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**LA THÈSE A ÉTÉ
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A STUDY OF CEREBRAL DOMINANCE IN CHILDREN
AT 3 AGE AND 3 INTELLIGENCE LEVELS

by Allan Anderson

Thesis presented to the School of
Graduate Studies of the University
of Ottawa as partial fulfilment of
the requirements for the degree of
Doctor of Philosophy

Ottawa, Canada, 1978

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CURRICULUM STUDIORUM

Allan M. Anderson was born Dec. 26, 1944 in Windsor, Ontario, Canada. He obtained the Bachelor of Arts degree (Honours Psychology) in 1967 and the Master of Arts (Clinical Psychology) in 1968 from the University of Windsor. The title of his masters research was The Relationship Between Social Desirability and Pupillary Size.

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ABSTRACT

The present research investigated the presence of hemisphere specialization for identification of verbal (digits) and non-verbal (environmental sounds) material on dichotic listening (DL) in 5, 8 and 11 yr. olds at one of three IQ ranges (>90 , 65-80, <61). The groups of subaverage IQ were of primary interest: though age of onset and exact development of hemisphere specialization in the average child are still not definitively established, even less is known about hemisphere specialization in the intellectually subaverage.

An overall significant ear advantage was present for number of digits (right ear advantage - REA), but not for environmental sounds, identified. Further analysis revealed only the 5 and 8 yr. olds of average IQ exhibited a significant REA for digit identification, suggesting any left hemisphere specialization for digit identification on DL was confined to these two groups. However, utilizing number of subjects exhibiting ear identification asymmetries, regardless of degree, suggested alternatively: 1) some left hemisphere specialization may be present in groups of subaverage IQ without Down's Syndrome; 2) some right hemisphere speech specialization may be present in the Down's Syndrome subgroups; 3) the REA may be developing beyond the age of 5 yr.

Implications of the current findings for future research were also discussed in detail.

INTRODUCTION

The present research investigated the presence and development of hemisphere specialization for verbal and non-verbal auditory material on DL in children at two levels of subaverage intelligence without medical evidence of brain damage (three age levels selected from special classes for slow learners with Slosson IQ's in the 65-80 range* and from special schools for the mentally retarded with Slosson IQ 61). Such hemisphere specialization was also compared with children of average IQ at the same three age levels selected from regular school classes. Hemisphere specialization was measured by relative ear advantage in identifying material on DL (simultaneous presentation of material of the same general category to each ear) because DL is the most extensively researched and validated measure of cerebral dominance devised to date for use in normal populations, and is especially appropriate for the type of children selected for the study.

These questions were studied for several reasons. First, the development of hemisphere specialization for processing of verbal material in children of subaverage intelli-

*Strictly speaking, only two of the three age groups with IQ's in the 65-80 range attended special classes. However the 5 yr. olds in this IQ range who were selected from regular kindergarten classes were expressly selected because the teacher believed that such children would eventually be placed in a special class for slow learners (see appendix D for a description of information presented to kindergarten teachers to guide them in selecting candidates).

With the exception of this footnote, all notes and references for the notes will be found in appendix N.

gence has been sparsely researched, with much of the research that has been conducted being seriously flawed and limited in scope. Second, the development of hemisphere specialization for processing of non-verbal material in children of sub-average intelligence has been even less adequately researched than has the development of left hemisphere specialization. Hence, no firm (or even tentative) conclusions of any kind can be drawn concerning the presence and development of hemisphere specialization in children of subaverage intelligence. Third, research results on clinical and normal populations have been ambiguous concerning the exact age of onset and subsequent development of left hemisphere specialization in the normal child. In regard specifically to the type of material utilized in the present study to reflect the presence of left hemisphere specialization (DL of digits), the development of the type, or types, of left hemisphere specialization associated with the REA for identification of verbal material on DL has not been conclusively established. Fourth, the pattern of development of the LEA for identification of non-verbal material on DL, and any related right hemisphere specialization, requires replication in the normal child at a young age (e.g. below 9 yr. of age) and study of any kind in the older normal child.

Thus, to investigate the development of hemisphere specialization for processing verbal and non-verbal auditory input in children of subaverage intelligence and to compare such development with children of average intelligence, relative ear differences in identification of digits and

environmental sounds on DL were studied in relation to chronological age and intelligence level. Nine age - IQ range groups were formed by selecting ten children at each of three IQ ranges and each of three age levels.

The present study will thus explore the development of ear asymmetries in children at two levels of subaverage intelligence with intact brains and compare this development with children of average intelligence. Due to the inconclusive nature of cerebral dominance research in the intellectually subaverage, the present study will be largely exploratory, with emphasis on the testing of absence of differences (null hypothesis) in ear asymmetries in children of average vs. subaverage intelligence.

Chapter I begins with a brief historical introduction and a description of some prominent conceptualizations of cerebral dominance. Clinical and experimental data in adults concerning the specialized nature of each hemisphere for the processing of certain types of input is then described, followed by discussion of the pertinent hemispheric literature in various child populations. The literature reviewed to that point is then summarized, prior to an entire section devoted to the employment of DL as a measure of cerebral dominance in general terms, and specifically concerning the types of children studied. A concluding section presents a rationale for, and a description of, the research problems to be investigated.

The second chapter outlines the sample, the instruments, the experimental procedures and the statistics employed in the

analysis of the data.

The third chapter presents the results with the verbal measure, followed by analysis of the data derived from the non-verbal measure.

The fourth and final chapter discusses the results with the verbal and non-verbal measure, and concludes with a general discussion of the implications of the present results for future research.

CHAPTER I

REVIEW OF THE LITERATURE

This chapter reviews the vast literature with adult and child populations and the extensive theorizing pertaining to such literature that have provided the background to the formulation of the current research.

Section A presents a brief historical introduction and some prominent conceptualizations of cerebral (functional hemispheric) dominance that have been forwarded. A sampling of research with clinical and normal adult populations that suggests the specialized nature of the left and the right hemisphere for the processing of certain types of information is provided in section B. Section C reviews research relevant to the development of such specialized hemispheric functioning in childhood, and its possible variation in development in children with language disorders and in children of subaverage intelligence. A summary of research reviewed to that point (section D) precedes a discussion of the dichotic listening technique (DL) as a measure of cerebral dominance (section E). The chapter concludes with a rationale for, and description of, the problems to be investigated (section F).

A. Historical Introduction and Conceptualizations of Cerebral Dominance

1. Historical Introduction

The study of brain-behaviour relationships has a lengthy history. For example, Benton (1964a) noted a reference to aphasia¹ as early as 3000 B.C. and pinpointed the beginning of its study to the writings of Hippocrates, 2500 years ago.

Dax is credited by some as first to note the association between specific lesions of the brain (i.e., left hemisphere lesions) and the presence of aphasia (Benton, 1964a; Goodglass & Quadfasel, 1954).² Since that time, a large amount of data has accumulated implicating the left hemisphere as predominant for the processing of speech and language input. If one accepts as an adequate definition of cerebral dominance for a specific function the greater importance of a particular cerebral hemisphere for the occurrence of that function (Geschwind, 1974), such data provides unequivocal evidence for the presence of left hemisphere dominance for speech and language. A sampling of such material, derived from both clinical and normal population samples, will be provided in the next section. But additional conceptualizations of cerebral dominance will first be considered.

2. Conceptualizations of Cerebral Dominance

A serious difficulty in the investigation of cerebral dominance has been the lack of a highly accurate, and at the same time safe, measure of cerebral dominance. Until the 1950's the traditional method of inferring cerebral dominance for language had been on the basis of hand preference³: the classical view was that all right handers have language represented in the left hemisphere; all left handers, in the right hemisphere (Benton, 1965). But this view was challenged by the finding of Goodglass and Quadfasel (1954) of a fairly high incidence of aphasia in 125 left-handers following left hemisphere unilateral lesions situated in the language zones.⁴ It was concluded that cerebral lateralization for language and handedness were not directly linked: left cerebral lateralization occurs more often than right-handedness, and left-handedness is more prevalent than right hemisphere dominance for language.

The advent of the intracarotid sodium amytal technique for the determination of hemispheric speech dominance (Wada & Rasmussen, 1960)⁵ further highlighted the imperfect correlation between handedness and speech dominance. Using sodium amytal injection, Branch, Milner and Rasmussen (1964) reported that in a Montreal Neurological Institute clinical population, 90% of all right handers and 64% of those left handers without indication of early left-sided brain damage exhibited left hemisphere dominance for speech. Branch et. al. (1964) noted

that right hemisphere speech dominance in right-handed normal populations is probably much lower than their 10% figure since all of their right handers were referred with some question of right hemisphere speech representation.

Subsequent research with aphasics (Geschwind & Levitsky, 1968; Geschwind, 1970, 1972; Penfield & Roberts, 1959), intracarotid injection of sodium amytal (Milner, 1974, 1975; Rossi & Rosadini, 1967) and unilateral electroconvulsive therapy (Pratt & Warrington, 1972) has suggested no more than 1-5% of right-handers exhibit right hemisphere speech specialization. The comparable figure estimated for left-handers (i.e., those with left hemisphere speech dominance) has varied from 55 to 70% (Blumstein, Goodglass & Tartter, 1975; Levy, 1974; Milner, 1974, 1975; Warrington & Pratt, 1973).

Besides sodium amytal other accurate clinical measures of cerebral dominance⁶ include direct electrical stimulation of a cortex exposed for brain surgery (Lezak, 1976) and unilateral electroconvulsive therapy (ECT) administered through the scalp and forehead (Pratt, Warrington & Halliday, 1971; Pratt & Warrington, 1972; Warrington & Pratt, 1973). Unfortunately, such intrusive procedures are justified only in very select clinical populations (e.g., when decisions concerning desirability of surgery are required).

Some experimental techniques that have been utilized with normal populations include differential electro-cortical

activity in the hemispheres for different tasks (e.g., Galin & Ornstein, 1972)⁷; lateral eye movements (e.g., Bakan, 1969); visual field recognition asymmetries during tachistoscopic exposure (e.g., Kimura, 1966, 1969), recognition time asymmetries to material presented to each ear or visual field (e.g., Moscovitch & Catlin, 1970); the phi test (Spreen, Miller & Benton, 1966) and DL (Kimura, 1967). Research results utilizing such techniques in adults will be described in the next section (B). Critical evaluation of each technique will be deferred until the measure selected for the present reviewer's thesis research (DL) is described in detail in section E.

Zangwill (1962) presented two views of cerebral dominance. One definition specified that one hemisphere exercises direct control over the other hemisphere. Zangwill (1962) and Shankweiler (1964) stated that no direct evidence has been provided to support this formulation (but see note 10). A second and more prevalent view has emphasized that the central mechanisms subserving speech, and possibly other higher functions as well, are located primarily in one hemisphere.⁸ This formulation, labelled the strict localization model by Moscovitch (1973), was derived from consistently noted clinical observations that unilateral hemispheric lesions do not produce equivalent deficits (see next section).

The accumulating evidence concerning the functional specialization of the hemisphere not dominant for speech

(e.g., differential impairment of spatial perception and memory, impairment in visuo-constructive activities and certain other non-verbal visual and auditory deficits with right, compared to left, lesion groups, e.g., see Dimond, 1972) has led the strict localizationist to postulate the dominance for such functions of the hemisphere not dominant for speech (Benton, 1965).

Dimond (1972) provided a third view of cerebral dominance in which the term is employed in a relative sense, a view described as "middle of the road" by Benton (1965). Most functions may be represented in both hemispheres, but one hemisphere may be superior in the processing of certain types of material, while the other hemisphere predominates in the processing of certain other types of input. Because this model has received its most substantial support from observations of patients whose forebrain commissures have been surgically sectioned, Moscovitch (1973) referred to this view as the split-brain model (the term "split-brain" will be employed throughout the remainder of this thesis to refer to individuals who have undergone forebrain commissure sectioning). Moscovitch (1973, 1976) has argued for an alternate model, that of "functional localization": verbal functions are represented in both hemispheres, but functionally localized on the dominant side and normally inhibited in the non-dominant side in normals and aphasics (provided the critical areas of the dominant hemisphere

producing the inhibition are not damaged in the aphasic). In split-brain and hemispherectomized patients (hemisphere that was removed being at time of removal dominant for language)⁹, the influence of the dominant hemisphere is removed, thereby releasing the minor hemisphere's verbal behaviour.^{10, 11}

B. Functional Differences Between the Hemispheres¹²

1. The Left Hemisphere

a) Research on Clinical Populations¹³

As noted earlier, an extensive amount of clinical material has implicated the left hemisphere as dominant in the vast majority of adults for the processing of speech and verbal input.

It was pointed out in the previous section that Branch et.al (1964) have determined through sodium amytal injection that in a clinical sample 90% of the right-handed and 64% of the left-handed exhibited left hemisphere dominance for speech and that even larger percentages have been noted in other studies.¹⁴ Consistent with this finding, lesions of the left hemisphere have been accompanied by speech and language impairment (Dennis, 1976; Luria, 1966; Milner, 1971; Newcombe, 1974; Penfield & Roberts, 1959; Russell & Espir, 1969; see reviews by Critchley, 1969; Dimond, 1972; Dobrokhotova & Braghina, 1974; and Piercy, 1964), defects in verbal memory (Meyer & Yates, 1955; Milner, 1962, 1967, 1971, 1974, 1975; Milner & Teuber, 1968), lower scores on verbal intelligence tests (Anderson, 1951; Costa & Vaughan, 1962; Stark, 1961¹⁵), and either reduced overall identification of digits on DL (Kimura, 1961b; Milner, Taylor & Sperry, 1968; Schulhoff & Goodglass, 1969; Shankweiler, 1966) or impairment in identification of digits at the right ear (Oxbury & Oxbury, 1969), resulting in absence of ear asymmetries or a left ear

advantage (LEA), in contrast to the right ear advantage (REA) found in controls (Moore & Weidner, 1975). Dimond (1972, p.166) concluded from his review of deficits after unilateral lesions: "the clinical evidence is overwhelming of the association of lesions of the left hemisphere with disturbances of language and the articulation of speech."

Assessment of the abilities of the hemispheres of split-brain patients, e.g., through presentation of material in contralateral visual field or hand (Bogen, 1969a; Ettlenger & Blakemore, 1969; Gazzaniga, Bogen & Sperry, 1965; Hurwitz, 1971; Nebes, 1974; Sperry, 1968; Sperry, Gazzaniga & Bogen, 1969¹⁶) and the performance of the remaining hemisphere of hemispherectomy patients (Bogen, 1969a; Gott, 1973; Griffiths & Davidson, 1966; Smith, 1966; Smith & Burkland, 1966), as well as selective disruption of object-naming and immediate verbal recall following electrical stimulation of certain left hemisphere sites in patients being treated surgically for epilepsy (Fedio & Van Buren, 1974; Penfield & Roberts, 1959), have further highlighted the specialized development of the left hemisphere for language and particularly expressive speech.

Now that the left hemisphere's specialization for speech and language functioning, and possibly for all types of symbolic material processing, is widely accepted, some efforts are being devoted to determine whether this dominance is dependent on a more basic specialization. In this regard, left hemisphere lesions in adults (compared to right hemisphere

damage or non-brain-damaged controls) have been associated with disturbance in temporal perception and auditory sequencing (Albert, 1972; Carmon & Nachshon, 1971¹⁷; Efron, 1963c; Gordon, M., 1967; Lackner & Teuber, 1973; Milner, 1971, 1974¹⁸; Swisher & Hirsh, 1972); sequential motor performance (Carmon 1971¹⁹), bilateral motor control (Wyke, 1966, 1967²⁰) and reaction time with increasing task complexity (Dee & Van Allen, 1973²¹). Naming and serial ordering ability in right-handers are also typically disrupted together and recover together after sodium amytal injection (Milner, 1974).

In a review of some of this research, as well as findings in normal populations, Krashen (1973b) and Bosshardt and Hormann (1975) argued that the more fundamental element may be temporal processing (including temporal ordering, duration, simultaneity, rhythm²²). Kimura and co-workers (1973a, in press, Kimura & Archibald, 1974, Lomas & Kimura, 1975) have speculated that the basis of the left hemisphere dominance they observed for movement copying, free movement (e.g., hand) during speech, sign language and for certain other manual behaviour²³, is specialization for a certain type of motor behaviour, such as complex motor sequencing²⁴. It has been more conservatively suggested that there may be some common factor involved in the control of body movement and speech processes (Dimond, 1972).

Though the evidence is much less clearly supportive,

lesion (Critchley, 1969; Hécaen, 1962; Luria, 1966) and split-brain studies (Gazzaniga, 1970; Nebes, 1974; Sperry, 1968, 1974; Sperry et.al. 1969) have also indicated a left hemisphere pre-eminence for calculation ability.²⁵ A review of data from sodium amytal and brain lesion studies has also led Lezak (1976) to suggest that different emotional reactions may be mediated by each hemisphere (e.g., left hemisphere inactivation or damage associated with depression, oversensitivity to, and exaggeration of disability).

b) Research on Normal Populations

Research data derived from various experimental measures of cerebral dominance in normal populations will now be reviewed. As earlier indicated, critical evaluation of each technique as a cerebral dominance measure will be deferred until the discussion of DL is presented in section E.

i) Phi-test. The phi-test as a measure of cerebral dominance is described by Spreen et.al. (1966):

If a person fixates on a small light source at short distance which is rapidly alternated with a more distant source, the near light appears to move to the position at which the double images of the distant light are seen. Similarly, if he focusses on the distant light, this light appears to move to the double images of the near light. Jasper (1932)²⁶ reported that in prolonged observation of this apparent movement most subjects saw the light move to one side rather than the other and that the perceived direction of movement is related to eye preference and/or cerebral hemisphere dominance. When the near light is fixated, the double images are seen with the nasal half of the retina of each eye; when the

distant light is fixated, the double images are seen with the temporal halves of the retinae. Since the pathways from the nasal halves of the retinae cross in the optic chiasm and continue to the contralateral occipital lobes, while the temporal fibers of the retinae are connected with the ipsilateral cortex, the direction of the apparent movement (phi phenomenon) may reflect a form of hemispheric cerebral dominance (Fig. 1).

Jasper argued that movement seen to the right on both fixations would indicate left cerebral dominance and movement seen to the left on both fixations would indicate right cerebral dominance. If the movement were perceived to the right on near fixation but to the left on far fixation, Jasper assumed an overriding effect of right eye dominance with no indication of cerebral dominance; similarly, a combination of "left-near" and "right-far" reported movements was interpreted as reflecting left eye dominance. Simultaneous movement in both directions and change of reported direction during the observation period were interpreted as indications of unstable cerebral dominance or ambilaterality. Jasper and Raney (1957)²⁷ reported a 4-weeks retest reliability of classification consistency of 90 to 97% (N=45). The agreement of "laterality" as determined by the phi-phenomenon was high with manual habit preference (97%) but low with measures of eye dominance and manual dexterity (63 and 65% respectively).

In his original study, Jasper (1932) reported that in 105 college students 48% of the 35 right-handed subjects and 12% of the 39 ambilateral subjects showed left hemisphere dominance according to these criteria while none of the 31 left-handed subjects and none of a group of 40 stutterers showed such dominance. In the left-handed group left hemisphere and left eye dominance was indicated; the stutterers showed a trend similar to the left-handers but also showed more "central ambilaterality."

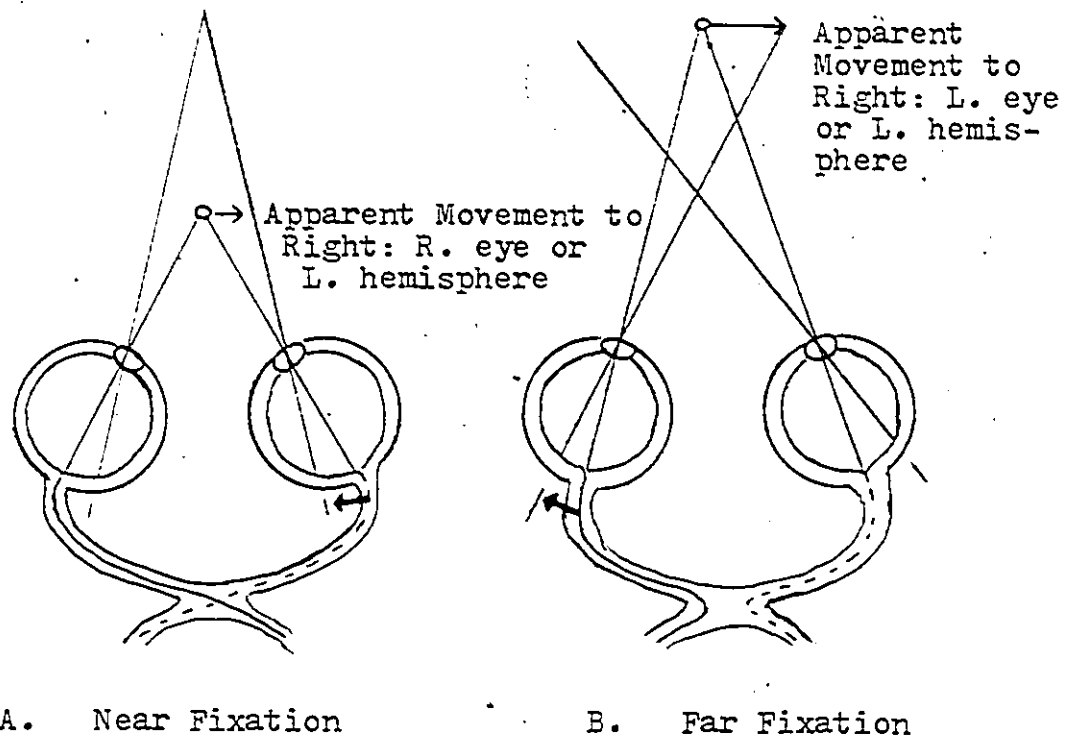


Figure 1. Diagram of the phi-test (McFie, 1952).
From Spreen et. al. (1966).

Jasper and Raney (1957) reported results of 45 children within the age range of 9-12 years. One was unable to see the movement. Of the remaining 42, 30 were classified as right-central, 6 as right-eyed, 4 as left-central, 1 as left-eyed, and 1 as indeterminate, according to Jasper's criteria. In a study of 12 cases of reading disability, McFie (1952)²⁸ found little or no apparent movement reported, while 9 out of 12 control cases reported consistent one-sided movement; two children reported periods of "ambilateral movement". Ettlenger and Jackson (1955)²⁹ reported that 3 out of 4 cases of reading disability showed indications of unstable cerebral dominance. Carter (1963)³⁰ found that out of 38 subjects only four demonstrated an ocular dominance as suggested in Jasper's classification. Since his subjects (students of optometry) complained about the difficulty of maintaining fixation, he added a fixation point at the same distance and located just above the target and reported that with the aid of this point no "ocular dominance" was reported by 27 subjects; 12 out of 19 right-handers showed the left-cerebral, three of 7 left-handers and one ambilateral subject the right cerebral combination. Two of the right handers were classified as slightly left cerebral, one of the left-handers as slightly right cerebral, three of the right-handers and two left-handers as ambilateral. Three subjects were unable to maintain fixation even when the fixation point was added. Carter reported a retest agreement of classification of 79%. He concluded that the cases of ocular dominance reported by Jasper were probably artefacts produced by subjects who either were unable to maintain fixation on one of the two distances (and therefore reported what probably was a monocularly perceived movement) or were "functionally one-eyed". He therefore discarded the notion of ocular dominance in the phi-test and described the use of a monocular and binocular three-target test (targets added to the left and right and at the same distance as the distant fixation light - no near fixation) as an indicator of cerebral dominance. (pp. 308-311).

Spreen et.al. (1966) then described their attempt to

replicate earlier findings investigating the phi-phenomenon and its relationship to other measures of laterality (handedness, hand strength, dexterity and eye preference tests) in normal children and adults. The hypothesis that the direction of movement on near fixation is related to other aspects of laterality was supported for reported handedness, eye preference and hand strength. But a reversal in direction of observed movement for near and distant fixation was not found, nor was ambilaterality in phi-phenomenon viewing related to manual ambilaterality or to eye dominance.

Any more recent studies utilizing or evaluating the phi-test as a measure of cerebral dominance have not come to the attention of the present reviewer.

ii) Visual field asymmetries. The tachistoscopic recall/recognition paradigm has been utilized fairly widely as a measure of cerebral dominance. This paradigm consists of the brief presentation of a stimulus display (e.g., arrangement of letters, digits, drawings). The subject fixates on a certain point and the stimulus material is presented on either (unilateral presentation) or both sides (bilateral presentation) of the fixation point. Immediately after the exposure, the subject is required to recall the stimulus information (White, 1969). A variation on this procedure is to instruct the subject to select the particular stimulus just presented from a visual stimulus array (e.g., see Gibson, Dimond & Gazzaniga, 1972; Olson, 1973).

The fact that in normal adults, the right visual field (RVF) has tended to identify language materials more readily than the left visual field (LVF) when the material was unilaterally presented to either visual field (Barton, Goodglass & Shai, 1965; Bryden, 1964, 1965; Bryden & Rainey, 1963; Dimond, 1972; Heron, 1957; Hilliard, 1973; McKeever, 1971; McKeever & Huling, 1970ab, 1971ab; Mishkin & Forgays, 1952), has been interpreted as a reflection of left hemisphere dominance for the processing of this type of material (Barton et al., 1965; Bryden, 1964; Dimond, 1972; Goodglass & Barton, 1963; Hilliard, 1973; Kimura, 1961a, 1966, 1973; McKeever, 1971; McKeever & Huling, 1970ab, 1971ab), especially if single element material is utilized and/or the material is presented at threshold levels (below 50 msec.) so as to preclude the occurrence of eye-movements and the influence of directional scan due to reading habits (see Bryden, 1964, 1966; White, 1969).³¹ We have already seen that there is extensive clinical evidence that the left hemisphere is in fact more efficient in the mediation of such material. This fact, coupled with the anatomical arrangement of the retinacerebral connections (i.e., representation of each half of the visual field in the contralateral hemisphere, see Fig. 2 which suggests that the RVF has direct access to the left hemisphere, the LVF, direct access to the right) has been forwarded as an explanation of the consistent RVF superiority obtained (e.g., Kimura, 1961a, 1966, 1969).

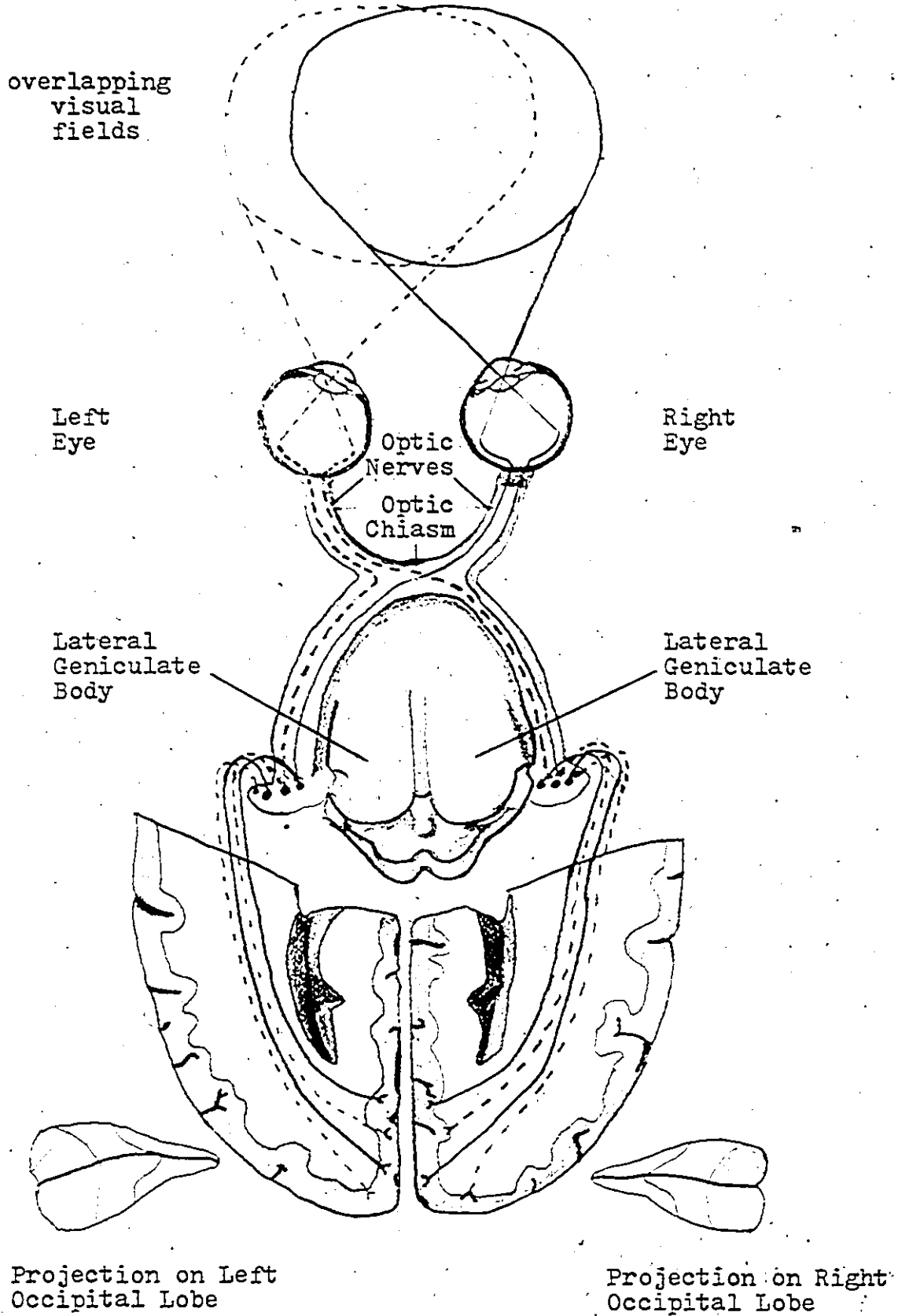


Figure 2. Anatomy of the visual system (from Netter, 1964).

However the riddle of how these functional and anatomical properties precisely determine visual field (VF) asymmetries during unilateral presentation has yet to be solved. One hypothesis that has been forwarded is that the VF that projects directly to the relevant specialized hemisphere benefits from a more efficient transmission of information by the shorter pathway to the analyzing center. Information presented to the other VF would have to reach the analyzing center of that same hemisphere via the corpus callosum or other forebrain commissures before being analyzed (McKeever & Huling, 1971^{lab}; Rizzolatti, Umiltà & Berlucchi, 1971). Such an indirect route would produce a longer communication time and some degradation of the original message; or the time factor may not be the critical variable, but the transcallosal route itself, which may reduce transmission fidelity. A second hypothesis postulates that any kind of stimulus input presented to one VF is processed by the contralateral hemisphere, but the speed and the accuracy of processing is dependent upon hemispheric specialization. In this view transmission of VF information from one hemisphere to the other would not be required (Geffen, Bradshaw & Wallace, 1971).³² A third hypothesis recognizes the role of hemispheric specialization in producing VF asymmetries, but ascribes the role to one of inducing attentional tendencies: when subjects are aware in advance of the nature of the stimulus material (e.g., if the material is entirely verbal or spatial non-verbal,

the subject realizes this fact after only a few trials), this awareness may produce preparatory activation of a particular hemisphere. This activation in turn generates a detectable attentional bias to the side corresponding to the differentially activated hemisphere, in this case, the contralateral VF (Kinsbourne, 1970, 1972). This latter explanation will be discussed in greater detail in the section devoted to DL as a measure of cerebral dominance.

Performance of subjects on modifications of the tachistoscopic recall/recognition paradigm (e.g., the divided VF technique employed by Dimond, 1969, 1970, 1971, the binocular fusion of digits studied by Carmon & Nachshon, 1973b) have further supported the view of the greater importance of the left hemisphere in terms of a general language analyzing system.

iii) Dichotic listening (DL). DL commonly consists of the presentation by means of a stereophonic tape recorder of material of a common category to each ear simultaneously. The subject is usually requested to report as much of this material as he is able. The rate of presentation and the type, amount and method of reporting the material (e.g., free order of report vs. reporting only from one ear or from a specific ear) all may be varied (Netley, 1972; Satz, 1968).

As DL is the measure adopted for the current thesis research, a detailed discussion of DL as a measure of cerebral dominance for particular types of information, including

comparison with other experimental measures, will be presented, although deferred to a later section. It will simply be stated at this point that the tendency of material presented to a particular ear to be recognized or identified more accurately than material presented to the second ear when the same category of material is simultaneously presented to the second ear has been interpreted as a reflection of the dominance of the hemisphere contralateral to that particular ear for the processing of that particular type of material (Kimura, 1967).

In normal adults, a REA for the identification of digits has been reported (Broadbent & Gregory, 1964; Bryden, 1965; Curry & Rutherford, 1967; Curry & Gregory, 1969; Dirks, 1964; Gordon, H., 1970; Inglis, 1965; Kimura, 1964, 1967; Nachshon & Carmon, 1973ab; Satz, 1968; Satz, Achenbach, Fennell & Pattishall, 1965; Schulhoff & Goodglass, 1969; Shankweiler & Studdert-Kennedy, 1967b; Zurif & Bryden, 1969). The REA for digits was sustained even under difficult listening conditions (digits and white noise or digits and 50 msec. interruption, Knox & Boone, 1970), even when presentation to the right ear was delayed by 10, 20, and 30 msec. (Satz, Levy & Tyson, 1970³³), or when responses were delayed for one and three seconds (Nachshon & Carmon, 1973b), or when the digit identification task was incorporated into a signal detection task (Haydon & Spellacy, 1974; Levy & Bowers, 1974). REA continued to be present even when a non-verbal response

was employed (Broadbent & Gregory, 1964), when material presented to the right ear was 10 db. less intense than material in the left ear (Thompson, Stafford, Cullen, Hughes, Lowe-Bell & Berlin, 1972) and when ear order of report was controlled (Bryden, 1963, 1965, 1967; Kimura, 1967; Satz et.al., 1965; Schulhoff & Goodglass, 1969; Zurif & Bryden, 1969).

