" in his right ear and "ga" in his left ear. The subject is then asked what he/she heard. In directed attention conditions, the subject is also asked to listen to a particular ear and report what is heard, although the stimuli are still presented to both ears. The stimuli reported by the subject are then interpreted as an "ear effect." The percentage of combined ear effects for each ear is then calculated, and an overall right or left ear superiority is reported for that type of stimuli. Researchers then interpret this ear advantage as evidence for either right or left hemispheric processing.

Although most neuropsychologists associate the dichotic listening procedure with Kimura's work in the 1960s, the technique was originally developed by Broadbent (1954, 1956). In his investigation of memory and speech
processing, Broadbent suggested that simultaneous presenta-
tion of speech messages to both ears does not result in a
two-fold gain in information (200 percent). Instead
performance reflects a "bottleneck" in sensory perceptual
analysis such that the subject cannot process both signals
together, resulting in a loss of information in one or both
channels. Through variations of tasks, Broadbent dis-
covered that loss of verbal-based information was greatest
(up to 20 percent less) for the left ear signal when the
subject was required to report both messages heard and when
the stimuli were very similar.

Kimura (1961a, b, 1962), in her studies of ear bias
and cerebral specialization, first speculated that there
might be poor linkages between the left ear and the
ipsilateral left hemisphere. This hypothesis was based on
documented physiological evidence for a preponderance of
nerve fibers running contralaterally from the hemispheres
and on research demonstrating left hemisphere specializa-
tion for speech (Porter and Hughes, 1983). Kimura solidi-
fied her position that the dichotic procedure was best
suited for behavioral assessments of cerebral specializa-
tion by reporting that both ears perform equally well when
tasks are presented monaurally. Therefore, if one wishes
to observe the behavioral results of the preponderance of
contralateral nerve fibers, stimuli must be presented
simultaneously to both ears. The results of Kimura's early work and others have substantiated the early hypotheses that the signal heard by the right ear has direct, contralateral access to the left hemisphere, while the left ear has connections to the right cerebral cortex.

Although the general form of Kimura's model has been supported, problems with the technique have surfaced. Critical analyses of past studies reveal that the dichotic listening situation allows the subject to use his own strategies for coping with the tasks (Bryden, 1978). Therefore, it is often difficult to determine if the results were reflective of an individual's processing strategies or different patterns of auditory asymmetry. This becomes particularly important when comparing good and poor readers because interpretation of differences in the overall magnitude of an ear advantage may not be the result of poorer language lateralization (Bryden, 1982). It may point to differences in strategies used to deal with perceptual information.

The type of stimuli chosen also affects the magnitude and direction of the ear differences reported (see Obrzut, Boliek, and Obrzut, 1986a). Many researchers now rely on the single pairs of stop-vowel nonsense syllables (e.g., ba, ga, pa) to minimize memory and semantic processes.
Even when consonant-vowel stimuli are used, questions arise as to whether response bias or attention are influencing results. Based on Kinsbourne's Attentional Bias Theory, the dichotic procedure has been revised by some researchers to include a precuing paradigm in addition to the standard free recall condition (Kirstein, 1971; Obrzut et al., 1981). By counterbalancing attentional instructions and combining the data from both directed attention conditions, the results are comparable to the free recall condition. As reviewed earlier, this precuing procedure has resulted in dramatic differences in ear report between normal and learning-disabled children (Obrzut et al., 1981; Obrzut et al., 1983).

Although some reviewers may paint a pessimistic picture of the dichotic listening procedure, recent modifications (directed attention and use of nonsense syllables and simple tone sequences) have increased the viability of the paradigm for providing valuable information about auditory processing. Dichotic procedures not only help researchers understand the normal nervous system in humans but also reveal the differences in abnormal subjects or unique populations, such as learning-disabled children or left-handed subjects. The following discussion will examine the pertinent dichotic research on the particular groups and methods employed in this study.
Learning-Disabled Populations. Dichotic listening experiments have become one of the favored techniques in studying children with learning disabilities. One major line of research has focused on the magnitude of the dichotic ear effect and whether functional lateralization increases with development. Several early studies report increases in ear effect with age and conclude that learning-disabled children show delays in left hemisphere development (e.g., Satz, Rardin, and Ross, 1971; Berlin, Hughes, Lowe-Bell, and Berlin, 1973). Other investigators have found no developmental trends in normal and learning-disabled subjects ranging in age from five through late adolescence (e.g., Hynd and Obrzut, 1977; Obrzut et al., 1981). While there are no definitive conclusions from this body of literature, Pirozzolo, Rayner, and Hynd (1983) report that an REA and presumed left cerebral hemisphere lateralization for speech are evident for subjects at a very early age, which is contrary to the developmental hypothesis. Also, they point to variations in dichotic results as being more a function of the stimuli presented which may tap abilities related to attention or auditory short-term memory (see Geffen, 1978).

Because these studies have produced such inconsistent findings and have had major methodological problems, the current study will not address the developmental lag
hypothesis. Instead, it focuses on the conclusion reached by several recent studies demonstrating that although right ear effects for verbal, dichotic stimuli were found in normal and learning-disabled populations, normals report right ear stimuli more accurately (e.g., Hynd et al., 1979).

Research reporting overall differences in performance on dichotic tasks have led to a new body of literature aimed at examining the effect of selective attention on performance. Based primarily on Kinsbourne's (1970) attentional model of functional asymmetry, researchers have revised the traditional dichotic paradigm by introducing prestimulus cuing (directed attention) in addition to the free recall condition (e.g., Hiscock and Kinsbourne, 1980a; Obrzut et al., 1981; Obrzut et al., 1983). The cuing conditions are used in an attempt to control for the effects of variability in selective attention. The hypothesis generated by this research is that the non-dominant hemisphere is suppressed when there is an expectancy for verbal or nonverbal stimuli. Learning-disabled children are viewed as having potential attentional deficits and are, therefore, unable to suppress the nondominant hemisphere during information processing. (Obrzut and Boliek, 1986).
One of the first studies to propose the selective attention hypothesis was Hynd et al. (1979), where 96 matched normal and learning-disabled children were given a dichotic listening task. The results indicated that although both groups showed a REA for verbal stimuli, the learning-disabled children were less accurate. The researchers concluded that there was no evidence of a developmental lag or delay between the groups but contended that the performance differences were attributable to deficits in selective attention. Bryden and Allard (1978), in their review of previous dichotic studies, also propose that learning-disabled children may have problems disentangling simultaneously occurring sounds and, therefore, often resort to guessing strategies in their responses.

Several studies have attempted to test the attentional bias hypothesis through the dichotic listening procedure (e.g., Dean and Hua, 1982; Hiscock and Kinsbourne, 1980a). However, only since the early 1980s have learning-disabled children been targeted as populations for these studies. Obrzut and his colleagues have provided growing evidence of the effect of attention bias on certain verbal, dichotic tasks with learning-disabled children.
In their initial study (Obrzut et al., 1981), 32 learning-disabled and 32 normal children were presented dichotic stimuli consisting of 30 pairs of synthesized consonant-vowel (CV) syllables. Both free recall and directed attention conditions were implemented in the study and a significant REA was found in both groups. However, in the directed left condition, only the learning-disabled group was able to reverse their ear effect and produce a LEA. The researchers concluded that learning-disabled children show an attentional bias on dichotic tasks when asked to focus their attention to a particular stimulus. Further, these children possibly have not developed the ability to suppress their nondominant hemisphere during verbal tasks (Kinsbourne, 1974) and may suffer from a defect in callosal functioning (Obrzut et al., 1981). Additional evidence for the validity of these findings has been obtained in several follow-up studies (Obrzut et al., 1983; Obrzut et al., 1986b; Boliek, 1986; Obrzut et al., 1985).

Results from recent studies comparing normal and learning-disabled children suggest that normal children cannot willingly attend to verbal stimuli received in the nondominant ear, thus supporting Kinsbourne and Hiscock's (1981) contention that there is a concurrent suppression of the right hemisphere when linguistic material is presented.
However, learning-disabled subjects have perhaps not established this reciprocal inhibition of the nondominant hemisphere and, therefore, are able to direct attention equally well to either perceptual field (Obrzut and Boliek, 1986). That is, these children perform as if there were little interaction of their two cerebral hemispheres. These conclusions provide support for the Hynd et al. (1979) hypothesis that there are deficits in transcollosal functioning in this population. Obrzut et al. (1985) also propose that while learning-disabled children may be impaired by these attentional deficits, they may also have inadequate processing abilities within the language areas of the left hemisphere.

Research into the etiology and behavioral correlates of learning disabilities has only recently become a focus of attention for neuropsychologists. While trends in information processing and attentional mechanisms have been identified and validated, the majority of studies have been directed at understanding verbal processing in normal and learning-disabled children. The present study continues the validation process for earlier hypotheses about the role of attention in cerebral function but additionally investigates nonverbal processing in these groups. The following discussion addresses the research conducted with dichotically presented tonal stimuli.
Central Auditory Processing of Tones. The functional asymmetry of the human brain is manifested in dichotic listening by a REA for verbal stimuli and a LEA for nonverbal stimuli (e.g., Kimura, 1964, 1967). However, this dichotomy between the two ears in the perception of verbal and nonverbal stimuli is not always unequivocal.

Early research using a melodies test similar to Kimura's (1964) found nonsignificant left ear advantage for the task but significant results from a chords test (Gordon, 1970). However, sodium amytal studies indicated that unilateral suppression of the right hemisphere blocked melodic expression with little disturbance of speech (Gordon and Bogen, 1974). In the mid-1970s, investigators turned their attention to the relative contribution of different aspects of music to the left ear effect (Gates and Bradshaw, 1977a, b). They generally found that while musical stimuli exhibited a LEA, temporal sequencing and rhythm were more likely to show a REA (Halerin et al., 1973; Robinson and Solomon, 1974). Subsequent nonverbal dichotic experiments point to a right hemisphere involvement in the perception of environmental sounds, melodies, and chords but a left hemisphere involvement in rhythm and in the perception of complex tonal sequences (Bryden, 1982).
Recent investigation into right hemisphere functioning in adults has centered on dichotic pitch recognition tests or complex tone tests. Gregory (1982) reported on a test of ear dominance in pitch perception in 222 subjects, where two tones of different frequency were presented simultaneously, one to each ear. The direction of ear dominance was measured by asking the subject to compare one dichotic chord with the reverse dichotic chord. Scores were obtained by tallying the number of left versus right ear reports. The results showed that 75 percent of the subjects were left-ear dominant and nearly 20 percent were right ear dominant. Further, there was no relationship between direction of ear dominance and handedness. While Gregory (1982) concluded that the dramatic results were reflective of right cerebral hemisphere involvement in pitch perception, he argued that there was "little evidence to suggest that ear dominance for pitch was due to asymmetries in the cerebral hemispheres rather than in the auditory nerve pathways" (p. 90).

Perhaps the most thorough research into auditory processing of tonal stimuli has been conducted by Efron and Yund over the past decade (e.g., Efron and Yund, 1974, 1975; Yund and Efron, 1977; Efron, Crandall, Koss, Divenyi, and Yund, 1983a) Efron et al. (1983b) note that the results of past dichotic experiments have been difficult to
integrate because different methods and stimulus parameters have been used. In fact, they argue whether past investigators have studied the same basic phenomenon or entirely different ones. In an attempt to resolve past contradictions and arrive at a single theoretical explanation, Efron et al. (1983b) attempted to duplicate three major methods used to study perceptual asymmetries for tonal stimuli. All three methods required the subject to make pitch discriminations, but the frequencies and intensities of the tones differed. Results from the experiments clearly revealed that ear dominance for tonal stimuli is determined by two stimulus parameters: (1) the value of the difference in frequency between the tones and the intensity of those tones and (2) the temporal complexity of the acoustic pattern. Strong left-ear dominance was found for pitch presented at 1650 and 1750 Hz, while right ear reversals were evidenced when the number of frequency or duration transitions in the pair of dichotic stimuli were increased.

Efron and his colleagues hypothesize that the results of dichotic experiments with tones may be explained by anatomical asymmetries in the primary and association cortex. They point to a study by Geschwind and Levitsky (1968) where they reported that of 100 adult brains studied, 65 percent had a larger planum temporale on the left side. This value resembles closely the LEA
distribution in many dichotic experiments. Additionally, several investigators (e.g., Chi, Dooling, and Gilles, 1977; Campain and Minckler, 1976) have reported that the primary auditory cortex is larger on the right than the left and occupies some of the area on the right side which is occupied by the planum temporale on the left. Thus Efron et al. (1983b) propose that "the tonic efferent outflow of the temporal lobe enhancement mechanism might be greater from the right than left side and would result in the left-ear advantage seen" (p. 279).

Although evidence is provided for anatomical explanations of nonverbal processing, these researchers are quick to note that they do not reject the concept of hemispheric specialization. Indeed, they acknowledge that the proposed mechanism for processing tones is based on the view that structural differences in the hemispheres are critically related to their processing capabilities for different types of acoustical stimuli. Thus, Efron and his colleagues (1983b) accept the idea of right-left differences in hemispheric functional capacities and do not reject the possibility that certain regions of the brain perform qualitatively different functions which cannot be performed by the contralateral side. Individual deviations then in ear report for tonal sequence might be the result
of "disease, trauma, or genetically determined developmental proclivities" (Efron et al., 1983b, p. 281).

The present study attempts to extend the available research on the auditory processing of tonal stimuli by examining perceptual asymmetries in normal and reading-disabled children. To date, no studies have focused on child populations or, more importantly, on children with identified verbal processing deficits. The study compares verbal and nonverbal processing in these two distinct groups and, additionally, examines the effect, if any, of handedness on these results. The following discussion outlines the available research on the interaction of handedness and performance on dichotic listening tasks.

**Left-Handed Populations.** Handedness has long been associated with patterns of cerebral dominance. Well over a hundred years of clinical case reports associating brain damage with disruption of language function have indicated that the vast majority of humans are right handed with left lateralized language function (Zangwill, 1967). Left handers have been shown to represent between 5 and 12 percent of the general population and appear to be more heterogeneous in speech representation (Bryden, 1982). Aphasia studies and sodium amytol testing have generally concluded that two-thirds of all left handers demonstrate left lateralized speech (e.g., Hécaen and Sauget, 1971;
Annett, 1975), while the remaining left handers are either bilateralized or right dominant for language function (Rasmussen and Milner, 1975). The incidence of right hemisphere speech is much higher in left handers than right handers, and bilateral speech is a characteristic associated primarily with left handedness (Bryden, 1982).

The majority of past studies on handedness have used rather crude measures of handedness and have combined mixed and pure dominance subjects in the same groups. As a result, many of the conclusions and hypotheses generated by early studies can be questioned. However, researchers in the past decade have employed more systematic and quantitative measures of hand preference and performance, which have made classification more reliable and valid and have made it possible to group subjects more accurately for research purposes. Currently the three most popular hand preference questionnaires originate from the work of Crovitz and Zener (1962), Annett (1970), and Oldfield (1971). Of the various performance measures available, speed of tapping seems to have the highest reliability (e.g., Todor and Doane, 1977; Peters and Durding, 1978).

Correct classification of left handedness in subjects becomes important to researchers only if the incidence of left handedness is related to other behavioral performance (Bryden, 1982). In the past, left-handed
subjects have been accused, perhaps falsely, of many things, such as lower intelligence, poor reading ability, impaired spatial ability (e.g., Corballis and Beale, 1976; Levy, 1969), a higher incidence of birth stress (Bakan, Dibb, and Reid, 1973), and a greater incidence of pathologies such as mental retardation (Satz, 1972). In a review of the literature on left handedness, Hardych and Petrinovitch (1977) state that the link between behavioral deficits and left hand dominance is a very weak one. Nevertheless, Satz (1972) and Corballis and Beale (1976) argue that deficits found in left handers are not a result of their handedness but because their localization of function is somehow abnormal.

How then can left handedness be associated with various pathologies and yet the literature concludes that left handers in the general population are as intelligent as right handers? Kinsbourne and Hiscock (1981) believe that this paradox is a result of two distinct etiologies for left dominance. Most people are left handed because of a genetic predisposition, although this can be affected by social pressures (e.g., Levy and Nagylaki, 1972; Annett, 1974, 1985; Morgan and Corballis, 1978). Other left handers were dextrals at birth but became left handed as a result of unilateral brain insult. This is now referred to in the literature as pathological left handedness (Satz,
1972; Satz, Baymur, and Van der Vlugt, 1979; Satz, Orsini, Saslow, and Henry, 1985). A thorough explanation of the syndrome is beyond the scope of this review, but, briefly, this position hypothesizes that early left-sided damage may be sufficient to shift handedness from the right to the left. These etiologies become important to researchers in terms of selecting subjects for studies on the behavioral correlates of handedness. Familial sinistrality, that is, the genetic predisposition for left handedness, becomes an important factor in subject selection, and screening out of potential pathological left handers becomes crucial.

The contributions of handedness and familial sinistrality to laterality effects on dichotic listening tasks have produced mixed results. Most studies of left handers thus far have shown strong right ear preferences in adults with no left-handed relatives, but studies of subjects with sinistral relatives have shown either strong right ear preferences (Lake and Bryden, 1976), or no consistent ear dominance (Higenbottam, 1973), or a smaller right ear preference for verbal stimuli (Lishman and McMeekan, 1977). Although there is currently no consensus as to the relationship of left handedness and family history to performance on dichotic tasks, at least some of the most recent literature proposes that right hemisphere
dominance for language in left handers is dependent on several variables.

Strength of handedness has emerged as one important variable in dichotic listening studies. As discussed earlier, the use of hand preference and performance tests has enabled researchers to classify subjects more accurately. Consequently, strong or weak hand preference can be initially determined. Dee (1971) reported that weak left handers showed a LEA for verbal, dichotic stimuli whereas strong left handers, like right handers, showed a REA. Other researchers have concluded that it is the strong left handers who show a left ear advantage in dichotic listening (Knox and Boone, 1970; Satz, Achenback, and Fennell, 1967). Demarest and Demarest (1980) found that strongly left-handed subjects exhibited a left ear advantage but that moderately lateralized subjects failed to show an ear advantage for verbal material. These researchers noted that strongly right-handed subjects consistently demonstrated the largest right ear advantage. Obrzut et al. (1986b) also reported that strongly left-handed subjects produced a LEA for verbal information which is suggestive of right hemisphere superiority for language processing.