A REA on DL has also been noted for identification of other types of verbal or verbal-like material (words - Bartz, Satz & Fennell, 1967, Bryden, 1964, Curry, 1967, Curry & Rutherford, 1967, Curry & Gregory, 1969, Dee, 1971, Dirks, 1964, Higenbottam, 1973; backward speech - Kimura & Folb, 1968; nonsense syllables - Curry & Rutherford, 1967, Kimura, 1967; consonant varied consonant-vowel and consonant-vowel-consonant syllables - Berlin, Hughes, Lowe-Bell & Berlin, 1973a, Blumstein, Goodglass & Tartter, 1975, Haggard & Parkinson, 1971, Oscar Berman, 1975, Shankweiler & Studdert-Kennedy, 1967ab, Spellacy & Blumstein, 1970, Studdert-Kennedy & Shankweiler, 1970). The REA was maintained even when subjects were not required to verbalize the response (Kimura, 1967), when syllables were 10 db. less intense in the right than in the left ear (Berlin et. al., 1973a), when only a particular ear was to be reported (Kirstein and Shankweiler, 1969) and whether instructions specified before or after test trials that one was to report input only from a specific ear (Bryden, 1969). Such results have almost invariably been interpreted as a reflection of the dominance of the left hemisphere for the analysis of such material.

A REA on DL has also been noted in the identification or recognition of non-verbal sounds differing in sequential, temporal and rhythm complexity (Halperin, Nachshon & Carmon, 1973; Papcun, Krashen, Terbeek & Harshman, 1974; Robinson & Solomon, 1974), as well as a larger REA for verbal material demanding greater temporal discrimination than for verbal material requiring less temporal discrimination (Allard & Scott, 1975). All four groups of researchers suggested that the hemisphere dominance revealed on DL is related to elements more basic than verbal vs. non-verbal (i.e., left hemisphere specialization for processing and discriminating sequential, temporal elements and patterns). As noted earlier, Bosshardt and Hormann (1975) have reviewed evidence that supports the proposal that temporal-sequential information processing provides the basis of the laterality effect in the reproduction of verbal auditory materials.³⁴ The observation of a positive correlation between REA for recognition of non-verbal rhythm sequence and five manual tasks led Natale (1977) to suggest more cautiously (as has Dimond, 1972) that there may be a common neurological basis of some kind to manual skills and speech processes.

Although ear asymmetries in performance do not usually appear unless the two ears are in direct competition (as in DL, see Kimura, 1967), REA in right handers for reacting to and identifying verbal material has been noted when input is restricted to one ear at a time and the complexity of the task is increased (e.g., Bakker, 1969, 1970 found the REA when digits were required to be identified in the order presented;

Morais & Darwin, 1974, found faster reaction to right ear input when categorization of consonant-vowel syllables was demanded). The REA has been found on other monaural tasks: sentences are recalled better at the right ear after distraction or when a noise background is provided to the same ear that is receiving the sentence (Frankfurter & Honeck, 1973; Jarvella & Herman, 1973).³⁵

iv) Reaction time. Differences in reaction time in identifying material unilaterally presented to the RVF or the LVF may also be employed as a measure of cerebral dominance (Geffen, Bradshaw & Nettleton, 1972; Moscovitch, 1973; Moscovitch & Catlin, 1970). Response time to RVF input was shown to be faster when the input involved identification of single letters (Moscovitch & Catlin, 1970) and linguistic analysis (Cohen, 1972; Geffen, Bradshaw & Nettleton, 1972; Moscovitch, 1973, 1976). Such results were interpreted as reflecting known cerebral asymmetries for speech and language processing in favour of greater involvement of the left hemisphere (e.g., Moscovitch, 1973 attributed faster reaction time to a shorter transmission directly to the left hemisphere from the RVF, in contrast to a longer transmission route necessitated by shifting of LVF input from the right to the left hemisphere).

Reaction time asymmetries to verbal and non-verbal input presented to each ear have also been employed to detect cerebral dominance. A REA has been reported for hand reaction speed and accuracy of monitoring of syllables (Springer, 1971),

and during the presentation of a letter to one ear, provided the second ear received noise (Springer, 1973), though Perl and Haggard (1975) obtained such an effect only after several trials. However, Catlin and Neville (1976) observed the REA even for stimuli presented monaurally and without noise in the contralateral eye. A faster reaction to right ear input was also noted for the classification of syllables (Morais & Darwin, 1974)³⁶ and to initial phones of syllables (Bever, Hurtig & Handel, 1976) monaurally presented. Once again such results were seen as a reflection of the dominance of the left hemisphere for the processing of this type of material.

v) Electro-cortical studies. Differential electro-cortical activity in the two hemispheres has also been a source of inference concerning hemispheric dominance. Increased alpha suppression in the left hemisphere (and increased alpha activity in the right hemisphere) during linguistic tasks, and alpha suppression in the right hemisphere (and augmented alpha activity in the left hemisphere) during non-verbal activities; have been reported (Dumas & Morgan, 1975; Galin & Ornstein, 1972; McKee, Humphrey & McAdam, 1973; Morgan, McDonald & MacDonald, 1971; Morgan, MacDonald & Hilgard, 1974; Robbins & McAdam, 1974). Alpha suppression of a cortical area seems to reflect information-processing in that area since the appearance of the alpha is thought to indicate a "shut-down" of information processing in that cortical area (Galin & Ornstein, 1972; Ornstein, 1972).

Hemispheric differences in elicitation of auditory

evoked potentials for verbal vs. non-verbal input (greater amplitude in left hemisphere to verbal stimuli; greater amplitude to non-verbal stimuli in right hemisphere) have also been found (McAdam & Whitaker, 1971; Morrell & Salamy, 1971; Wood et.al., 1971).³⁷

Although the results of Haaland (1974) were ambiguous concerning auditory evoked potentials during DL tasks, Neville (1974) observed that digits on DL (which produced the typical REA) elicited auditory evoked potentials of greater amplitude for earlier components and shorter latencies for later components from the left than from the right hemisphere. The results were interpreted as providing strong support for the hypothesis of hemispheric functional asymmetries, both in terms of earlier behavioural (e.g., DL) and psychophysiological evidence. (Morrell & Salamy, 1971; Wood et.al., 1971; Cohn, 1971; McAdam & Whitaker, 1971; Fedio & Buchsbaum, 1971; Buchsbaum & Fedio, 1969).

vi) Lateral eye movements (LEM). The tendency of subjects to shift their eyes to the right has been associated with verbal, linguistic activities and dominance of the left hemisphere for processing of the cognitive input associated with such activities (Bakan, 1969, 1971; Kinsbourne, 1972, 1974a; Kocel et.al., 1972; Weitan & Etaugh, 1974a). Negative results were reported by Ehrlichman, Weiner and Baker (1974).

The consistency of eye shifts in response to reflective questions in turn was linked to higher scores on the

Scholastic Aptitude Test (Bakan, 1969, 1971; Weitan & Etaugh, 1974b).³⁸ The latter researchers suggested the attempt to relate incomplete cerebral dominance to intellectual deficits should not be discarded (refer to later literature review section entitled "The Development of Cerebral Dominance," specifically the portion of the subsection on the development of cerebral dominance in deviate populations dealing with the intellectually subaverage for more detailed discussion of the topic of cerebral dominance and intellectual deficits).

vii) Electroconvulsive therapy (ECT). Hemispheric dominance for language may be revealed by degree of language disruption when each hemisphere is separately electrically stimulated. In right handers greater disruption in language functioning immediately after left hemisphere stimulation occurred in nearly every case (Pratt & Warrington, 1972) and in 70% of left-handed subjects (Pratt et. al., 1971; Pratt & Warrington, 1972). Relatively more extensive disruption in word association has also been reported after ECT administered to the left hemisphere to control depression (Fleminger & Bunce, 1975).

viii) Other techniques. The following methods have also been suggested for assessing cerebral dominance for language, but in each case, little or no evaluative research has been conducted: how an individual holds his pen (Levy, 1974); presence of verbal transformation effect, which is the phenomenon experienced when people listen to a word or phrase

repeated by a loop of tape (Perl, 1970); asymmetries in the free motion of the hands during speech (Kimura, 1973b); and the tendency to return the eye to a specified target position in the dark (Heywood, 1973).

Variations of DL have been cited earlier in this review (e.g., monaural presentation, pursuit auditory tracking of dichotically presented tones).

c) Concluding Comment

It was noted in the introduction that language was the first higher cognitive function that was found to be asymmetrically represented in the cerebral hemispheres of man. Language remains the best documented case for hemispheric specialization (Dimond, 1972; Nebes, 1974) and the most widely accepted (Small, 1973).

2. The Right Hemisphere

a) Research on Clinical Populations

The following auditory non-verbal deficits have been associated with right hemisphere damage: 1) loss of musical abilities, especially with right temporal lobe lesions (Chase, 1967; Luria, 1973; Milner, 1962, 1967; see reviews by Bogen, 1969b, Wertheim, 1969), including depressed overall performance on DL (Schulhoff & Goodglass, 1969; Shankweiler, 1966) and a defect in processing an element possibly basic to musical skills, tonal quality (Chase, 1967; Swisher & Hirsh, 1972 - see the next subsection for further discussion of right hemisphere specialization for music and its components). 2) judgment

of auditory duration, "time" errors after right temporal lobectomy (Milner, 1962, 1967, though Gordon, M., 1967, reported more errors after left-sided lesions). 3) identification of environmental sounds, such as coughing, whistling, cat meowing (Spreen, Benton & Fincham, 1965; Vignolo, 1969).

Visual perceptual and visual-spatial impairments of various types have also been observed after right hemisphere lesions (see reviews by Critchley, 1969; Bogen, 1969b): 1) perception of visual non-language material - overlapping figures (De Renzi, 1969), nonsense figures and irregular visual material (Kimura, 1963a; Milner, 1967), line slope (Benton, Hannay & Varney, 1975; Warrington & Rabin, 1970), number of dots and incomplete realistic figures and letters (Warrington & James, 1967ac), letters in a perceptually demanding form (Scotti, 1969 - recognition of letters presented in conventional form were more impaired by left posterior hemisphere damage), dot position (Hannay, Varney & Benton, 1976; Taylor & Warrington, 1973; Warrington & Rabin, 1970; but non-supportive results from Ratcliffe & Davies-Jones, 1972), size of gap (Warrington & Rabin, 1970³⁹); recognition of faces and facial features (Benton, 1969; Benton & Van Allen, 1968; De Renzi, 1969; De Renzi & Spinnler, 1966; De Renzi, Faglioni & Spinnler, 1968; Hecaen & Angelergues, 1962; Milner, 1968; Warrington & James, 1967b; Yin, 1970). 2) visual memory - temporal ordering of visual events after right frontal lobectomy and non-verbal sequencing and visual location

after right temporal lobectomy (Milner, 1971, 1974)⁴⁰, as well as other visual memory defects (Milner, 1967, 1975). 3) performance on visually guided mazes and modifying behaviour on the basis of visual cues (Milner, 1967). 4) Visuo-constructive deficits - copying of geometric figures (Bogen, 1969a), constructing block designs (Critchley, 1969; Hécaen, Penfield, Bertrand, Malmo, 1956; but see note 39), handling spatial aspects of writing (Hécaen, & Marcie, 1974).

The hypothesis of right hemisphere dominance for visual-spatial processing is further supported from split-brain (dot enumeration - Teng & Sperry, 1974; copying geometric figures - Bogen, 1969a; drawing and constructing block designs - see Gazzaniga, 1967, 1970, Sperry, 1968, and Nebes, 1974 for extensive reviews) and hemispherectomy studies (Bogen, 1969a; Dimond, 1972; Kohn & Dennis, 1974ab), whether the brain disorder leading to hemispherectomy appeared in infancy or in adulthood. Observations of split-brain and hemispherectomy subjects has also suggested a right hemisphere specialization for visual and tactile geometrical discrimination, perhaps because of the visual-spatial requirements involved in such discriminations (Franco & Sperry, 1977).

The following tactual-spatial, directional and proprioceptive disturbances have been reported subsequent to right hemisphere lesions: tactually-guided maze performance (Corkin, 1965⁴¹), tactile recognition of direction (De Renzi, Faglioni & Scotti, 1968, 1970; Fontinot & Benton, 1971⁴²), tactual 3-dimensional size and form discrimination (Weinstein,

1964) and impaired tactile sensitivity on both sides of the body (Ball, 1974)⁴³, findings also supported from split-brain research (Levy-Agresti & Sperry, 1968; Milner & Taylor, 1972; Nebes, 1971b, 1972, 1973; Zaidel & Sperry, 1973).

Right hemisphere damage has also been associated with lower scores on non-verbal intelligence tests (Anderson, 1951; Costa & Vaughan, 1962; Stark, 1961)⁴⁴ and inadequate emotional reactions, such as passivity, complacency and general arousal reduction, denial and lack of awareness of disability and euphoria (Lezak, 1976; see Dobrokhova & Braghina, 1974 for review of some relevant, presumably Russian, literature). Dobrokhova and Braghina (1974) also concluded that right hemisphere lesions result in deficits in perception of the environment, space, time and in self-perception.⁴⁵

Sperry (1968) emphasized that the inability of the right hemisphere of commissurotomy patients to express itself verbally (e.g., words or objects projected to the right hemisphere via the LVF or tactually through the left hand cannot be identified verbally) does not mean that this hemisphere is "word blind", "word deaf" or "tactually alexic". Rather, the hemisphere disconnected from the hemisphere dominant for language is able to comprehend written and spoken language to some extent, though this comprehension is often masked because this comprehension cannot be expressed by verbal response.⁴⁶

Thus, clinical studies suggest the dominance of the right hemisphere for certain non-verbal auditory and tactile-

visual spatial and spatial-directional processes, which may explain, at least in part, the deficient performance on non-verbal intelligence tests and other deficits noted in patients with right hemisphere lesions.

b) Research on Normal Populations

i) Visual field asymmetries. LVF superiority for the recognition of certain non-verbal spatial material presented unilaterally and tachistoscopically at near threshold levels has been related to right hemisphere dominance for that material (e.g., direct projection to the hemisphere that clinical research just presented has suggested is dominant for various types of non-verbal, spatial information processing. The reader may want to refer to the earlier presented brief descriptive rationale of this technique as a measure of cerebral dominance).

The following types of tasks involving non-verbal spatial material have yielded LVF recognition superiorities: dot and form enumeration (Kimura, 1966; Kimura & Durnford, 1974), localization of dots on a spatial map (Kimura, 1969; Kimura & Durnford, 1974⁴⁷), analysis of 3-dimensional spatial information and identification of line slope (Durnford & Kimura, 1971; Fontinot & Benton, 1972⁴⁸; Kimura, 1973a; Kimura & Durnford, 1974⁴⁹), recognition of block design (Schell & Satz, 1970)⁵⁰, the identification of complex forms of low verbal association (Dee & Fontinot, 1973; Fontinot, 1973⁵¹), reproduction of dotted figures (McKeever & Huling, 1970c)⁵², and facial recognition (Hilliard, 1973). Other evidence with

normal subjects also has suggested a right hemisphere superiority for facial recognition (Gilbert, 1973).⁵³

It should be noted that many other types of non-verbal visual-spatial material have failed to elicit VF asymmetries (e.g., geometric forms - Bryden, 1960, Bryden & Rainey, 1963, Heron, 1957; nonsense forms or certain dot arrays - Heron, 1957, Kimura, 1966, Terrace, 1959; and various other shapes and forms - Kimura, 1969, Kimura & Durnford, 1974).

ii) Reaction-time studies. Reaction time to unknown facial material (Rizzolatti et.al., 1971) and other spatially encoded material (Klatsky & Atkinson, 1971 and two of three groups studied by Umilta, Rizzolatti, Marzi, Zamboni, Franzini, Camarda and Berlucchi, 1974) is shorter when such material appears in the LVF than when input is via the RVF.

Moscovitch (1973) has reviewed several other reaction time studies that indicate that the right hemisphere's processing capability for visual-spatial material may be superior to that possessed by the left hemisphere.

iii) Dichotic listening. In normal populations a LEA on DL has been noted for several types of non-verbal auditory material. A LEA has been obtained for the identification of environmental sounds (Curry, 1967, 1968⁵⁴) and the recognition of non-verbal human sounds (King & Kimura, 1972), emotional intonation of both verbal (Haggard & Parkinson, 1971) and non-verbal (Carmon & Nachshon, 1973a) content, non-verbal "intonational contours" (Blumstein & Cooper¹⁹⁷⁴ - even when the in-

tonations were part of a phonetic medium), pitch pure tones (Curry, 1968; Darwin, 1971; Spreen et.al., 1970) and melodies (Blumstein et.al., 1975; Cook, 1973; Dee, 1971; Higenbottam, 1973; Kimura, 1964, 1967; King & Kimura, 1972; Schulhoff & Goodglass, 1969; Spellacy, 1970), even when the comparison musical stimulus was not presented for five seconds after the stimulus presentation (Spellacy, 1970; Spreen, Spellacy & Reid, 1970, though the LEA disappeared at the longest S-R level of 12 sec.) and even when ear order of report was controlled (Schulhoff & Goodglass, 1969). Such results have been interpreted by these authors as a reflection of the dominance of the right hemisphere for the processing of such auditory non-verbal material.

Gordon, H. (1970) found that the LEA for music recognition was specifically related to chordal sounds (rich timbre and tonal qualities devoid of all temporal aspects of music). Melodies lacking timbre and tonal qualities failed to elicit ear asymmetry. Gordon (1970) related the LEA to right hemisphere dominance for analysis of pitch variations, a hypothesis in agreement with the clinical data of Milner (1967) and Bogen and Bogen (1969) which seemed to pinpoint the basis of the right hemisphere music specialization to analysis of musical tonal pitch of a complex nature.⁵⁵

iv) Electro-cortical research. During the performance of linguistic, spatial and musical tasks, relatively less electroencephalogram alpha activity occurs in the hemisphere

that research earlier reviewed has suggested as the more important for that type of information processing. The relevant observation in the present context is that relatively less alpha is present in the right hemisphere when subjects engage in spatial (Dumas & Morgan, 1975; Galin & Ornstein, 1972; Morgan et. al., 1971; Robbins & McAdam, 1974) or musical tasks (McKee et. al., 1973).

Hemispheric differences in auditory evoked potential activity for non-verbal vs. verbal input (greater amplitude in right hemisphere to non-verbal stimuli, greater amplitude to verbal input in left hemisphere) have also been noted (McAdam & Whitaker, 1971; Morrell & Salamy, 1971; Wood et. al., 1971).

v) Tactual asymmetries. In two separate experiments, Hermelin and O'Connor (1971) found braille readers to be more accurate in reading with the left hand. They speculated that the input may be analyzed as a spatial item in the right hemisphere prior to any verbal processing in the left hemisphere.

Benton, Levin and Varney (1973) observed superior tactile recognition of direction by the left hand in normal adults. Witelson (1974, in press) similarly noted superior recognition of nonsense shapes presented to the left hand (right hemisphere) of males of 6-14 yr. when the two hands were simultaneously presented with a different nonsense shape.

In adults in comparison with right side sensitivity, lower pressure thresholds have been found for the left thumb, left palm, left forearm and foot (Murray & Hagen, 1973; Weinstein & Sersen, 1961⁵⁶). The greater left thumb sensitivity

may even be present in 6-9 yr. olds (Ghent, 1961; Kimura, 1963b). Weinstein and Sersen (1961) provided indirect evidence that the lower pressure threshold of the left thumb is related to the greater role of the "minor" hemisphere in pressure sensitivity.

However, Nebes (1971a) failed to find a greater left hand superiority on a tactual performance task and failure to observe hand pressure perception differences has also been reported (Carmon, Bilstrom & Benton, 1969; Fennell, Satz & Wise, 1967). After citing a few of the above and other studies, Blakemore and Iversen (1972) concluded that evidence is contradictory concerning the presence of pressure perception and other somatosensory asymmetries.

The present reviewer would suspect that one factor in some of the contrary evidence concerning the presence of somatosensory asymmetries is the confounding of tactual-tactile sensitivity with spatial and spatial-directional dominance (e.g., many of the studies finding tactual asymmetries utilized a spatial-directional task).

vi) Lateral eye movements. The tendency of subjects to shift their eyes to the left has been associated with non-verbal, non-language spatial tasks and dominance of the right hemisphere in mediating such tasks, compared to right directional shift in relation to left hemisphere mediated tasks (Bakan, 1969, 1971). However other studies investigating eye movements associated with non-language tasks have provided much less clearly supportive (Kocel et. al., 1972;

Kinsbourne, 1972; Weitan & Etaugh, 1974a) or clearly negative (Ehrlichman et. al., 1974) results.

c) Uncertainties Concerning Right Hemisphere
Functional Specialization

Although the above review of research pertaining to right hemisphere functioning suggested a fair amount of clinical and experimental support for right hemisphere functional specialization, many non-supportive studies were also cited either in the main text or in the notes. For this and other reasons, the hypothesis of right hemisphere specialization still encounters skepticism.

Bogen (1969b) enumerated some arguments that caution against acceptance of the view of right hemisphere specialization: the use of non-verbal "performance" tests to assess hemispheric functioning, though such tests were not originally devised to detect lateralization of cerebral activity; the selection problem when one attempts to compare right vs. left hemisphere lesion groups, with the very real possibility that right hemisphere lesion groups may contain more seriously damaged individuals (e.g., since language symptoms often accompany left hemisphere tumours, such subjects may be referred at an earlier stage in the development of their disease; also, right hemisphere damage may be associated with more radical surgical intervention because of the lessened possibility of post-operation aphasia)⁵⁷; the obscuring of certain left hemisphere defects by intellectual disorganization often associated with dominant hemisphere injury; inability of cer-

tain left hemisphere lesion patients (since circumscribed defect in awareness in left hemisphere) to be aware of such symptoms as the visual illusions more often reported by right hemisphere lesion individuals.

One must also consider the arguments of Semmes (1968) concerning the physiological organization of the cerebral hemispheres and the possibility that such organization may produce a type of "pseudo-dominance". On the basis of results from several studies investigating lateralized lesion effects on sensory and motor capacities of the hands (e.g., damage in the left hemisphere tending to produce localized disturbances ipsilaterally or contralaterally, whereas right hemisphere damage interferes more diffusely with performance), Semmes (1968) postulated a parallel difference in physiological organization of the two hemispheres: focal representation in the left hemisphere and diffuse representation in the right hemisphere. Thus:

It is proposed that focal representation of elementary functions in the left hemisphere favors integration of similar units and consequently specialization for behaviours which demand fine sensorimotor control, such as manual skills and speech. Conversely, diffuse representation of elementary functions in the right hemisphere may lead to integration of dissimilar units and hence specialization for behaviours requiring multimodal coordination, such as the various spatial abilities....

It is clear that in the focally organized hemisphere (F), even a small lesion, if crucially placed, will produce deficit, whereas in the diffusely-organized hemisphere (D), a similar lesion will have less or no effect, and the same will be true for any small D lesion, regardless of its location. Thus for a unitary function investigated with relatively

small lesions, F will seem to be the dominant hemisphere. Only massive or complete lesions of F and D will produce similar effects and thereby distinguish this condition from true dominance.

If one considers a more complex form of behaviour, however, one which is not unitary but which is based on two or more independent factors, the D hemisphere may seem to be the dominant one. This will be so because lesions of different loci in F can disturb one factor without having any effect on the others, whereas lesions in D will either disturb all or several of the factors concomitantly, if the damage is sufficiently extensive, or will fail to disturb any of the factors. Thus, the most severe deficits in the behaviour, as well as the least effects on it, will result from D lesions (Semmes, 1968, pp. 11, 19-20).

But even this hypothesis has not been supported by subsequent empirical evidence: Corkin, Milner and Rasmussen (1970) and Corkin, Milner and Taylor (1973) both found persistent sensory loss to occur only with lesions in the post-central gyrus of either hemisphere, with no evidence of more diffuse deficits and more diffuse somatosensory functioning in the right hemisphere.

Luria (1973) has also warned that the brain appears to act as a functional whole. If so, lesion of an area that is part of the system may disrupt the whole process and create the appearance of localization in that area.

Such cautions emphasize the danger of inferring hemispheric specialization in the normal brain from study of the pathological brain. Nebes (1974) argued that observation of split-brain patients offers great promise because their hemispheres are "relatively intact" and available for independent assessment. In such patients, one may determine relative dis-

abilities associated with lateralized brain damage.

However, commissurotomies are usually performed because of intractable epilepsy (Nebes, 1974), and one can never be very confident about the normality of the development of hemispheric specialization in such a situation.⁵⁸ Moscovitch (1973) has suggested that an accurate picture of brain functioning in normal individuals can in all probability only be derived from the study of normal (i.e., brain-intact) individuals. Several experimental techniques that permit such studies were cited by Moscovitch (1973), with particular stress laid on the potential of reaction time techniques in revealing absolute, rather than relative performance levels of the hemispheres on verbal (and presumably other) tasks.

d) Concluding Comment

In addition to the reservations that should be held concerning speculation of right hemisphere functioning in the normal brain based on extrapolation from studies of the pathological brain, it should also be emphasized that experimental findings in normal populations have failed to yield as consistently positive results in regard to measures thought to reflect specialization of the right hemisphere for non-verbal, non-language information processing compared to measures thought to reflect left hemisphere specialization for verbal, language information processing (in addition to the studies reviewed to this point, see Bryden, 1976b; Geffen et al., 1972; Milner, 1971; Small, 1973; White, 1972⁵⁹).

3. General Comments

Although a summary statement of the specialized nature of hemispheric functions may be formulated in terms of single words or phrases, such as verbal vs. non-verbal and spatial or language vs. non-language, such descriptions are not entirely adequate. Non-verbal is more adequate than spatial because the specialization of the right hemisphere seems not to be confined to spatial functioning or a specific modality, but processing of non-verbal input generally (see Bogen, 1969b and studies revealed to this point).⁶⁰ Bogen (1969b) pointed out that non-verbal is not a completely adequate term for several reasons (e.g., the distinguishing feature of major hemisphere functioning is not the possession of words, but the utilization of words in propositions; Bogen, 1969b attributed the distinction to Hughlings Jackson.⁶¹). Bogen (1969b) thus advocated the term propositional for left hemisphere functioning, but suggested the term appositional in place of the Jacksonian term "automatic" for the right hemisphere's use of words.

The right hemisphere recognizes stimuli (including words), apposes or collates this data, compares this with previous data and while receiving the very same stimuli as the other hemisphere, is often arriving at different results

The difficulty in characterizing the ability of the right hemisphere⁶² arises from our ignorance - we have barely scratched the surface of a vast unknown. We would do well therefore to choose arbitrarily a word, homologous in structure with the word "propositional" but sufficiently ambiguous to permit provisional use. For example, we can say that the right hemisphere has a highly developed "appositional" capacity. This term implies a

capacity for apposing or comparing of perceptions, schemas, engrams, etc., but has in addition the virtue that it implies very little else. If it is correct that the right hemisphere excels in capacities as yet unknown to us, the full meaning of "appositional" will emerge as these capacities are further studied and understood. The word "appositional" has the essential virtue of suggesting a capacity as important as "propositional", reflecting a belief in the importance of right hemisphere function. (Bogen, 1969b, pp. 148-150).

The present reviewer would add that the verbal vs. non-verbal distinction is inadequate because the left hemisphere's specialization is not confined to verbalized material or words or even words in propositions, but seems to include language in general, whether verbal, written or in other forms (e.g., gestural), if by language one means a general system of communication and symbolization. The left hemisphere's specialization may include the symbolic function, in the sense utilized by Piaget to refer to general forms of representation, the general ability to represent reality in thought (representational thought) and distinguish between signifier and significant (see Flavell, 1963 for a description of Piaget's distinction between symbolic and language functioning).

If the left hemisphere specialization in turn is dependent on a more elementary specialization, such as for timing, sequencing and/or fine motor movement, perhaps such a more basic element is crucial in all forms of general communication and/or representational thought (e.g., time, sequence and motor involvement at the receptive and processing level for concrete vs. symbolic and abstract thought, as well as at the expressive

level for fine motor movement involved in expressive speech and gestures).

The nature of the information processing that each hemisphere seems to be specialized for has also led to hypotheses concerning the right hemisphere being specialized for wholistic, Gestalt, integrative perception, the left hemisphere for logical, sequential (linear), analytical and categorical functions.⁶³

C. The Development of Cerebral Dominance

This section will review research on normal and deviate populations relevant to the development of hemispheric functional specialization; the possibility of sex differences in such development will also be considered.

1. Research on Clinical Populations

There is ample clinical evidence of an increasing left hemisphere lateralization of speech and language function with age in childhood with a paralleling decrease in "plasticity" in terms of the ability of the right hemisphere to assume the functions that are becoming increasingly lateralized in the left hemisphere. However, the complexity of the human brain and of inference of functioning on the basis of clinical (and non-clinical) data, hopefully obvious to the reader by this point, is clearly illustrated by the conflicting schools of thought about the specific age of completion of development of hemisphere specialization for speech and language. On the basis of frequency of occurrence, severity and degree of re-

covery from aphasia and speech disorders associated with cerebral trauma differing depending upon the occurrence of trauma in children in contrast to adults (e.g., critical upper age limit for cerebral insult onset and successful recovery from any resultant aphasic symptoms), cerebral dominance is thought by some to be completed by 10-14 yr. of age (Basser, 1962; Chase, 1972; Ettlenger & Blakemore, 1969; Geschwind, 1968; Hécaen, 1976; Hurwitz, 1971; Lenneberg, 1967; Penfield, 1965; Penfield & Roberts, 1959; Smith, 1972; Sugar, 1952).⁶⁴ A more specific formulation is that a newborn with damage to the left hemisphere develops language normally with the right hemisphere (or with other undamaged portions of the left hemisphere), a 2-3 year old may lose language to some extent after left hemisphere injury but quickly recovers (Dimond, 1972), speech is very rarely affected by right hemisphere lesions occurring beyond the age of 5 (Lenneberg, 1967, Kinsbourne, 1974b), but beyond puberty recovery from aphasia after left hemisphere insult is always limited or non-existent (Lenneberg, 1967)⁶⁵. In fact, if the age of injury occurs during the first few years of life, no aphasia of any kind has often been noted, regardless of side of lesion (Basser, 1962; Gardiner et al., 1955; Krynauw, 1950; McFie, 1961; Piercy, 1964; Wilson, 1970)⁶⁶.

A second school of thought is represented by Krashen (1973a) who suggested that lateralization may be complete as early as the age of 5 yr., with transfer being rare after this age, although perhaps still possible until puberty (though he

felt data to be rare concerning recovery after a unilateral lesion occurring between 5 yr. and puberty). Krashen (1973a) re-interpreted the data of Bassler, 1962 (see below), arguing that the oldest child studied by Bassler to show any speech disruption after right hemisphere damage was 5 yr. old. Thus, Krashen (1973a) noted that completion of lateralization and transfer may not be directly linked.

Results from the study of hemispherectomized patients, persons who have undergone the surgical removal of one of their cerebral hemispheres, will now be discussed in some detail as an illustration of inference of the presence of lateralized language functioning from study of the damaged brain. Important independent variables in these situations are age when the hemisphere first became diseased (Smith, 1972) and the anatomical and functional integrity of the remaining structures (Smith & Sugar, 1975)⁶⁷.

In an extensive report of the effects of unilateral lesions (102 cases) and subsequent hemispherectomy (35 of the 102) on speech development, Bassler (1962) found that 13 of 15 left lesion (87%) and 7 of 15 right lesion occurrences (47%) after the acquisition of speech (about 1-10 yr.-old) were associated with some disturbance of speech (these percentages are roughly comparable to disruptions found by Hecaen, 1976 in a study of patients of roughly similar age whose unilateral lesions did not necessarily lead to hemispherectomy). Therefore 65% of those suffering speech disturbance (13 of 20) had left hemisphere lesions and 35% had right hemisphere lesions.

Extent of recovery was not described clearly by Bassler, but Hecaen (1976) found disturbance to be temporary in all children, recovery varying from a few days to 2 yr., independent of side or site of lesion. In those situations studied by Bassler (1962) where the lesion occurred before onset of speech (usually before one yr., "most frequently in the first six months"), no statistical difference was noted for age of onset of speech between the left (34 cases) and right (38 cases) lesion groups. As Krashen (1973a) has pointed out, since the oldest child suffering speech disturbance after right hemisphere lesions was 5 yr., the results suggest that speech lateralization may possibly be complete by this age, and certainly that some specialization has occurred before the age of 10 yr., the age of the oldest child at lesion onset in the study and the age emphasized by Bassler and several subsequent commentators.⁶⁸ A similar pattern was described by Wilson (1970).

Bassler (1962) offered three possibilities for the development of cerebral dominance for speech: initially both hemispheres are involved with subsequent lateralization in most cases (based on fairly high incidence of childhood speech anomalies after right hemisphere lesion compared to adults); left cerebral laterality for speech from birth (based on occurrence of extensive lesioning of the right hemisphere early in life without alteration of speech development); right cerebral dominance for speech from birth (based on patients suffering from left hemisphere lesion early in

life without disruption of speech development). Bassler (1962) stated that the first possibility is the most prevalent, and the third possibility the rarest occurrence.

In his discussion of the data reported by Bassler (1962) and the view expressed by Penfield (1965) concerning the equipotentiality of the cortex at an early age ("the uncommitted cortex"), Dimond (1972) cited what he termed the prevalent view that speech dominance appears prior to, and as a facilitative agent for, speech development. But Dimond (1972) disagreed with this view:

The evidence suggests, however, that lateralization of the speech processes follows only after language acquisition has occurred as the result in so far as we can judge of intense bilateral activity of the brain At the stages at which the child is learning about language, the cerebral hemispheres show equipotentiality, at a later stage the child is learning to use language and it is at this time we witness the lateralization of the speech processes. (p. 168).

Bassler (1962) and Lenneberg (1967) appear to concur with this view.

Dimond (1972) also stated that motor functions in persons who develop cerebral pathology in one hemisphere early in life are not greatly affected by removal of that hemisphere. Until a certain age, the potential remains for re-learning and transfer of motor functions from one hemisphere to the second hemisphere. In his discussion of the effects of hemispherectomy, and in his general speculations on this topic and at other points in his book, Dimond (1972) indicated that he believes that speech specialization does not become

completely consolidated and that functional plasticity and transfer or re-learning of speech is the rule rather than the exception until adolescence.

Gott (1973) has also provided evidence of plasticity in the younger brain. In a study of the cognitive abilities of three hemispherectomy patients (a 12 yr. old who exhibited a left hemisphere malignancy discovered at age 8, a 16 yr. old who developed status epilepticus in the right hemisphere at age 6, a 34 yr. old whose right hemisphere became diseased and removed at age 28), Gott (1973) reported evidence that after right hemispherectomy in the mature brain (the 34 yr. old patient), the left hemisphere maintained its marked proficiency in verbal compared to non-verbal cognitive functions. However, in the developing younger brain (disease appearing at 6 and 8 yr.), regardless of which hemisphere was removed, less difference was present between abilities in verbal and non-verbal functions, though these two subjects performed at a generally lower overall level.

Isaacson & Nonneman (1973) disagreed with what they described as the prevalent view that brain injury tends to be less debilitating in direct proportion to the youth of the organism. These authors pointed out that studies of motor activities after brain damage in early life vs. later have tended to support this prevalent view; but when proper behavioural criteria are applied, behavioural impairments after early brain damage are often fully as large as after later damage. Rudel and Teuber (1971) and Teuber (1972) also ex-

pressed reservations concerning this prevalent view.⁶⁹ Such reservations are not necessarily in conflict with the statements of Dimond (1972), or those of Lenneberg(1967)⁷⁰, if behavioural criteria are specified and one carefully distinguishes between the types of abilities that suffer and fail to suffer permanent debilitation.

In this regard Morgan (1965) distinguished between sensory and motor deficits on the one hand and intelligence test performance on the other hand: the younger the age at which brain injury occurs, the greater the subsequent recovery of sensory and motor functions, but the greater the impairment on intelligence test performance.⁷¹

Morgan (1965) also distinguished between verbal and non-verbal aspects of intelligence tests. He stated that injury early in life is associated with lower scores on verbal and non-verbal tasks, but those injured in adolescence show an impairment only in non-verbal items if the lesion is not specifically in the speech area.⁷² Morgan (1965) explained these age dependent results in terms of hemispheric specialisation of function and the difference between learning ability and retention of information already learned. Children suffering brain injury at a young age are able to learn or re-learn speech, and though their IQ's tend to remain low, they exhibit none of the speech and language disabilities observed in the older individual suffering recent injuries to the hemisphere dominant for speech.

However, even when children are separated into right

vs. left hemisphere lesion groups, verbal and non-verbal scores tend to be lower than in the child with an intact brain, with no significant differences between verbal and non-verbal performance (Annett, 1973; Pennington, Galliani & Voegele, 1965; Reed & Reitan, 1969; - non-supportive findings, Fedio & Mirsky, 1969). Pennington et. al. (1965) and Reed and Reitan (1969) actually implied that the lack of difference in verbal vs. non-verbal scores in their samples of children in contrast to the verbal vs. non-verbal score discrepancies fairly consistently noted in adults with lateralized lesions on the Wechsler-Bellevue or the Wechsler Adult Intelligence Scale⁷⁵ may be due to a lack of verbal vs. non-verbal functional brain lateralization in children.

This type of research thus suggests that brain injury produces a global intellectual deficit in the young child regardless of side of lesion, while more specific types of intellectual deficit (e.g., verbal vs. non-verbal) occur with lateralized brain damage in the adult.

In terms of the overall discussion of developing lateralization and its consolidation in childhood, this pattern of differential verbal-nonverbal intelligence test score discrepancy in children vs. adults suggests the following process; because of greater plasticity the child's brain is able to re-organize itself so that the verbal or non-verbal function that would have been expected to become lateralized in the hemisphere that sustained the lesion if the lesion had not

occurred instead becomes lateralized in the opposite, intact hemisphere.⁷⁴ The intact hemisphere thus fails to specialize as extensively (or because of plasticity is able to reduce its specialization) as it would have without the injury. However, this mediation of verbal and non-verbal processing within the same hemisphere is accomplished at the expense of loss in overall intellectual functioning (see Milner, 1969). In the adult, the undamaged hemisphere is not capable of assuming the functions that had been mediated by the damaged hemisphere. The result is a deficit in the verbal or non-verbal intellectual skill previously mediated by the now damaged hemisphere. However, the undamaged hemisphere maintains its specialization for the processing of the type of information for which it has become specialized without the interference caused by an acceptance of additional information processing responsibility. The result is a maintenance of those abilities mediated by the intact hemisphere (normal probability of the relevant verbal or non-verbal intellectual abilities falling in normal range) and a reduction in the abilities mediated by the injured hemisphere (relatively lower corresponding non-verbal or verbal IQ).⁷⁵

In discussion of the capacities of the cerebral hemispheres of split-brain patients, Gazzaniga (1967) observed that the extent of adult right hemisphere language is in no way comparable to that present either in the left hemisphere of the adult or in the child's right hemisphere.

Up to the age of 4 or so, it would appear from a variety of neurological observations, the right hemisphere is about as proficient in handling language as the left. Moreover, studies of the child's development of language and particularly with respect to grammar, strongly suggest that the foundations of grammar - a ground plan for language, so to speak - are somehow inherent in the human organism and are fully realized between the ages of 2 and 3. In other words, in the young child each hemisphere is about equally developed with respect to language and speech function. We are thus faced with the interesting question of why the right hemisphere at an early age and stage of development possesses substantial language capacities, whereas at a more adult stage it possesses a rather poor capacity. It is difficult to conceive of the underlying neurological mechanism that would allow for the establishment of a capacity of a high order in a particular hemisphere on a temporary basis. The implication is that during maturation the processes and systems active in making this capacity manifest are somehow inhibited and dismantled in the right hemisphere and allowed to reside only in the dominant hemisphere. (p. 27).

Whether the right hemisphere capacity is dismantled or merely inhibited in the course of development is an intriguing question. Bogen (1969a) has stated:

The agraphia [a typical defect of the left hand of split-brain patients described by Bogen, 1969a] is evidently the result of a lack (or inhibition) of functioning connections between intact gnostic and intact effector elements of the right hemisphere. That some active inhibitory process is involved is the more attractive hypothesis since it suggests that we may find a specific method to enable the right hemisphere to write (or speak) after left hemisphere damage. This notion implies that as a particular function comes to be progressively more active in one hemisphere, it is progressively more inhibited in the other; and it is conceivable that release from inhibitory process would uncover a capacity which has been suppressed rather than lost. (p.102).

Geschwind (1968, 1969) argued in a similar vein when he speculated that the right hemisphere may be prevented from full participation in language activity unless inhibition by the left hemisphere is removed by approximately age 12 (1968), and that the right hemisphere lack of functioning is a problem of retrieval (1969). The model of functional localization (Moscovitch, 1973) also is an inhibitory model: removal of the dominant hemisphere's influence (e.g., in split-brain or hemispherectomy patients) releases the latent capacity of the right hemisphere.⁷⁷

Other researchers have also speculated about the age at which speech specialization may occur. On DL Netley (1972) observed that hemispherectomized patients who suffered infantile injuries (at a mean age of 17 months) identified fewer digits presented to the ear ipsilateral to the remaining hemisphere, than did the congenitally injured. These results were interpreted as indicating that injury in infancy has a relatively permanent effect on the capacity to identify dichotic material presented to the ear ipsilateral to the remaining hemisphere. This pattern in turn was related to the presence of some left hemisphere speech specialization and some predominance of contralateral vs. ipsilateral auditory pathways, both of which are irreversibly established as early as 17 months (Netley, 1972).

Similarly, Bogen (1969b) quoted a statement that the two hemispheres are equipotential or nearly equipotential by the age of initial speech acquisition and that lateralization

begins in the second year in parallel with speech acquisition.⁷⁸ Bogen (1969b) also added that his speculations concerning an oppositional mode of thought also imply that the hemispheres are equipotential for this function initially. But the oppositional mode is freer to exploit the intellectual potential of the second hemisphere as the ability to propositionize begins to become specialized in the left hemisphere.⁷⁹

It has also been reported that the laterality of brain lesions of early onset (e.g., infancy), leading to hemiplegia and hemispherectomy is relevant for speech defects (more defects in right hemiplegics - Annett, 1973) of a subtle receptive nature (Dennis & Kohn, 1975 - better performance in those having undergone right hemispherectomy than those having undergone left hemispherectomy). Earlier research on the same sample (Kohn & Dennis, 1974b) led Dennis & Kohn (1975) to conclude that extensive early right hemisphere damage did not result in a complete left hemisphere compensation, since right hemispherectomy patients failed to handle spatial tasks as well as left hemispherectomy patients. Annett (1973) concluded that factors inducing left hemisphere specialization can't be fully compensated for in some when early left-sided lesions occur, and that "the factors inducing left hemisphere language specialization appear to antedate infantile cerebral lesion and to be remarkably resilient in the face of early left damage" (p. 24). The finding of Dennis and Whitaker (1976) of deficiency of two left hemispherectomy patients in several language areas, in comparison with a right hemis-

pherectomy patient, though hemispherectomy occurred before speech onset in all three cases, led to the conclusion that "Language development in an isolated right hemisphere, even under seizure-free conditions, results in incomplete language acquisition" (p.404).

Thus, the above studies (Annett, 1973; Dennis & Kohn, 1975; Dennis & Whitaker, 1976; Kohn & Dennis, 1974b) reported that very early extensive lateralized brain pathology in either hemisphere did not allow the other hemisphere to handle certain functions as efficiently as would have been the case if such functions had been handled primarily by the hemisphere ordinarily dominant for those functions, even in the complete absence of the damaged hemisphere.

Rudel, Teuber and Twitchell (1974) speculated that functional hemispheric specialization may even be present prior to birth: they noted differential deficits in children diagnosed as suffering brain damage of pre- or perinatal origin. Children with neurological signs predominantly on the left side of their body (suggesting right cerebral damage) experienced disproportionate difficulty on non-verbal compared to verbal tasks, while children with neurological symptoms implicating the left hemisphere exhibited an opposite pattern of difficulties. Rudel, et.al. (1974) explained the discrepancy of their findings (i.e., behavioural deficits present later even if brain damage occurred at or prior to birth) with the language recovery noted by Bassler (1962) as perhaps due to whether the left hemisphere damage involved classical language areas. Language may not transfer

after very early brain damage unless the classical language zones are involved (Milner, 1969). In the review by Basser (1962) the hemisphere was impaired enough in many cases to eventually necessitate a hemispherectomy. The subjects used by Rudel et. al. (1974) were thought to have less extensive lesions, which in turn may have permitted the lesioned left hemisphere to continue to be dominant for language. However, the maintenance of dominance by a damaged hemisphere presumably produced the verbal deficits and "a surprisingly adult-like pattern of hemispheric specialization".^{80, 81, 82}

There is in fact evidence of the presence of an anatomical and physiological basis for hemispheric specialization at or before birth. A larger planum temporale (part of Wernicke's area of the temporal speech cortex behind Heschl's gyrus) has been found in the left hemisphere in a large percentage of adult brains (Geschwind & Levitsky, 1968; Witelson & Pallie, 1973; studies cited by Geschwind, 1970, 1972⁸³, Hécaen, 1976⁸⁴ and Selnes, 1974⁸⁵), infant brains (Witelson & Pallie, 1973; studies cited by Geschwind, 1970, 1972 - see note 83, and Hécaen, 1976 - see note 84) and even fetal brains (study cited by Hécaen, 1976 - see note 84; Geschwind, 1974 and Milner, 1974 both noted Wada reported such asymmetries as young as 20 weeks post-conception). Hemispheric asymmetries in angiography, blood volume and blood circulation are also present in human brains (Carmon & Gombos, 1970; studies cited by Geschwind, 1974⁸⁶ and Selnes, 1974⁸⁷), although no

differences were found at autopsy in amino acid levels in left vs. right Broca's and Wernicke's area (study cited by Selnes, 1974⁸⁸), 89, 90

A third school of thought concerning the age of onset of functional lateralization is thus that hemisphere specialization does not develop at all, but is present from the very beginning (e.g., Kinsbourne, 1975c).

The presence of anatomical asymmetries at birth or earlier, and the evidence that functional asymmetries may be present at this time or as early as the second year of life may seem to conflict with the critical age of 10-14⁹¹, the age range beyond which injury to the left hemisphere so often causes permanent language deficits. However the contradiction may be resolved by distinguishing between presence of an anatomical basis for the hemispheric asymmetries and the very early appearance of some specialization vs. the consolidation of such specialization over a number of years and accompanying loss of "plasticity" with greater consolidation (a somewhat similar explanation is offered by Hécaen, 1976, Kimura, 1963b and Krashen, 1973a). One may then link these states of specialization and consolidation to the permanence of language disturbances associated with lateralized brain lesions. Thus we have seen that temporary aphasic systems have been observed in children of 1 or 1½ - 10 yr. (e.g., Basser, 1962; Lenneberg, 1967; Sugar, 1952). The permanence of the language symptoms that have been noted in

some children of this age and younger (e.g., Fedio & Mirsky, 1969; Rudel et. al., 1974) may be explained by the fact that the damage failed to include critical portions (e.g., classical language areas) of the dominant hemisphere: hence language functioning continued to be mediated by a damaged hemisphere rather than transferring to the undamaged, highly "plastic" (at this age) second hemisphere.⁹²

2. Research on Normal Populations

a) Visual Field Asymmetries

Forgays (1953) noted a RVF superiority for the tachistoscopic recognition of 3- and 4- letter English words in children in each of grades 8 - 10, that was not present in children in each of grades 2 - 7.

A RVF superiority for word recognition in normal and poor reading grade 7 groups (McKeever & Huling, 1970a) was interpreted in terms of language dominance of the left hemisphere. The discrepancy with the data of Forgays (1953) was explained in terms of methodological improvements (e.g., exposure duration below threshold for eye movements to occur, employment of a fixation number).

On both bilateral and unilateral presentation, Carmon, Nachshon and Starinsky (1976) found a RVF-superiority in Hebrew children in grade 5 and 7 for 2- and 4- letter Hebrew words (even though the scanning of Hebrew words from right to left would eliminate any left to right reading scan bias), a superiority that was absent in Hebrew children in grades 1 and 3. These results were interpreted as reflecting the pre-

sence of left hemisphere dominance by grade 5. However, a RVF word (English) recognition superiority was found on both unilateral and bilateral presentations in children whose reading was average or above in each of grades 2 - 6 (Olson, 1973).

Witelson (1975) found a superior LVF recognition of pictures of people in 6 - 14 yr. old males.

b) Tactual Asymmetries

When the fingers of each hand were simultaneously presented with a different nonsense shape ("dichotomous stimulation"), a left hand recognition superiority was observed in 6 - 14 yr. old males (Witelson, 1974, 1975) that was also present in 5 yr. old, but not 3 or 4 yr. old, right-handed males (Witelson, in press). Linguistic information (letters) failed to yield differences (Witelson, 1974) or a right hand superiority (Witelson, 1975).

There is also evidence that greater left thumb sensitivity (and possibly right hemisphere specialization) may be present in 6 - 9 yr. olds (Ghent, 1961; Kimura, 1963b).

c) Dichotic Listening (DL)

The rationale for the fact that ear performance asymmetries on DL have been employed for the current thesis research, as an indicator of hemispheric dominance for the processing of the type of material presented dichotically, will be presented in detail in a later section. It will simply be re-iterated at this point that on DL the superior ability of

one ear to identify material presented to it, relative to the performance of the other ear, has been interpreted as a reflection of the dominance of the hemisphere contralateral to that ear for the processing of that general category of material (Kimura, 1967).

Thus the fact that the REA on DL has been noted as early as the age of 4-6 yr. for the identification of digits (Borowy, 1974; Geffner & Hochberg, 1971; Kimura, 1963b, 1967; two samples of Knox & Kimura, 1970; Sommers & Taylor, 1972; Sommers, Brady & Moore, 1975; Witelson, 1975)⁹³ and syllables (Berlin et. al., 1973a; Dorman & Geffner, 1974⁹⁴; Geffner & Dorman, 1976; Hynd & Obrzut, 1977), and the age of 3-6 yr. for the identification of words (Brunt & Goetzinger, 1968⁹⁵; Goodglass, 1973; Ingram, 1975; Knox & Kimura, 1970; Masterton, 1975; Nagafuchi, 1970; Piazza, 1977; Schulman-Galambos, 1977; Slorach & Noehr, 1974; Sommers & Taylor, 1972; Sommers et. al., 1975), and even younger children⁹⁶, has been interpreted as a reflection of the presence of left hemisphere language dominance by these ages.

Researchers have also noted that this REA for verbal material undergoes very little change in the older (i.e., 7-13 yr. old) child and seems to be identical to results with adults (Berlin et. al., 1973a; Geffen, 1976; Goodglass, 1973; Hynd & Obrzut, 1977; Knox & Kimura, 1970; Krashen & Harshman, 1972; Mirabile, Porter, Hughes & Berlin, submitted; Nagafuchi, 1970; a study cited by Porter & Berlin, 1975⁹⁷; Schulman-Galambos, 1977; Springer & Eisenson, 1977; Tobey, Cullen,

Gallagher & Ramp, 1976; Witelson, 1975). Such findings have led to the hypothesis that the adult pattern of left hemisphere lateralization for language mediation has been established by the age of 5 or 6 (e.g., Berlin et.al., 1973a; Dorman & Geffner, 1974; Knox & Kimura, 1970; Krashen, 1973a; Krashen & Harshman, 1972) or younger (e.g. Piazza 1977).

A LEA for identification of non-verbal environmental sounds (e.g., water pouring, clock ticking) in two samples of children of 5-8 yr. who exhibited the REA for the identification of digits led Knox and Kimura (1970) to conclude that in their sample the functional differentiation of the left and the right hemisphere had in effect attained the adult pattern, as indicated by attainment of the adult pattern of ear performances on DL. Piazza (1977) has extended this hypothesis to the age of 3 yr: she found a LEA for environmental sound identification in 3 yr. and 5 yr. old males and females and 4 yr. old males, and a significant REA for identification of words in four of the five groups. However, one could interpret her data concerning word identification as showing developing REA beyond 3 yr. since the 3 yr. old males and 4 yr. old females failed to exhibit the significant REA that both 5 yr. old groups exhibited.

Also, the data of Bryden (1970), Bryden and Allard (1973, in press), Darby and Satz, 1973, Satz, Bakker, Teunissen, Goebel and Vander Vlugt (1975), Witelson and Rabinovitch (1972), and Zurif and Carson (1970) has raised some doubt whether the development of ear performance asym-

metries on DL (at least for digit identification) has stabilized even by 5 years of age.

Zurif and Carson (1970) failed to obtain a significant REA in 14 grade 4 normal and 14 grade 4 poor readers (classified as dyslexic since normal IQ, no evidence of brain damage and average achievement in arithmetic). The failure to observe a significant REA in the grade 4 normal reading group has at least four interpretations. 1) Left hemisphere dominance for language is present since the REA of the normal readers approached a significant level (.10). If a larger sample had been employed, a significant REA would have been present. This is the explanation offered by Zurif and Carson (1970). 2) Left hemisphere language specialization is present in the right-handed subjects. Most studies finding a REA on DL with verbal materials in children have included only right-handed children (e.g., Berlin et. al., 1975b; Dorman & Geffner, 1974; Geffen, 1976; Ingram, 1975; Kimura, 1965b, 1967; Knox & Kimura, 1970; Mirabile et.al., submitted; Schulman & Galambos, 1977; Witelson, 1975). Non-right-handed populations have consistently exhibited a more variable performance pattern on numerous indicators of cerebral dominance than have right-handed populations (e.g., on the sodium amytal measure - Branch et. al., 1964; in ear and VF asymmetry studies - Bryden, 1965, 1970, Buffery, 1974, Curry, 1967, Curry & Rutherford, 1967, Dee, 1971, Fennell, Satz; Van den Abell, Bowers & Thomas, undated, Gilbert & Bakan, 1973, Hécaen & Sauguet, 1971, Higgenbottom, 1973, Hines & Satz, 1971, 1974, Kimura, 1975b, Knox &

Boone, 1970, Levy, 1969, Marshall, 1973, McGlone & Davidson, 1973, McKeever & Gill, 1972, Miller, 1971, Nebes, 1971a, Newcombe & Ratcliffe, 1973, Satz et. al., 1965, 1967, Zurif & Bryden, 1969; in unilateral ECT - Warrington & Pratt, 1973; in studies of relative EEG activity in the two cerebral hemispheres - Giannitrapani, 1967; and unilateral brain injury effects - Benton, 1965, Satz, 1977a. The more highly variable dominance pattern exhibited in left-handed populations has also been discussed by Bogen, 1969b, Goodglass & Quadfasel, 1954, Levy, 1974 and Penfield & Roberts, 1959, among others).⁹⁸ Thus the inclusion of two left-handers and three others of indeterminant handedness (as indicated by responses to a 14-item questionnaire) among the 14 subjects in the normal reader group may have obscured the REA usually found in right-handed samples. 3) Left hemisphere dominance is present. However the REA is obscured by a decreasing ear difference as the left ear improves its overall performance relative to the right ear due to a ceiling effect on the relatively easier DL task used with children compared to adults (Kimura, 1963b; Satz et. al., 1975). 4) Left hemisphere dominance for language is still being established. This latter interpretation would be in conflict with the view that left hemisphere language lateralization had completed its development and attained the adult pattern by the age of 5 yr.

Witelson and Rabinovitch (1972) also noted a non-significant ear superiority on DL (digit) in a group of average achievers of approximately the same age as studied by Zurif

and Carson (1970). Unfortunately, the results of Zurif and Carson (1970) and Witelson and Rabinovitch (1972) are inconclusive in terms of development trends on DL (e.g., any possible changes in ear dominance in children beyond the age of 5 yr.) because only one age group was studied.

However, five studies have appeared that did utilize different age groups and that also reported an increasing ear asymmetry for the identification of verbal materials well beyond the age of 5 yr. (Bryden, 1970; Bryden & Allard, 1973, in press; Darby & Satz, 1973; Satz et. al., 1975).

Bryden (1970) noted an increasing REA with grade level for digit identification in right-handed children in grade 2, 4 and 6 (decreasing REA with left handers). The difference between the handedness groups failed to reach significance until the grade 6 level. In addition, "assuming a close relation between dichotic listening laterality and cerebral dominance, the present data indicate that the adult pattern is not achieved until grade 6 in boys and grade 4 in girls" (Bryden, 1970, p.449). But Bryden (1970) can be criticized for his interpretation of his data and his failure to provide sufficiently detailed statistical analysis.⁹⁹

In a study of 6, 8, 10, 12 and 14 yr. old males and females analyzing only first responses, Bryden and Allard (1973) noted a tendency toward a REA for syllable identification by 10 yr. that did not reach statistical significance until 12 and 14 yr. Bryden and Allard (in press)

also found evidence for developing lateralization in 8, 10 and 12 yr. olds when a scoring procedure designed to correct for ear order of report bias was utilized.

Satz et.al. (1975) reviewed five of the studies that have demonstrated a REA for verbal material by the age of 4 or 5 yr. (i.e., Berlin et. al., 1973a; Geffner & Hochberg, 1971; Kimura, 1965b; Knox & Kimura, 1970; Nagafuchi, 1970) that was maintained in older children. The fact that such studies demonstrated that degree of ear asymmetries (and inferred language lateralization) did not change (or even decreased slightly) was seen by Satz et. al. (1975) as conflicting with expectations from a developmental or maturational process view of hemispheric lateralization and discrepant with clinical data of incidence of, and recovery from, speech disturbances in brain-injured children. Such discrepant results were explained by Satz et. al. (1975) in terms of procedural artifacts or method of scoring and analyzing responses (e.g., in the studies of Kimura, 1965b and Knox & Kimura, 1970, the presence of a ceiling effect). Thus Satz et. al. (1975) utilized a more difficult task (30 series of 4 digit pairs, and a multivariate analysis of regression model) with 5, 6, 7, 9 and 11 yr. old male and female groups in an effort to eliminate any ceiling effect. Although ear asymmetry was not significant until the age of 9, Satz et. al. (1975) did find a higher right ear score at age 5; they also noted a similar tendency in two other investigations that failed to report a significant REA until much older (i.e., Bryden & Allard,

1973; Darby & Satz, 1973¹⁰⁰ - Darby and Satz, 1973 reportedly obtained a significant REA in normal 12 yr. olds that was absent in 12 yr. old dyslexics and 5 and 7 yr. old normals and dyslexics). Although their primary purpose was to investigate other variables, several other studies conducted by Satz and his co-workers have supported the hypothesis that ear asymmetries on DL (especially for digits) continue to develop beyond the age of 5 yr. (Satz, Rardin & Ross, 1971; Satz & Friel, 1973; Satz & Van Nostrand, 1973, Sparrow & Satz 1970).

It should be pointed out that several studies earlier cited that have found a REA with verbal materials on DL in younger children have employed words or syllables (Berlin et al., 1973; Dorman & Geffner, 1974; Geffner & Dorman, 1976; Goodglass, 1973; Hynd & Obrzut, 1977; Ingram, 1975; Krashen & Harshman, 1972; Mirabile et al., submitted; Nagafuchi, 1970; Piazza, 1977; Sadick, in preparation, see note 94; Sobotka, 1974, see note 97; Sommers & Taylor, 1972; Tobey et al. 1976), and/or restricted themselves to a narrow age range (e.g., Dorman & Geffner, 1974; Geffner & Hochberg, 1971; Geffner & Dorman, 1976; Piazza, 1977; Sadick, in prep.; Sommers & Taylor, 1972), and/or omitted statistical analysis of ear differences at each age level (e.g., Hynd & Obrzut, 1977; Knox & Kimura, 1970; Mirabile et al., submitted; Schulman-Galambos, 1977; Sommers & Taylor, 1972; Witelson, 1975); or else details of experimental methodology, analysis,

etc., were not accessible to the present reviewer (e.g., secondary references or abstracts only available - Borowy, 1974, Sadick, in prep., Sobotka, 1974). Many of these studies also failed to obtain a significant REA in several of the age groups studied (e.g., Geffner & Hochberg, 1971; Geffner & Dorman, 1976; Ingram, 1975; Kimura, 1963b; Nagfuchi, 1970).

The only studies that the present reviewer has uncovered that have investigated ear asymmetries utilizing digits on DL and that have included a relatively wider age range are those of Borowy (1974), Bryden and Allard (in press), Darby and Satz (1975), Kimura (1963b, 1967), Knox and Kimura (1970), Satz et. al., (1975), Sobotka (1974), and Witelson (1975). In this specific sense the developmental pattern suggested from findings of Bryden (1970), Bryden and Allard (in press), Darby and Satz (1975) and Satz et. al. (1975) stand in contradiction only to that suggested from the data of Borowy (1974), Sobotka (1974) and the Kimura studies. When this list is reduced further to primary reference literature employing digits on DL and references providing sufficiently detailed analysis and description of methodology, only Satz et. al. (1975) vs. Kimura (1963b, 1967) remain.

The DL research pertaining to development of ear asymmetries of verbal material across a fair age range reveals much less consistent support for the permanent establishment of the REA for digit identification by 5-6 yr. (support-

Borowy, 1974, Kimura, 1963b, 1967, Knox & Kimura, 1970, Sobotka, 1974, Witelson, 1975; non-support-Bryden, 1970, Bryden & Allard, in press; Darby & Satz, 1973, Satz et. al., 1975; even when these studies are screened to eliminate inaccessible and inadequately described or analyzed research - Satz et. al., 1975 vs. Kimura, 1963b, 1967) than for the permanent establishment of the REA for verbal material other than digits (support-Berlin et. al., 1973a, Geffen, 1976, Goodglass, 1973, Hynd & Obrzut, 1977, Knox & Kimura, 1970, Krashen & Harshman, 1972, Mirabile et. al., submitted, Nagafuchi, 1970, Schulman-Galambos, 1977, Sobotka, 1974 vs. Bryden, 1973, in press). This present state of knowledge differs from that known at the time a DL digit task was selected by the present reviewer as his left hemisphere measure (spring-summer, 1974); at that time the results utilizing digit and other verbal measures were in essential agreement that ear asymmetries were permanently established by 5-6 yr. It thus did not appear crucial at that time to employ both digits and another verbal measure in the same study, nor to make any digit task employed relatively complex (e.g., 4-pair digit sets as utilized by Satz et. al., 1975).

The differing consistency of results concerning the development of ear asymmetries dependent on the type of verbal input employed suggests the following possibilities: 1) left hemisphere dominance, or at least that aspect of left hemisphere dominance tapped by DL of verbal input, is firmly

established by age 5-6 and syllables and words other than digits may provide a more sensitive measure than digit material of the presence of such dominance 2) left hemisphere dominance, or at least that aspect of left hemisphere dominance tapped by DL of verbal input, is not firmly established by the age of 5-6 yr. and the digit measure may be the more sensitive indicator of this unstable state of left hemisphere dominance, especially if the digit task is made sufficiently complex (e.g., several digit pairs presented) to reduce any ceiling effects 3) digits, especially more complex digit material, in comparison with other verbal material, may represent a discrete type of information in terms of left hemisphere specialization (i.e., two different types of left hemisphere specialization being tapped - see Porter & Berlin, 1975).

Thus, despite the number of DL studies with children conducted to date, the age of onset and development of the type, or types, of left hemisphere specialization elicited by verbal DL measures, remain to be definitively established.

In regard to the development of any LEA for identification of non-verbal dichotically presented input, the only relevant paper to appear in the literature, prior to the present reviewer's selection of environmental sounds as his measure of right hemisphere specialization, was that of Knox and Kimura (1970). Although a significant LEA was observed overall in two samples of 5-8 yr. old males and females

for identification of environmental sounds, only four of eight age-sex groups in the first sample exhibited a significant LEA (experiment I), while no statistical analysis was provided for each age-sex group of the second sample (experiment II - quite possibly four or more of the eight age-sex groups would have failed to exhibit a significant LEA, as the level of overall significance was .001 in exp. I and .05 in exp. II). Knox and Kimura (1970) also failed to obtain a significant overall LEA in the only sample (exp. II) asked to identify animal sounds.

Only one other developmental study has since appeared: Piazza (1977) found an overall LEA that was also significant in five of six 3-5 yr. male and female groups. Hence, the pattern of development of the LEA in DL of non-verbal material requires further study, both in terms of children older than 8 yr. and in terms of replication and further investigation of developmental trends in younger children.

d) Monaural Listening (ML)

Results have been contradictory on a monaural task of reporting digits in the order presented. No REA was found in normal 6-12 yr. olds (Bakker, 1967), but a significant REA was found in 7-13 yr. olds (Bakker, 1970) and 10 yr. olds (Bakker, 1969). It was later reported that the REA was not present in younger children (i.e., 7-8 yr.) and present in older children (i.e., 9-11 yr.) only if the children were good readers (Bakker et. al., 1973). A more consistent ear

superiority (LEA) was obtained in reproducing ML "Morse-like sound patterns", whenever such a task was included with the digit task (Bakker, 1967, 1968, 1970).

Unfortunately, the Bakker team research effort provides little useful information concerning the development of hemisphere asymmetries since the studies suffer from serious sampling (no screening for hearing defects, handedness or causes of any reading deficits observed), statistical (tendency to omit analysis of subjects failing to show ear differences, over-interpretation of non-significant data) and general design weaknesses (confounding of variables).

Another ML task utilized by Van Duyne, D'Alonzo and Scanlan (1976) has obtained a REA in 6yr. olds on a relatively complex (7- and 8- stimulus attributes), but not more complex (9-stimulus attributes) verbal task; a REA did not appear in 5 yr. olds on either task.

e) Electro-cortical Studies

When reaction to auditory input has been utilized (e.g., auditory evoked potentials), asymmetrical activity in the left hemisphere with verbal material and in the right hemisphere with non-verbal material have been reported in infants (studies cited by Levy, in press and Witelson, 1975¹⁰¹), asymmetrical activity in the infant brain being similar to that found in children and adults (study cited by Selnes, 1974¹⁰²).

f) Lateral Eye Movements

The study of lateral eye movements in children has

not been investigated to any extent. In a study of 4-6.3 yr. olds, Schroeder (1976) found only 14 children shifted their eyes to the right, 19 shifted eyes left and 12 failed to shift their eyes in any consistent direction.

Kinsbourne (1975a) cited an unpublished study (Kinsbourne & Jardno) with 5 yr. olds where verbal thinking (verbal questions) tended to induce momentary gaze shifts and head-turn to the right, while spatial questions tended to induce head turn and eye shifts to the left.

3. Sex Differences

Developmental data derived from experimental measures of cerebral dominance may be utilized to determine if there seem to be any sex differences in how cerebral dominance might develop. Although the present discussion will emphasize results with DL, other data will also occasionally be cited.

Kimura (1973a) and Bryden (1970) both suggested that speech lateralization, as indicated by ear asymmetries on DL, may develop earlier in females than in males. However, Kimura (1973a) does not cite supportive data and her own results (e.g., Kimura, 1963b, 1967; Knox & Kimura, 1970; as well as the data of Bryden, 1970 - see note 99) generally fail to support this hypothesis. In addition, with the exception of one investigation (Geffner & Dorman, 1976) and a very specific component of a second study (Mirabile et. al., submitted), neither study having utilized digits, research has consistently failed to obtain sex differences on age of onset or degree of the REA

for the identification of verbal material on DL (Berlin et. al., 1973; Borowy, 1974; Bryden & Allard, in press; Geffner & Hochberg, 1971; Hynd & Obrzut, 1977; Ingram, 1975; Kimura, 1963b; Knox & Kimura, 1970; Nagafuchi, 1970; Piazza, 1977; Satz et. al., 1975; Schulman-Galambos, 1977; Sommers & Taylor, 1972). Therefore, the evidence is overwhelming that there are no sex differences in the development of the type of left hemisphere functioning tapped by the traditional DL paradigm.