The contributions of handedness, familial sinistrality, and sex to the laterality effects on dichotic listening tasks has been examined by several current
researchers. Demarest and Demarest (1981) found that left handers as a group exhibited left ear advantages, and right handers showed right ear advantages in auditory asymmetry. Left handers with familial sinistrality exhibited this reversed laterality on the dichotic words task, with females showing the greatest variation in asymmetry. Piazza (1980) reported that various factors affected hemispheric specialization to different extents. In the study's verbal dichotic task, left-handed males demonstrated significant REA while females were more bilateral. Although Piazza noted that handedness was the single significant factor in lateralization with the tasks in her study, familial sinistrality enhanced the effect of left handedness, that is, produced weaker typical or more bilateral, atypical specialization. Hugdahl and Andersson (1984) also found a significant left ear advantage for left-handed sinistral subjects but concluded that right hemisphere dominance for language (LEA) is not related to a single factor but is dependent on the interaction of handedness, gender, familial sinistrality, and hand posture in writing. Obrzut et al. (1986b) also reported a LEA in left-handed children for dichotically presented verbal stimuli but found that they were susceptible to attentional shifting. Therefore, right hemisphere processing of
language among left handers may also be related to attentional strategies or manipulation.

The preceding pages have been concerned with the relationship between handedness, other subject variables, and speech lateralization in adults. Noticeably missing from this review have been investigations of the relationship of handedness to the functions of the minor hemisphere. Only Piazza (1980) attempts to address nonverbal processing by right and left handers, but her results were conflicting. In the environmental sounds dichotic task, males displayed no significant ear advantage. However, left-handed females had a significant REA, and right-handed females had a significant LEA. In the melodies dichotic task, right-handed males showed a nonsignificant LEA, and left-handed males displayed a nonsignificant REA. Right-handed females demonstrated a significant LEA, and left-handed females showed a nonsignificant REA. The Piazza study did not employ a tonal task such as the one utilized in this study, therefore, comparisons would be difficult to make. Nevertheless, it is crucial that researchers interested in the relationship between handedness and auditory processing begin to examine the specialization for nonverbal information processing in left-handed subjects.

Also missing from this body of literature are any documented results of dichotic procedures used with
left-handed children or learning-disabled populations. Obrzut and his colleagues (Obrzut et al., 1986b) report on an initial study of left-handed, good readers, where a significant LEA for CVC stimuli was found. Additionally, it was noted that left handers were able to increase correct recognition of right ear presentation on cue from the examiner. Accenting these results, right handers presented a REA regardless of the cuing conditions. The present study extends the work of these researchers by including left-handed good readers and left-handed reading-disabled children in the subject population and, additionally, controls for familial sinistrality and strength of handedness which have been associated with atypical auditory processing.

Conclusions

This chapter attempted to present the theoretical and research base for the following study. The review of literature focused on the broad area of cerebral laterali-

zation but was primarily concerned with auditory asym-

metries in the human species as measured by the dichotic listening paradigm. While much of our current research base has been derived from studies of adult populations, the review attempted to integrate results of research with child populations and learning-disabled children when available.
Research results from various behavioral indices of laterality have basically concluded that right-handed learning-disabled children, like their normal counterparts, have left lateralized language function. They differ in that they are not as accurate and that they are able to shift their attention to cued stimuli, unlike children who have no verbal processing problems. The literature remains unclear whether these differences are due to incomplete cerebral dominance, neurological or structural deficits, or developmental delays (Obrzut and Boliek, 1986).

The research is sparse or nonexistent when the issues of handedness or right hemisphere processing in children are introduced. In this light, the present study provides initial findings and hypotheses about the interaction of handedness and attention on both the verbal and nonverbal processing of good readers and reading-disabled children. Further, the study attempts to address some of the deficiencies cited in previous studies in an effort to separate out experimental effects from effects due to cerebral lateralization.
CHAPTER 2
METHODOLOGY

The present study was designed to examine the brain lateralization of verbal and nonverbal stimuli through the measurement of perceptual asymmetries in the auditory cerebral cortex. Of primary importance was the determination of laterality differences between left- and right-handed good readers and left- and right-handed reading-disabled children when presented verbal and nonverbal information in a dichotic listening procedure. Additionally, the effects of directed attention conditions on lateralized performance were investigated.

Method

Subject Sample

A sample of 60 elementary school students was selected from one large Catholic school system and a large southwestern school district. The children ranged in age from 7-1 to 12-8 years of age ($\bar{x} = 10.5$) and were matched on the basis of chronological age and handedness. The subjects were all average to above average in intellectual ability. Table 1 presents descriptive data on the subject.
Table 1. Means and Standard Deviations for Age and IQ by Sample Groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Gender</th>
<th>Age</th>
<th>IQ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>F</td>
<td>$\bar{X}$</td>
</tr>
<tr>
<td>Right-Handed Good Readers</td>
<td>4</td>
<td>11</td>
<td>10.27</td>
</tr>
<tr>
<td>Left-Handed Good Readers</td>
<td>7</td>
<td>8</td>
<td>10.47</td>
</tr>
<tr>
<td>Right-Handed Reading Disabled</td>
<td>9</td>
<td>6</td>
<td>10.50</td>
</tr>
<tr>
<td>Left-Handed Reading Disabled</td>
<td>11</td>
<td>4</td>
<td>10.80</td>
</tr>
</tbody>
</table>
pool including gender and means and standard deviations for age and IQ. Thirty reading-disabled subjects (15 right handed and 15 left handed) who had been placed according to federal guidelines into learning-disabled programs were matched with 15 right-handed and 15 left-handed good readers.

The reading-disabled children were selected on the basis of average intellectual potential as measured by the WISC-R > 85, evidence of a processing deficit, and a two-year achievement deficit in reading. In addition, all subjects in the sample, experienced specific reading disabilities of an auditory-linguistic nature.

The good readers were selected on the basis of teacher recommendation, achievement scores in reading of greater than 75 percent on the district-wide achievement tests, and scores of greater than 90 on the Peabody Picture Vocabulary Test-Revised (PPVT-R). The PPVT-R provides a measure of receptive vocabulary but was utilized in this study as an estimate of verbal intelligence. Teacher recommendations indicated that the subjects were above-average readers with strong study skills and consistently good marks in reading.

Parental consent forms (see Appendices A and B) were sent to the parents of children who were recommended by teachers to take part in the study and met selection
criteria. All subjects were enrolled as full-time students in the public or private school district. The districts were comprised of over 55,000 students.

Screening Instruments

The medical records of all subjects in the study were initially screened for potential hearing impairments. Handedness was established by observing each child's hand preference for eight activities included on the Edinburgh Handedness Inventory (Oldfield, 1971): writing their name, cutting with scissors, drawing, using a spoon, using a knife, brushing teeth, throwing a ball, and removing the lid from a box. Both left- and right-handed subjects performed all eight tasks with their dominant hand. In addition, left-handed children were screened for familial sinistrality and were only included in the final sample if they had other left-handed family members. The greatest percentage of left-handed subjects had one or more immediate family members such as a parent or sibling who were left handed. A few subjects reported aunts, uncles, cousins, or grandparents as left handed.

The PPVT-R (Dunn and Dunn, 1981) was administered to all good readers in an effort to screen out subjects with below average receptive vocabulary and verbal intelligence. Poor performance on the PPVT-R could have adversely
affected the subject's performance on the dichotic listening tasks.

Materials and Apparatus

The stimulus materials consisted of two dichotic tapes designed specifically for the dichotic listening tasks. The tape recorder channeled one taped stimulus to the left ear while another stimulus was presented simultaneously to the right ear. Stimulus inputs were synchronized for onset, duration, and amplitude. One dichotic tape consisted of 30 pairs of synthesized consonant-vowel (CV) syllables differing only in initial consonant (see Appendix C). This tape was prepared at the Kresge Hearing Research Laboratory in New Orleans, Louisiana. The second tape consisted of a tone task involving the presentation of two tones, one at 1650 Hz (low) and the other at 1750 Hz (high). Fifteen monaural trials were initially given, followed by 46 test trials. Of the test trials, 30 were dichotic (15 H/L, 15 L/H) and 16 were monaural "catch" trials (see Appendix D). This tape was derived from the work of Efron, Koss, and Yund (1983) and was obtained from M. P. Bryden at the University of Waterloo, Waterloo, Ontario, Canada.

All dichotic stimuli were presented through a TEAC A-23005X two-channel tape recorder and were received through Koss K-6 stereophonic headphones at a hearing
amplitude of 70 dB. A calibration tone on the individual dichotic tapes was used to monitor each channel. The ambient noise level was maintained at approximately 40 dB. The presentation of the CV syllables represented all possible nonidentical pairings of the dichotic stimuli, with an interpair stimulus interval (ISI) of six seconds. In the tone task, the sequence high/low was heard in one ear, while simultaneously the sequence low/high was heard in the other ear. The presentation of tone was randomly rotated in the 30 dichotic trials.

Procedure

Each subject was examined individually in a quiet room. The CV dichotic task was introduced by stating: "You will hear one word in your left ear and another word in your right ear at the same time. It will sound like two people are talking to you at the same time." Each child was then shown the list of CV syllables typed on a sheet of paper. After the examiner pronounced the words, the subject was asked to repeat them. The tonal task was introduced by stating: "You will now hear two tones in each ear at the same time. One tone will be higher than the other. Your job is to tell me whether you heard 'high-low' or 'low-high' tones." Each child was then given 15 monaural trials to provide practice and to ensure that he or she could make the discrimination. Most subjects
required two to three monaural trials in order to reach 95 percent accuracy.

Three conditions were employed for each of the stimulus tapes in an attempt to assess the child's ability to direct attention. In the Free Recall (FR-control) condition, the child was asked to listen to both ears and report what was heard after each stimulus presentation. The second condition involved directing the child to listen only to the left ear (DL) and report what was heard, while the third condition directed attention to the right ear (DR). The order of trial presentations was counterbalanced for all six possible combinations (FR-DL-DR, FR-DR-DL, DR-DL-FR, DR-FR-DL, DL-DR-FR, DL-FR-DR). During all trials, children were instructed to maintain their gaze straight ahead (central hemispace).

In the CV stimulus presentation, each child was presented with a total of 90 trials, with 30 trials in each condition. There were 15 monaural trials initially given each subject at the beginning of the tonal stimulus presentation, followed by 138 test trials—46 per condition. Of these 138 tonal trials, 90 were dichotic and 48 were monaural "catch" trials. Results were calculated only from the 90 dichotic presentations.
Reliability and Value of the Dichotic Listening Procedure

The dichotic listening procedure was initially developed by Broadbent (1954) but was applied and researched further by Doreen Kimura (1961a, b). Although the general form of Kimura's procedure was maintained, the technique was revised and refined in attempts to control for factors affecting the reliable measurement of cerebral lateralization. As a result of two and one-half decades of research, the dichotic listening technique now includes several possible procedural choices, is currently utilized for the presentation of various types of verbal and nonverbal stimuli, and often employs attentional monitoring procedures. It is now generally accepted by researchers as a noninvasive means of assessing speech lateralization in human subjects.

Reliability of the dichotic listening procedure is rarely reported in the literature, and Bryden (1982) warns against making sweeping conclusions about the organization of the human brain solely on the basis of dichotic results. He notes that studies of speech lateralization involving suppression of cortical functioning through sodium amyotal have reported the incidence of left hemispheric speech in right-handed subjects at the levels of 97-99 percent. Reports of right ear dominance in dichotic listening studies rarely report levels over 75-85 percent. This
discrepancy perhaps relates to reliability issues with the dichotic procedure itself. Hines and Satz (1974) also attribute a portion of the unreliability of these measures to a statistical limiting factor, that is, the reliability of difference scores decreases as the correlation between their component scores increases. Researchers who have reported reliability measures on the procedure include Bryden (1975) with values of .61 and .66, Bakker, Van der Vlugt, and Claushuis (1978) with a value of .80, and Blumstein, Goodglass, and Tartter (1975) with a value of .74. Although these values are not as high as desired, the fact remains that it is nearly impossible to control for all factors affecting cerebral lateralization using a noninvasive procedure. Thus, these reliability values are generally accepted as sufficient for research but not for diagnostic purposes.

Validity of the dichotic procedure is most often presented in the form of concurrent measures. For example, by correlating ear advantage to linguistic inputs with the medically verified hemisphere for speech, Kimura (1967) found high concurrence in neurological patients. The development of sodium amytal techniques for the assessment of speech lateralization in clinical populations (Wada and Rasmussen, 1960) has made it possible to determine that the incidence of left hemispheric speech in right handers is
between 95-99 percent (e.g., Rasmussen and Milner, 1977; Rossi and Rosandini, 1967), while the incidence of right ear superiority for dichotic listening tasks in normal right handers is in the range of 75-85 percent (Bryden, 1982). Additional clinical reports of the sensitivity of dichotic word lists to lateralized cerebral damage in patients with disconnected hemispheres also contribute to validation of the dichotic listening procedure (e.g., Schulhoff and Goodglass, 1969; Mazzucchi and Parma, 1978). Recent research (Porter and Hughes, 1983; Obrzut et al., 1985) also suggests that the technique may be useful in assessing lateralization of information processing and in understanding the nature of central auditory processing in normal and learning-disabled populations.

Much of the recent criticism of the dichotic listening procedure concerns the lack of control over task parameters. One of the most important parameters is the nature of the dichotic stimuli used which affects the direction of ear report and the overall accuracy of performance. Stimuli with simple acoustic-phonetic structures, such as vowels, have yielded small ear differences and higher overall performance (Shankweiler and Studdert-Kennedy, 1967; Studdert-Kennedy and Shankweiler, 1970). Responses to meaningful stimuli such as words, digits, melodies, and sentences have also resulted in
smaller ear differences and varied performance levels (Zurif, 1974; Zurif and Mendelson, 1972). Attentional strategies used in conjunction with meaningful stimuli have produced even more inconsistent and confusing laterality outcomes (Obrzut, Boliek, and Obrzut, 1986).

Studdert-Kennedy and Shankweiler (1967, 1970) popularized a new approach to dichotic studies by finding robust right ear effects for consonant-vowel (CV) stimulus sets with six stop consonants in a common vowel environment (e.g., ba, da, ga, pa, ta, ka). This stimulus set has minimized the involvement of memory and semantic processes while highlighting the central auditory mechanisms (Porter and Hughes, 1983). Comparisons of CV and CVC stimuli (Studdert-Kennedy and Shankweiler, 1970; Boliek, 1986) support stronger ear effects for CV than CVC syllables in dichotic procedures. Therefore, CV stimuli have evolved as the most accepted task strategy for dichotic listening experiments.

In the past decade, a number of studies have investigated perceptual asymmetries for tonal stimuli and have reported significant left ear dominance in the right handers (e.g., Sidtis, 1980, 1981; Gregory, 1982; Halperin, Nachshon, and Carmon, 1973). Although dichotic procedures utilizing tones are relatively rare and results are often confusing because of differences in methods and stimulus
parameters, Efron, Koss, and Yund (1983) report convincing
evidence for left ear dominance in 63 right-handed subjects
when presented with high/low tonal stimuli presented at
1650 Hz and 1750 Hz levels. This important study repli­
cates several previous dichotic experiments which show an
initial LEA for tones but a shift toward right ear domi­
nance when the frequency difference is increased. The
experimental data now available on tonal stimuli used in
dichotic procedures reveal that ear dominance for tones is
determined by at least two stimulus parameters: the value
of the difference between tones and the temporal complexity
of the acoustic pattern (Efron, Koss, and Yund, 1983).
Bryden (personal communication, 1986) and others currently
recommend use of the simple high/low tonal stimuli pre­
sented dichotically at 1650 Hz (low) and 1750 Hz (high)
levels.

In summary, it is evident that a REA is produced in
right-handed subjects for dichotically presented verbal
stimuli, thus indicating left hemisphere specialization for
language. Although not as well documented, there appears
to be a LEA in right-handed subjects for tonal stimuli,
which is related to right hemisphere specialization for
simple acoustical sounds. The CV stimulus and high/low
tonal stimuli represent the best methods available for
assessing lateralization of these particular information
processing mechanisms. Finally, attentional techniques and the use of synthesized pairs of stimuli in the dichotic procedure help control for extraneous factors which may influence the interpretation of the lateralization results.

Limitations of the Study

There is a large body of research evidence indicating that the left and right cerebral hemispheres process information differently from each other. Noninvasive perceptual laterality techniques such as the dichotic listening procedures have been used extensively in studies investigating cerebral hemisphere asymmetry. However, it has been difficult to control for all possible extraneous factors which might influence the interpretation of perceptual laterality. This study attempted to control for subject characteristics (e.g., IQ, age, handedness, family sinistrality), attentional biasing, and type of stimuli. However, there were some factors which were beyond the scope of this study and, therefore, must be addressed as limitations.

One major limitation of this study was that only auditory asymmetries were addressed in the procedure. Although there was an attempt to investigate both verbal and nonverbal stimuli with the same subjects, no attempt was made to substantiate the laterality hypotheses through the use of techniques such as time sharing, visual half
field, or electrophysiological measures. Another limitation was that developmental factors of the subjects were not considered in terms of the design or the interpretation of the results. The decision not to examine age group differences in laterality outcomes was based primarily on a study by Hynd et al. (1979) which found no developmental trend for cerebral lateralization in 96 normal and learning-disabled children.

In addition, no attempt was made to subtype reading-disabled children, in spite of the literature which hypothesizes that the neuropsychological profiles of reading-disabled children will be very diverse. Subtyping of reading-disabled children in terms of specific neuropsychological profiles is a relatively recent development, and the methods available to subtype subjects remain untested and highly debatable. However, because the majority of reading-disabled children experience auditory-linguistic problems, this deficit was selected as a criteria for subject selection in the study.

In an attempt to determine familial sinistrality for handedness, information on hand preference of immediate and extended family was included on the parent permission form (Appendix B). The accuracy of such written reports might be considered suspect and is another limitation of the study. Formal interviews with the subject's family and
actual testing of handedness (especially left-handed persons) would have been preferred but was eliminated in the design due to time constraints. Finally, the data collected in the study were treated only as group data, although some researchers (e.g., Bryden and Sprott, 1981) stress the importance of measuring individual differences in the magnitude of laterality.

Hypotheses and Statistical Analysis

The following null hypotheses were tested in an examination of the effects of directed attention and verbal and nonverbal stimuli on the lateralized performance in dichotic listening tasks between left- and right-handed good readers and reading-disabled children.

$H_1$ - There will be no significant difference in ear report in the free recall and directed attention conditions between good reader and reading-disabled right-handed children for CV stimuli.

$H_2$ - There will be no significant difference in ear report in the free recall and directed attention conditions between good reader and reading-disabled left-handed children for CV stimuli.
H₃ - There will be no significant difference in ear report in the free recall and directed attention conditions between right- and left-handed good readers for CV stimuli.