Some data from other measures has been interpreted as evidence of earlier maturation of the female left hemisphere (precise temporal regulation of finger movement - Wolff & Hurwitz, 1976; ML of verbal material - Van Duyne et. al, 1976, Van Duyne, Bakker & De Jong, 1977).¹⁰³

There is similarly little support for the hypothesis of sex differences in the development of the LEA for non-verbal input on DL. Knox and Kimura (1970) discussed the higher overall scores of 5-8 yr. old males, compared to females, for the identification of non-verbal environmental sounds in one of four experiments in terms of possible greater right hemisphere lateralization in males for this type of information-processing. However, Knox and Kimura (1970) failed to comment on the absence of sex differences in overall environmental sound identification in a second experiment, the fact that females in the first study actually demonstrated a LEA earlier than males (6 vs. 7 yr.) and that no sex differences

in extent of LEA were noted in either study.¹⁰⁴ It appears likely that any sex differences observed by Knox and Kimura (1970) were due to chance, which is supported by the finding of no sex effect for environmental sound identification in 3, 4, and 5 yr. old males and females who exhibited an overall LEA and significant LEA in five of the six age-sex groups (Piazza, 1977). Krashen (1973a) does make reference to an unpublished study finding a sex effect in adults; however, no details were provided other than that a REA for males and no ear differences for females were obtained for identification of environmental sounds under certain conditions.

There is however some evidence for earlier onset and development in males of the type of right hemisphere specialization associated with identification of nonsense shapes simultaneously presented to each hand (Witelson, 1974, 1975, 1976, in press), 5 and 6 yr. old males exhibiting a left hand identification superiority that didn't appear in females until the age of 13 yr.¹⁰⁵

To summarize present knowledge of sex differences in hemisphere specialization: although there is some data to suggest that there may be sex differences for hemisphere specialization for some types of information, the differences seem very slight and difficult to demonstrate on any consistent basis (Bryden, 1976), probably because of the specificity of any specialization (e.g., possibly for only a certain aspect of left or right hemisphere dominance); there is strong evidence

of the absence of sex differences in the onset, development and final status in the adult of the types of hemisphere dominance tapped by the conventional DL procedures.

4. The Development of Cerebral Dominance in Deviate Populations

a) Language Disorder¹⁰⁶

i) Theories. Many theorists have postulated that learning disorders result from a failure to establish cerebral dominance, especially specialization of the left hemisphere for verbal functioning (e.g., Mach, Orton, Woody & Rheingold). Abnormal specialization of the right hemisphere has been suggested as well (e.g., Witelson, 1977ab). Others have argued for a more general cerebral lag and/or dysfunction, such as a failure of the left hemisphere to fully develop (e.g., Kinsbourne, 1975a; Satz & Sparrow, 1970; Shankweiler, 1964; Witelson, 1975, 1977ab).

Fellows (1968) described an early theory which stated that discrimination of symmetrical figures (e.g., b and d; p and q) occurs only as a result of the development of a slight bodily asymmetry (particularly in the brain) that produces lateral dominance.¹⁰⁷

A similar theory of orientation perception emphasizing the importance of lateral dominance is described by Fellows (1968):

But whereas Mach gave a mainly behavioural account of the relationship between laterality and orientation, Orton attempted to express the relationship in neurological terms....

For Orton the clue to the neurological disorder underlying reading backwardness was the frequent occurrence of reversals. He distinguished two sorts of reversal errors:

(1) kinetic reversals, in which the order of letters in a word or the order of words in a sentence is reversed; and (2) static reversals, which involve confusing a single letter with its mirror-image. In the present survey we have considered only static reversals, since we are primarily interested in the discrimination of orientation and not in the process involved in the temporal confusion of sequential images. However, it is possible to interpret a kinetic as a static reversal if we regard the whole word or phrase as a unit of perception, or a Gestalt. Orton himself seems to interpret it in this way.

The tendency towards reversals in reading Orton termed "strephosymbolia" which literally means "twisted symbols". So, for Orton, strephosymbolia is a cause, and maybe the cause, of reading backwardness. Here, we shall be specifically concerned with outlining Orton's account of how a certain neurological process causes the child to confuse different orientations of the same visual form. His argument goes as follows.

The patterns of excitation that are aroused in the two cortical hemispheres by a single figure are identical except that they are mirror-images of each other. He writes,

The brain contains right and left visual areas which are exactly alike except for their opposite orientation, and we think, therefore, that the existence in the non-dominant hemisphere of engrams of different orientation from those in the dominant hemisphere cannot be lightly dismissed as the probable source of static and kinetic reversals and of the spontaneous ability in mirror reading and mirror writing. (1937, p. 155)¹²⁰

So, according to this theory, the discrimination of orientation problem arises in the following way. Since a single form arouses two patterns of excitation (engrams) which are mirror-images, so should we expect the mirror-image of this form to arouse the same two patterns though this time in the opposite hemispheres.

If this is the case, how then do we manage to discriminate a figure from its mirror-image at all? Orton's answer to this is the same as Mach's - through the development of lateral dominance. His explanation of how it works, however, is different.

Mach, it will be recalled, hypothesized that the stimulation resulting from the symmetrical movements of the eyes would be modified by laterality. Orton, on the other hand, argued that lateral dominance enabled one cortical hemisphere to suppress the engrams of the other. This meant that a single form would arouse only a single pattern of excitation in the cortex of an individual in whom lateral dominance had developed; and the mirror-images of this form would arouse a different pattern (i.e., the mirror-image of the former).

So, it is Orton's theory that mirror-image discrimination is difficult when there is a similarity between the engrams in the two hemispheres, and that this happens when there is incomplete dominance. With the development of laterality the excitations in the non-dominant hemisphere are elided leaving a relatively simple shape discrimination to be made within the dominant hemisphere. (pp.147-149).

In his review of cerebral dominance in dyslexia¹⁰⁸, Zangwill (1962) speculated that dyslexia in the poorly lateralized (e.g., weak, mixed or inconsistent lateral preference) may differ significantly from dyslexia in the fully lateralized.

It is difficult to arrive at any clearcut conclusions. If however, it is agreed that dyslexia presents more frequently among the ill-lateralized, and if lack of definite lateral specialization implies atypical cerebral dominance, it follows that atypical cerebral dominance is characteristic of a fair proportion of backward readers. The dyslexia itself may result from early brain injury, constitutional defect in maturation, or retardation secondary to stress. Indeed, it may well be due to a combination of these factors. At all events, fuller understanding of reading and its disorders must presuppose fuller understanding of the ways in which asymmetrical functions become established in the human brain. (Zangwill, 1962, p.113).

Shankweiler (1964) referred to the proposal of Orton

(1967) that dyslexia is a result of weakened cerebral dominance, as reflected in the frequency of occurrence of weak lateralization or a family history of sinistrality. It was pointed out that Orton proceeded considerably beyond the empirical evidence of lateralization of speech and language functions in the brain and their relation to handedness in his postulation that the major hemisphere directly controls the minor hemisphere in the co-ordination of all activities, (e.g., in the quote above taken from Fellows, 1968, it is clear that Orton believed that the dominant hemisphere suppresses activity in the other hemisphere). Though Shankweiler (1964) concluded that there is no evidence to support this latter view,¹⁰⁹ he noted the association of dyslexia with left-handedness and ambilaterality remains a crucial fact to be explained.

Shankweiler (1964) stated that two different types of developmental dyslexia are suggested by Wechsler Verbal-Performance scale studies and associated EEG activity in dyslexic children (four studies are cited).

Taken at face value these results suggest that different types of dyslexia may arise depending on whether the major or the minor hemisphere is involved. Whether the abnormality of development stems from mild cerebral damage, delayed maturation, or as is likely to be the case, a combination of these causes, cannot definitely be stated. (Shankweiler, 1964, p. 60).

The role of cerebral dominance in dyslexia has also been discussed by Critchley (1966, 1972). He found that 100 dyslexics performed similarly to a normal group in direction.

of gaze, though he noted McFie and later Ettlinger and Jackson¹¹⁰ to have reported that dyslexics failed to exhibit a clear-cut directional tendency on the Jasper-Raney-Phi-test.

This suggests a lack of one-sided occipital dominance which may well be the evidence of non-maturation. This state, often spoken of as "cerebral ambilaterality", is believed by some to be associated with an unstable cerebral organization, one which is particularly sensitive to the effects of stress.

That both cerebral ambilaterality and dyslexia are to be equated with immaturity of cerebral development, is the view most widely held today among neurologists. W. Goody and M. Reinhold (1969),¹¹¹ who have entertained the same notions of maturational lag, have expressed them in somewhat different terms. They stressed the hypothesis that in normal circumstances asymmetry of the functions of the two cerebral hemispheres is established as a child develops, and that this asymmetry of function is closely related to the performance of reading and writing. Children with developmental dyslexia, however fail to establish asymmetry of function in the cerebral hemispheres (Critchley, 1972, p. 70).

In his discussions of aphasia, delayed speech, stuttering, and retarded reading, Delacato (1959, 1963, 1966) emphasized the importance of underlying neurological organization. From birth it was argued that neurological organization proceeds toward the cortex, development is regular and sequential, organization at a lower (i.e., ordinarily earlier developing) level is necessary for organization to occur in a higher (i.e., ordinarily later developing) level. The organization of the subcortex is a prerequisite for organization of the cortex, and cerebral dominance cannot proceed until cortical organization has occurred. Treatment is initiated at the lowest level where neurological organization has failed to develop properly. In terms of the present discussion

of language disorder in relation to cerebral dominance, training proceeds until the point when establishment of cerebral dominance becomes the goal. Training to promote cerebral dominance involves establishing the consistent use of a foot, eye, and hand on a particular side of the body, the assumption being that training to enforce unilateral sidedness will encourage dominance of the cerebral hemisphere that controls that side.

Satz and Sparrow (1970) postulated a lag in maturation of the left hemisphere in dyslexia, the behavioural deficits present being similar to adults with left cerebral damage and including right-left confusion, finger agnosia, calculation, writing and visuo-construction difficulties and lower verbal intelligence. Kinsbourne (1975a) has similarly argued that many of the manifestations of selective reading disability are a result of general delay in left hemisphere maturation, rather than being attributable to a delay in specific lateralization, such as for language representation.

However, the presence of abnormal cerebral dominance in dyslexia is thought by Witelson (1975, 1977ab) to apply only to right hemisphere specialization: left hemisphere speech specialization is thought to be normal, but in the context of a general left hemisphere dysfunctioning.

In addition to his theorizing about dyslexia and lack of cerebral dominance, Orton (1928) also proposed that mixed speech dominance was the essential causative factor in stuttering. 112

Specific research will now be reviewed relating to the issue of lack of cerebral dominance and impaired cerebral functioning factors in dyslexia and stuttering.

ii) Visual field asymmetries. In a specific group of poor readers of 8 - 9 yr. of age Olson (1973) failed to find a RVF superiority for the recognition of 3 and 4-letter words presented tachistoscopically, whether the material was presented unilaterally or bilaterally. A 10 - 11 yr. old group and normal reading 8 - 11 yr. olds did exhibit the usual RVF superiority. The group of poor readers possessed no known physical, intellectual, emotional or cultural deficits.

Similarly, no VF differences in recognition of pictures of figures of people have been noted in dyslexics, compared to a LVF superiority in groups of normal reading 6 - 14 yr. old boys (Witelson, 1975).

Marcel et. al. (1974) found a greater number of RVF recognitions of 5-letter words unilaterally presented in good as contrasted to poor readers, 7 - 8 yr. of age. However, poor reading is related to a myriad of factors (Johnson & Myklebust, 1967; Mackworth, 1972), and a weakness of this latter study is the fact that unlike Olson (1973) and Witelson (1975), no attempt was made to control for any of these factors in the poor readers.

iii) Auditory asymmetries. We have seen that there is some ambiguity about the exact pattern of the development of ear asymmetries on DL in the normal child, though the stronger thrust of the research results is that REA for identification

of verbal material (especially for syllables and words other than digits) is present in the 5 yr. old. At the same time children with serious reading problems are slower in developing the REA for digits (Satz et. al., 1971; Satz & Friel, 1974; Sparrow & Satz, 1970; Witelson & Rabinovitch, 1972; Zurif & Carson, 1970; studies cited by Kimura, 1967¹¹³, Zurif and Carson, 1970¹¹⁴, and Satz et. al., 1975 - see note 100) or obtain lower scores overall for digit (McKeever & Van Deventer, 1975; Satz & Friel, 1973, 1974; Witelson, 1975; Witelson & Rabinovitch, 1972) and syllable identification (Springer & Eisenson, 1977; Tobey et. al., 1976; study cited by Tobey et. al., 1976¹¹⁵). Such results have been interpreted as reflecting a maturational lag in the lateralization of the mechanisms subserving language behavior (Kimura, 1967; Zurif & Carson, 1970) or a disorder of left hemisphere functioning (Witelson, 1975; Witelson & Rabinovitch, 1972), possibly related to a more general lag in maturation of the entire left hemisphere (Satz et. al., 1971; Satz & Friel, 1973, 1974¹¹⁶; Sparrow & Satz, 1970) or at least an indication of an atypical development of such cerebral speech processing (Sommers & Taylor, 1972; Witelson & Rabinovitch, 1972). Such results in turn provide support for at least some aspects of the theorizing of Orton, Mach, Delacato and Sparrow and Satz.

It should be noted that these studies tended to carefully select their poor reading samples (i.e., restrict poor readers to children fitting the definition of dyslexia provided by Money, 1962, see note 108).

Thus, the fairly consistent finding of a REA on DL for the identification of verbal materials in young children (e.g., 5 - 6 yr. olds) is thought to reflect left hemisphere language specialization; the absence, or lessened size, of the REA and lower overall scores of dyslexic children at these ages and older have been interpreted as supporting the hypothesis of reduced and abnormal states of left hemisphere functional specialization.¹¹⁷

A different view of the development of language specialization has been forwarded by Bakker et. al. (1973), based on a ML measure of language dominance: that a strong degree of language lateralization is associated with reading achievement only in the older child (e.g., 9 - 11 yr.). Bakker et. al. (1973) found only a minimal REA in 7 - 8 yr. old good readers in identifying digits in the sequence monaurally presented, while 9 - 11 yr. olds exhibited a strong REA. Hence Bakker et. al., 1973 (like Bryden, 1970; Bryden & Allard, 1973, in press; and Satz et. al., 1975) postulated that language lateralization in the normal child is far from complete by the age of 5 yr.¹¹⁸.

However, other studies with this ML procedure have been contradictory: absence of an REA for ordered digits and letter-enumeration (Bakker, 1967, 1968) vs. a REA in 7 - 13 yr. olds (Bakker, 1969, 1970). The fact that the whole Bakker series of studies suffers from various selection, statistical and general methodological limitations (see earlier discussion),

and that the procedure has not been utilized to any extent beyond the Bakker group suggests that the Bakker data provides highly doubtful information concerning the normal development of language dominance and its relationship to reading skills.

But one might wish to adopt a less critical stance in at least accepting the Bakker ML data in general, if not in specific, terms (i.e., entertain the possibility that, in general, the Bakker ML technique may elicit a reduced REA in younger children, compared to DL, that only attains significance in older children). If so, one might explain the difference in development of ear asymmetries on the two tasks on the basis of the following reasoning. The REA for ML appeared to be due to the ordered recall and temporal sequence requirement of such tasks (Bakker, 1969), since ML without the requirement to report digits in the order presented failed to elicit ear differences (Kimura, 1967) and since temporal sequencing seems to be language (usually left) hemisphere mediated (Bosshardt & Hormann, 1975; Carmon, 1971; Carmon & Nachshon, 1971; Efron, 1963abc; Gordon, M., 1967; Halperin et al., 1973; Krashen, 1973b; Lackner & Teuber, 1973; Papcun et al., 1974; Robinson & Solomon, 1974).¹¹⁹ Perhaps this fact and the left hemisphere specialization for language (e.g., digit and letters as language symbols), together with the slight numerical advantage of contralateral vs. ipsilateral auditory nerve fibers arising from a particular ear, is sufficient to produce the REA¹²⁰ without the need of simultaneous input to both ears

that Kimura (1967) believed to be required to produce ear asymmetries.¹²¹

If the temporal-sequential requirement of the Bakker ML task is what prevents the occurrence of the REA until an older age, since the REA generally appears in younger and older age groups in the absence of such temporal-sequential task demands (i.e., on free recall on DL), one is left with the following hypothesis that would reconcile the apparent discrepancies in developmental performance on the two tasks. Lateralization may be present and fully developed in 5 - 6 yr. olds¹²² for those aspects of language that involve little or no temporal-sequential processes (e.g., single words and phrases, recall of digits and words in any order); but those aspects of language involving complex temporal-sequential relationships (e.g., syntax-ordering of words in sentences and sentence structure formulation; ordering of several sentences on a particular topic, recall of digits in proper order) may not become lateralized, or at least fully lateralized, until a later age. Thus free recall on DL and the sequenced recall on ML may be measuring different aspects of left hemisphere dominance.¹²³

Better designed research with the Bakker ML technique, possibly in association with DL¹²⁴ and other studies in general involving the development of left hemisphere specialization for temporal information processing, will determine the validity of such a hypothesis.¹²⁵

Attempts to discover whether difficulties in expressive

speech are associated with abnormal ear asymmetries for verbal material on DL have yielded contradictory results. Abnormal ear asymmetries have been reported in children with serious speech delay (Sommers & Taylor, 1972) and in child (Sommers, Brady & Moore, 1975) and adult stutterers (Curry & Gregory, 1969; Sommers et. al., 1975).¹²⁶ However, normal ear asymmetries were found in child (Slorach & Noehr, 1974), adolescent (Gruber & Powell, 1974¹²⁷) and adult stutterers (Dorman & Porter, 1975¹²⁸; Sussman & MacNeilage, 1975b).¹²⁹

iv) Miscellaneous studies. One might argue that DL in itself may not be sufficient to detect the nature of any deviation in cerebral dominance among stutterers because DL may tap receptive speech specialization (e.g., see Brown & Jaffe, 1975; Kinsbourne, 1974b), whereas the difficulties of stutterers obviously lie in the expressive speech area.¹³⁰

In this regard, Sussman and MacNeilage (1975bc) found a REA in adult stutterers in reporting syllables on DL, but no ear differences on pursuit auditory tracking (matching through jaw movements continuously varying pure tone presented to one ear with a second tone presented to the other ear). These results were interpreted in terms of abnormal speech production (auditory tracking) and normal speech perception (DL) in stutterers in comparison to normal speech groups.

Any expressive speech lateralization abnormality in stutterers may be related to anomalous EEG activity (com-

pared to normal controls) in the frontal areas of the left and right hemisphere of stutterers, even when the stutterers were not about to speak. (Zimmerman & Knott, 1974).¹³¹

Witelson (1975) found no hand differences in the recognition of nonsense shapes presented "dichotomously" and a better left hand identification of letters among a dyslexic group, in contrast with a left hand superiority in recognizing nonsense shapes and a right hand superiority on letter identification in a normal reading group.

b) Subaverage Intelligence

Empirical investigation of cerebral dominance in the intellectually subaverage, including the mentally retarded, has been scarce. As pointed out earlier, various clinical and research techniques have been utilized to assess cerebral dominance in brain-damaged and non-brain-damaged individuals. However, the present reviewer is not aware of any detailed studies of the subsequent effects of lateralized brain lesion in the intellectually subaverage (whether restricted to samples with or without evidence of prior brain-damage), nor is he aware of any observations with sodium amytal or ECT to infer states of cerebral dominance in such individuals.

The situation is only marginally better concerning experimental cerebral dominance measures that may be utilized in the general population to study cerebral dominance in relation to intellectual variables (e.g., only two studies have looked at ear asymmetries in relation to IQ). Jones and Spreen

(1967) noted a REA for the identification of 1-syllable nouns on DL in 6 - 12 yr. olds with IQ's of 69 - 95. Ear advantage did not vary with mental or chronological age, but this study was extremely poorly designed (e.g., effect of mental and chronological age confounded, no control group included)¹³², and did not intend to investigate, nor did it discuss, the relation of ear asymmetries to cerebral dominance. Bakker (1969) likewise did not find any correlation in 10 yr. olds between ear dominance on ML (for identification of 4- and 5-letter sequences) and intelligence (82-146 IQ range). However, the primary purpose of Bakker (1969) was to investigate variables other than intelligence, the sample was quite restricted (e.g., age-wise and in terms of subaverage intelligence), and a largely non-validated cerebral dominance measure was employed (the reader will also recall the criticisms earlier levied against the Bakker series of studies).

Hence the data of Bakker (1969) and Jones and Spreen (1967) both suggest that, in the age and IQ ranges studied, IQ was not related to ear differences. But methodological limitations in both studies, pointed out above, do not permit any general conclusions about hemisphere specialization in children in relation to IQ level.

However, there is some empirical data from DL (Borowy, 1974; Geffner & Hochberg, 1971; Kimura, 1967) and from other experimental measures (LEM - Weitan and Etaugh 1974b; visual evoked response potentials, VER-Bigum, Dustman & Beck, 1970,

Dustman, Schenkenberg & Beck, 1975, Galbraith, Glidden & Buck, 1975, Rhodes, Dustman & Beck, 1969) and from limb, eye and ear preference and consistency (Berman, 1971; Levy, 1969; Miller, 1971) that might relate to the issue of hemisphere specialization in the intellectually subaverage.

A smaller REA for the identification of digits on DL has been reported in two 5 yr. old male samples (Kimura, 1967), 4 - 7 yr. olds (Geffner & Hochberg, 1971) and 5 - 11 yr. old males and females (Borowy, 1974) from lower, compared to middle and "well-to-do", socioeconomic levels. Geffner and Hochberg (1971) and Kimura (1967) both suggested that intellectual factors might be one source of the lower asymmetries in the lower socioeconomic groups.^{133, 134}

Weitan and Etaugh (1974b) found that subjects with higher scores on the Scholastic Aptitude Test exhibited more consistent LEM than those with lower scores. Because consistency of LEM was seen as an indicator of the presence of cerebral lateralization, it was concluded that there appears to be a direct relationship between degree of cerebral lateralization and academic aptitude, and that the hypothesis relating incomplete lateralization to intellectual deficits should continue to be entertained.

"Bright" (WISC IQ in 120-140 range, mean -130) 10 yr. olds (Rhodes et. al., 1969) obtained a consistently larger amplitude of late components of the VER in the right (in contrast to the left) hemisphere, an asymmetry absent in "dull"

10 yr. olds (WISC IQ in 70-90 range, mean -79). However, the same laboratory (Dustman, Schenkenberg & Beck, 1975) later found hemisphere VER amplitude differences were similar in two groups of 4 - 15 yr. olds differing in mean IQ (110 vs. 88).

The hemisphere asymmetry in VER amplitude noted in "bright" (Rhodes et. al., 1969) and other normal groups at various ages (Dustman et. al., 1975; Schenkenberg & Dustman, 1970) was found to be present in 6 - 15 yr. olds, but absent in a Down's Syndrome group matched for sex, handedness and age (Bigum et. al., 1970). Dustman et. al. (1975) have summarized their series of findings on the VER in humans as follows:

With the majority of children and adults examined in our laboratory the visual evoked response was found to be greater in the minor or right hemisphere. This difference was most striking in recordings from central scalp. This hemispheric asymmetry increased during mental activity, decreased during periods of relaxation and was diminished or abolished during ingestion of alcohol. It was absent in children afflicted with Down's Syndrome and in children with reduced intelligence (p. 301).

Dustman et. al. (1975) speculated that the VER hemispheric asymmetry may be related to spontaneous EEG alpha rhythm, right hemisphere dominance for visual perception or level of attention caused by differential reticular formation activation in each hemisphere, such hemisphere differentiation possibly being less developed or missing in the less efficient brain.

However, Galbraith et. al. (1975) have reported that a Down's Syndrome group did exhibit a hemisphere asymmetry, in this instance in favour of the left hemisphere for the early component of the VER that a matched normal group (mean age - 22.8 yr.) exhibited, but only at the lowest light intensity (control group exhibited the left hemisphere asymmetry for both early and late components, and at all three light intensities). It was concluded: "The results suggest that evoked response asymmetry is not uniquely characteristic of the nonretarded nervous system, as previously reported, but rather appears to depend upon the choice of stimulus parameter" (pp. 320-321).

In 8 - 14 yr. olds with and without evidence of brain-damage, Berman (1971) found a significant correlation between intelligence (IQ range 45-145) and consistency of lateralization on joint measures of hand, foot, eye and ear preference and dominance and lowest consistency in subjects in the 45-75 IQ range without evidence of brain-damage (lower even than subjects in 45-75 IQ range with evidence of brain-damage). Berman (1971) felt the latter finding raised the question of absence or reduction of cerebral dominance as a causative factor in mental retardation. His reasoning was as follows: since brain-damage makes the relationship between dominance and intelligence less predictable because brain-damage affects intelligence, the finding that was obtained would be predicted if cerebral dominance has any causative relationship to in-

telligence, namely that the group without brain-damage in the 45-75 IQ range would obtain lower scores than the group with brain-damage in the same IQ range. This reasoning appears to be quite tenuous; there were also serious methodological shortcomings in the Berman (1971) study (e.g., absence of any measure of cerebral dominance besides joint measures of limb, eye and ear laterality, confounding of CA with intelligence).

Some association between cerebral dominance and intellectual ability has also been suggested by Levy (1969) and Miller (1971). The lower intellectual ability suggested by lower performance in left handers (Levy, 1969) and mixed handers (Miller, 1971) on non-verbal tests, in comparison with right handers, was explained in terms of less extensive hemisphere specialization in the non-right handed. However, the latter two studies failed to employ any measures specifically designed or adapted to measure cerebral dominance, and their speculations are based on observation of subjects at the higher intellectual levels (e.g., university samples).

To the knowledge of the present reviewer, besides Berman (1971), Dustman et. al., (1975), and Galbraith et. al. (1975), Kershner (1973; Kershner & Jeng, 1972; Kershner & Kershner, 1973) is the only other writer to have discussed at any length the topic of cerebral dominance in the mentally retarded. However, he provides little empirical evidence to support his speculations about absence of hemisphere specialization in the mentally retarded (e.g., Kershner,

1973 and Kershner & Jeng, 1972 failed to cite any supportive data; Kershner & Kershner, 1973 cited only the Rhodes et. al., 1969 study and failed to note its limited nature).

The restricted nature of the few studies conducted to date that might be relevant to any relationship between intelligence and cerebral dominance can be summarized as follows: conflicting VER results in Down's Syndrome (Bigum et. al., 1970 vs. Galbraith et.al., 1975) and other samples varying in intelligence (Rhodes et. al., 1969 vs. Dustman et. al., 1975); serious methodological flaws (Bakker, 1969; Berman, 1971; Jones & Spreen, 1967); quite restricted samples (Bakker, 1969; Levy, 1969; Miller, 1971; Rhodes et. al., 1969, Weitan & Etaugh, 1974b); non-validated and/or questionable indicators of cerebral dominance (Bakker, 1969; Berman, 1971; Levy, 1969; Miller, 1971; Rhodes et. al., 1969; Weitan & Etaugh, 1974b); indirect evidence (Berman, 1971; Borowy, 1974; Briggs & Nebes, 1976, see note 133; Geffner & Hochberg, 1971; Kimura, 1967; Levy, 1969; Miller, 1971; Weitan & Etaugh, 1974b - some of indirect evidence also not supported in other studies, e.g., see note 134).

Thus, because of the inadequate and completely non-definitive nature of research conducted to date on the topic, no firm conclusions of any kind can be drawn concerning the occurrence and development of hemisphere specialization in populations of subaverage intelligence.

D. Summary of Issues Reviewed

The present review has covered the following areas. There is strong clinical and experimental evidence that in the vast majority of adults (almost all right handers and the majority of left handers), the left hemisphere is specialized for the processing of verbal, language and language-like information. More speculatively, the left hemisphere may be the main site for temporal perception, sequential analysis and analytical, linear, logical and categorical thought. Though the evidence is somewhat less extensive, more ambiguous, and quite controversial, the right hemisphere is thought to be specialized for certain types of non-verbal visual, auditory and tactual information processing (e.g., visual-spatial, facial recognition, music, environmental sounds, tactual-spatial, and more speculatively, "wholistic" Gestalt perception, non-linear thought and certain types of emotional perception and/or mediation). Left hemisphere functional specialization appears to develop in early childhood (i.e., 1½ - 5 yr., with some degree of specialization perhaps even being present at birth, and perhaps continuing to develop until as late as puberty). Whether such specialization completes its development by puberty or much earlier, the consolidation of such specialization and accompanying "plasticity" of hemispheric organization until the conclusion of such consolidation appear to continue until puberty. Some sort of parallel developmental process may occur in relation to right hemisphere functional specialization, though the research and speculation concerning

the development of right hemisphere specialization is a relatively neglected area.

Such hemisphere specialization appears to be reflected in differential involvement of the hemispheres of adults and children in the handling of verbal, language vs. certain types of non-verbal, non-language material that is reflected in asymmetries in lateral perceptual and perceptual-motor performance (e.g., tachistoscope VF recognition and ear identification asymmetries on DL, VF and ear reaction time differences, IEM) and possibly in lateralized electro-cortical activity. Although the results with stutterers have been contradictory, there is a fair amount of experimental support (e.g., data from DL) for the possibility that dyslexics exhibit either specific abnormal development of left hemisphere language specialization or an abnormal general development and/or general dysfunctioning of the left hemisphere. The paucity of research and impossibility of firm conclusions pertaining to cerebral dominance in the intellectually subaverage were also noted.

The research review suggested absence of evidence that sex differences exist in the onset, development and final status in the adult of the type of left and right hemisphere dominance tapped by conventional DL, although there is inconsistent evidence that sex differences may exist for hemisphere specialization for some specific material tapped by some other cerebral dominance measures (e.g., visual-spatial processing).

A separate section will now be devoted to an evaluation of DL, the research tool employed in the present study to assess hemisphere functional specialization.

E. Dichotic Listening as a Measure of Cerebral Dominance¹³⁵

This section will provide a rationale for DL as a measure of cerebral dominance and its specific selection for the present thesis research by presenting: 1) an anatomical-physiological description of the auditory system; 2) models proposed to explain how DL input might interact within this anatomical-physiological system; 3) an outline of objections to the use of DL as a cerebral dominance measure; 4) comparisons of DL with other cerebral dominance measures.

1. Anatomy and Physiology of the Auditory System

Netter (1964) has provided a graphic illustration and a verbal description of the anatomy of the auditory system. Fibers from the cochlear nerve enter the brain stem at the lateral side of the pons and immediately separate to enter and synapse in the dorsal and ventral cochlear nuclei. The acoustic pathways to the cortex are described as complex: many of the fibers decussate (i.e., cross over to the opposite side of the central nervous system) after synapsing in the cochlear nuclei, and whether they decussate or not, proceed to synapse or pass around the superior olivary complex, the nucleus of the lateral lemniscus and the inferior colliculus on the roof of the midbrain before synapsing in the medial geniculate body of the thalamus. From the medial geniculate body impulses radiate to Heschl's gyrus on the supratemporal plane (auditory cortex). Hence, due to the partial decussation, input from one ear activates both cerebral hemispheres.

However, there is strong electrophysiological evidence that suggests that crossed auditory pathways are more effective than uncrossed pathways. In a study of auditory fibers between the medial geniculate nuclei and the auditory cortices of the dog, Tunturi (1946) reported a smaller amplitude of cortical response to ipsilateral than to contralateral stimulation, though the cortical response was similar in latency, duration, wave form and initial sign. Rosenzweig (1951) reported cortical electrical responses in cats to clicks delivered monaurally to be significantly greater in amplitude in the contralateral hemisphere than in the hemisphere ipsilateral to the ear of input. Rosenzweig (1951) concluded that each ear is served by a population of cortical units, but that the population representing the contralateral ear is larger than that representing the ipsilateral ear, although such populations overlap in that some units serve both ears. It was also suggested by Rosenzweig (1951) that an analogous situation exists in ear representation at the level of the medial geniculate nuclei. A lower threshold to contralateral ear intensity, interaural intensity differences and interaural time differences has similarly been observed in chinchillas (Benson & Teas, 1976).

In addition to a greater absolute number of contralateral compared to ipsilateral auditory pathways, Rosenzweig (1951) also proposed a functional pre-eminence of the contralateral routes: before the two pathways reach the hemispheres

a point of overlap occurs between the pathways where the contralateral fibers are able to occlude impulses from the ipsilateral pathways. Thus stimuli presented simultaneously to each ear would result in the partial occlusion of impulses arriving along the ipsilateral route, and the advantage of contralateral vs. ipsilateral input would be increased.

Kimura (1967) further suggested that central occlusion may occur " ... when two different speech sounds must compete for overlapping pathways in the dominant hemisphere, the slight advantage of the contralateral input over the ipsilateral may be further enhanced by central competition." (p. 171).

There is both behavioural and physiological evidence to support the hypothesis of suppression or occlusion of ipsilateral by contralateral pathways when both pathways are simultaneously activated. Behaviourally, split-brain patients reported very few (Milner et. al., 1968) or no (Sparks & Geschwind, 1968) digits presented to the left ear on DL, compared to the quantity identified at the right ear (Milner et. al., 1968). But the left ear performed on par with the right ear when the digits were presented monaurally. The suppression of the ipsilateral input when a competing stimulus (contralateral ear input) was present was interpreted as behavioural evidence of the functional dominance of the human contralateral auditory projection system.

Physiologically, the existence of fibers in which there is suppression of responses to ipsilateral stimulation by contralateral stimulation has actually been demonstrated by Goldberg and Brown (1969) from recordings of units in the superior olive of dogs and by Mast (1970) from recordings in the dorsal cochlear nucleus of chinchillas.

2. The Dichotic Listening Technique

It was pointed out in an earlier section that DL commonly consists of the presentation by means of a stereophonic tape recorder of material to each ear simultaneously.

The technique was introduced by Broadbent (1954) to study attention and memory and adapted by Kimura (1961a) to investigate cerebral lateral asymmetry of function and the detection of lateralized lesion effects. Specifically, it was noted that unilateral temporal lobectomy impaired the recognition of digits arriving at the ear contralateral to the side of the operation and total number of digits correctly identified by both ears was affected by left temporal, but not right temporal, damage and subsequent lobectomy (Kimura, 1961b). Also, digits presented dichotically were recognized more frequently through the ear contralateral to the hemisphere dominant for speech than from the ipsilateral ear (Kimura, 1961a). Hemispheric dominance was clearly known or was determined through sodium amytal injection in doubtful cases. Kimura (1961a) interpreted her results as consistent with her earlier suggestion (1961b) that crossed auditory pathways are

stronger than uncrossed pathways, and that the dominant temporal lobe is more important than the non-dominant lobe in the perception of speech sounds (see Meyer & Yates, 1955 and studies reviewed earlier).

Kimura (1967) referred to some of the electrophysiological evidence from animals described above (e.g., Rosenzweig, 1951, Tunturi, 1946) suggesting that crossed auditory routes are stronger than uncrossed auditory pathways, and also felt her earlier data (Kimura, 1961a) confirmed the suggestion by Bocca et. al. (1955)¹³⁶ and Singha (1959)¹³⁷ that this situation applies to humans as well.

The explanation for the right ear superiority on the digits test then, was that the right ear had better connections with the left hemisphere than did the left ear, and since the left hemisphere was the one in which speech sounds were presumably analyzed, the right ear sounds had the advantage of having better access to these speech centres. (p. 164).

It was also noted by Kimura (1967) that the percentage of right handers (90%) and left handers (above 60%) exhibiting language dominance in the left hemisphere in a clinical population, as determined by the sodium amytal technique (Branch et. al., 1964), corresponded roughly to the DL ear asymmetry pattern (for digits) observed between normal left and right handers by Bryden (1965) and Satz et. al. (1965)¹³⁸.

The evidence is thus overwhelming that the asymmetrical functioning of the 2 halves of the brain for speech is reflected in unequal perception of words presented dichotically to left and right ears. In an unselected group of normal subjects, speech

functions will be represented predominantly in the left hemisphere, and the left cerebral dominance will be reflected in a right ear superiority on the dichotic digits test. (p. 167).

After citing studies demonstrating a right hemisphere superiority for the processing of melodies (Milner, 1962) which is reflected in a LEA for melody recognition on DL (Kimura, 1964; Shankweiler, 1966), and depressed overall performance on DL for melody recognition after right temporal lobectomy (Shankweiler, 1966), Kimura (1967) presented a schematic neuroanatomical model to account for dual auditory asymmetries. This schematic arrangement is presented in fig. 3, which depicts connections between each ear and each auditory cortex and the functional differences between the two hemispheres. It was postulated that the dominance of the right temporal lobe in the assimilation of melodic patterns is reflected in a LEA, and the dominance of the left temporal lobe for the assimilation of words is reflected in a REA.

Sparks and Geschwind (1968) discovered that virtually complete suppression of left ear performance on DL resulted from sectioning of the anterior commissure and corpus callosum. This effect (corroborated by Milner, et. al., 1968), and the fact that the Kimura model does not explain why an injury to either hemisphere selectively impairs the message from the contralateral ear,¹³⁹ led Sparks and Geschwind (1968) to present an alternate model of the mechanism involved in ear asymmetries. The findings of Sparks, Goodglass and Nickel,

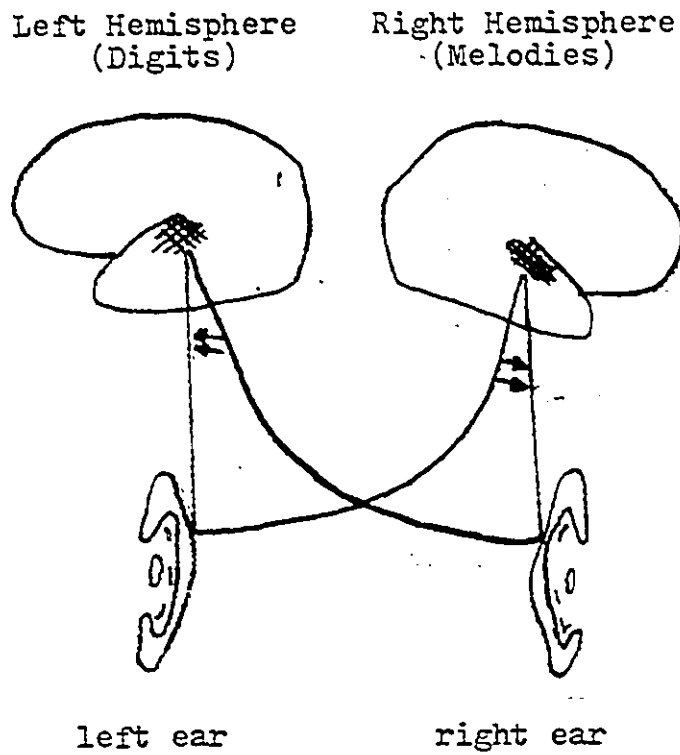


Figure 3. Neuroanatomical model for auditory functional asymmetries (from Kimura, 1967).

1970ab (that in a left hemisphere stroke-induced aphasia group a paradoxical left ear inferiority on DL of words and especially digits was reported) led to a slight modification of the Sparks and Geschwind (1968) model which was claimed to explain all observations reported to that date. This altered model is presented in fig. 4.

... this model conjectures first that the only significant inputs to each temporal lobe are from the contralateral ear, where each arrives in the primary auditory area and is elaborated in the adjacent (Wernicke's) auditory association area. Auditory information is also presumably shared transcallosally by fibres between auditory association areas. While a callosal pathway for audition has been demonstrated in animals physiologically, it is conjectured only by analogy from other callosal connections that this pathway links the auditory association areas, rather than the primary sensory centers. Of the callosal pathways, only that returning the left-ear signal to the left auditory association area is of interest, since oral report is presumed to issue from the left hemisphere. By this model, a lesion in the left temporal cortex (X) degrades the right-ear signal both at the primary sensory and at the association area levels, while affecting the left-ear signal only at the association area level. The result is impairment for both ears, worse in the right. A deeper going lesion (Y) on the left may reach the transcallosal pathway, severely impairing the input from the left ear. The result is impairment in both ears, worse on the left. A lesion in the right temporal cortex (Z) degrades only the left-ear input, leaving the right-ear report intact. This model not only accounts for the findings of Sparks and Geschwind (1968) and Milner, Taylor, and Sperry (1968) in callosally sectioned Ss, but shows why ipsilateral ear extinction may be confined to left-hemisphere-injured Ss. The distinction between primary and association area function for the first time suggests why the right ear is usually the more impaired after left-hemisphere damage.

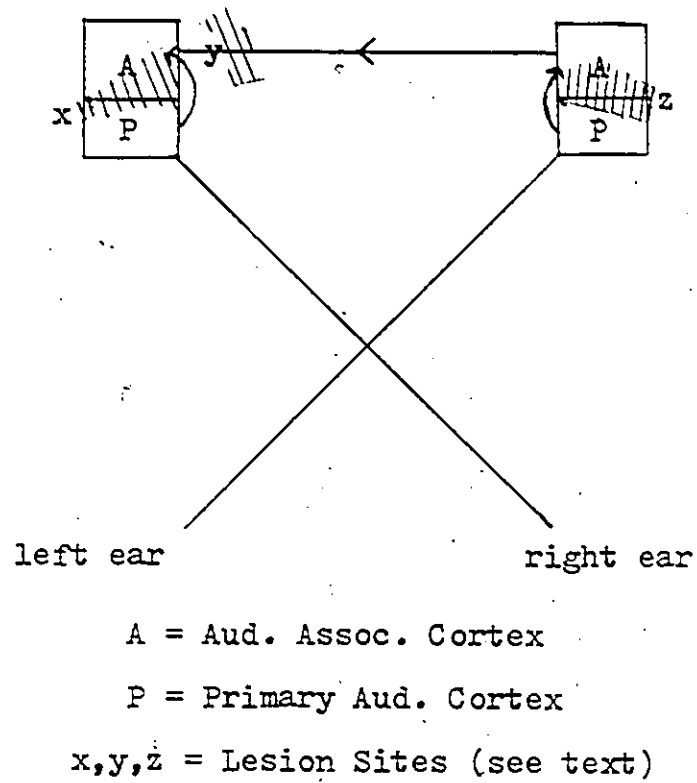


Figure 4. Proposed model for hemisphere functional asymmetries and lesion effects in dichotic listening (from Sparks, Goodglass & Nickel, 1970b).

The normal right-ear dominance effect is attributed to the information loss suffered by the extra step of transcallosal transmission to the left-ear signal. (Sparks, Goodglass & Nickel, 1970b, p. 196).

An essentially similar description has been forwarded by Berlin et. al. (1973b) who have added two refinements to this type of model: the importance of distinguishing, if appropriate, between the left anterior temporal cortex as the site of the left temporal lobe lesion and the left posterior temporal-parietal cortex as the site dominant for language and speech processing; and the possible contribution of both hemispheres (e.g. right and left temporal lobe) in DL.^{140, 141}

3. Objections to Dichotic Listening as a Measure of Cerebral Dominance¹⁴²

Inglis (1965) and Inglis and Ankus (1965) have argued that the REA on DL for verbal materials is not due to a perceptual or recognition superiority at the right ear, but to response strategies, the REA depending upon order of report from the two ears. A typical DL procedure is a 3-pair presentation of digits followed by the reporting of these three digit pairs. All digits presented to one ear tend to be reported before digits presented to the second ear (Broadbent, 1954; Bryden, 1962; Satz et. al., 1965), and the first ear reported generally is the more accurate. The ear reported first in adults is very often the right ear (Bartz et. al., 1967ab), although Satz et. al. (1965) and Carr (1969) found the right ear and the left ear were reported first in approximately equal proportions, the REA occurring on the delayed storage half-

spans rather than when the right ear was reported first. Hence Inglis (1965) and Inglis and Ankus (1965) postulated that the poorer performance of the left ear may be solely due to forgetting occurring by the time the subject reports from the second ear. The importance of ear order of report was suggested in 5 - 10 yr. olds (Inglis & Sykes, 1967) where digits presented to the right ear reported second were not identified significantly any more frequently in any of 18 comparisons (6 age levels with 1-, 2- and 3- pair sets) than digits reported second from the left ear (though right ear score numerically higher on 12 of the comparisons). On material reported first, a REA was present on 13 of 18 comparisons, but significant on only three comparisons. There was also no significant preference to report digits from the right ear first.

However, the REA is evident even when response rivalry between the ears and any attendant response strategies are controlled by requiring subjects to report either from the right or left ear (Bryden, 1967; Kimura, 1967; Schulhoff & Goodglass, 1969). Other manipulations of reporting (e.g., report all material from one ear first) may affect accuracy, but do not eliminate the REA (Bryden, 1963; Satz et. al., 1965). The REA has persisted even when multiple choice recognition, rather than recall is employed (Broadbent & Gregory, 1964), and when syllables are presented in single pairs on each trial (Kirstein & Shankweiler, 1969; Shankweiler, 1971), such procedures presumably minimizing any "ear order of report" and memory factors.

Oxbury, Oxbury and Gardiner (1967) offered a similar explanation to that forwarded by Inglis (1965): that the REA on DL may be due to an attentional bias toward the right ear when free recall is employed. When ear order of report was randomized, Oxbury et. al. (1967) failed to find an ear performance asymmetry, though there was a difference between first and second channel reported. But Satz (1968) argued that design and procedure weaknesses were present in the study of Oxbury et. al., 1967 (e.g., slower rate of digit presentation, questionable tape quality). Satz (1968) cited seven studies that found a REA even when order of report was controlled¹⁴³, results replicated in other studies as well (Bryden, 1965, 1967, 1969, Zurif, & Bryden, 1969). The REA is present even when ear order of report is taken into account in the scoring procedure (Bryden, 1970) and when comparisons between ears involve ears reported first or ears reported second, or whether the comparison is limited to those trials on which all numbers are reported from the second ear (Bryden, 1967). There is thus strong evidence that the REA for identification of verbal materials on DL is due primarily to perception, rather than order of report, effects.

Even if it is granted that order of report is one source of variation in DL (e.g., the REA under controlled order of report, though significant, may be attenuated compared to a free recall situation), Satz (1968) pointed out that the tendency of subjects to report from the right ear first still requires

explanation. It was argued by Satz (1968) and Bryden (1967) that the Kimura perceptual model provides the most reasonable and most parsimonious interpretation.

The tendency to employ ear order of report, especially at the faster rates of presentation (e.g., pairs separated by .5 sec. in 2- and 3- pair sets) has also been demonstrated in 9 - 10-yr. olds (Witelson & Rabinovitch, 1971), 6 - 14 yr. old normal reading and dyslexic boys (Witelson, 1975), and 4 - 7 yr. olds (Geffner & Hochberg, 1971; Witelson & Rabinovitch, 1971). Thus, normal children, at least as young as 4 yr., and dyslexics, at least as young as 6 yr., appear to spontaneously adopt the same recall strategies as adults do under the same conditions.

Additional evidence interpreted as supportive of the Kimura perceptual hypothesis vs. the memory or storage model of Inglis (1965) is provided by DL studies in which response is delayed. Spellacy (1970) and Spreen et. al. (1970) suggested that the storage hypothesis would predict increases in ear asymmetries with longer delays because of greater loss with time of the material stored in the unattended channel; a decrease of such ear asymmetries with longer delays would be predicted by the perceptual hypothesis since differential input processing occurs at the perceptual level. The difference between the two channels would be maximal at short intervals since longer delays would produce an equal amount of decay from both ears, which eventually would reduce ear differ-

ences. Using different S-R delays in DL of musical input, Spellacy (1970) and Spreen et. al. (1970) found the earlier demonstrated LEA for the recognition of such stimuli (e.g., Kimura, 1964) to decrease significantly at the longest S-R delays employed (12 sec.). These results were thus interpreted as support for the perceptual model.

Nachshon and Carmon (1973a) reported a similar REA with S-R delays of 0, 1 and 3 sec. for DL of digits. By offering a slightly different prediction based on the Kimura model from that of Spreen et. al., 1970 (that decay of input as a function of time producing identical performance decrement in the two ears would lead to a prediction of constant ear differences, regardless of S-R delay), Nachshon and Carmon (1973a) interpreted their findings as supportive of the Kimura perceptual model.¹⁴⁴

Another proponent of an attentional explanation in ear asymmetry performance is Treisman and Geffen (1968). Treisman and Geffen (1968) had subjects shadow connected prose in one ear, while responding manually ("tapping") to designated cues irrespective of ear. A REA was observed both in shadowing and in tapping when the tapping cue appeared in the ear where input was not being shadowed. Treisman and Geffen (1968) interpreted these results as indicating that ear asymmetries appeared only when the attention of subjects was directed to some other aspect of the task, the REA being produced by a difference in the distribution of attention to left and right

ear input reaching the left hemisphere speech areas. They suggested the difference in distribution of attention might possibly be due to unequal perceptual capacity of speech mechanisms activated by left vs. right ear input (the reasoning here would appear to be completely tautological, that right ear messages are perceived more effectively because they are attended to, but they are attended to because they are perceived more effectively!!!!). Geffen (1976) later rejected the attention explanation after finding an equal REA in 5, 7 and 11 yr. olds on a DL monitoring task (both a reaction time and accuracy REA for 1-syllable nouns) even after signal detection analysis ruled out response bias factors. Geffen (1976) noted the attention hypothesis fails to explain why the ear advantage is right rather than left, why the REA is due to certain aspects of the speech signal and why non-verbal input elicits a LEA.

Kinsbourne (1970) also related lateral perceptual asymmetries (e.g., ear or VF recognition superiorities) to hemispheric specialization in man. Thus Kinsbourne (1970) did accept the first component of the Kimura model, the statement that observed lateral asymmetries in human perception are related to asymmetries of representation of function in the cerebral hemispheres. However Kinsbourne (1970) did not accept the second component of Kimura's (1966) explanation that the effects are a consequence of more efficient information channeling by the shorter input pathway.¹⁴⁵ Instead

Kinsbourne (1970) postulated that the lateral asymmetries are a function of differential expectancy which occurs because preponderant activation of one hemisphere with certain types of material biases attention to the contralateral side. This view has obvious similarities to the position of Inglis (1965), Oxbury et. al. (1967), and Treisman and Geffen (1968).¹⁴⁶

Kinsbourne (1970, 1973, 1975b) has presented experimental evidence, primarily through VF input, for his hypothetical attentional model to explain lateral asymmetries (e.g., a RVF superiority for the identification of the presence and location of a line gap occurred only with concurrent verbal activity). A significantly faster right hand reaction to light with verbal, compared to non-verbal warning signals (but no differences for the left hand - Bowers & Heilman, 1976) has also been interpreted as providing partial support to the model of Kinsbourne (1970). Additional evidence that suggests that attention plays at least some role in perceptual and hemisphere-related asymmetries has been provided by Klein, Moscovitch and Vigna (1976) and Moscovitch (in press). In order to control for such attentional or expectancy biases, Kinsbourne (1970) suggested the random presentation of different types of material (e.g., verbal and nonverbal material are intermingled on DL, so that a subject will hear randomly either two words or two melodies; if lateral asymmetries are due to attentional biases, the attentional model would predict that when word and music recognition are analyzed, one or both of the asym-

metries will fail to appear).¹⁴⁷

However, there is a good deal of evidence pertaining to reaction time to VF information that fails to support the Kinsbourne attentional hypothesis, or at least suggests that other factors are as important or more important in promoting perceptual asymmetries. In an investigation of reaction time to name and physical matching presented to the RVF or LVF, Geffen et. al. (1972) noted practically no effects when expectancies of subjects were varied (i.e., faster reaction continued to occur to stimuli to be matched on the basis of names when the stimuli were presented in the RVF, and faster reaction also was sustained in the LVF when matching was on the basis of physical cues). Cohen (1972), in a very similar design, obtained clearcut reaction time differences in favour of the RVF for name matching and LVF superiority for physical matching, even though the order of presentation of material was randomized. Citing these latter two studies and additional data (e.g., Springer, 1973), Moscovitch (1975) concluded that attentional biases may augment, but not cause such perceptual asymmetries. More recent studies have continued to obtain VF reaction time (Berlucchi et. al., 1974; Moscovitch, 1976) or recognition asymmetries (Dee & Hannay, 1973) in the predicted (Kimura) direction when verbal and non-verbal material is randomly varied.

Dee and Hannay (1973) concluded that expectancy plays a very minor role (if any) in asymmetry of perceptual performance.¹⁴⁸

The present reviewer has not been able to discover any studies in the auditory modality (e.g., DL) where verbal and non-verbal information have been randomly presented.¹⁴⁹ However, Morais (1975) has noted that, on ML, a REA was noted for speech, even when subjects knew in advance the side of presentation. Morais (1975) felt that this result could not be attributed to lateral bias in voluntary attention.

Although the reader is reminded that the occurrence of ear asymmetries on DL is dependent to some extent on type of material employed (e.g., recall the differing consistency of results concerning ear asymmetries on DL depending upon the type of verbal input utilized; Brunt and Goetzinger, 1968 also found a REA with the Kimura digits and Katz words, but not Dirks words test on the same adult sample¹⁵⁰), one would have to agree wholeheartedly with the conclusion (Dimond, 1972) that the evidence is substantial concerning the presence of ear dominance effects on DL, especially ear asymmetries for the identification of verbal material.

The DL measure is also a reliable and stable measure of ear asymmetries. The following test-retest correlations have been reported: 1) with digits - .86 overall in normal adults (Hines & Satz, 1974), .81 overall in elementary school children (Sommers, Moore, Brady & Jackson, in press), with only 10% showing a definite change in ear dominance (Pizzamiglio, Pascalis & Vignali, 1974); 2) with other verbal material - range of .79 to .90 for the right ear and .45 to .86 for the left ear

in right handers on four separate occasions,¹⁵¹ with slightly lower correlations in left handers (Fennell et. al, 1977ab), .91 or higher in aphasic adults (see Sommers et. al., 1975), .90 in elementary school children (Sommers et. al, in press), test-retest correlations that remain statistically unaltered (see Berlin, 1977) even 8 yr. later (Troendle et. al., 1974), and with 71% maintaining their ear asymmetry on second testing (Blumstein et. al., 1975). The higher test-retest correlation in elementary school children for words (.90), compared to digits (.81), reported by Sommers et. al (in press), is a replication of DL findings in adults of greater test-retest reliability of words, compared to digits (see Ingram, 1975).

In summary, there is strong evidence that DL is a valid measure of hemisphere specialization (i.e., primarily reflects the presence of hemisphere specialization) and that the Kimura model and its adaptations provide the most well-substantiated and parsimonious explanation to date of the relationship between DL effects and hemisphere specialization. Although its test-retest reliability places some restrictions on its validity (reliability is a necessary, but not sufficient condition for validity - Cronbach & Meehl, 1955) and usefulness for clinical prediction, reliability studies conducted to date clearly support the continued utilization of DL as a research tool in assessing the presence of cerebral dominance.

4. Comparisons of Dichotic Listening with Other Cerebral Dominance Measures

A detailed rationale and supportive research for the employment of DL as a measure of cerebral dominance have now been presented. This subsection will compare DL with other measures of cerebral dominance (ECT, sodium amytal, phi-test, and VF, reaction time, electro-cortical, LEM and tactual asymmetries, pursuit auditory tracking, and other techniques), both in general terms, and specifically in reference to the samples of children selected for the reviewer's thesis study.

Although ECT and sodium amytal may in all probability provide the most accurate indicators of speech and language dominance devised to date (and dominance for any non-verbal functions of the hemisphere not dominant for speech), for obvious reasons their use should be restricted to select clinical populations (e.g., to provide information about crucial clinical decisions).

The phi-test has not been extensively researched, presumably because of its limited potential usefulness as a cerebral dominance measure. The last paper the present reviewer is aware of that assessed the phi-test as a cerebral dominance measure (Spreeen et. al., 1966) concluded: 1) the technique does not appear to be a more reliable predictor of cerebral dominance than handedness or other laterality tests; 2) these results, especially when one considers test

apparatus complexity and skill required of both subject and tester, do not encourage further use of the test in clinical studies. The present reviewer would add that the skill required of the subject would preclude its use in young children, especially of subaverage intelligence.

There is a great deal of debate about whether the tachistoscope - VF technique, especially with bilateral presentations, reflects cerebral dominance primarily, or the influence of directional scan associated with reading habits, or procedural artifacts, such as a bias produced by fixation procedures employed (Bryden, 1966; Carmon, Kleiner & Nachshon, 1975; Carmon et. al., 1976; Hines, 1972ab; Kaufer, Morais & Bertelson, 1975; Kershner, Thomas & Callaway, 1977; McKeever, 1971, 1974; McKeever & Huling, 1971ab; McKeever, Suberi & Van Deventer, 1972; McKeever & Gill, 1972; Olson, 1973; White, 1969; 1973). The unilateral presentation procedure, particularly with single stimuli presented at brief exposure, seems to be the least contaminated measure of cerebral dominance (Bryden, 1964, 1965, 1966; White, 1969, 1972). However, in an extensive review of relevant research, White (1969) concluded that the data relating cerebral lateralization to VF asymmetry is not as clear-cut or as conclusive as are the comparable auditory data.

Also, few studies have been conducted with visual tests in lobe-damaged patients (White, 1969) and even fewer in such patients employing material presented tachistoscopically to

each VF (e.g., see earlier literature review). The present reviewer is not aware of any VF validity studies comparable to Kimura (1961ab) relating known or clinically determined cerebral dominance to DL performance for digit identification, and the only VF test-retest research known to the present reviewer only recently appeared (Fennell, et. al., 1977ab).

The few VF studies that have been conducted in children have also yielded conflicting results (Carmon et.al, 1976; Forgyas, 1953; McKeeven & Huling, 1970a; Olson, 1973).

Again, even if the VF technique is accepted as a measure of cerebral dominance accurate enough for experimental purposes, the VF viewing and rapid exposure requirements would render this measure inappropriate with young, especially young intellectually limited, children (e.g., the necessity to attend visually to a fixation point or to submit to special devices, such as contact lenses - see Dimond, Bures, Farrington & Brouwers, 1975 - to insure material is exposed only to the intended VF, requirement to indicate recognition or identification of material viewed by selecting from visual display, by speech etc., in contrast to, for example, a simple repetition of a speech sound heard on DL). The difficulty of VF task requirements may explain the fact that the youngest children studied with this technique to date, to the knowledge of the present reviewer, are 6 yr. olds (Carmon et. al., 1976; Witelson, 1975) and grade 2 level children (Olson, 1973).

Moscovitch (1973) has provided a detailed review of reaction-time research in normal populations; he also presents a case for the potential utility of the technique in substantiating the different models of cerebral dominance. It is argued that this technique will provide evidence concerning absolute hemisphere functional differences in normals (e.g., whether a particular hemisphere plays any role in certain types of information processing), while the value of VF and DL measures is acknowledged in continuing to contribute to our knowledge of relative hemisphere functional differences. In this regard, the present writer's research is interested in the development of relative differences in hemisphere specialization.

In addition, the reaction time technique has not been researched nearly as extensively as DL (e.g., see Moscovitch, 1973 review), including a scarcity, if not a complete absence, of validity and reliability studies. The present reviewer knows of no studies of reaction time in children.

This scarcity of research utilizing the reaction time technique as a cerebral dominance measure in children may again be due to task requirements (e.g., the procedure outlined by Moscovitch, 1973, for visual material requires proper fixation and the ability to indicate any identification or recognition of the material fixated, along the dimension required, by selecting the relevant response option provided). Again, without significant simplification, such task requirements would be completely inappropriate for very

young, and young children of sub-average intelligence.

Any relationship between electro-cortical measures and cerebral dominance has not been clearly established.

Although hemisphere differences in elicitation of visual and auditory evoked potentials that follow the verbal vs. non-verbal dichotomy have been reported in adults (Buchsbaum & Fedio, 1969; Cohn, 1971; Fedio & Buchsbaum, 1971; McAdam & Whitaker, 1971; Molfese, 1972; Morrell & Salamy, 1971; Schenkenberg & Dustman, 1970; Wood et. al., 1971) and replicated in infants and young children (Schenkenberg & Dustman, 1970 and studies cited in notes 101 and 102), negative evidence has also been reported (e.g., Davis & Wada, 1977 with 5 week old infants; adults-Neville, 1974). Gazzaniga (1970) and Friedman, Simson, Ritter and Rapin (1975) both concluded that only a marginal or no relationship exists between evoked potentials effects and hemisphere functional differences (e.g., as reflected by other perceptual measures of hemisphere functioning). An illustration of this possibly only marginal relationship is the unstable occurrence of auditory evoked potentials of greater amplitude for early components and shorter latencies for later components in the left, compared to the right, hemisphere in response to DL of digits which produced the REA (Neville, 1974 vs. Haaland, 1974). Also, no validity or reliability studies comparable to those conducted on DL have been reported.

Regardless of their accuracy in reflecting states of

cerebral dominance, employment of electro-cortical measures in studying the types of children included in the reviewer's thesis research would present numerous practical problems (e.g., parent permission likely harder to procure, given the necessity of data gathering in a laboratory setting, and desirability of presence of parents concerning reactions of many young and low functioning children to lab setting, electrode placements, etc.).

The present reviewer is also sceptical about the usefulness of LEM in reflecting cerebral dominance, an attitude shared by at least one highly respected neuropsychologist (Reitan, 1976). The technique has not been thoroughly researched (see relevant research earlier reviewed). A plausible explanation is also lacking of why LEM would be related to hemisphere dominance, although observations have been offered that may be relevant to any relationship (e.g., Bakan, 1971, stated that eye movements to the left or right result from stimulation of the right or left oculomotor area, respectively; Kinsbourne, 1974c, noted temporary anesthetization of one hemisphere through sodium amytal injection is followed by sudden extreme movement of gaze toward the side of anesthesia - Kinsbourne concluded that each hemisphere must contribute a tonic influence to direction of gaze).

Techniques reviewed to this point as cerebral dominance measures (with the possible exception of the phi-test) may be utilized to assess hemisphere specialization for either language

or non-language processing. However, this dual purpose potential does not appear to be the case for tactual and other somatosensory asymmetries. Evidence for somatosensory asymmetries that relate to hemisphere asymmetries is either contradictory (e.g., evidence reviewed by Blakemore et. al., 1972 concerning pressure perception, focal vs. diffuse disruption depending on hemisphere damaged, tactile discrimination), or would seem to relate solely to right hemisphere specialization (e.g., clinical populations - Corkin, 1965; DeRenzi et. al., 1968, 1970, Levy-Agresti & Sperry, 1968; normal adults - Benton et. al., 1973, Murray & Hagen, 1973; normal children - Ghent, 1961, Kimura, 1963b, Witelson, 1974, 1975, in press).

Even if one wished to employ tactual asymmetries as a measure of right hemisphere specialization, while choosing some other means of assessing left hemisphere specialization, task requirements again would likely be beyond young children, especially young, intellectually subaverage children.

ML is another technique that has not been adequately researched. The ordered recall monaural listening technique has been researched primarily by Bakker (1967, 1968, 1969, 1970, 1973); and the latter studies are open to serious criticism on sampling, general design and statistical grounds (see earlier). There has also been little research with other types of ML (see relevant portion of this review), e.g., no validity or reliability studies or models offered of the processes involved.

Pursuit auditory tracking and other techniques suggested as cerebral dominance measures (see earlier) have as yet been so little researched that a major study would have to be undertaken to establish whether and to what degree any of these techniques are related to cerebral dominance; only then should one consider any of the specific techniques as the sole or major measure of the presence of cerebral dominance in a Ph.D level thesis.

Thus, the dichotic presentation of verbal material was selected for the present study because DL of verbal material is the mostly extensively researched, validated and accepted measure of hemisphere specialization for language processing (Goodglass, 1973); DL also demands only minimal capabilities of subjects (i.e., repeat or identify sounds heard). Digit material was specifically selected as the verbal measure (in spring-summer, 1974) because its employment until that point had consistently yielded a REA in adults under a variety of conditions, and in children (Kimura, 1963b, 1967, Knox & Kimura, 1970; the only non-supportive study in children to that point, Bryden, 1970 providing ambiguous and inadequately analyzed results, see note 99; the unpublished research of Bryden & Allard, 1973 and Darby & Satz, 1973 was not cited in the literature until the Satz et. al., 1975 paper; and other non-supportive research also appeared subsequent to the spring-summer of 1974, e.g., Bryden & Allard, in press, Satz et. al,

1975).¹⁵² The specific digit tape utilized in the present study also yielded a REA in adults in a pilot study conducted by the present reviewer (see appendix A).

Despite the cautions earlier discussed concerning the possibility of the existence of right hemisphere specialization, it was decided to utilize in the present thesis research a task possibly measuring right hemisphere dominance because of the informative potential of data from concurrent measures of right and left hemisphere functioning (e.g., whether any asymmetries for language material precedes, occurs simultaneously with, or follows the appearance of asymmetries for non-language material). Auditory non-verbal information was decided upon, and specifically non-verbal auditory material on DL, because of the complimentary and non-disparate nature of such material and its administration with the auditory verbal information selected as the elicitor of left hemisphere processing, because of minimal capabilities demanded of subjects (repeat or select sounds heard) and because the literature has provided consistent support for right hemisphere specialization in adults for such auditory non-language material as melodies (clinical - Bogen, 1969b, Chase, 1967, Milner, 1962, 1967, Luria, 1973, Schulhoff & Goodglass, 1969, Shankweiler, 1969; DL - see literature review) and environmental sounds (clinical-Spreen et.al., 1965, Spinnler & Vignolo, 1966, Vignolo, 1969; DL - Curry, 1967, 1968).

Environmental sounds were specifically selected as the auditory non-language material because melody recognition has been noted to be too difficult for young children (Kimura, 1974, personal communication) and because the identification of environmental sounds on DL has yielded a LEA in adults (Curry, 1967, 1968) that has been replicated in 5-8 yr. olds (Knox & Kimura, 1970) and 3-5 yr. olds (Piazza, 1977), the LEA apparently being a reflection of the right hemisphere dominance for processing of such non-language material (see Kimura, 1964, 1967). The fact that the types of children studied in the thesis research were capable of performing the environmental sound identification (and digit) task was confirmed in the pilot study, which also suggested that a LEA might be found in a larger sample (see appendix A).

F. Problems Investigated in Current Study

1. Rationale for the Study

a) development of hemisphere specialization for verbal and non-verbal material in children of subaverage intelligence requires more definitive study:

i) no conclusions currently can be drawn because of serious limitations in each investigation conducted to date possibly relevant to the issue: conflicting VER results in comparisons of Down's Syndrome and normal samples (Bigum et. al., 1970 vs. Galbraith et. al., 1975) and in comparing average and "bright" with "dull" children (Dustman et. al., 1975 vs. Rhodes et. al., 1969), in any case the origin of the VER and the relationship of VER hemisphere asymmetries to verbal-non-verbal hemisphere and related perceptual asymmetries not clearly established (see Dustman et. al., 1975); serious methodological flaws (Bakker, 1969; Berman, 1971; Jones & Spreen, 1967); restricted samples - range of subaverage IQ not extending significantly downward (Bakker, 1969; Dustman et. al., 1975; Rhodes et. al., 1969) or only samples of at least average IQ studied (Levy, 1969; Miller, 1971; Weitan & Etaugh, 1974b); highly questionable or at least as yet non-validated indices of cerebral dominance (Bakker, 1969; Berman, 1971; Dustman et. al., 1975; Levy, 1969; Miller, 1971; Rhodes et. al., 1969; Weitan & Etaugh, 1974b);

indirect evidence, some of which has not been replicated, e.g., the socioeconomic level variable, see note 154 (Borowy, 1974; Briggs & Nebes, 1976, see note 153; Geffen & Hochberg, 1971; Kimura, 1967; Weitan & Staugh, 1974b).

ii) with the exception of Berman (1971), none of above studies screened samples for presence of brain-damage; however, study of intellectually subaverage and significantly subaverage should include some experimental control for any confounding of any brain-damage present, as the incidence of brain-damage is known to vary roughly inversely with intellectual level in the intellectually subaverage (Kushlick & Blunden, 1975) and brain-damage is likely associated with abnormal states of cerebral dominance (e.g., Bogen, 1969a suggested that very early brain-damage of a diffuse nature is associated with reduced hemisphere specialization; whether brain-damage is diffuse or focal, and whether it occurs at birth or during childhood, one would expect deviation from the normal pattern of development of cerebral dominance if damage to a critical left hemisphere area resulted in transfer to the right hemisphere, see Milner, 1969.¹⁵³

Thus, the primary purpose of this study is to investigate the occurrence of the type of left and right hemisphere dominance associated with the development of ear asymmetries for the identification of verbal and non-

verbal auditory input on DL in children of subaverage intelligence screened for absence of medical evidence of the presence of a brain lesion.¹⁵⁴

- b) inclusion of some form of control group is desirable:
- i) to compare groups of children with subaverage IQ with children of average IQ.
 - ii) the development of the type, or types of left hemisphere specialization associated with the REA for identification of auditory-verbal material has not been conclusively established in the average child, neither the REA on DL (despite extensive research in children) or on ML (few studies and those that have been done have yielded contradictory results and are seriously flawed - e.g., Bakker, 1967 vs. Bakker, 1970, Bakker et. al., 1973).
 - iii) the development of the type, or types of right hemisphere specialization associated with the LEA for nonverbal material requires further study (e.g., DL-in the child older than 8 yr. as the oldest child studied to date on DL is 8 yr. - Knox & Kimura, 1970, with replication and further investigation of developmental trends required in younger children, given somewhat ambiguous results of Knox & Kimura, 1970, for identification of environmental sounds at each age level, with no over-all LEA observed for identification of animal sounds; and given that a second study of identification of environmental sounds - Piazza, 1977, 3 to 5 yr. olds - appeared only after the present study was completed¹⁵⁵; ML - studies

finding LEA in children in reproducing "Morse-like sound patterns"-Bakker, 1967, 1968, 1970- seriously flawed in design and/or sampling).