H₄ - There will be no significant difference in ear report in the free recall and directed attention conditions between right- and left-handed reading-disabled children for CV stimuli.

H₅ - There will be no significant difference in ear report across conditions and groups for CV stimuli.

H₆ - There will be no significant difference in ear report in the free recall and directed attention conditions between good reader and reading-disabled right-handed children for tonal stimuli.

H₇ - There will be no significant difference in ear report in the free recall and directed attention conditions between good reader and reading-disabled left-handed children for tonal stimuli.

H₈ - There will be no significant difference in ear report in the free recall and directed attention conditions between right- and left-handed good readers for tonal stimuli.
H9 - There will be no significant difference in ear report in the free recall and directed attention conditions between right- and left-handed reading-disabled children for tonal stimuli.

H10 - There will be no significant difference in ear report across conditions and groups for tonal stimuli.

The ten hypotheses were analyzed using a 4 (group) X 3 (dichotic conditions) X 2 (ears) factorial analysis of variance with repeated measures on the last two factors. This analysis was used separately for both the CV and tonal stimuli. The correct right ear and left ear scores were converted to correct mean percentage scores. A probability level of .05 was used to determine statistical significance for the acceptance or rejection of the null hypotheses. The Tukey post-hoc test for pairwise analyses was employed for significant interactions with < .05 probabilities for significance. The Tukey procedure was selected because it provides familywise (FW) and alpha control when all of the pairwise comparisons are being conducted (Keppel, 1982). The analyses were conducted using the Biomedical Data Processing program (BMDP8V - Analysis of Variance - Equal Cell Size Mixed Models) developed at the University of California.
CHAPTER 3
RESULTS

This chapter will present descriptive statistics as well as results from the three-factorial analysis of variance procedure. The factors in the analysis included ear report (left ear, right ear), conditions of directed attention (free recall, directed left, directed right), and subject groups (left- and right-handed good readers, left- and right-handed reading disabled). Two separate analyses of variance with repeated measures on the ear and condition factors were calculated for the verbal and nonverbal stimulus presentations. Results from the analyses will be used to test the hypotheses concerning differences in ear report between left- and right-handed good readers and learning-disabled children under the various focused attention conditions. These results will be presented by stimulus condition.

**Consonant-Vowel Stimuli**

Table 2 contains the mean percentage scores of left and right ear report by group and dichotic listening condition when subjects were presented with the consonant-
Table 2. Mean Percentage of Left Ear and Right Ear Correct Report by Dichotic Listening Condition and CV Stimuli with Left- and Right-Handed Good Readers and Reading-Disabled Children (N = 60).

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Free Recall</th>
<th>Directed Left</th>
<th>Directed Right</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Right-Handed Good Readers</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>M</td>
<td>29.07</td>
<td>29.40</td>
<td>31.33</td>
</tr>
<tr>
<td>SD</td>
<td>6.94</td>
<td>9.96</td>
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</tr>
<tr>
<td>Left-Handed Good Readers</td>
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<tr>
<td>M</td>
<td>44.93</td>
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<tr>
<td>SD</td>
<td>9.51</td>
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<tr>
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<td>38.53</td>
</tr>
<tr>
<td>SD</td>
<td>8.66</td>
<td>9.23</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
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<td>50.07</td>
</tr>
<tr>
<td>SD</td>
<td>8.63</td>
<td>8.11</td>
<td>7.76</td>
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vowel (CV) stimuli. Ear advantage, as reported by percentage scores, was analyzed using a 4 (groups) x 3 (conditions) x 2 (ears) ANOVA with repeated measures on the last two factors. The analysis, as reported in Table 3, revealed one main effect, two two-way interactions, and one three-way interaction. Post hoc pairwise comparisons were employed using Tukey tests with significance levels set at \( p < .05 \). All null hypotheses for CV stimuli, as stated in Chapter 2, were rejected. The following discussion will address Hypotheses 1 through 5.

A main effect for ear, \( F(1,56) = 7.34, p < .01 \), indicated that there was a right ear advantage (REA) across groups and dichotic conditions for CV stimuli. The REA suggests that the left hemisphere was dominant in the processing of verbal stimuli as was expected.

Significant two-way interactions were found between group and ear, \( F(3,56) = 20.65, p < .001 \), and between condition and ear, \( F(2,112) = 71.23, p < .001 \). Although the results of these two-way interactions suggest that there are differences in ear report across conditions and groups, it is important to consider these interactions within the context of the three-way interaction.

The significant three-way interaction among group, condition, and ear, \( F(6,112) = 5.56, p < .001 \), was most critical in understanding the differences in verbal
Table 3. Analysis of Variance - CV Stimuli.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
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<th>F</th>
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</thead>
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</tr>
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<td>Subject (Group)</td>
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<tr>
<td>Condition</td>
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<td>.01</td>
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<tr>
<td>Ear</td>
<td>1</td>
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</tr>
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<td>Group x Condition</td>
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<tr>
<td>Group x Ear</td>
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<td>4912.6</td>
<td>20.65**</td>
</tr>
<tr>
<td>Condition x Ear</td>
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<td>3615.9</td>
<td>71.23**</td>
</tr>
<tr>
<td>Group x Condition x Ear</td>
<td>6</td>
<td>282.43</td>
<td>5.56**</td>
</tr>
<tr>
<td>Subject x Condition (Group)</td>
<td>112</td>
<td>24.071</td>
<td></td>
</tr>
<tr>
<td>Subject x Ear (Group)</td>
<td>56</td>
<td>237.85</td>
<td></td>
</tr>
<tr>
<td>Subject x Condition x Ear (Group)</td>
<td>112</td>
<td>50.767</td>
<td></td>
</tr>
</tbody>
</table>

*p < .01  
**p < .001
processing across groups and conditions. This interaction suggests that left and right ear reports were different for the four groups and varied across the three conditions. These results are presented for each group in the following discussion and are displayed graphically in Figure 1.

Right-Handed Good Readers

Analysis of simple effects, as displayed in Figure 1, revealed that right-handed good readers produced a consistent REA across conditions of free recall, $\bar{d}_T(24,112) = 20.53, p < .02$, directed left, $\bar{d}_T(24,112) = 12.34, p < .02$, and directed right, $\bar{d}_T(24,112) = 22.00, p < .01$. This strong REA across conditions indicated that the left hemisphere was more efficient in processing verbal stimuli and that attentional manipulations did not increase the processing efficiency of either hemisphere in this population.

Left-Handed Good Readers

Analysis of simple effects, as displayed in Figure 1, suggested that left-handed good readers produced a left ear advantage (LEA), or right hemisphere processing, for CV stimuli in free recall, $\bar{d}_T(24,112) = 11.13, p < .01$ and in the directed left condition, $\bar{d}_T(24,112) = 16.2, p < .01$. A nonsignificant REA shift in attention was noted in the
Figure 1. Left and Right Ear Reports for CV Stimuli by Group and Verbal Cuing Conditions.
directed right condition, $\overline{d}_T(24,112) = 2.6$ N.S. Although this group of children did not show significant differences in RE report across conditions, their LE report was significantly greater in the directed left condition when compared to the directed right condition, $\overline{d}_T(24,112) = 9.47$, $p < .05$. It appeared that left-handed good readers demonstrated a LE performance bias, or right hemisphere processing, for verbal stimuli except in the directed right condition. These subjects were able to increase their RE responses when cued to the right to a degree that there was no ear difference between LE and RE performance. Although only a nonsignificant shift in attention, this increased RE report suggests that attentional manipulation may be responsible for the increased efficiency of the left hemisphere in the directed right condition.

Right-Handed Reading Disabled

Analysis of simple effects, as displayed in Figure 1, revealed that right-handed reading-disabled children produced a REA, or left hemisphere processing, in free recall, $\overline{d}_T(24,112) = 21.6$, $p < .01$, and in the directed right condition, $\overline{d}_T(24,112) = 27.33$, $p < .01$. A nonsignificant LEA shift in attention was noted in the directed left condition, $\overline{d}_T(24,112) = .93$ N.S. This group of children significantly increased their LE report from
free recall to directed left, $\overline{d}_T(24,112) = 10.73$, $p < .01$, which resulted in no ear differences between LE and RE performance in the cued left condition.

Therefore, right-handed reading-disabled children produced a strong REA for verbal stimuli much like the right-handed good readers in the free recall and directed right conditions. However, they were able to shift attention to the right hemisphere in the directed left condition. Although only a nonsignificant shift was shown, this increased LE report suggests that attentional factors increased the efficiency of right hemisphere processing for verbal stimuli in the right-handed reading-disabled group.

Left-Handed Reading Disabled

Analysis of simple effects, as displayed in Figure 1, suggested that left-handed reading-disabled children produced a LEA, or right hemisphere processing, in free recall, $\overline{d}_T(24,112) = 12.06$, $p < .01$, and in the directed left condition, $\overline{d}_T(24,112) = 22.14$, $p < .01$. A nonsignificant REA shift in attention was noted in the directed right condition, $\overline{d}_T(24,112) = 8.73$ N.S., which parallels the findings for left-handed good readers. This group of children significantly increased their RE report from free recall to directed right, $\overline{d}_T(24,112) = 9.86$, $p < .05$, and from directed left to directed right, $\overline{d}_T(24,112) = 17.8$, $p$
which resulted in no ear differences between LE and RE performance in the cued right condition.