Samples of children of average intelligence will thus be included primarily to provide comparative data to that derived from the samples of primary interest, the samples of children of subaverage intelligence; but the data from the samples of children of average intelligence will also address the contradictory literature findings concerning age of onset of the REA for digit identification and will permit further exploration of developmental trends of any LEA for identification of environmental sounds.

2. Design and Hypotheses

The main independent variables employed in the present research are age (5, 8, 11 yr.), intelligence range, (IQ > 90, 65-80, < 61) and ear of presentation of digits and environmental sounds on DL (10 subjects in each age-IQ range). The main dependent variable employed is number of digits or environmental sounds correctly identified. The experimental design for analysis of this data is thus that of 3-way analysis of variance [A-age(3), B-intelligence (3), and C-ears (2), with repeated measures on the last factor and with factor B nested within factor A (Winer, 1971)]. This design is represented schematically in figure 5.

Ear of Presentation		Left ear		
		Right ear		
		IQ Range		
		>90	65-80	<61
A G E	5 yr.	10Ss	10Ss	10Ss
	8 yr.	10Ss	10Ss	10Ss
	11 yr.	10Ss	10Ss	10Ss

Figure 5. Schematic representation of analysis of variance design adopted for thesis research.

These variables were selected to observe the occurrence and extent of ear asymmetries in identification in relation to intelligence and age. The following null hypotheses will be tested by means of the analysis of variance and any further analysis warranted.

Verbal Material:

Hypothesis 1: there will be no significant REA overall for overall identification of digits (experimental hypothesis - overall significant REA, predicted from findings of overall REA in most studies of normal children employing verbal material on DL and from the fact that children of lower and higher IQ have exhibited similar ear asymmetries for the identification of auditory verbal materials, see the methodologically inadequate research of Bakker, 1969 and Jones & Spreen, 1967).

Hypothesis 2: the REA, or its absence, for overall identification of digits will be similar across age levels and intelligence ranges; predicted from findings of a REA at age 5 for identification of verbal input on DL that does not change in older age groups (Berlin et.al., 1973a; Geffen, 1976; Goodglass, 1973; Hynd & Obrzut, 1977; Kimura, 1963b, 1967; Knox & Kimura, 1970; Krashen & Harshman, 1972; Mirabile et.al., submitted; Nagafuchi, 1970; Schulman-Galambos, 1977; Springer & Eisenson, 1977; Tobey et.al., 1976; Witelson, 1975), and from the fact that children of lower and higher IQ have exhibited similar ear asymmetries for the identification of auditory verbal material (Bakker, 1969; Jones & Spreen, 1967).

Hypothesis 3: there will be no significant REA in each age-IQ range group for overall identification of digits (experimental hypothesis - significant REA in each group; see rationale above for hypothesis 1 and 2)

Hypothesis 4: the REA, or its absence, for overall digit identification will be similar in each age-IQ range group (see rationale above for hypothesis 2)

Hypothesis 5: there will be no significant REA overall for identification of digits from the 1-pair sets (experimental hypothesis - overall significant REA; predicted from findings of an overall significant REA for identification of digits from 1-pair, 2-pair and 3-pair sets combined - Kimura, 1963b, 1967; Knox & Kimura, 1970 - and from the finding that children of lower and higher IQ have exhibited similar ear asymmetries in identifying auditory verbal material (Bakker, 1969; Jones & Spreen, 1967)

Hypothesis 6: the REA, or its absence, for identification of digits from the 1-pair sets will be similar across age levels and intelligence ranges (see rationale above for hypothesis 2)

Hypothesis 7: there will be no significant REA overall for identification of digits from the 2-pair sets (experimental hypothesis - overall significant REA; predicted from the REA found for identification specifically on 2-pair sets - Geffner & Hochberg, 1971 - and when performance on other digit sets are combined with results on 2-pair sets - Kimura, 1963b, 1967; Knox & Kimura, 1970; Sommers & Taylor, 1972; Witelson, 1975)

Hypothesis 8: the REA, or its absence, for identification of digits from the 2-pair sets will be similar across age levels and intelligence ranges (see rationale above for hypothesis 2)

Hypothesis 9: there will be no significant REA overall for identification of digits from the 3-pair sets (experimental hypothesis - overall significant REA; predicted from the REA found for identification specifically on 3-pair sets - Borowy, 1974; Inglis & Sykes, 1967; McKeever & Van Deventer, 1975; Sobotka, 1974 - and when performance on other digit sets are combined with 3-pair set scores - Kimura, 1965b, 1967; Knox & Kimura, 1970; Sommers & Taylor, 1972; Witelson, 1975)

Hypothesis 10: the REA, or its absence, for identification of digits from the 3-pair sets will be similar across age levels and intelligence ranges (see rationale above for hypothesis 2)

Non-verbal Material:

Hypothesis 11: there will be no significant LEA overall for identification of environmental sounds (experimental hypothesis - overall significant LEA; predicted from overall LEA in children for the identification of auditory non-verbal materials - Bakker, 1967, 1968, 1970 - though seriously flawed, Knox & Kimura, 1970; Piazza, 1977 - and similar VER amplitude asymmetries in children varying in IQ - Dustman et.al., 1975)

Hypothesis 12: the LEA, or its absence, for overall environmental sound identification will be similar across age levels and intelligence ranges (a similar LEA was found in children at each age from 3 to 8 yr. for the identification of environmental sounds - Knox & Kimura, 1970, Piazza, 1977 - and similar VER amplitude asymmetries in children varying in IQ - Dustman et.al., 1975)

Hypothesis 13: there will be no significant LEA in each age-IQ range group (experimental hypothesis - significant LEA in each group; see rationale above for hypothesis 12)

Hypothesis 14: the LEA, or its absence, will be similar in each age-IQ range group (see rationale above for hypothesis 12)

Thus, the primary purpose of the study is to investigate the presence of hemisphere specialization for verbal and non-verbal material in children at two levels of subaverage intelligence and at 5 age levels without medical evidence of brain lesion; direct comparisons with children of average intelligence will also contribute to our knowledge of the presence of such hemisphere specialization in the course of normal development (i.e., in child populations of average and sub-average intelligence alike), particularly in light of the fact that the age of onset and exact course of normal development of hemisphere specialization in populations of average intelligence are still not definitively established.


CHAPTER II

RESEARCH METHOD

This chapter presents the methodology adopted for the present research. The nature of the subject population is first described, followed by a delineation of the nature of the experimental stimuli, the method whereby these stimuli were constructed, the equipment that permitted the presentation of the experimental stimuli and the specific procedure utilized in the experiment. The chapter closes with a discussion of the nature of the dependent variable and the statistical analysis that utilized this dependent variable.

A. Subject Sample

The subjects employed for the present research were 90 children attending regular classes and special classes for slow learners operated by the Ottawa Roman Catholic Separate School Board, three special schools for the mentally retarded operated by the Ottawa Board of Education, and one special school for the mentally retarded operated by the Carleton Board of Education. Written parental permission was obtained before any child was selected for inclusion in the study (see appendix B for sample letter). This 90 subject sample was chosen on the basis of age (three age levels - 5 to 5½ yr., 8 to 8½ yr., 11 to 11½ yr.), IQ scores (IQ > 90, 65-80 or < 61 on the Slosson Intelligence Test - SIT, 1963),¹⁵⁶ handedness



(employment of right hand for pencil work and on at least two of 5 other handedness tasks), audiometric testing and absence of medical evidence of brain damage. A total of 10 subjects (five males, five females) was selected for each age and IQ range combination. Every subject whose SIT IQ was greater than 90 was enrolled in a regular class; all 8 and 11 yr. old subjects whose SIT IQ's fell in the 65 - 80 range were attending a special class, while the 5 yr. olds with SIT IQ's in this range were attending regular kindergartens; and every subject whose Slosson IQ was less than 61 was a pupil at a special school for the mentally retarded. Mean CA, IQ and MA for each age - IQ range group is provided in appendix C. The specific steps followed in selecting the sample of 90 subjects will now be outlined.

Prior to any testing, Ontario School Record, health and any other available information were examined to determine the age of the child, whether there was any indication of brain injury or hearing defects, and whether it was probable that a particular child would obtain a SIT IQ score within one of the three ranges selected for the current study.

Teachers of children still eligible at this point were asked to select only eligible children who employed their right hand for written work (see appendix D for a description of guidelines presented to teachers to aid in the selection of appropriate candidates). These children were provided with letters and consent forms to take home to their parents. Only

children whose parents consented to have their children participate were included in the next step of the study.

All children were seen individually. Each child was first tested for handedness on six different tasks (write or print name or draw with a pencil, catch a piece of paper - three times, throw a piece of paper - three times, show how to hammer a nail, comb hair, brush teeth). If the child employed the left hand for the pencil task, testing was terminated and the child excluded from the study at that point (such was the case with seven children).

It was initially planned to also exclude any child who did not employ the right hand consistently on at least three of the five remaining handedness tasks (therefore to include only children utilizing the right hand consistently on four of the six tasks). However, due to the extreme difficulty in obtaining as many as 10 children in all of the groups of sub-average intelligence meeting all other selection requirements and also choosing their right hand consistently on four of the six tasks, this criterion was relaxed to employment of the right hand on the pencil task and consistently on two of the remaining five tasks. All children employing the right hand on the pencil task met this latter requirement. If the child's IQ fell in one of the appropriate ranges on the SIT next administered (such was not the case with 19 children¹⁵⁷), the child was seen on a second occasion (within two weeks).

On this second occasion, the child was administered

an audiometric test (Lafayette Instruments). Both ears were tested for hearing, beginning with a 110 decibel sound presented at each of 11 frequency levels in ascending order of frequency beginning with 125 c.p.s. and ending at 8000 c.p.s. and proceeding to 80, 60, 40, 20 and 10 db in descending order of db level (see appendix E for specific instructions and a sample scoring sheet). Therefore a total of 66 sounds were presented to each ear (six db levels x 11 c.p.s. frequency levels). A difference between the ears of five or more failures in detecting the presence of the sounds was arbitrarily selected as an indication that the ears differed significantly in hearing capacity. In such situations the ear with the superior hearing capacity might identify more sounds than the second ear simply because of its superior hearing acuity rather than because of any differences in neuropsychological processing of material presented to that ear. Hence any subjects whose ears exhibited a difference of five or more in detecting the presence of a sound were dropped from the study at this point. Three children were excluded for this reason.¹⁵⁸

Initial screening of the 11 yr. olds with IQ below 61 meeting all selection criteria yielded four of ten children exhibiting Down's children. Because it was not possible to obtain more than six appropriate children with IQ below 61 at this age level who did not exhibit Down's Syndrome (also applicable to a varying extent at other two age levels as well), and because of the inherent interest in studying the child

with Down's Syndrome as a natural portion of children at this IQ level without medical evidence of brain-damage, it was decided to retain the four 11 yr. olds with Down's Syndrome and to include four children with Down's Syndrome in the 5 and 8 yr. old groups.

B. Dichotic Listening Tapes

Two different DL tapes were constructed by two sound engineers in a sound recording studio of the Department of Communications, University of Ottawa.

The tape containing the verbal stimuli consisted of 37 digits on each channel, all numbers recorded from a master recording of the numbers 1 to 6, 8 to 10 and the number 12 spoken by the same voice. The numbers were combined into various pairings by aligning a number on a particular channel with a number of the second channel so that both numbers sounded simultaneously. This tape thus consisted of 37 pairs of numbers.

The timing between the various pairs of numbers was arranged as follows. Each of the first seven pairs were presented with a time separation between pairs of 15 sec. (therefore seven combinations of 1-pair sets). The next 12 digit-pairs were presented in 2-pair sets, with a time separation of .5 sec. between each member-pair of the set and a time separation of 15 sec. between 2-pair sets. There were thus six combinations of 2-pair sets. The final 18 number-pairs were arranged into 3-pair sets with time separations of .5

sec. between each member-pair and a time separation of 15 sec. between 3-pair sets. Thus, the tape contained six combinations of 3-pair sets (see table 1).

The tape containing the non-verbal stimuli consisted of a series of 26 familiar environmental sounds, 13 recorded on each channel. All environmental sounds were obtained from sound effects records (audio fidelity DFS7006 - vol. 1, audio fidelity DFS7010 - vol. 2, audio fidelity DFS7011 - vol. 3, audio fidelity DFS7015 - vol. 4, audio fidelity DFS7016 - vol. 5). Each of the 13 environmental sounds recorded on the one channel were aligned with one of the 13 sounds on the second channel such that the two sounds occurred simultaneously, each sound pair occurring 15 sec. after a previous sound pair. The specific sounds that were paired and the specific order of presentation of the sound pairs are presented in table 2.

The specific recording information, supplied by one of the sound engineers, is described in appendix F.

Specific instructions to introduce each section of each DL task or familiarization period (i.e., for the digits, different sets of instructions to precede presentation of the 1-pair, 2-pair and 3-pair combinations; for environmental sounds, different sets of instructions to explain the non-dichotic familiarization phase and the actual DL task) were pre-recorded by the experimenter on Ampex Professional G31 recording tape with the Sony recorder described below. These taped instructions in turn were spliced onto the appropriate

Table 1

1-pair, 2-pair and 3-pair Sets of Numbers Employed as Verbal Stimuli, Each Member of Pair Recorded on Separate Channels on Stereophonic Tape, and Aligned such that First Number of Pair Sounded Simultaneously with Second Member of Pair

1 pair sets	2 pair sets	3 pair sets
1 - 8	8 - 3	3 - 1
	1 - 5	9 - 8
3 - 12		5 - 4
	10 - 4	
9 - 11	2 - 12	2 - 5
		8 - 3
2 - 6	9 - 1	10 - 12
	3 - 8	
8 - 5		4 - 10
	12 - 2	3 - 2
10 - 2	5 - 10	1 - 5
4 - 9	4 - 9	8 - 1
	1 - 5	5 - 9
		12 - 10
	8 - 3	
	10 - 12	9 - 12
		1 - 3
		4 - 5
		1 - 5
		6 - 2
		4 - 9

Table 2

Environmental Sound Pairs Employed as Non-verbal Stimuli,
Each Member of Pair Recorded on Separate Channels on
Stereophonic Tape and Aligned such that First Member of
Pair Sounded Simultaneously with Second Member of Pair

dog barking	doorbell
dialing a telephone	clock ticking
children jumping in a pool	gas engine starting
water pouring in a pail	kittens
thunderstorm	blacksmith's anvil
fire engine	sink draining
horses neighing	cuckoo clock
tap dancing	babbling brook
door creaking	glass breaking
lions roaring	fire crackers
water dripping in a pail	toilet flushing
horses trotting on a dirt road	bowling
typewriter	cash register

sections of the DL tapes by means of a Bib ($\frac{1}{4}$ track, no. 765-366) splicer.

C. Experimental Apparatus

The materials used for preliminary screening of subjects (handedness tasks, SIT, and audiometer) have previously been cited.

The basic materials of the experimental apparatus for the presentation of the DL tapes included a Sony Stereophonic 3-head solid state (TC-630) tape recorder, an extension cord, one set of Pioneer Stereophonic headphones (SE-2P, no. 1), one set of Philips Stereophonic headphones, and two pre-recorded DL tapes previously described (Ampex Professional G31 recording tape).

A Sharp Stereophonic tape recorder had been employed during the initial portion of a pilot study. Data from the first part of the pilot study, scores for 24 children on DL of digits and environmental sounds presented through a Sharp tape recorder, will be found in appendix A. Detailed analysis of the sound characteristics of this tape recorder revealed a significant discrepancy between the two channels (and subsequent discrepancy between input presented through the headphone sets to one ear vs. the second ear). Hence, this tape recorder was replaced by the Sony tape recorder for the second part of the pilot study, performance of seven adults on the DL (digits) task. These adults exhibited a significant REA

(see appendix A). The pilot study thus revealed a fault in the test equipment, that the type of children selected for the current thesis research are able to perform the digits and environmental sounds tasks, and that the digits tape yielded a significant REA in a sample of adults presumably characterized by left-hemisphere dominance for speech and language.

Immediately after the conclusion of the pilot study, detailed analysis of sounds emanating from the two channels of the Sony recorder and the Pioneer headphone set revealed very minimal differences (see appendix G for specific sound comparison procedure and graphic comparison, based on testing on 3 different occasions, of the sound characteristics from the two channels of the Sony passing through the Pioneer headphone set). Hence the Sony tape recorder and Pioneer headphone set (for use by the subject) were utilized for the study proper. Appendix G also reveals that the sounds emanating from the two channels one-half through the study (after testing of 43rd. subject) and at the conclusion of the study remained very similar.

D. Experimental Procedure

Each child included in the experimental sample was tested on two separate occasions at the school he or she attended (time lapse between testing was less than two weeks in all cases). The actual experiment was conducted during

the second session after the child had been administered the audiometric examination. The procedure for the presentation of the environmental sounds included a familiarization and a testing (DL) phase.

The following steps and settings were implemented with the Sony tape recorder and headphone sets for the monaural familiarization phase. The Pioneer headphone set was plugged into the insert jacket on the right ("headphone Listen") of the Sony tape recorder control panel (see appendix H for a drawing of the control panel), "Power amp." turned to "on", and "knob for mode" (L-stereo-R) set to L or R, depending on whether the headphone on a subject was placed with connection cord of headphone over the left or right ear of the subject, respectively. This procedure permitted only sounds on a particular channel (that is, only one member of each pair of sounds) to be presented singly and stereophonically. If the "knob for mode" had been set to "stereo," a sound from each channel would have been presented simultaneously, one to each ear. The SP selector was placed at "Lid.", volume set at the third indicator beyond "min.", the Philips headphone set was plugged into the Headphone monitor, knobs for "L-Monitor-R" set to face downward, the power main switch was placed on "on" and the "noise suppress" turned to "off", the Pioneer headphone set was placed on the head of the subject, the headphone position adjusted to fit comfortably on the ears of the subject (if necessary), the Philips headphone set was placed on

the head of the experimenter and the subject was presented with the pre-recorded instruments for the stereophonic presentation of a single sound while the experimenter monitored the sounds through his headphone set. These pre-recorded instructions were as follows:

You are going to hear different sounds through these earphones. After you hear each sound, tell me what the sound is. If you are not sure, take a guess and I will then tell you what the sound is. You will then hear the sound two more times and each time I will tell you the name of the sound.

The experimenter then stopped the tape and asked if there were any questions. The experimenter kept in view a written copy of the taped instructions just presented; questions were answered by re-reading relevant parts of the instructions. The tape was then forwarded to the first environmental sound on the tape (tape run over ~~the instructions for the DL phase,~~ see below), and the subject was presented three consecutive times via the headphones with each of the 13 sounds on that side (channel) of the sound pairs (i.e., channel dependent on whether the familiarization at that point was being conducted with the "knob for mode" turned to R or L). The subject was not asked to name the sound after each monaural presentation, but each time was provided with the verbal label for the sound. At the conclusion of the 3-exposure presentation of each of the 13 sounds, earphones were removed from the subject, the "rewind" control knob operated until the beginning of the sound pairs was reached and the "knob for mode" (L-stereo-R) was turned to L (if previously set on R) or to R (if previously set on L).

The Pioneer headphone set was replaced on the head of the S in the same orientation in which it was initially placed, the Philips headphone set on the head of the experimenter, the tape control knob was turned to "forward" and each of the 13 sounds on the opposite side of the pairs (opposite channel) was presented monaurally three times in identical fashion to the 13 sounds initially presented from the opposite channel.¹⁵⁹ The Pioneer headphone set was then removed from the subject and "rewind" control knob was operated until a point on the tape just before where the instructions for the DL test began. These instructions were situated on the tape just after the instructions for the familiarization phase and immediately before the first sound pair. The Pioneer and Philips headphone connections were then switched (i.e., Pioneer headphone plugged into "Headphone monitor" L-Monitor-R, Philips headphone set plugged into "Headphone Listen") and "knob for mode" L-stereo-R turned to stereo. The Pioneer headphone set was placed on the subject in the same orientation that it had been placed for the familiarization phase (i.e., connection to cord placed over right or left ear), the Philips headphone set was placed on the head of the experimenter and the tape control knob turned to "forward". The following instructions were then heard through both headphone sets:

Now you are going to hear these sounds again, only this time you will hear two different sounds at the same time, one sound in one ear, a different sound in the other ear. Tell me what are the sounds you hear.

After the presentation of these instructions, the tape was stopped and the subject was asked if there were any questions. Questions were answered by re-reading relevant parts of the instructions, a written copy of which was situated in view of the experimenter. The environmental sounds tape was then presented dichotically to the subject through the Pioneer headphone set with the experimenter monitoring the sounds through the Philips headphone set. Responses of the subject were recorded by the experimenter on prepared record sheets.

When all 15 environmental sound pairs were presented and responded to, the headphones were removed from the subject and the experimenter, the control knob was turned to "rewind" and the tape was completely rewound and removed. The digits tape reel was then connected to the tape recorder, with all adjustment knobs still in the positions utilized for DL of environmental sounds (including Pioneer headphone set connected to "headphone monitor", Philips headphone set to "headphone listen"). The Pioneer headphone set was then placed onto the head of the subject in identical orientation to that used for listening to environmental sounds, and the control knob was turned to "forward". The following instructions were then presented through the headphone sets:

Now you are going to hear two different numbers at the same time, one number in one ear, a different number in the other ear. Tell me the numbers you hear.

The tape was then stopped and the subject was asked if

there were any questions. A written copy of these instructions were kept in view and any questions were answered by re-reading the relevant parts of the instructions. The first number-pair to be presented was then described as a practice item and the tape recorder control knob was turned to "forward". Whether or not the subject responded with one or both numbers presented, the control knob was turned to the stop position, the two numbers just presented dichotically were repeated by the experimenter and the subject was asked if there were any further questions. Questions again were answered by re-reading of relevant parts of the written instructions. The control knob was then turned to "forward" and the 1-pair sets of digits were then heard by the subject and the experimenter through their respective headphone sets. The experimenter recorded on prepared record sheets the responses of the subject. At the conclusion of the 1-pair set testing, instructions for the 2-pair set testing were presented through the headphones without interruption. These instructions were as follows:

Now you are going to hear two different numbers at the same time, one number in one ear, a different number in the other ear, but these two numbers will be followed very closely by two more numbers presented at the same time, one to each ear. After you have heard the four numbers, tell me as many of the numbers that you heard as you can.

When the instructions had been presented in their entirety, the tape was not stopped unless the subject forwarded a question when asked by the experimenter. Questions were again responded to by re-reading relevant parts of the instruc-

tions, a written copy of which was also available to the experimenter. If the tape had been stopped for questions, the control knob was turned to "forward" and the responses of the subject were recorded on the prepared record sheet.

At the conclusion of testing on the 2-pair sets, instructions for the 3-pair presentation were heard through the headphones without any interruption. These latter instructions consisted of the following statements:

Now you are going to hear two different numbers at the same time, one number in one ear, a different number in the other ear and these two numbers will also be followed very closely by two numbers presented at the same time to each ear. However, another two numbers, one to each ear, will follow very closely. After you have heard the six numbers, tell me as many of the numbers that you heard as you can.

Responses of the subject were recorded on the record sheet and testing terminated at the conclusion of the 3-pair set presentation, at which time headphone sets were removed.

Channels were balanced in each age - IQ range group by placing headphones in identical orientation on all listening phases (i.e., environmental sound familiarization, identification of environmental sounds and digits on DL) with three females and two females in each age-IQ range group, and reversing the orientation of the headphones for the remaining two females and three males of each group. Thus, each age-IQ range group was exactly equated in terms of sound channels presented to each ear and number of males and females being presented channels at each ear.

E. Statistical Design and Statistical Analysis

1. Main Analysis

Separate 3-way analysis of variance calculations [A (3 age levels) x B (3 IQ levels) x C (2 ears), repeated measures on factor C and with factor B nested within factor A (Winer, 1971)], were carried out on the main dependent variables, the number of digits (verbal) or environmental sounds (non-verbal) dichotically presented which were correctly identified. The first number-pair of the digits tape was a practice item and was not utilized in the statistical analysis.

To determine if a sex effect was being obscured by combining the data from the five males and five females of each age-IQ range group for identification of digits, a 4-way analysis of variance [A (3 age levels) x B (3 IQ levels) x C (2 sexes) x D (2 ears) and with factor B nested within factor A (Kirk, 1968)] was also conducted on the number of digits identified.

2. Supplementary Analysis

Separate single factor (two ears) analysis of variance computations (repeated measures) were conducted on the number of digits correctly identified on DL by each age-IQ range group (Winer, 1971). Separate 3-way analysis of variance calculations were also carried out separately on the digits from 1-pair, 2-pair and 3-pair sets correctly identified.

The performance on all digit sets combined of the children with Down's Syndrome was also compared overall and at each age level with the remainder of children with IQ below 61 by means of a 3-way analysis of variance involving unequal group size, least squares solution (Winer, 1971).

Informal supplementary analysis was also provided for the number of subjects exhibiting ear advantage for digit and environmental sound identification, number of subjects showing ear advantage in subjects exhibiting consistent vs. non-consistent hand preference, and for performance on environmental sound identification of the Down's Syndrome children, compared to that of the remainder of subjects, in the three age groups with IQ below 61.

CHAPTER III

RESULTS

This chapter first presents results of statistical analysis of data obtained on the verbal measure (section A), followed by findings on the non-verbal measure (section B).

An overall summary of results is provided in table 3, which outlines F-test findings from several analysis of variance computations, as well as some informal analysis of data obtained from the verbal and non-verbal material. Table 3 summarizes the following information:

1) Verbal material: since 4-way analysis of variance for all digits identified reveals no effect for sex, the data for each sex in each age-IQ group was combined (3-way analysis of variance, table 5), which yielded a significant overall ear effect (REA) and significant age and IQ range nested in age effects on overall digit identification, the significant REA being due primarily to the 5 yr. and 8 yr. groups with IQ above 90, and, to a lesser extent, the 5 yr. 65-80 IQ group (table 9); approximately twice as many subjects exhibited a REA as exhibited a LEA (table 10); REA was largest on the 1-pair sets, least on the 2-pair sets (tables 6-8); although Down's Syndrome children seemed to exhibit some tendency toward LEA and other children ($IQ > 61$) showed some tendency toward REA, especially in terms of number of other children showing a REA (table 12), there were no statistical differences

Table 3

Summary of Level of Significance of F-tests Showing Extent of Asymmetry of Number of Digits Identified at each Ear and Several Informal Comparisons (e.g., Number of Subjects Overall and in Relation to Hand Preference Consistency Showing REA/LEA; N.S. = nonsignificance)

VERBAL MATERIAL					
Male vs. female	.05 (REA); sex effect & all interactions with sex-N.S.				
All subjects	all digits - .025 (REA); 1-pair sets - .025 (REA); 2-pair sets-completely N.S. REA; 3-pair sets - .125 (N.S. REA)				
Age-IQ range groups	> 90	65-80	< 61		
5 yr.	.05 (REA)	.125(REA)	N.S. REA		
8 yr.	.05 (REA)	N.S. REA	N.S. REA		
11 yr.	N.S. REA	N.S. REA	N.S. REA		
IQ < 61 groups	N.S.; Dawn's Syndrome vs. remainder - N.S				
	REA	LEA			
All subjects	55	28	(66% - REA)		
Subjects with consistent hand usage	45	22	(67% - REA)		
Subjects with non-consistent hand usage	10	6	(63% - REA)		
NON-VERBAL MATERIAL					
All subjects	N.S. REA				
	REA	LEA	No. identified		
Male vs. female			R	L	
m.	17	19	332	315	
f.	17	16	293	294	
IQ < 61 groups	D.S.				
	other				
	3	5	45	47	
	7	4	78	67	
All subjects	33	35	(LEA - 51.5%)		
Subjects with consistent hand usage	27	26	(LEA - 49.1%)		
Subjects with non-consistent hand usage	6	9	(LEA - 60%)		

in overall identification or at each ear in Down's Syndrome vs. other children (table 13).

2) Non-verbal material: 3-way analysis of variance (table 15) revealed no overall ear effect in the nine age-IQ range groups for identification of environmental sounds, a result supported by roughly identical numbers of subjects showing a REA (35) vs. LEA (33, table 16); ear differences did not appear to be related to sex (table 14) or consistency of handedness usage (table 17), although 62.5% of Down's Syndrome children exhibiting ear advantage exhibited LEA vs. 36% of other children ($IQ > 61$) who exhibited an ear advantage manifested a LEA.

A. Verbal Material

The 4-way analysis of variance of the number of digits identified, conducted to detect the presence of any sex effects (see table 4) revealed F-ratios significant at the .01 level (2-tailed) for factor A (age) and factor B nested in A (IQ range nested within the age factor) and at the .05 level (1-tailed) for factor D (ears), but no significant sex effect (factor C) or interactions with sex.

Because of the absence of a sex effect, the data for males and females in each age-IQ range group was combined for a 3-way analysis of variance (table 5), which yielded F-tests significant at the .01 level (2-tailed) for factor A (age) and factor B nested in A (IQ range nested within the age factor)

TABLE 4

Summary and Summary Tables for 4-Way Analysis of Variance of Number of Digits Identified for Right (d2) and Left (d1) Ear Presentations in the 5 Males (c1) vs. 5 Females (c2) at the 3 Age (a1-5 yr., a2-8 yr., a3-11 yr.) and 3 IQ Range (b1-IQ > 90, b2-IQ 65-80, b3-IQ < 61) Nested Under Age Factor Levels

Source of Variation	SS	df	MS	F
<u>Between subjects</u>	<u>11215.495</u>	<u>89</u>		
A (age)	3210.478	2	1605.239	89.346**
B:A (IQ range nested in age)	6516.267	6	1086.045	60.448**
C (sex)	7.605	1	7.605	
AC	23.680	2	11.840	
BC:A	163.863	6	27.311	1.520
Subjects within groups	1293.600	72	17.967	
<u>Within subjects</u>	<u>2555.5</u>	<u>90</u>		
D (ears)	101.250	1	101.250	3.468*
AD	50.695	2	25.348	
DC	16.795	1	16.795	
ACD	49.545	2	24.773	
BD:A	59.597	6	9.933	
BCD:A	175.197	6	29.200	
B x subjects within groups	2102.4	72	29.200	

** $p < .01$ $F_{.99}(2,72) = 4.94$; $p < .01$ $F_{.99}(6,72) = 3.09$ (2-tailed)

* $p < .05$ $F_{.95}(1,72) = 2.78$ (1-tailed)

AB Summary Table

	b1	b2	b3	Total
a1	328	286	150	764
a2	487	365	171	1023
a3	618	494	270	1382
	<u>1433</u>	<u>1145</u>	<u>591</u>	<u>3169</u>

AC Summary Table

	c1	c2	Total
a1	373	391	764
a2	523	500	1023
a3	707	675	1382
	<u>1603</u>	<u>1566</u>	<u>3169</u>

AD Summary Table

	d1	d2	Total
a1	340	424	764
a2	489	534	1023
a3	688	694	1382
	<u>1517</u>	<u>1652</u>	<u>3169</u>

BC Summary Table

	c1	e2	Total
b1	734	699	1433
b2	550	595	1145
b3	319	272	591
	<u>1603</u>	<u>1566</u>	<u>3169</u>

TABLE 4 (Cont'd)

BD Summary Table				CD Summary Table			
	d1	d2	Total		d1	d2	Total
b1	676	757	1433	c1	754	849	1603
b2	551	594	1145	c2	763	803	1566
b3	290	301	591		1517	1652	3169
	1517	1652	3169				

ACD Summary Table					BCD Summary Table			
	al	a2	a3	Total	b1	b2	b3	Total
c1	d1 169	235	350	754	354	263	137	754
	d2 204	288	357	849	380	287	182	849
c2	d1 171	254	338	763	322	288	153	763
	d2 220	246	337	803	377	307	119	803
	764	1023	1382	3169	1433	1145	591	3169

ABC Summary Table				ABD Summary Table		
	c1	c2	Total	d1	d2	Total
al	b1(a1) 158	170	328	140	188	328
	b2(a1) 139	147	286	130	156	286
	b3(a1) 76	74	150	70	80	150
a2	b1(a2) 258	229	487	229	258	487
	b2(a2) 164	201	365	179	186	365
	b3(a2) 101	70	171	81	90	171
a3	b1(a3) 318	300	618	307	311	618
	b2(a3) 247	247	494	242	252	494
	b3(a3) 142	128	270	139	131	270
	1603	1566	3169	1517	1652	3169

ABCD Summary Table						
	c1:			c2		Total
	d1	d2		d1	d2	Total
al	b1(a1) 77	81		63	107	328
	b2(a1) 65	74		65	82	286
	b3(a1) 27	49		43	31	150
a2	b1(a2) 121	137		108	121	487
	b2(a2) 75	89		104	97	365
	b3(a2) 39	62		42	28	171
a3	b1(a3) 156	162		151	149	618
	b2(a3) 123	124		119	128	494
	b3(a3) 71	71		68	60	270
	754	849		763	803	3169

TABLE 4 (Cont'd)

ABCDS Summary Table

		c1			c2		
		d1	d2	Total	d1	d2	Total
	b1	13	17	30	18	17	35
		17	16	33	14	26	40
		8	17	25	13	13	26
		21	15	36	11	29	40
		18	16	34	7	22	29
a1	b2	11	18	29	9	18	27
		21	14	35	12	19	31
		4	4	8	12	12	24
		15	21	36	14	16	30
		14	17	31	18	17	35
	b3	9	10	19	4	4	8
		2	15	17	9	6	15
		1	1	2	19	4	23
		12	19	31	7	9	16
		3	4	7	4	8	12
	b1	28	21	29	21	25	46
		19	31	50	23	27	50
		27	28	55	19	18	37
		25	30	55	26	27	53
		22	27	49	19	24	43
a2	b2	18	19	37	19	17	36
		15	21	36	34	14	48
		13	19	32	17	24	41
		6	13	19	17	22	39
		23	17	40	17	20	37
	b3	7	12	19	24	14	38
		3	9	12	12	2	14
		8	13	21	7	5	12
		13	19	32	2	5	7
		8	9	17	0	2	2
	b1	31	32	63	32	28	60
		29	33	62	33	30	63
		33	34	67	31	35	66
		33	33	66	24	30	54
		30	30	60	31	26	57
a3	b2	30	26	56	17	23	40
		25	19	44	25	28	43
		23	28	51	33	29	62
		25	28	53	25	28	53
		20	23	43	19	20	39
	b3	19	13	32	21	11	32
		15	17	32	11	22	33
		15	18	33	6	4	10
		11	3	14	13	9	22
		11	20	31	17	14	31

TABLE 5

Summary and Summary Tables for 3-Way Analysis of Variance of Number of Digit Identification for Right (c2) and Left (c1) Ear Presentations at the 3 Age (a1-5 yr., a2-8 yr., a3-11 yr.) and 3 IQ Range (b1-IQ>90, b2-IQ 65-80, b3-IQ<61) Nested Under Age Factor Levels

Source of Variation	SS	df	MS	F
<u>Between subjects</u>	<u>11995.495</u>	<u>89</u>		
A (age)	3210.478	2	1605.239	57.31**
B:A(IQ range nested in age)	6516.267	6	1086.045	38.77**
S:AB (subjects nested in AB)	2268.750	81	28.009	
<u>Within subjects</u>	<u>1775.500</u>	<u>90</u>		
C (ears)	101.250	1	101.250	5.24*
AC	50.700	2	25.350	1.31
BC:A	59.600	6	9.933	
SC:AB	1563.950	81	19.308	

** $p < .01$ $F_{.99}(2,81) = 4.91$; $p < .01$ $F_{.99}(6,81) = 3.07$ (2-tailed)

* $p < .025$ $F_{.975}(1,81) = 3.97$ (1-tailed)

ABC Summary Table				AB Summary Table			
	c1	c2	Total	b1	b2	b3	Total
a1	140	188	328	328	286	150	764
b2(a1)	130	156	286	487	365	171	1023
b3(a1)	70	80	150	618	494	270	1382
				1433	1145	591	3169
a2	229	258	487				
b2(a2)	179	186	365				
b3(a2)	81	90	171				
a3	307	311	618				
b2(a3)	242	252	494				
b3(a3)	139	131	270				
	1517	1652	3169				

AC Summary Table			
	c1	c2	Total
a1	340	424	764
a2	489	534	1023
a3	688	694	1382
	1517	1652	3169

BC Summary Table			
	c1	c2	Total
b1	676	757	1433
b2	551	594	1145
b3	290	301	591
	1517	1652	3169

and at the .025 level (1-tailed) for factor C (ears).