Comparison of groups revealed that both left-handed sample groups were LE dominant for verbal stimuli in free recall and directed left and were able to direct auditory attention to the right ear, producing a nonsignificant shift toward a RE report. The groups differed in that the reading-disabled subjects were able to shift their attention to a greater degree in the directed right condition, thus producing more RE reports. Their performance more nearly parallels the right-handed reading-disabled subjects in that they both produced significant shifts in attention from the free recall condition to the directed attention condition which activated their nondominant hemisphere. These findings suggest that reading-disabled children, in general, are more susceptible to verbal manipulations as they process verbal stimuli.

**Tonal Stimuli**

Table 4 contains the mean percentage scores of left and right ear report by group and dichotic listening condition when subjects were presented with the tonal stimuli. Ear advantage, as reported by percentage scores, was analyzed using a 4 (groups) x 3 (conditions) x 2 (ears) ANOVA with repeated measures on the last two factors. The analysis, as reported in Table 5, revealed one main effect
Table 4. Mean Percentage of Left Ear and Right Ear Correct Report by Dichotic Listening Condition and Tonal Stimuli with Left- and Right-Handed Good Readers and Reading-Disabled Children (N = 60).

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Free Recall</th>
<th>Directed Left</th>
<th>Directed Right</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td><strong>Groups</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right-Handed</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Good Readers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>68.67</td>
<td>31.27</td>
<td>64.00</td>
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<tr>
<td>Left-Handed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good Readers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>48.80</td>
<td>51.20</td>
<td>56.87</td>
</tr>
<tr>
<td>SD</td>
<td>18.91</td>
<td>18.91</td>
<td>24.40</td>
</tr>
<tr>
<td>Right-Handed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading Disabled</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>61.67</td>
<td>38.33</td>
<td>63.20</td>
</tr>
<tr>
<td>Left-Handed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading Disabled</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>59.53</td>
<td>40.47</td>
<td>61.87</td>
</tr>
<tr>
<td>SD</td>
<td>11.19</td>
<td>11.19</td>
<td>10.20</td>
</tr>
</tbody>
</table>
Table 5. Analysis of Variance - Tonal Stimuli.

<table>
<thead>
<tr>
<th>Source</th>
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<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
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<td>Group</td>
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<td>.2250</td>
<td>1.59</td>
</tr>
<tr>
<td>Subject (Group)</td>
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<td>.14167</td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>2</td>
<td>.1000</td>
<td>.71</td>
</tr>
<tr>
<td>Ear</td>
<td>1</td>
<td>30932</td>
<td>22.11**</td>
</tr>
<tr>
<td>Group x Condition</td>
<td>6</td>
<td>.1000</td>
<td>.71</td>
</tr>
<tr>
<td>Group x Ear</td>
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<td>1.55</td>
</tr>
<tr>
<td>Condition x Ear</td>
<td>2</td>
<td>749.88</td>
<td>4.43*</td>
</tr>
<tr>
<td>Group x Condition x Ear</td>
<td>6</td>
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<td>1.81</td>
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<tr>
<td>Subject x Condition (Group)</td>
<td>112</td>
<td>.14167</td>
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<tr>
<td>Subject x Ear (Group)</td>
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<td></td>
</tr>
<tr>
<td>Subject x Condition x Ear (Group)</td>
<td>112</td>
<td>169.33</td>
<td></td>
</tr>
</tbody>
</table>

*p < .01  **p < .001
and one two-way interaction. Post hoc pairwise comparisons were employed using Tukey tests with significance levels set at \( p < .05 \). All null hypotheses for tonal stimuli, as stated in Chapter 2, were accepted. The following discussion addresses Hypotheses 6 through 10.

A main effect for ear, \( F(1,56) = 22.11, p < .001 \), indicated that there was a LEA across groups and conditions for tonal stimuli. The LEA suggests that the right hemisphere was dominant in the processing of nonverbal stimuli as was hypothesized.

A significant two-way interaction was found between condition and ear, \( F(2,112) = 4.43, p < .01 \). This interaction demonstrates the significant LEA in free recall, \( \bar{dT}(6,112) = 19.35, p < .01 \), directed left, \( dT(6,112) = 23.08, p < .01 \), and directed right conditions, \( \bar{dT}(6,112) = 13.18, p < .01 \). The largest between-ear difference was found in the directed left condition, which suggests that the right hemisphere was enhanced slightly, but not significantly, while the left hemisphere was suppressed. The results dramatically show that the tonal stimuli used in this study was processed almost exclusively by the right hemisphere in all subjects and under all conditions. These conclusions indicate that reading ability, handedness, and verbal cuing had no significant impact on the processing of simple tonal information by the right hemisphere.
Summary

This chapter presented the findings of the statistical analyses of the data collected for this investigation. The three-factorial ANOVA conducted with the CV stimuli revealed one main effect for ear and two significant two-way interactions for group x ear and condition x ear. Of primary importance was the significant three-way interaction among group x condition x ear.

When examining the CV stimuli results, the major findings included an overall REA (left hemisphere processing) for right-handed good readers and reading-disabled children and a LEA (right hemisphere processing) for left-handed good readers and reading-disabled children. The right-handed good readers were the only group to maintain a consistent ear report (REA) across all conditions.

As a group, the left-handed good readers showed a LEA during the free recall and directed left conditions and had a nonsignificant REA trend in the directed right condition. These findings suggest that left- and right-handed good readers process language-based information in opposite hemispheres but that the left-handed group is able to direct attention to the nondominant hemisphere (left) when given simple verbal cues.

The right-handed reading-disabled group produced a strong REA for verbal stimuli in the free recall and
directed right conditions but were able to shift their attention and report more left-ear stimuli in the directed left condition. Although it did not result in a significant LEA overall, this group's LE report was significantly higher for the directed left condition than in the free recall condition. These findings suggest that right-handed reading-disabled subjects are also susceptible to manipulation of attention.

Left-handed reading-disabled subjects, like their other left-handed counterparts, demonstrated a LEA for verbal stimuli in the free recall and directed left conditions. They were also able to shift their attention to the right ear during the directed right condition. The results of the analyses indicated that the two left-handed groups were remarkably similar in ear report but that the reading-disabled children were somewhat more successful in reporting right ear CV stimuli in the directed right condition. although not statistically determined, Figure 1 also indicates that the left-handed groups were not as strongly lateralized as the right-handed groups in the free recall condition.

Examination of the three-way ANOVA conducted with the tonal stimuli revealed one main effect for ear and a significant two-way interaction for condition x ear. The strong main effect for ear suggests a LEA, right hemisphere
processing, across groups and condition for tonal stimuli. The two-way interaction revealed a slightly larger between-ear difference in the directed left condition. However, there was a significant LEA in all three conditions. These results indicate that tonal stimuli are produced in the right hemisphere by nearly all subjects and are not affected by verbal cuing, reading ability, or handedness.
CHAPTER 4

DISCUSSION

This chapter will discuss the relationship of previous research findings and theoretical postures to the results derived from this study. The outcomes from this investigation will also be discussed in terms of methodological, theoretical, and practical implications. Finally, recommendations for future research will be proposed.

Purpose of the Study

The purpose of this study was to investigate the differences in cerebral lateralization of verbal and nonverbal stimuli between left- and right-handed good readers and reading-disabled children. A dichotic listening paradigm was employed which utilized directed attention conditions with consonant-vowel (CV) and tonal stimuli. Particular attention was given to determining the most effective combination of stimulus type and directed attention condition on the cerebral laterality of the four groups.

A number of theories have been generated to explain the differences in cerebral asymmetries for verbal and
nonverbal information. However, there has been little consensus among researchers in terms of a single, viable model which explains functional laterality in humans. Further, models describing the learning-disabled child or the effects of handedness on laterality issues in children have been controversial and inconclusive. Therefore, this study was designed to clarify further major theoretical issues and to provide initial results on the cerebral lateralization of left- and right-handed good readers and reading-disabled children when presented verbal and nonverbal information through a dichotic listening procedure.

Summary of Results

Auditory asymmetries were the perceptual modality examined in this study. Laterality was inferred by measurement of left ear (i.e., right hemisphere processing) and right ear (i.e., left hemisphere processing) reports. Laterality differences between left- and right-handed good readers and left- and right-handed reading-disabled children will be presented in the following discussion with particular attention given to the asymmetries resulting from changes in stimulus and directed attention conditions.
Right-Handed Good Readers

The overall results from this study indicated that right-handed good readers produced a consistent REA for CV stimuli across conditions. This significant REA suggests that the left hemisphere was more efficient than the right hemisphere in processing verbal stimuli. This finding is consistent with previous dichotic listening studies employing children as subjects (e.g., Obrzut et al., 1980; Obrzut et al., 1981). Verbal cuing produced no significant change in ear report which lends support to the theory of overall right ear bias in the processing of verbal stimuli and is consistent with previous dichotic studies using verbal cuing with children (e.g., Obrzut et al., 1983; Obrzut et al., 1985). These results further support Kinsbourne and Hiscock's (1981) contention that there is a concurrent and unrelenting suppression of the right hemisphere when linguistic material is presented auditorily. The REA produced by these right-handed good readers is consistent with the theoretical position that verbal or language-based information presented auditorily travels from the right ear to the contralateral left hemisphere more rapidly than it does to the ipsilateral right hemisphere where it is processed and interpreted (Kimura, 1961a, b; Bryden, 1982).
When tonal stimuli were presented to this group, there was a consistent LEA reported across conditions. This significant LEA suggests that the right hemisphere was more efficient than the left hemisphere in processing simple tonal stimuli. This finding is comparable to several previous dichotic pitch recognition studies using right-handed adults (Sidtis, 1981; Gregory, 1982; Efron et al., 1983). Examination of individual results showed that fourteen children reported LE stimuli consistently across conditions, while one child reported RE stimuli in all conditions. However, the overall percentages for this group, 93 percent LEA and 7 percent REA, are much higher than those previously reported by Gregory (1982) where of 222 subjects, 75 percent were LE dominant and 20 percent were RE dominant.