A graphic portrayal of the latter significant effects is provided in Fig. 6 and 7, which depict the effects on overall ear performance of IQ range at the three ages (fig. 6) and compare the performance at each ear of these same three IQ ranges at the three ages (fig. 7). The significant effect of factor A (age) is revealed in Fig. 6 and 7 by the consistent trend of the number of digits identified overall and at each ear to vary in direct proportion to age at all three IQ range levels. A roughly parallel decrease in number of digits identified overall and at each ear in the three age groups as intelligence decreases reflects the significant effect of the nested factor (IQ range nested in the age factor).

In regard to the significant effect of factor C (ears) revealed in table 5, inspection of the AC and BC summary tables of Table 5 indicates a REA for identification of digits at all three age levels (AC summary table) and all three IQ range levels (BC summary table). However, when the ear performance of each of the nine age-IQ range groups is examined (see ABC summary table of Table 5 and Fig. 7, which show the number of digits identified by the left ear and right ear of the nine groups), only eight of the nine groups showed a REA, the exception being the 11 yr. old group with IQ below 61.

The performance of the nine age-IQ range groups continued to yield age (factor A) and IQ range nested in age

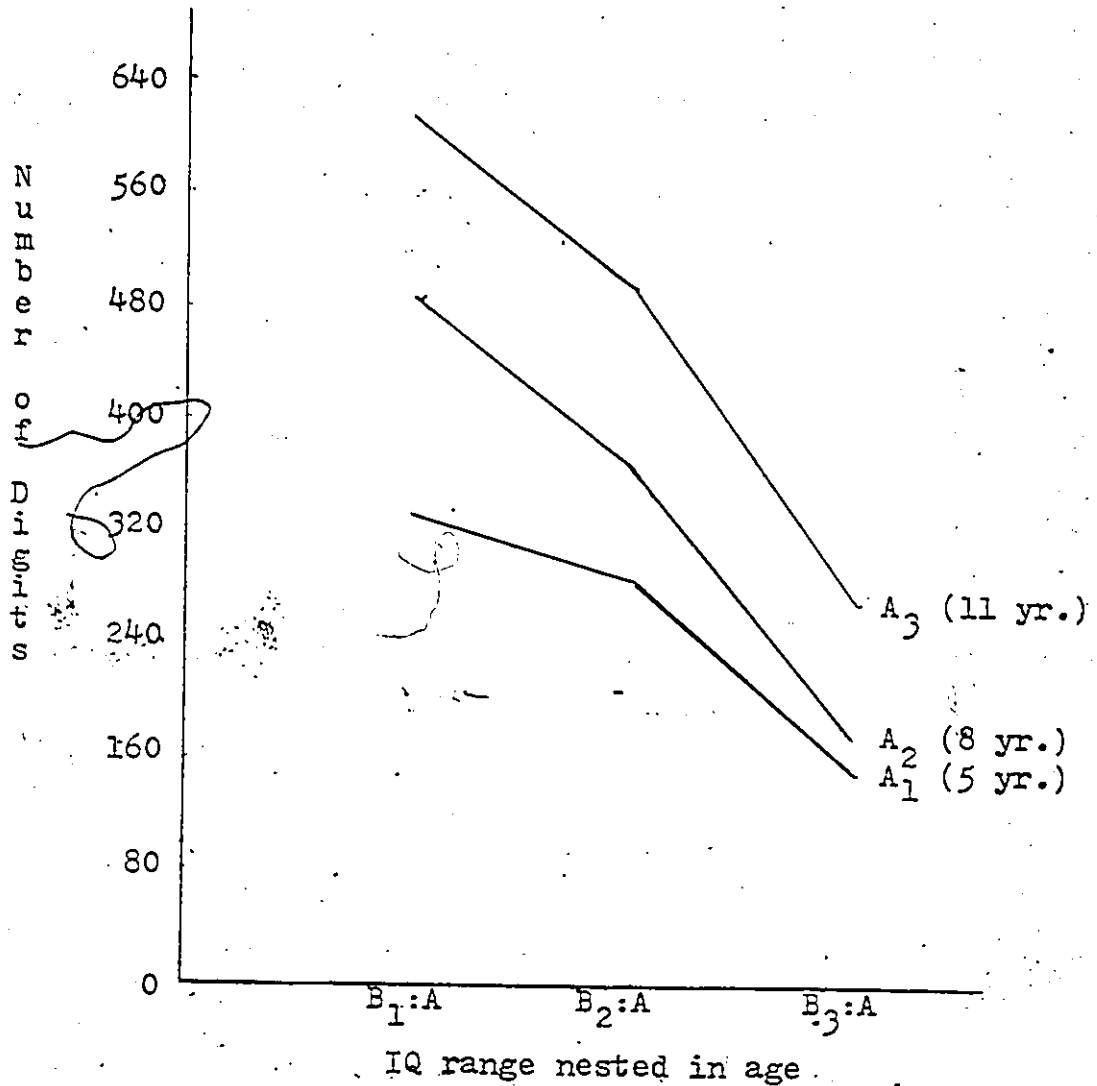


Figure 6. Total number of digits identified by each age (A)-IQ range (B₁-IQ > 90, B₂-IQ 65-80, B₃-IQ < 61) nested in age group. Each group was composed of 10 subjects.

Note: The data for plotting figure 6 was obtained from the ABC and AB summary tables in Table 5.

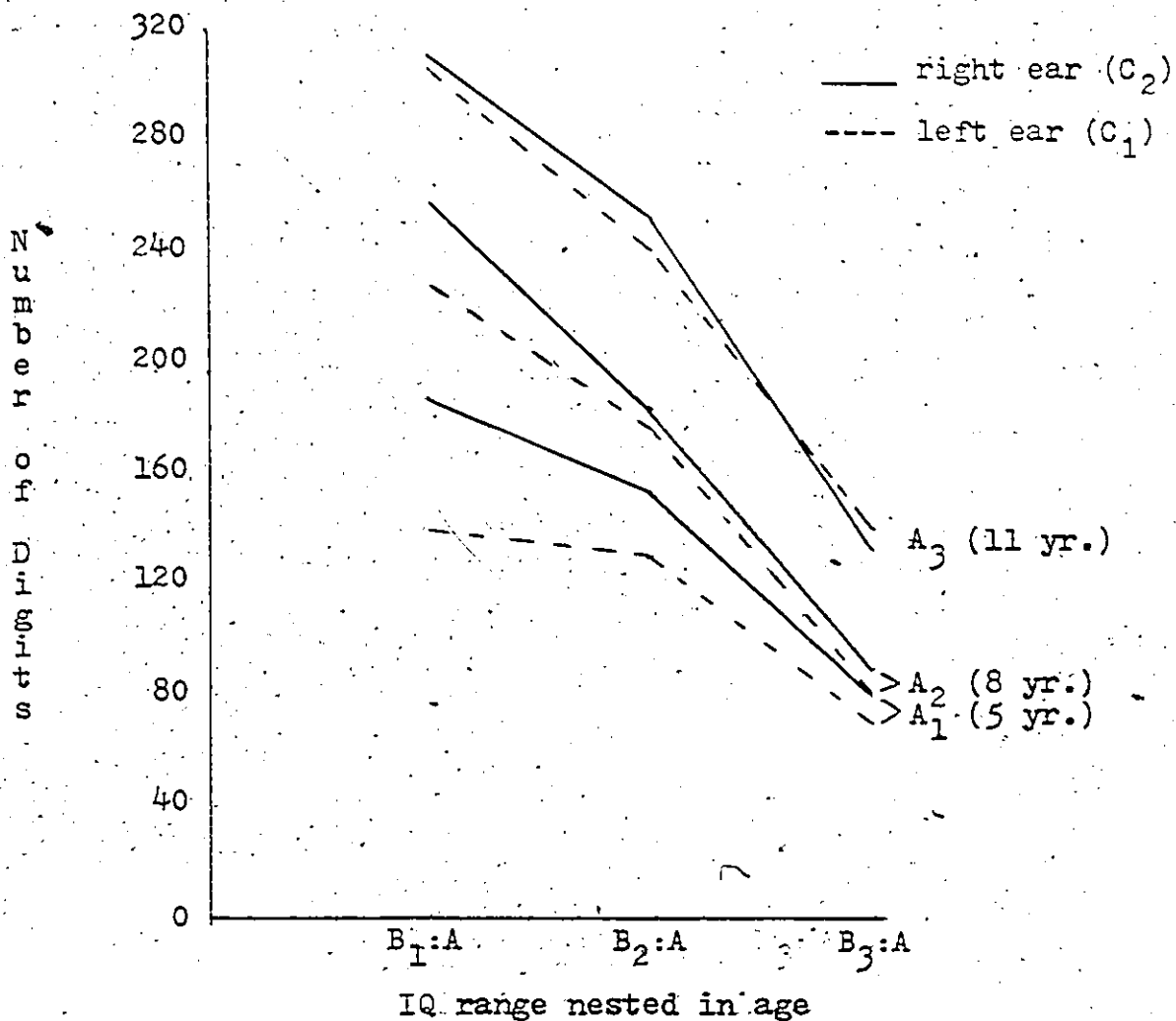


Figure 7. Comparison of number of digits presented to each ear identified by each age (A)-IQ range (B₁-IQ > 90, B₂-IQ 65-80, B₃-IQ < 61) nested in age group. Each group was composed of 10 subjects.

Note: The data for plotting figure 7 was obtained from the ABC and AB summary tables of Table 5.

(factor B nested in A) factors significant at the .01 level when the data was separately analyzed on results from 1-pair, 2-pair and 3-pair digits sets (tables 6 - 8), although the significant ear effect (factor C) was maintained only on the 1-pair sets (.025 level).

Separate single factor analysis of variance calculations for each of the nine age-IQ range groups on all digits yielded statistical comparison of the extent to which each group was contributing to the overall REA (table 9).

Table 10 presents the numbers of subjects exhibiting a REA or LEA, regardless of degree, for the nine age-IQ range groups and for other group combinations. The data in this table suggests a REA in the majority of subjects (55 vs. 28, with seven failing to exhibit any ear advantage), and in the vast majority of the age-IQ range groups (i.e., eight of the nine groups contained a greater number of subjects who exhibited a REA, compared to a LEA, the exception once again being the 11 yr. olds with $IQ > 61$). Inspection of part iii) of table 10 reveals the REA was present in 17 subjects at the 5 yr. age level, in 22 subjects at the 8 yr. age level and in 16 subjects at the 11 yr. age level; inspection of part iv) suggests that the number of subjects showing ear asymmetries at each IQ range differed only minimally from the number of subjects at the other IQ range levels (27 subjects in the $IQ > 90$ range range, 28 subjects in the

TABLE 6

Summary and Summary Tables for 3-Way Analysis of Variance of Number of Digits from 1-Pair Sets Identified for Right (c2) and Left (c1) Ear Presentations at the 3 Age (a1-5 yr., a2-8 yr., a3-11 yr.) and IQ Range (b1-IQ >90, b2-IQ 65-80, b3-IQ <61) Nested Under Age Factor Levels

Source of Variation	SS	df	MS	F
<u>Between subjects</u>				
A (age)	386.228	89		
B:A (IQ range nested in age)	89.728	2	44.864	54.203**
S:AB (subjects nested in AB)	229.450	6	38.242	46.202**
	67.050	81	.828	
<u>Within subjects</u>				
C (ears)	240.500	90		
AC	15.605	1	15.605	6.238*
BC:A	8.761	2	4.381	1.751
SC:AB	13.483	6	2.247	
	202.650	81	2.508	

** $p < .01$ $F_{.99}(2,81)$; $p < .01$ $F_{.99}(96,81) = 3.07$ (2-tailed)

* $p < .25$ $F_{.975}(1,81) = 3.97$ (1-tailed)

ABC Summary Table

		c1	c2	Total
a1	b1	25	46	71
	b2	27	29	56
	b3	16	26	42
a2	b1	53	55	108
	b2	36	47	83
	b3	20	26	46
a3	b1	58	59	117
	b2	48	53	101
	b3	29	24	53
		312	365	677

AB Summary Table

	b1	b2	b3	Total
a1	71	56	42	169
a2	108	83	46	237
a3	117	101	53	271
	296	240	141	677

AC Summary Table

	c1	c2	Total
a1	68	101	169
a2	109	128	237
a3	135	136	271
	312	365	677

BC Summary Table

	c1	c2	Total
b1	136	160	296
b2	111	129	240
b3	65	76	141
	312	365	677

Table 7

Summary and Summary Tables for 3-Way Analysis of Variance of Number of Digits from 2-Pair Sets Identified for Right (c2) and Left (c1) Ear Presentations at the 3 Age (a1-5 yr., a2-8 yr., a3-11 yr.) and IQ Range (b1-IQ >90, b2-IQ 65-80, b3-IQ <61) Nested Under Age Factor Levels

Source of Variation	SS	df	MS	F
<u>Between subjects</u>	<u>1619.450</u>	<u>89</u>		
A(age)	372.233	2	186.117	37.741**
B:A(IQ range nested in age)	847.767	6	141.294	28.652**
S:AB(subject nested in AB)	399.450	81	4.931	
<u>Within subjects</u>	<u>250.500</u>	<u>90</u>		
C(ears)	2.006	1	2.006	
AC	4.011	2	2.006	
BC:A	32.233	6	5.372	2.050
SC:AB	212.250	81	2.620	

**p<.01 F_{.99}(2,81) = 4.91; p<.01 F_{.99}(6,81) = 3.07 (2-tailed)

p<.25 F_{.75}(6,81) = 1.35

ABC Summary Table

	c1	c2	Total
a1 b1	48	63	111
a1 b2	48	53	101
a1 b3	24	23	107
a2 b1	76	94	170
a2 b2	66	58	124
a2 b3	35	25	60
a3 b1	106	110	216
a3 b2	85	82	167
a3 b3	44	43	87
	<u>532</u>	<u>551</u>	<u>1083</u>

AB Summary Table

	b1	b2	b3	Total
a1	111	101	47	259
a2	170	124	60	354
a3	216	167	87	470
	<u>497</u>	<u>392</u>	<u>194</u>	<u>1083</u>

AC Summary Table

	c1	c2	Total
a1	120	139	259
a2	177	177	354
a3	235	235	470
	<u>532</u>	<u>551</u>	<u>1083</u>

BC Summary Table

	c1	c2	Total
b1	230	267	497
b2	199	193	392
b3	103	91	194
	<u>532</u>	<u>551</u>	<u>1083</u>

Table 8

Summary and Summary Tables for 3-Way Analysis of Variance of Number of Digits from 3-Pair Sets Identified for Right (c2) and Left (c1) Ear Presentations at the 3 Age (a1-5yr., a2-8yr., a3-11 yr.) and IQ Range (b1-IQ >90, b2-IQ 65-80, b3-IQ <61) Nested Under Age Factor Levels

Source of Variation	SS	df	MS	F
<u>Between subjects</u>	<u>2801.16</u>	<u>89</u>		
A (age)	810.68	2	405.34	51.05**
B:A (IQ range nested in age)	1347.43	6	224.57	28.28**
S:AB (subject nested in AB)	643.05	81	7.94	
<u>Within subjects</u>	<u>722.50</u>	<u>90</u>		
C (ears)	20.673	1	20.673	2.46
AC	6.41	2	3.205	
BC:A	13.36	6	2.226	
SC:AB	682.05	81	8.42	

** $p < .01$ $F_{.99}(2,81) = 4.91$; $p < .01$ $F_{.99}(6,81) = 3.07$ (2-tailed)
 $p < .125$ $F_{.875}(1,81) = 1.34$ (1-tailed)

ABC Summary Table					AB Summary Table				
		c1	c2	Total		b1	b2	b3	Total
a1	b1	67	79	146	a1	146	129	61	336
	b2	55	74	129	a2	209	158	65	432
	b3	30	31	61	a3	285	226	130	641
						640	513	256	1409
a2	b1	101	108	209					
	b2	77	81	158					
	b3	26	39	65					
a3	b1	143	142	285					
	b2	109	117	226					
	b3	66	64	130					
		674	735	1409		674	735	1409	

BC Summary Table			
	c1	c2	Total
b1	311	329	640
b2	241	272	513
b3	122	134	256
	674	735	1409

Table 9

Summary of Degree of Statistical Significance-(1-tailed) of
 9 Single Factor Analysis of Variance (Repeated Measures on
 Ears) Statistics Derived for the 9 Age-IQ Range Groups (N.S.
 = not significant at any level)

Age	IQ Range		
	>90	65-80	<61
5 yr.	.05 (REA)	.125 (REA)	N.S. (REA)
8 yr.	.05 (REA)	N.S. (REA)	N.S. (REA)
11 yr.	N.S. (REA)	N.S. (REA)	N.S. (LEA)

Note: The analysis of variance table associated with each of the 9 analysis of variance computations is presented in appendix I.

Table 10

Number of Subjects in Various Groupings Exhibiting Ear Dominance for Digit Identification and Specific Direction of the Ear Dominance

i)					
Age	IQ Range	Ear		Total	No Dominance
		L	R		
5 yr.	>90	4	5	9	1
	65-80	2	6	8	2
	<61	2	6	8	2
8 yr.	>90	2	8	10	0
	65-80	3	7	10	0
	<61	3	7	10	0
11 yr.	>90	3	5	8	2
	65-80	3	7	10	0
	<61	6	4	10	0
		28	55	83	7

ii)					iii)			
Age	IQ Range			Total	Age	Ear		Total
	>90	65-80	<61			L	R	
5 yr.	9	8	8	25	5 yr.	8	17	25
8 yr.	10	10	10	30	8 yr.	8	22	30
11 yr.	8	10	10	28	11 yr.	12	16	28
	27	28	28	83		28	55	83

iv)				
IQ Range	Ear		Total	
	L	R		
>90	9	18	27	
65-80	8	20	28	
<61	11	17	28	
	28	55	83	

65 - 80 IQ range, 28 subjects in the IQ < 61 range) and only minimally in their tendency to demonstrate REA specifically (18 subjects in the IQ > 90 range, 20 subjects in the 65 - 80 IQ range and 17 subjects in the IQ < 61 range).

Ear asymmetries, regardless of degree, are classified in table 11 in terms of employment of the right hand on all six handedness tasks vs. those not completely consistent in hand preference. Whereas overall, 66% of those exhibiting ear asymmetries exhibited a REA (i.e., 55 of 83 subjects), table 11 shows that 67% of those consistently employing the right hand and exhibiting ear asymmetries exhibited a REA (45 of 67 subjects) vs. 63% of those not consistently employing their right hand (10 of 16). Of the 19 subjects referred to in table 11 who were not consistent in their hand usage, seven employed the right hand on three of the six handedness tasks, seven employed the right hand on four of the six handedness tasks and five selected their right hand on five of the six tests (number of subjects showing right hand preference on three, four or five of the tasks for each age-IQ group is summarized in appendix J). In subjects employing their right hand on three and four of the six tests, 50% in each group who exhibited an ear dominance exhibited a REA (three of six subjects in each group), while 100% of the subjects employing their right hand on five of the six handedness tests (four of four) exhibited a REA.

Comparisons of the performance at each ear of Down's

Table 11

Number of Subjects Showing Left, Right or No, Ear Dominance for Digit Identification in Subjects Employing Right Hand on All 6 Handedness Tasks vs. the Remainder of Subjects

	Ear		No difference	Total
	L	R		
Consistent R. hand usage	22	45	4	71
Inconsistent hand usage	6	10	3	19
	28	55	7	90

Syndrome and non-Down's Syndrome children with IQ below 61 (table 12) suggested possible ear dominance differences, whether ear dominance is determined by asymmetries in number of digits identified overall at each ear or by number of subjects overall exhibiting ear asymmetries.

However, the 3-way analysis of variance (unequal cell frequency, least squares solution) conducted on the data on digits identified (table 13) yielded a significant F-statistic for age (factor B), but not for ear (factor C) or the Down's Syndrome vs. non-Down's Syndrome factor (factor A).

B. Non-verbal Material

The combined performance of all males is compared to that of all females in table 14 for the identification of environmental sounds from the DL tape. Because the data in table 14 clearly suggested the absence of sex differences, the scores for males and females at each age-IQ range level were combined for a 3-way analysis of variance (table 15), which yielded F-ratios significant at the .01 level (2-tailed) for factor A (age) and factor B nested in A (IQ range nested in the age factor), but an entirely absent ear effect (factor C). These results are described in graphic form in fig. 8 and 9, where the significant effect of factor A (age) is revealed by the consistent trend of the number of environmental sounds presented to each ear identified to vary in direct proportion to age at all three IQ range levels. The significant effect of IQ range nested within the age factor can be seen in fig. 8 and 9 by the decrease in overall and right and left ear

Table 12

Number of Digits Presented to the Left and the Right Ears Identified by Children with Down's Syndrome (N = 12) Compared to Children without Down's Syndrome (N = 18) in the 3 Age Groups with SIT IQ < 61 and Number of Subjects in Each Group Showing Left, Right or No, Ear Dominance

	No. of digits identified		No. of subjects showing ear asymmetries		
	L.ear	R.ear	L.ear	R.ear	No diff.
Down's Syndrome	125	116	6	5	1
Other	165	185	5	12	1
	290	301	11	17	2

Note: The raw data from which this table was derived is presented in appendix K.

Table 13

Summary and Summary Tables for 3-Way Analysis of Variance (Least Squares Solution for Unequal Cell Size) of Number of Digits Identified for Right (c2) and Left (c1) Ear Presentations in the Down's Syndrome (a1) vs. Non-Down's Syndrome (a2) Children with IQ < 61 Across the 3 Age Levels (b1-5 yr., b2-8 yr., b3-11 yr.)

Source of Variation	SS	df	MS	F
<u>Between subjects</u>	<u>511.58</u>	<u>89</u>		
A (Down's Syndrome vs. others)	.490	1	.490	
B (Age)	147.10	2	73.55	17.657**
AB	15.891	2	6.945	1.667
Subjects within groups	349.903	84	4.166	
<u>Within subjects</u>	<u>5507.167</u>	<u>90</u>		
C (ears)	.672	1	.672	
AC	4.157	1	4.157	
BC	1.011	2	.506	
ABC	39.424	2	19.712	
CX subjects within groups	5461.903	84	65.023	

** $p < .01$, $F_{.99}(2,84) = 4.90$; $p < .25$, $F_{.75}(2,84) = 1.41$ (2-tailed)

ABC Summary Table					AB Summary Table					
		c1	c2	Total		b1	b2	b3	Total	
a1	b1	16	34	50	a1	50	75	116	241	
	b2	47	28	75		a2	100	93	157	350
	b3	62	54	116			150	168	273	591
a2	b1	54	46	100	AC Summary Table					
	b2	37	56	93		c1	c2	Total		
	b3	74	83	157	a1	125	116	241		
		290	301	591	a2	165	185	350		
						290	301	591		
BC Summary Table										
		c1	c2	Total						
	b1	70	80	150						
	b2	84	84	168						
	b3	136	137	273						
		290	301	591						

Table 14

Combined Performance of All Males (N = 45) and All Females (N = 45) on Number of Environmental Sounds Identified at Each Ear and Numbers Showing Left, Right, or No, Ear Dominance

	No. of environmental sounds identified		No. of subjects showing ear asymmetries		
	L.ear	R.ear	L.ear	R.ear	No diff.
males	315	332	19	17	9
females	294	295	16	17	12

Table 15

Summary and Summary Tables for 3-Way Analysis of Variance of Number of Environmental Sounds Identified on Left (c1) and Right (c2) Presentations at the 3 Age (a1-5 yr., a2-8 yr., a3-11 yr.) and 3 IQ Range (b1-IQ > 90, b2-65-80, b3-IQ < 61) Nested Under Age Factor Levels.

Source of Variations	SS	df	MS	F
<u>Between subjects</u>	<u>2172.245</u>	<u>89</u>		
A (age)	706.478	2	353.239	47.79**
B:A (IQ range nested in age)	867.067	6	144.511	19.55**
S:AB (Subject nested in AB)	598.700	81	7.391	
<u>Within subjects</u>	<u>216.00</u>	<u>90</u>		
C (ears)	1.422	1	1.422	
AC	1.345	2	.673	
BC:A	7.133	6	1.189	
SC:AB	206.100	81	2.544	

** $p < .01$ $F_{.99}(2,81) = 4.91$; $p < .01$ $F_{.99}(6,81) = 3.07$ (2-tailed)

ABC Summary Table					AB Summary Table				
		c1	c2	Total		b1	b2	b3	Total
a1	b1	67	70	137	a1	137	89	37	263
	b2	46	43	89	a2	184	152	81	417
	b3	14	23	37	a3	230	205	119	554
						551	446	237	1234
a2	b1	93	91	184	AC Summary Table				
	b2	72	80	152		c1	c2	Total	
	b3	39	42	81	a1	127	136	263	
a3	b1	116	114	230	a2	204	213	417	
	b2	101	104	205	a3	278	276	554	
	b3	61	58	119		609	625	1234	
		609	625	1234					

BC Summary Table			
	c1	c2	Total
b1	276	275	551
b2	219	227	446
b3	114	123	237
	609	625	1234

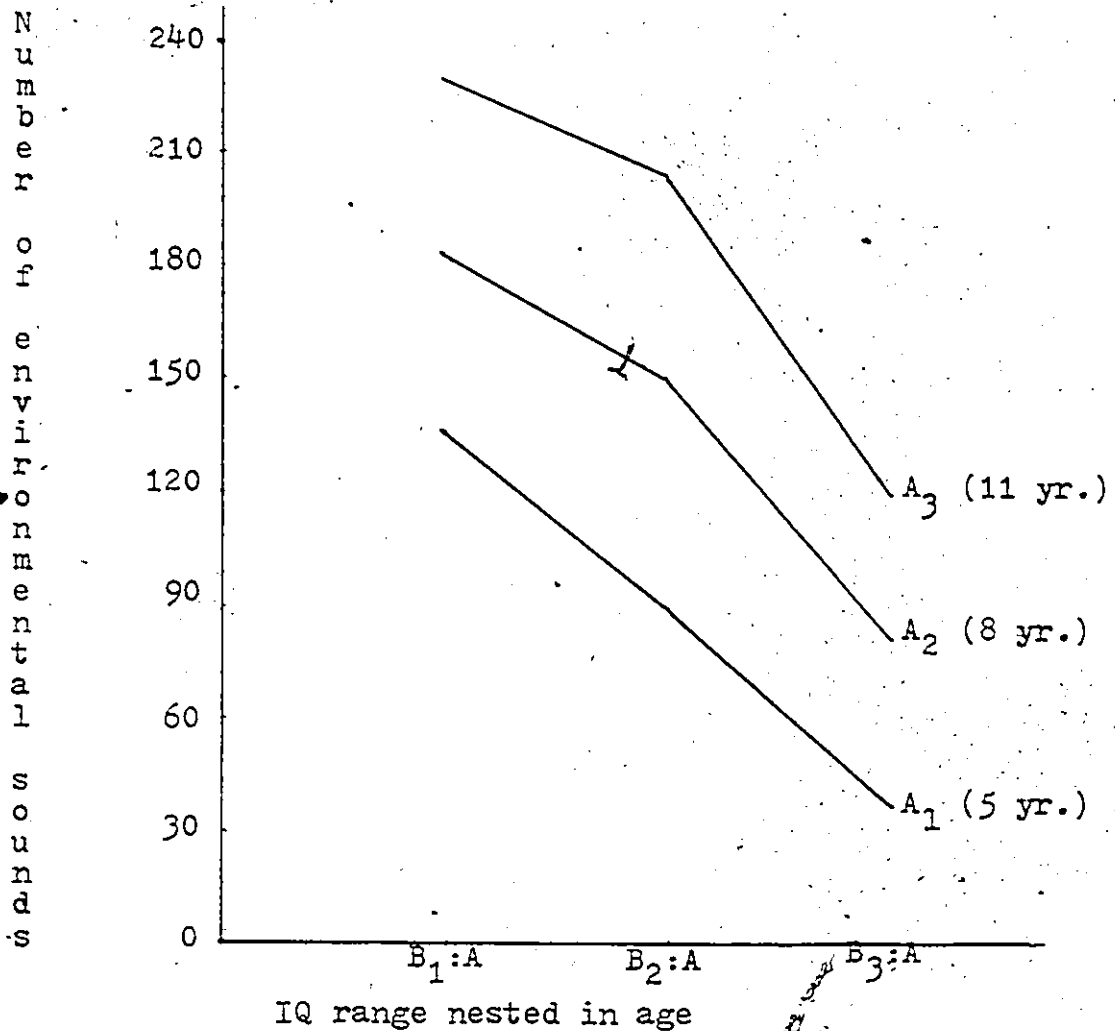


Figure 8 - Total number of environmental sounds identified by each age (A) - IQ range (B₁-IQ>90, B₂-65-80 IQ, B₃-IQ<61) nested in age groups. Each group was composed of 10 subjects.

Note: The data for plotting figure 8 was obtained from the AB summary table of Table 15.

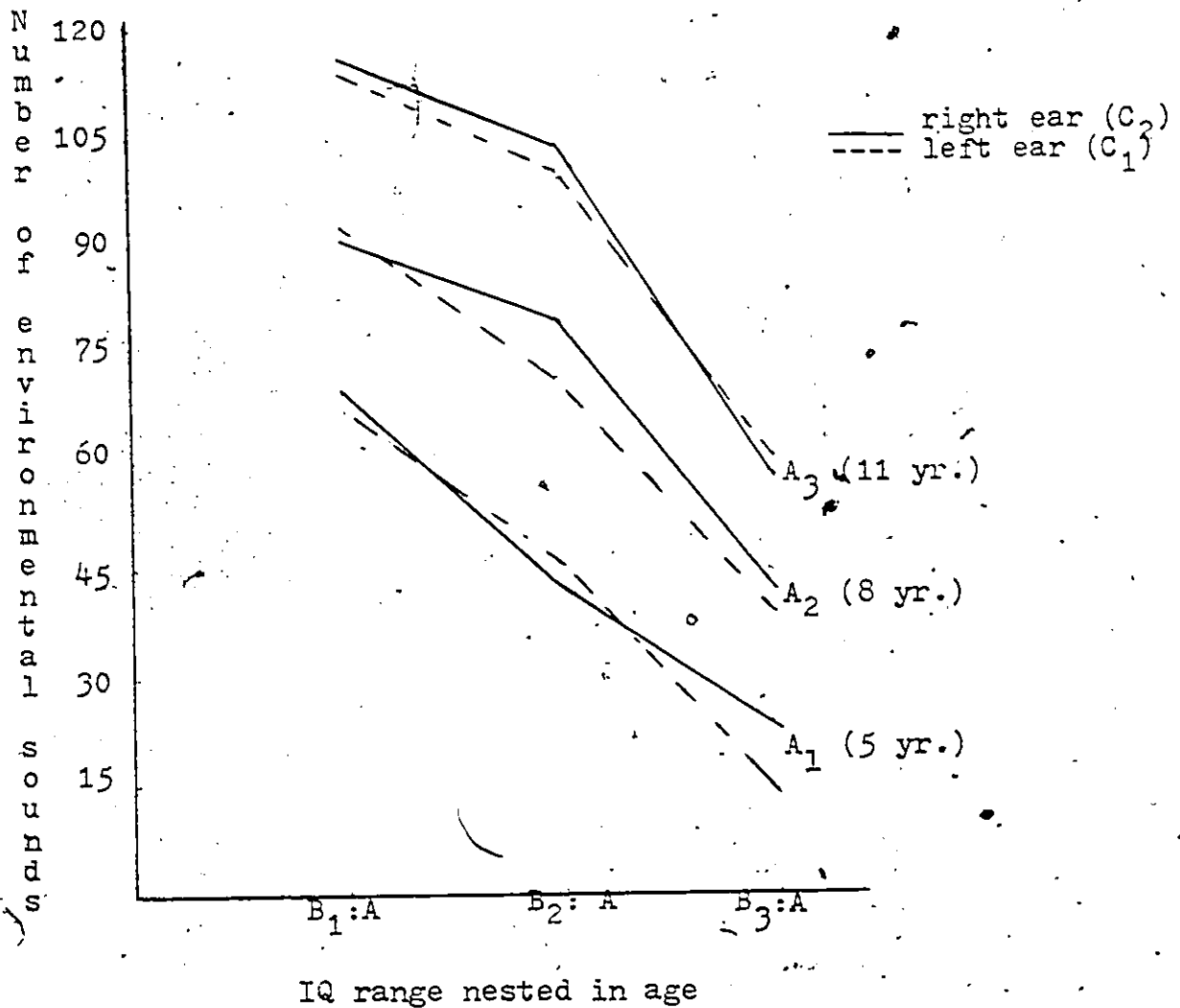


Figure 9 - Comparison of number of environmental sounds presented to each ear identified by each age (A) - IQ range (B₁-IQ>90, B₂-65-80 IQ, B₃-IQ<61) nested in age group. Each group was composed of 10 subjects.