Verbal cuing during the tonal task produced no significant changes in ear report which lends support to the theory of overall LE bias in the processing of dichotically presented tonal stimuli. No previous studies have employed the directed attention paradigm, therefore, these are initial and important results. Additionally, this is the first study to investigate ear dominance for pitch in child populations. The consistent LEA produced by these right-handed good readers supports the theoretical position that there may be anatomical and functional
asymmetries in the primary and auditory association cortex which results in hemispheric specialization directed toward the right hemisphere when subjects are presented with a dichotic pitch recognition task. The individual differences which are evident in this study and previous experiments may be related to what Efron et al. (1983b) call second- and third-order anatomical and functional brain asymmetries.

Left-Handed Good Readers

Results from this study indicated that left-handed good readers with sinistral relatives produced a consistent LEA (right hemisphere processing) for CV stimuli in the free recall and directed left conditions. However, they were able to shift their attention to the RE during the directed right condition, thus producing no ear differences between LE and RE performance. Unlike the right-handed good reader results, these findings suggest that left and right hemisphere processing varied significantly depending upon the attentional variables. Obrzut et al. (1986b) also reported a LEA in strongly left-handed good readers for dichotically presented verbal stimuli and found that they were susceptible to attentional shifting in the directed right condition. Therefore, right hemisphere processing of language among left-handed good readers may be related to attentional strategies or manipulation. As a group, the
left handers were able to willingly attend to verbal stimuli received in their nondominant ear which suggests greater flexibility or malleability in cortical functioning than was found in the right-handed good reader group.

The results of this investigation also support earlier studies which found that a large proportion of left-handed adults are either bilateralized or right hemisphere dominant for language function (Rasmussen and Milner, 1975; Bryden, 1982). Additionally, Demarest and Demarest (1981) reported that left handers with familial sinistrality exhibited this reversed laterality on dichotic words tasks. The present study further suggests that right hemisphere dominance for language (LEA) is related to strength of handedness and familial sinistrality and that left handers, as a group, are more susceptible to attentional bias than are their right-handed counterparts. These findings, which replicate the Obrzut et al. (1986b) study, also lend support to the attentional theory of cerebral lateralization (Kinsbourne, 1970) and suggest that each cerebral hemisphere can be activated by directing attention to the contralateral sensory field. Although no strong theoretical position is proposed in the literature, this sensitivity to attentional strategies may be interpreted as resulting from the bilateral representation of language functioning in strongly left-handed subjects.
When tonal stimuli were presented to this group, there was a consistent LEA reported across conditions, suggesting right hemisphere processing. These findings are consistent with previous studies of right-handed adults which utilized the tonal stimuli paradigm (e.g., Efron et al., 1983b). However, no studies have attempted to investigate handedness as a factor in nonverbal auditory processing. The present study indicates that thirteen of the fifteen left-handed good readers (86 percent) reported LE stimuli consistently across conditions, while two subjects (14 percent) reported consistent RE stimuli in all conditions. It is unclear from these results whether handedness was a significant factor in the two cases of reversed cerebral dominance for nonverbal tonal stimuli or whether these children fell in the approximated 20 percent of all subjects, right- or left-handed, reporting REA for tonal stimuli found in the Gregory (1982) investigation. Nonetheless, it is noteworthy that these two individuals appeared to demonstrate reversed dominance for both lower-order verbal (LEA) and tonal (REA) stimuli. According to Efron et al. (1983b), individual deviations such as these may be genetically predetermined. The remaining thirteen subjects reported LEA in both verbal and nonverbal experimental conditions, which suggests increased capacity of the right hemisphere in verbal and nonverbal cognitive
functioning. This finding separates the group dramatically from their right-handed good reader counterparts.

Right-Handed Reading Disabled

The right-handed reading-disabled group did not demonstrate a consistent REA across all experimental conditions as did their right-handed good reader counterparts. These results indicated that left and right hemisphere processing varied depending on the attentional conditions. This group produced a strong REA for CVs in the free recall and directed right conditions but were able to shift attention toward the right hemisphere in the directed left condition. Previous studies of learning-disabled children have also found that this group is able to shift attention to the left ear in a dichotic experiment (e.g., Obrzut et al., 1983; Obrzut et al., 1985). However, the present study did not demonstrate a significant shift in attention, as was found in these earlier studies, but showed equal, simultaneous involvement from both left and right hemispheres in the directed left condition. Two recent studies of identical design have also found this nonsignificant leftward shift in attention (Boliek, 1986; Obrzut et al., 1986b). Perhaps the variability in results across studies may partially be due to the heterogeneity of most reading-disabled groups.
Response to dichotically presented tonal stimuli resulted in a consistent LEA across conditions. Unlike those results reported for the CV stimuli, no shifting of attention in directed conditions was noted. This strong LEA suggests that the right hemisphere was more efficient than the left hemisphere in processing simple tonal stimuli and that this population is not susceptible to attentional shifts when presented with right hemisphere tonal tasks. Unlike the two good reader groups, all fifteen right-handed reading-disabled subjects were LE dominant for tones, which supports the theoretical position that there may be functional and anatomical asymmetries in the auditory cortex which provide for interpretation of dichotic pitch tasks in the right hemisphere. Although only initial findings are presented, this study further proposes that right-handed reading-disabled subjects and left- and right-handed good reader subjects do not differ in right hemisphere (nonverbal) processing of simple tones. While the groups may differ dramatically in left hemisphere functioning, their right hemisphere abilities appear similar and seem unaffected by auditory problems of a linguistic nature. These findings are in contrast to those of Witelson (1976) who found a lack of right hemisphere specialization for spatial processing and deficient left
hemisphere processing of linguistic stimuli in dyslexic boys.

Left-Handed Reading Disabled

Initial results from this anomalous group reveal a consistent LEA (right hemisphere processing) for CV stimuli in the free recall and directed left conditions. Like their left-handed good reader counterparts, the reading-disabled group was able to shift their attention to the RE during the directed right condition, thus producing no ear differences between LE and RE performance. However, this shift in attention produced more RE reports than were found in the good reader group. This demonstrated ability to shift attention at a consistently high level from the free recall to the directed attention condition, which activates the nondominant hemisphere, more nearly parallels the results from the right-handed reading-disabled subjects, albeit in the opposite direction. Although verbal processing appears to be primarily represented in the right hemisphere, this group was equally sensitive to attentional strategies, as were their right-handed reading-disabled counterparts. Therefore, it follows that this group's results may be interpreted similarly. Reading-disabled children, in general, appear to be more susceptible to attentional strategies which "may suggest a weaker underlying structure and a lesser ability to suppress the
nondominant hemisphere when required" (Boliek, 1986, p. 118).

Investigation into the nonverbal processing of left-handed reading-disabled children resulted in the same consistent LEA across conditions, which was also reported for the three previous groups. Again, no shifting of attention in the directed conditions was noted, and the results suggest that the right hemisphere was more efficient than the left hemisphere in processing simple tonal stimuli. These findings across groups suggest that certain portions of the brain may perform qualitatively different functions which cannot be performed by the contralateral side and generally support structural and functional theories of brain organization for the processing of nonverbal stimuli. On an individual subject basis, no reversals in hemispheric process of verbal and nonverbal stimuli were found in this left-handed group. The results generally support the position that there is an increased capacity within the right hemisphere of left-handed subjects to process both verbal and nonverbal information.

Summary

The conclusions which are made on the basis of the results from this study apply to the described populations in the investigation and can be summarized as follows:
Right-handed good readers demonstrated a REA for CV stimuli across all conditions. This group appears to be strongly lateralized to the left hemisphere for verbal stimuli and is resistant to attentional manipulation. In contrast, the left-handed good readers produced a LEA for verbal stimuli in the free recall and directed left conditions. This performance suggests that they are lateralized to the right hemisphere for some language function. However, this group was able to shift their attention to the right ear during the directed right condition which resulted in nearly equivalent left and right hemisphere processing. These results support earlier research findings and indicate that strongly left-handed children with sinistral relatives may be bilateralized for language function.

Right-handed reading-disabled children showed a REA for CV stimuli in the free recall and directed right conditions but were able to direct attention slightly to the LE during the directed left condition. This group appears to be lateralized to the left hemisphere for verbal stimuli but is susceptible to attentional manipulation. The left-handed reading-disabled children displayed similar shifts in attention but were more strongly lateralized to the right hemisphere for language function. These results indicate that reading-disabled children, regardless of hand
dominance, may have difficulty suppressing the nondominant hemisphere when attentional manipulation is used.

All subject groups demonstrated a strong LEA for tonal stimuli across all conditions. This lateralization to the right hemisphere for simple tone processing is supported in the adult literature. Right hemisphere tasks also appear less susceptible to attentional manipulation and do not appear related to handedness or reading ability.

**Theoretical Implications**

The results from the present study indicate that right-handed good readers have a strong underlying structure for processing language-based information in the left hemisphere. Their left-handed counterparts appear to have reversed hemispheric dominance for verbal processing (right hemisphere) but additionally have the capacity to utilize both hemispheres when their attention is directed. Because these children are doing well in academic endeavors, there is no indication that this bilateralization in any way interferes with their ability to process verbal information.

Left- and right-handed reading-disabled children presented a more dynamic processing system where both hemispheres were involved in processing verbal stimuli. The results from this study suggest that the dominant hemisphere for language was often not able to suppress the
nondominant hemisphere, thus resulting in a lack of consistent lateralization. This weaker system perhaps influences the normal processing ability for verbal information and results in more academic problems for this group of children.

The outcomes from this study also provide theoretical implications in the neuropsychological functioning of the four groups of children. The results dramatically separate the right-handed good readers from the other groups in terms of their consistent ear report across directed attention conditions for CV stimuli. The findings lend additional support to Kimura's (1961a, b) structural theory of lateralization and Kinsbourne's (1970) attentional model, whereby the presentation of stimuli activates the appropriate hemisphere and thus biases attention to the contralateral side of space. The results from the tonal stimuli across all four groups also support these theoretical positions in that the right hemisphere is structurally prewired to interpret simple pitch discriminations.

Examination of the findings from the remaining three groups (left-handed good readers, left- and right-handed reading disabled) suggests that their performances during the CV experiment were perhaps varied as a result of either their handedness or reading ability. Although all three groups were able to direct attention to their
nondominant hemisphere for language, the explanation for this shift in processing is perhaps different for the groups.

Demarest and Demarest (1981) recently concluded from their review of the literature that left handers, as a group, are less predictable than right handers on verbal dichotic tasks. Dee (1971) reported that left handers with sinistral relatives exhibited LE preferences on dichotic listening tasks without directed attention conditions. Other researchers have concluded that left handers with a family history of left handedness are the most bilaterally organized (Hecaen and Sauget, 1971; Sheehan and Smith, 1986). Because of the many methodological problems in prior handedness studies, the only significant conclusion which can be made is that there is a continuum of lateralization from highly lateralized to bilateralized cerebral organization in left-handed normal subjects. The present investigation provides important information on the auditory processing of two separate groups of left handers who differ only in their ability to perform academically on reading tasks. Because both groups were determined to be strongly left handed and had sinistral family members, the findings may help to delineate further the factors affecting auditory processing of information.
The present study replicates the recent study by Obrzut et al. (1986) which found a LEA in left-handed good readers but additionally noted a susceptibility to attentional shifting. The present left-handed good readers demonstrated a laterality pattern suggesting activation of the right hemisphere for verbal processing in two conditions but increased left hemisphere functioning in the directed left condition. The available literature would appear to support the interpretation of these results as an example of bilateral cerebral organization of verbal processor capabilities, although the results from both of these related studies conclude that these children are more lateralized to the right than to the left when given CV stimuli. This greater flexibility in the processing of verbal information separates the group dramatically from their right-handed counterparts.

The left- and right-handed reading-disabled children demonstrated nearly identical patterns of verbal processing, although their dominant hemisphere for language was reversed. Both reading-disabled groups were able to activate their nondominant and generally showed a more dynamic cortical system than did their right-handed good reader counterparts. These findings generally support the attentional theory presented by Kinsbourne (1970) and provide additional support for the Hynd et al. (1979) and
Obrzut et al. (1981) hypothesis that learning-disabled children have difficulty suppressing their nondominant hemisphere, thus resulting in a division of attention between the two hemispheres. Unlike the left-handed good readers, who demonstrated more bilateral auditory processing abilities, these reading-disabled children may not be able to interpret accurately and encode verbal information because of their lack of functional autonomy between the hemispheres.

Finally, this study has provided initial findings on the nonverbal processing of anomalous groups of children. It is particularly important to stress the lack of significant differences between groups and the overall LEA for tonal stimuli. While previous dichotic studies have shown significant differences in the auditory processing of verbal information between good readers and reading-disabled children, this study hypothesizes that right hemisphere processing is generally unaffected by left hemisphere dysfunction and that neither handedness nor attentional manipulation affects these results for any of the groups. This strongly suggests that the source of the reading-disabled child's difficulties may be primarily in the inability of the left hemisphere to assume its dominant role in the processing of verbal information.
Recommendations for Future Research

The effects of handedness and patterns of cerebral organization on dichotic listening performance in children have been noticeably absent in the literature. This study provided initial results for left-handed reading-disabled children and the first replication of findings for the left-handed good reader group. Because the CV results were so similar for both left-handed groups, further investigations should be designed to examine possible structural and functional brain organizational differences between these groups. Additionally, examination of processing differences between consistent and inconsistent left-handed children and those with or without left-handed relatives may provide additional information. Incorporation of an electrophysiological experiment with the dichotic listening procedure also appears promising. This would provide a more direct, physiological measurement of the subject's auditory functioning.

Revision of the tonal task used in this study is recommended before replication. Extension of the interpair stimulus interval from three to six seconds is required. The addition of two similar tonal stimuli (high-high and low-low) would provide four potential responses and would increase the reliability and validity of the task. Forty-five to sixty monaural trials seem necessary for most child
subjects, and extension of the dichotic presentations from thirty to ninety appears warranted.
APPENDIX A

PARENTAL CONSENT FORMS
Informed Consent

Dear Parent:

There will be a research project entitled "Verbal and Nonverbal Auditory Processing Among Right- and Left-Handed Children" conducted in the District using elementary school children. The purpose of the study is to examine how children who are right- and left-handed good readers or reading disabled process both language and nonlanguage-based information. The project will also investigate how certain attentional strategies can help children learn school-related material.

The process involves having the children listen to a tape with earphones. The tape will consist of simple verbal sounds like ba, ca, and da, as well as high and low tones. These verbal and nonverbal sounds will be presented in pairs with one word or tone sequence presented to the right ear and another word or tone sequence presented to the left ear at the same time via headphones. Because the stimuli are presented at the same time, what sound the child recalls measures attention and information processing. Children will be given specific instructions as they listen and will be required to report what sounds he/she hears.

All testing will be done in the school building where the children attend class and will require approximately one hour of the child's time. The researcher will schedule this time so as to minimize disruption of the daily classroom instructional process. In addition, the procedures described above do not involve any physical risks or discomfort to the children as they participate.

Children in the study will not be identified individually in any way, and individual performance will be kept confidential. The results of the study will be presented as group results in summary form to the district.

The investigators will answer any inquiries that parents may have concerning the study and/or procedures. Participation of children in the study is voluntary, and lack of participation or withdrawal of a child from the study will not in any way affect his/her educational treatment or status.

Names:  Dr. John E. Obrzut, Ph.D.
         Mrs. Pamela Conrad, Doctoral Student
         UNIVERSITY OF ARIZONA
Phone:   621-7829
APPENDIX B

PARENT PERMISSION FORM
PERMISSION SLIP

I have read the attached research procedures and purposes and hereby consent to the participation of my son/daughter, ________________________, in this study. I have explained the procedures to my child, and in keeping with his/her level of understanding, he/she has agreed to participate in this study.

Please list all left-handed relatives, including immediate family members. Indicate first name and relation to your child.

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Parent or Guardian Signature

Date
APPENDIX C

DICHOTIC LISTENING TASK CV STIMULI
**CONDITION**

**DICHOTIC LISTENING TASK**

**CV STIMULI**

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APPENDIX D

DICHOTIC LISTENING TASK-TONAL STIMULI
DICHOTIC LISTENING TASK
TONAL STIMULI

Name: ___________________ School and Grade: ___________________
Subject Group: ________ Condition: ___________________

Practice (Monaural)

1. L Lo-Hi  __  19. D Hi-Lo __
2. L Hi-Lo __  20. R Lo-Hi __
3. L Lo-Hi __  21. D Hi-Lo __
4. R Hi-Lo __  22. D Hi-Lo __
5. L Lo-Hi __  23. R Lo-Hi __
   __  24. L Lo-Hi __
6. L Lo-Hi __  25. D Hi-Lo __
7. R Lo-Hi __  26. D Hi-Lo __
8. L Lo-Hi __  27. D Lo-Hi __
9. R Hi-Lo __  28. D Hi-Lo __
10. R Hi-Lo __  29. D Lo-Hi __
11. L Hi-Lo __  30. D Lo-Hi __
12. R Lo-Hi __  31. D Hi-Lo __
13. L Lo-Hi __  32. D Hi-Lo __
14. R Hi-Lo __  33. D Lo-Hi __
15. L Hi-Lo __  34. L Lo-Hi __
   __  35. L Lo-Hi __
   __  36. L Hi-Lo __

Tonal Stimuli

Dichotic

1. D Lo-Hi __  37. D Lo-Hi __
2. D Lo-Hi __  38. L Hi-Lo __
3. D Hi-Lo __  39. D Hi-Lo __
4. D Hi-Lo __  40. D Hi-Lo __
5. L Lo-Hi __  41. R Hi-Lo __
6. D Lo-Hi __  42. D Hi-Lo __
7. R Hi-Lo __  43. D Hi-Lo __
8. D Lo-Hi __  44. D Lo-Hi __
9. L Lo-Hi __  45. D Lo-Hi __
10. D Lo-Hi __  46. D Hi-Lo __
11. D Lo-Hi __  47. R Hi-Lo __
12. D Hi-Lo __  48. D Lo-Hi __
13. L Hi-Lo __
14. L Hi-Lo __
15. R Lo-Hi __
16. D Hi-Lo __
17. L Hi-Lo __
18. R Hi-Lo __
REFERENCES