Note: The data for plotting Figure 9 was obtained from the ABC summary table of Table 15.

performance for environmental sound identification in the three age groups as IQ range level decreases.

Table 16 presents the number of subjects in various groupings that exhibited a REA or LEA, regardless of degree, for environmental sound identification. The data in table 16 suggests no tendency for a majority of subjects overall or a majority of subjects in any particular age - IQ range or their groupings to exhibit a particular ear asymmetry for environmental sound identification (e.g., the data of part i reveals that no more than five of the 10 subjects in any of the nine age-IQ range groups exhibited a specific ear dominance). The only suggestion of possible specific ear asymmetry dominance occurred at the 11 yr. old level, where 14 of 25 subjects exhibiting ear dominance exhibited a LEA (see part iii of table 16).

The ear dominance pattern of identification of environmental sounds in those subjects who employed their right hand on all six handedness tasks (49.1% of such subjects exhibiting an ear advantage exhibited a LEA, see table 17) did not differ markedly from those who were not completely consistent in their hand usage (60% of such subjects exhibiting an ear advantage exhibited a LEA), percentages in turn not markedly different from the 51.5% exhibiting LEA of all subjects exhibiting ear advantage (35 of 68).

Of the 19 subjects referred to in table 17 who were not completely consistent in their hand preference, there

Table 16

Number of Subjects in Various Groupings Exhibiting Ear Dominance for Environmental Sound Identification and Specific Direction of the Ear Dominance

i)					
Age	IQ Range	Ear		Total	No Dominance
		L	R		
5 yr.	>90	4	5	9	1
	65-80	5	3	8	2
	<61	3	4	7	3
8 yr.	>90	5	4	9	1
	65-80	2	5	7	3
	<61	2	1	3	7
11 yr.	>90	5	3	8	2
	65-80	5	3	8	2
	<61	4	5	9	1
		35	33	68	22

ii)					iii)			
Age	IQ Range			Total	Age	Ear		Total
	>90	65-80	<61			L	R	
5 yr.	9	8	7	24	5 yr.	12	12	24
8 yr.	9	7	3	19	8 yr.	9	10	19
11 yr.	8	8	9	25	11 yr.	14	11	25
	26	23	19	68		35	33	68

iv)			
IQ Range	Ear		Total
	L	R	
>90	14	12	26
65-80	12	11	23
<61	9	10	19
	35	33	68

Table 17

Number of Subjects Showing Left, Right or No, Ear Dominance for Environmental Sound Identification in Subjects Employing Right Hand on all 6 Handedness Tasks vs. the Remainder of Subjects.

	Ear		no difference	Total
	L	R		
Consistent R. hand usage.	26	27	18	71
Inconsistent hand usage	9	6	4	19
	35	33	22	90

seemed to be no trend toward different ear dominance patterns in the seven subjects who employed their right hand on three of the six handedness tasks vs. the seven who selected their right hand on four of the items, vs. the five who utilized their right hand on five of the six tasks. In subjects employing their right hand on three and four of the six tests, 50% in each group who exhibited an ear dominance exhibited a LEA; in subjects who employed their right hand on five of the six tasks, 60% who exhibited an ear dominance exhibited a LEA.

Informal comparisons at each ear of the environmental sound identification performance of the 12 subjects with Down's Syndrome (four at each age level) and the 18 other children with IQ scores below 61 (table 18) indicates that the children with Down's Syndrome showed some tendency to exhibit a different ear dominance pattern from children of the same IQ range without Down's Syndrome, whether the ear dominance is based on number of environmental sounds identified overall at each ear or relative number of subjects overall exhibiting a particular ear identification superiority.

Table 18.

Number of Environmental Sounds Presented to the Left and Right Ears Identified by Children with Down's Syndrome (N = 12) Compared to Children Without Down's Syndrome (N = 18) in the 3 Age Groups with SIT IQ < 61 and Number of Subjects in Each Group Showing Left, Right or No, Ear Dominance.

	No. of env. sounds identified		No. of subjects showing ear asymmetries		
	L.ear	R.ear	L.ear	R.ear	No diff.
Down's Syndrome	47	45	5	3	4
Other	67	78	4	7	7
	<u>114</u>	<u>123</u>	<u>9</u>	<u>10</u>	<u>11</u>

Note: The data presented here was derived from appendix L.

CHAPTER IV

DISCUSSION

The three independent variables manipulated in the present investigation in an attempt to study the development of cerebral dominance for the processing of verbal and non-verbal auditory input were age (three age levels), Slosson IQ (three IQ ranges) and ear of presentation (right vs. left ear). The combination of the first two independent variables resulted in the inclusion of nine age - IQ range groups (10 subjects per group). Performance of these 90 subjects was then observed in relation to the third independent variable manipulated, right vs. left ear presentation of material. The number of items presented dichotically correctly identified was the main performance measure (dependent variable) studied and extent of differences in number of items presented at each ear correctly identified was utilized as the main index of the presence of cerebral dominance.

Other performance indices of cerebral dominance to be considered are number of subjects overall and number of subjects in the various age - IQ range groups who exhibited any ear identification asymmetries, and analysis of number of digits on the 1- , 2- and 3-pair sets of digits identified separately on right and left ear presentation. Results with the verbal material will be considered first, followed by a discussion of ear performance differences on the non-verbal

material; the chapter concludes with a general discussion of the results and their implications for future research.

A. Verbal Material

The absence of a sex effect and any interaction with the sex variable on the 4-way analysis of variance (table 4 of chapter III) supports previous findings of lack of sex differences in children in identification of verbal input on DL (Berlin et. al., 1973; Borowy, 1974, Bryden & Allard, in press; Geffner & Hochberg, 1971; Hynd & Obrzut, 1977; Ingram, 1975; Kimura, 1963b; Knox & Kimura, 1970; Nagafuchi, 1970; Piazza, 1977; Satz et. al., 1975; Schulman - Galambos, 1977; Sommers & Taylor, 1972), and justified combining of data for males and females in each age-IQ group for further analysis.

The resulting 3-way analysis of variance for all digits identified and separate 3-way analysis of variance on the digits identified from each of the 1-, 2- and 3-pair sets indicated that age and IQ range nested within the age factor were highly significant in each analysis. These significant main effects demonstrated that overall ear performance increased as a direct function of age and IQ range (e.g., inspection of figure 6 of chapter III revealed that the older each group at a particular IQ range and the higher the IQ range of a particular age group, the higher the overall performance). The same trend held specifically for identification of all digit material presented either to the right or the left ear (see figure 7). This increase in overall accuracy

with age has been noted in earlier DL research (Berlin et.al., 1973; Geffen, 1976; Mirabile et. al., submitted; Satz et. al., 1975; Schulman-Galambos, 1977; Sobotka, 1974; Tobey et.al., 1976; Witelson, 1975; Hynd & Obrzut, 1977 noted no increase with age). However, this trend did not reveal the extent of ear performance differences, nor the nature of any differences in relation to age or IQ range.

Such ear performance asymmetries were revealed by the significant overall REA for identification of all digits and digits from 1-pair sets that did not interact with age or intellectual level (e.g., AC and BC summary tables of appendix J and K show the REA to be present at each age and IQ range, though in only eight of the nine age-IQ range groups). Therefore, in terms of the hypotheses outlined at the conclusion of chapter I, null hypotheses 1 and 5, predicting an absence of overall REA on all digits identified and on digits identified from the 1-pair sets, were not supported; the absence of interaction of the significant REA with age or intelligence level on both analyses supported null hypotheses 2 and 6. The absence of significant ear and interactions with ear effects on identification of digits from the 2- and 3-pair sets supported null hypotheses 7-10.

Each 5 yr. old ^{group} exhibited a REA; however, the single-factor analysis of variance computations conducted for each age-IQ group revealed the superiority to be significant at the .05 level in the IQ above 90 group, at the .125 level for the 65-80 IQ group and not at all for the IQ below 61 group.

Thus, adoption of the .05 level as the critical cut-off point leads to the conclusion that only the IQ above 90 group exhibited a significant REA. The latter significant result and the differing degree of non-significance for the two other 5 yr. old groups suggested an increasing REA as intellectual level increased. Therefore, null hypothesis 3 and 4, predicting similar non-significant ear asymmetries or a similar significant REA for all age-IQ groups, were only partially supported (supported in two of the 5 yr. old groups, not supported in the 5 yr. olds with $IQ > 90$).

The finding of a significant REA in the IQ above 90 sample is in agreement with earlier DL results with normal 5 yr. olds on digit identification (Borowy, 1974; Geffner & Hochberg, 1971; Kimura, 1963b, 1967; Knox & Kimura, 1970 - 2 samples; Sommers & Taylor, 1972; Sommers et. al., 1975) and with normal 5-6 yr. olds on identification of words (Geffner, 1976; Goodglass, 1973; Knox & Kimura, 1970-2 different tests; Masterton, 1975; Piazza, 1977; Schulman-Galambos, 1977; Slorach & Nøehr, 1974; Sommers & Taylor, 1972) and syllables (Berlin et. al., 1973a; Dorman & Geffner, 1974; Geffner & Dorman, 1976; Hynd & Obrzut, 1977; Krashen & Harshman, 1972; Sadick, in prep.), even when non-verbal responding is employed (Knox & Kimura, 1970).

Despite the absence of ear interaction with age and IQ effects, the trend in fig. 7 and the data in appendix J suggested that ear differences on all digits identified might not be as pronounced at the older ages (i.e., REA of 84 at

age 5 yr., 45 at age 8 yr. and six at age 11 yr.) and lower IQ ranges (i.e., REA of 81 in the three groups combined with IQ>90, 43 in the 65-80 IQ range groups combined and 11 in the three groups with IQ<61). The results of the single-factor analysis of variance conducted on the data from each age-IQ range group (see table 9 of chapter III) supported the presence of age and IQ-related differences. In regard to age, two of the three 5 yr. old groups obtained a REA that approached (65-80 IQ range) or attained (IQ>90) the .05 level of significance; at age 8 yr. only one of the three groups yielded such a result (IQ>90 group attained the .05 level); no 11 yr. old group exhibited even a tendency toward statistically significant differences. In regard to IQ range all three groups in the IQ below 61 range failed to attain or approach a statistically significant REA, in contrast to one (5 yr. old - .125 significance level) of the three groups whose IQ fell in the 65-80 range approaching the .05 significance level and two (5 and 8 yr. olds) of the three groups with IQ above 90 actually attaining the .05 significance level. Thus, the major sources of the overall REA for all digits identified in the nine age - IQ range groups were the 5 and 8 yr. olds in the IQ above 90 range, and, to a lesser extent, the 5 yr. olds in the 65-80 IQ range. In addition, two of the three groups with IQ above 90 obtained a significant REA, in contrast to none of the six groups of subaverage IQ; and although the 5 yr. old level was a major source of the REA (two 5 yr. old groups), the biggest contrast in extent of

REA between groups with IQ above 90 and groups of subaverage intelligence occurred at the 8 yr. old level (IQ>90 group - .05 level, neither subaverage IQ group exhibiting even a tendency toward a significant REA). The findings in the 8 yr. olds thus also provide only partial support to null hypothesis 3 and 4 (support from two of the groups, not supported in the 8 yr. old IQ>90 group), while results in all 3 groups of 11 yr. olds supported null hypothesis 3 and 4.

These results thus support the speculation referred to in the literature review that mentally retarded populations may not possess functionally specialized hemispheres (Berman, 1971; Dustman et. al., 1975; Kershner, 1973; Kershner & Jeng, 1972; Kershner & Kershner, 1973), or at least support the possibility that that aspect of left hemisphere speech specialization tapped on DL of digits may be less pronounced or later occurring in the types of children of subaverage intelligence included in the current thesis research. Although some very insubstantial evidence that might relate to these possibilities was also cited in the literature review (e.g., Bakker, 1969; Berman, 1971; Dustman et. al., 1975; Rhodes et. al., 1969; Weitan & Etaugh, 1974b), the present findings provide the first adequately designed demonstration of differences in extent of ear asymmetries and possible left hemisphere speech specialization differences in children of average vs. subaverage intelligence.

The fact that the only group of subaverage intelligence whose REA approached some level of statistical significance (5 yr. olds, 65-80 IQ) exhibited a less marked asym-

metry than the 5 yr. olds of average IQ suggests reduced left hemisphere specialization for speech in this group of sub-average IQ, compared to the 5 yr. olds with average IQ. But such a trend to approach a significant REA suggests that the hypothesis of some degree of left hemisphere specialization for speech in the 5 yr. old group with 65-80 IQ should not as yet be ruled out completely, nor should the hypothesis of greater degree of specialization in the latter group than may be present in the 5 yr. old group with IQ below 61.

Accepting the data for the 8 yr. olds at face value for all digits identified (i.e., that ear asymmetries for digit identification significant at the .05 level indicate presence of hemisphere specialization and that complete absence of statistical significance of any kind indicates absence of hemisphere specialization) would lead to the conclusion that the difference in degree of left hemisphere speech specialization between the groups with an average and subaverage IQ was greatest at the age of 8 yr. At this age, the group with average IQ would be seen as possessing a specialized left hemisphere for speech, while the other two IQ range groups would be seen as possessing a hemisphere much less specialized (or completely non-specialized) for speech.

Also, the age changes in degree of ear asymmetries for identification of digits accepted at face value might lead to the conclusion that the 8 yr. olds with 65-80 IQ lost the degree of specialization reflected in a trend toward

significant REA present in the 5 yr. olds in the same IQ range, and the 11 yr. olds with IQ above 90 lost the degree of specialization reflected in the significant REA present in the 5 and 8 yr. olds of average IQ.

However, this latter explanation is incompatible with a maturational or developmental process view postulating increasing lateralization with age (Satz et. al., 1975). Satz et. al. (1975) also have argued that this explanation is at variance with the pattern suggested from the incidence and recovery of speech disturbances in brain-injured children (e.g., Basser, 1962; Lenneberg, 1967).

An alternate explanation is that some factor other than hemisphere specialization was reducing the extent of ear asymmetries at the older ages and was obscuring the presence of left hemisphere specialization or any further development of left hemisphere specialization. In regard to the latter possibility, Satz et. al. (1975) have suggested that developmental trends may be obscured because of a ceiling effect on the test items, older children exhibiting a less pronounced ear asymmetry because the left ear is able to continue to improve its performance to a greater extent than the right ear which had been performing nearer to its ceiling level at an earlier age. Kimura (1963b) had earlier forwarded a similar explanation for what she interpreted as a slight reduction of the REA in her older groups (4-9 yr. olds were studied). For this reason Satz et. al. (1975) employed a 4-pair digit task to increase task complexity and thereby reduce

or eliminate the influence of the ceiling effect.

However, the data of Kimura (1963b), Satz et. al. (1975) and other results could be interpreted as demonstrating that the ceiling effect is in fact only a very minor element in reducing ear asymmetries in older children. In the case of Kimura (1963b) her data may be viewed as revealing little or no developmental changes in the REA: 4, 5 and 6 yr. old males and females exhibited a REA significant at the .01 or .05 level, one 7 yr. and one 9 yr. old group (both males) at the .05 and .01 level respectively, with the greatest asymmetry occurring in the 8 yr. old males and females (both at .01 level). Satz et. al. (1975) themselves have cited the data of Geffner and Hochberg (1971) and Knox and Kimura (1970) to support the importance of the ceiling effect. However, Knox and Kimura (1970) found no significant age by ear interaction effect on separate digit and syllable identification tasks in 5-8 yr. olds, failed to provide statistics for ear asymmetries at each age level and made no suggestion of reduced ear asymmetries in older children. In the 4-7 yr. olds studied by Geffner and Hochberg (1971), a decreasing REA with age was suggested only from the raw data of the middle class groups, whereas there was an equally significant REA on statistical analysis in these four age groups. From the "middle class", the occurrence of a significant REA occurred only in the 7 yr. old "lower class" groups and there was an absence of age by ear interaction effects.

Satz et. al. (1975) themselves provided only indirect

support by observing an increasing REA in 5, 6, 7, 9 and 11 yr. olds that reached significance only in the 9 and 11 yr. olds when a more difficult digit task (4-pair sets) was utilized; unfortunately, less difficult tasks were not included for direct comparison purposes. There also appears to be no difference in likelihood of finding evidence for ear asymmetries in terms of digit task difficulty (e.g., equally significant REA with 2- and 3-pair sets of Bryden, 1970 and Witelson, 1975 vs. 3-pair sets of Borowy, 1974, Darby & Satz, 1973 and Sobotka, 1974).

In any case, there are several ways of determining whether the ceiling effect was operating in the present research to cloud the presence of an increasing left hemisphere specialization for speech that would have been reflected in increasing REA for digit identification with age if the task had been sufficiently difficult.

If one notes the performance of the 5, 8 and 11 yr. olds (table 9 and ABC summary tables of tables 5 to 8) when such children were performing at a relatively lower level in terms of total number of digits identified (i.e., the 65-80 IQ and IQ<61 groups compared to the IQ>90 groups), one sees that there appears to be no particular trend for groups in these two lower IQ ranges to continue to exhibit increasing ear asymmetries beyond the age when the IQ above 90 groups ceased to do so (i.e., any REA did not appear to increase in the two lower IQ range groups at age 8 or 11 yr., compared to the IQ>90 groups at the same ages). Such an in-

terpretation is also supported by the absence of a significant IQ-ear interaction nested in age effect, which is a combination of IQ-ear interaction and age - IQ-ear interaction effects in the standard analysis of variance design. Changes that did occur with age were in the opposite direction: a decrease in ear asymmetries at a younger age than in groups performing closer to ceiling level (e.g., for all digits identified - 8 yr. olds with IQ in 65-80 range failed to obtain an F-ratio that approached a statistically significant level, though the 5 yr. old 65-80 IQ range group obtained a .125 level, while the 8 yr. olds with IQ>90 continued to show the REA significant at the .05 level that the 5 yr. olds with IQ>90 exhibited). Hence, when statistical comparisons in the pattern of the development of degree of ear asymmetries for all digits identified were made among children who differed in terms of their distance from the ceiling level of the test (IQ>90 vs. 65-80 and IQ range <61), the only difference pertained to decreasing ear asymmetries at an earlier age (65-80 IQ range), or an absence of change (IQ<61), rather than to ear asymmetries continuing to increase to a greater extent at later ages in those groups performing farther from the ceiling level of the task.

One also can compare the performance of all groups on the 1- , 2- and 3-pair digit sets separately, since the task demands during the 2-pair set presentations presumably were more complex and taxing than during the 1-pair set presentation, with demands during the 3-pair set presentation

presumably being the most complex and taxing. The influence of the ceiling effect presumably would be mitigated to some extent on these relatively more difficult portions of the digit identification task, with the expectation of a larger REA on the 2-pair sets than on the 1-pair sets, and the largest REA being predicted for the 3-pair sets. However, the 3-way analysis of variance computations on the digits identified on 1-, 2- and 3-pair sets separately yielded the largest REA overall on the 1-pair sets (.025 significance level), least on the 2-pair set data (completely non-significant), 3-pair set data being intermediate (.125 significance level), see tables 6-8 of chapter III. Hence, statistical analysis of portions of the data which presumably would be less affected by any ceiling effect revealed a reduced (3-pair) or completely absent REA (2-pair) and the portion of the data that presumably would be most affected by the ceiling effect (1-pair) showed a significant REA (.025) and was the main source of the overall REA for all digits identified.

The minimal influence of a ceiling effect on ear asymmetries on the DL digit tape employed in the current study is further suggested by the significant REA found in the pilot study with seven adults (see appendix A), since any ceiling effect would presumably exert its maximum influence (i.e., eliminate the REA) in such subjects. Thus, any reduction of ear asymmetries with age in the present study seem entirely unrelated to any ceiling level present on the specific DL task utilized. 160

Porter and Berlin (1975) have offered an alternate explanation to that of Satz et. al. (1975) to reconcile the findings of Satz et. al. (1975) and Bryden and Allard (1973) with results from the five other studies cited by Satz et. al. 1975 (Berlin et. al., 1973; Geffner & Hochberg, 1971; Kimura, 1963; Knox & Kimura, 1970; Nagafuchi, 1970). Porter and Berlin (1975) suggested that different DL tasks may be assessing different levels of language processing that mature at different rates (e.g., 4-pair digit task employed by Satz et. al., 1975, may be tapping more slowly maturing memory processes, and single-pair nonsense syllables and fewer digit pair tasks may tap earlier maturing auditory and phonetic processes). However, the finding of a non-changing REA in children in kindergarten to gr. 5 and in college students on a presumably quite difficult DL task, recall of monosyllable nouns presented in 3-pair sets (Schulman-Galambos, 1977), fails to support this explanation.

If the variable suggested by Porter and Berlin (1975) were affecting the present results, one would again expect

3-pair sets in the 8 and 11 yr. olds (or at least in the 11 yr. olds) to elicit a more pronounced REA than that elicited by the 1- and 2-pair sets. Such an expectation is based on the inference that the 3-pair sets would presumably be tapping relatively more slowly maturing memory processes than that elicited by the 1- and 2-pair sets. But, as indicated above, the REA was least for the identification of digits from the 3-pair sets.

Another method of reflecting developmental trends on DL is to consider the number of subjects overall and in a particular age-IQ range group exhibiting a REA or LEA, regardless of degree (e.g., Bryden, 1970). A substantially larger number of subjects overall exhibited a REA on the digit input, compared to a LEA (55 vs. 28, with seven exhibiting no ear differences, see table 10 of chapter III). Thus, 66% of subjects exhibiting asymmetries showed a REA and 61% of all subjects exhibited the REA. If a 67% cut-off point is arbitrarily adopted to classify previous DL research with verbal material as indicating a fairly sensitive measure of that aspect of left hemisphere specialization tapped by DL of verbal materials (i.e., above 67% suggesting a fairly sensitive measure, less than 68% indicating a fairly insensitive measure), previous research is equally divided between those whose results suggested a fairly insensitive measure (Bever, 1971, see note 96; Bryden, 1965, 1966 - [three different samples], 1970, 1975; Bryden & Allard, in press [grade 2 and 4 samples]) and those indicating a fairly sensitive measure (Ling, 1971; see note 93; Satz et. al., 1965; Sommers & Taylor, 1972; Witelson, 1975; Witelson & Rabinovitch, 1972; another sample of Bryden, 1966, 1970, 1975 and Bryden & Allard, in press). Unfortunately other relevant child studies have failed to report percentage of subjects exhibiting REA. The assumption made in classifying such studies as having employed sensitive vs. insensitive indices is of course that the type of left hemisphere speech specialization tapped by verbal DL was invariably present in each subject of all samples studied, with

failure to obtain a REA in a particular subject due to the insensitive nature of the test, rather than because that aspect of left hemisphere specialization was absent. Such an assumption would be challenged by many (e.g., recall the conflicting views and evidence concerning age of onset and development of left hemisphere dominance presented in the literature review). This assumption would be an especially dubious one in the present study: the relatively larger number of subjects who failed to exhibit REA may have been to some degree indicative of absence or lessened degree of left hemisphere specialization in the child of subaverage IQ, rather than evidence of an insensitive measure. Thus, when one considers that percentage of subjects in the present samples is roughly as large or larger than one-half of the samples in research reporting number of children exhibiting REA for identification of verbal materials on DL, despite the inclusion of subjects more likely to be lacking a specialized left hemisphere or exhibiting reduced specialization, one must conclude that the present number of subjects exhibiting REA argues for the sensitive nature of the instrument employed (sensitive both to presence and absence of left hemisphere dominance; the extent of an asymmetry in a particular subject in turn may reflect extent of left hemisphere specialization tapped by digit identification on DL, see below).

In regard to developmental trends, the number of subjects manifesting a REA had increased in each 8 yr. old group, compared to their IQ range counterparts at the 5 yr. old

level (especially the IQ>90 group), though this trend reversed itself in two of the 11 yr. old groups (17 of 30 at age 5 revealed a REA, 22 at age 8 and 16 at age 11, see table 10). For IQ range, there appeared to be similar numbers of subjects exhibiting a REA at each IQ level (table 10 - 18 of 30 subjects with IQ>90, 20 with 65-80 IQ, and 17 with IQ<61). In the five age-IQ groups of subaverage intelligence who contained a majority of subjects exhibiting a REA, 70% was the lowest percentage exhibiting a REA of those demonstrating an ear advantage. This percentage compares favourably with the 66% and 67% for all subjects and the 30 subjects with IQ above 90, respectively (see table 10).

Thus, as suggested in a literature review note (note 99 reference to Berlin et. al, 1973a and Witelson & Rabinovitch, 1972) concerning the possibility of different methods of reflecting ear dominance leading to different conclusions concerning the development of ear ~~asymmetries~~, different conclusions concerning the presence and development of the REA were suggested when number of subjects in each group exhibiting REA was employed as the dependent variable (i.e., in the present samples, number of subjects demonstrating REA for digit identification on DL may be increasing beyond the age of 5, perhaps even beyond the age of 8; and number of subjects exhibiting the REA may not be affected by intellectual level).

The seemingly disparate conclusions from the two methods of studying ear and related cerebral, dominance may actually be complimentary, rather than contradictory. Perhaps

the extent of the REA does not increase in the 8 and/or 11 yr. olds once it is present (refer to studies in literature review reporting a REA in 4-6 yr. olds that did not change in older age groups), for example in the 5 and/or 8 yr. olds. Although the REA may not appear in some until after the age of 5 and perhaps not even until after the age of 8 in those who haven't acquired the REA until that point, the first appearance of the REA at the 8 yr. level did not represent a change to a REA sufficiently strong to be reflected either in the first appearance in the 8 yr. olds of subaverage IQ of a statistically significant REA for digits identified or in an increase of the degree of statistical significance of the REA at 8 yr., compared to 5 yr. at the IQ above 90 level. Also, although a very similar number of 5 and 8 yr. olds at each IQ level and within each age-IQ group may be exhibiting a REA (see parts i and iv of table 10), the extent of the REA is greater in the 5 and 8 yr. olds at the IQ > 90 level than at the two subaverage IQ levels (since significant REA present in the two groups of average IQ for identification of all digits vs. non-significant REA in all four groups of subaverage IQ).

Thus, the two methods of reflecting ear and hemisphere-related performance may be measuring slightly different degrees of left hemisphere dominance: the simple presence of left hemisphere specialization, regardless of degree, in the case of classification of REA on the basis of a higher right ear score, regardless of degree; the degree to which the REA and left hemisphere specialization is present in the case of

analysis based on number of digits identified at each ear.

Although Berlin (1977) argues against the hypothesis that extent of a REA reflects the magnitude of left hemisphere speech and language specialization, while few other authors have discussed the issue directly, many researchers have implicitly accepted the hypothesis. The present researcher would agree with Berlin (1977, p.305) that "...a dichotic listening task [is not] an immutable index of left hemisphere linguistic superiority", but would advocate that postulating the extent of a particular REA, in a carefully designed study, as providing some approximation to extent of the type of left hemisphere specialization tapped by verbal DL is not an unreasonable speculation, and a speculation that affords a reasonable explanation to the present results.

If the latter explanation is applicable to the present data, the results on the two methods suggest that the REA may be present in both groups of 5 yr. olds and both groups of 8 yr. olds of subaverage IQ, but that the REA present in these groups is not as pronounced as in the 5 yr. olds of average IQ. The earlier mentioned caution that the hypothesis of some degree of left hemisphere specialization should not be ruled out for the 5 yr. old 65-80 IQ group should thus perhaps be extended to all four 5 and 8 yr. old groups of subaverage intelligence (and to the 11 yr. 65-80 IQ group as well, because seven of these 10 subjects exhibited a REA).

It has also been noted that, although the data of table

12 suggested ear dominance might differ in children with and without Down's Syndrome with IQ below 61, statistical analysis failed to reveal such performance differences on number of digits identified overall or at each ear (table 13). Despite this failure to obtain ear differences for digit identification, the proportion of children with Down's Syndrome exhibiting REA appeared to differ markedly from the proportion of children without Down's Syndrome (table 12). Thus, utilizing this second means of studying ear performance in the two subgroups of children with IQ below 61 revealed 70% of children without Down's Syndrome who yielded an ear advantage exhibited a REA, in comparison to 66% on the overall sample of 90 subjects and the 67% of the 30 subjects with IQ above 90 (table 10). These percentages suggest that at least as many of the children with IQ below 61 without Down's Syndrome exhibited a REA as at any particular age or IQ level or age-IQ group studied.

In terms of age trends in the IQ below 61 groups, the data in appendix K suggested no particular ear advantage at 5 yr. in the children without Down's Syndrome (i.e., LEA for all digits identified, but more subjects showing REA), while the 8 and 11 yr. olds without Down's Syndrome showed a fairly clear REA (i.e., on either method of reflecting ear performance). For the children with Down's Syndrome, the 5 yr. olds exhibited a REA and the 8 and 11 yr. olds yielded a LEA with either method. Thus, the failure to obtain a significant REA in the 8 and 11 yr. olds with IQ below 61 may in large part have

been caused by the LEA present in the Down's Syndrome children in each age group. The above discussed speculation of some degree of REA and any related left hemisphere specialization in the 5 and 8 yr. olds of subaverage intelligence (four groups) and the 11 yr. 65-80 IQ group should accordingly be extended to 11 yr. olds with IQ below 61 without Down's Syndrome, with the possibility also that any REA in the 8 yr. olds with IQ below 61 applies only to those children without Down's Syndrome.

These results obviously require replication with larger samples concerning the possibility of a LEA in Down's Syndrome children, and to confirm the presence in the non-Down's Syndrome children with IQ below 61 of a REA for the identification of digit material on DL. Due to the scarcity and non-definitive nature of research of cerebral dominance in the intellectually subaverage, including Down's Syndrome, little guidance is provided in this regard from the research literature (e.g., see summary on p. 92 of literature review; concerning Down's Syndrome specifically, the Bigum et. al., 1970 and Galbraith et. al., 1975 VER research with Down's Syndrome and matched normal samples provided inconsistent results, failed to include matched samples of similar IQ without Down's Syndrome, involved children in one study - Bigum et. al., 1970 - and adults in the Galbraith et. al., 1975 study; with the origin of the VER hemisphere asymmetry and relationship to hemisphere language vs. non-language specialization in any case being obscure - Dustman et. al., 1975), nor from

publications devoted exclusively to Down's Syndrome (e.g., Benda, 1969).

Results on digit identification, either overall or for any particular age-IQ group or age or IQ level, were not affected by inclusion of subjects who were not completely consistent on the handedness tasks; only seven of the 90 subjects employed their right hand on three and only seven on four of the six handedness tasks and these subjects were fairly equally distributed across IQ ranges (three with IQ < 61, two with 65-80 IQ, 2 with IQ > 90 in each of the seven subjects, see appendix J). In any case, ear asymmetries were similar in children employing their right hand completely consistently, compared to the remainder of subjects (table 11).

B. Non-Verbal Material

The apparent absence of a sex effect for the identification of the environmental sounds suggested from inspection of table 14 supports previous findings of the absence of sex differences in children in the identification of such material on DL (Knox & Kimura, 1970; Piazza, 1977) and justified combining of data for males and females in each age-IQ group for further analysis.

The resulting 3-way analysis of variance of the number of environmental sounds identified (table 15) indicated that age and IQ range nested in the age factor were highly significant. These significant main effects demonstrated that overall ear performance increased as a direct function of age and IQ range (e.g., inspection of figure 8 of chapter III

reveals that the older each group at a particular IQ range and the higher the IQ range at a particular age, the larger the number of environmental sounds identified). The same trend held specifically for identification of material presented either at the right or the left ear (figure 9). Knox & Kimura (1970) similarly have reported an increasing identification of non-verbal sounds on DL with age in 5 - 8 yr. olds (environmental sounds in one sample, animal sounds in a second sample). However, no other effects even approached significance. (i.e., F-ratios less than unity).

The absence of a significant ear advantage differs from the LEA for the identification of environmental sounds found in 5-8 yr. olds (Knox & Kimura, 1970 - 2 studies), 3-5 yr. olds (Piazza, 1977) and in adults (Curry, 1967, 1968). Unfortunately, although an unpublished study has been cited (by Krashen, 1973a) that elicited a REA on DL for environmental sound identification in males and no ear differences for females under certain conditions, no additional details were provided other than that the study was by Krashen and Spitz.

The number of subjects exhibiting LEA and REA for environmental sound identification across all samples was also similar (i.e., 35 subjects showed a LEA, 33, a REA; 22 subjects failed to manifest any ear dominance, see table 16), and only slight differences were present within or among age or IQ range groupings and age-IQ groups. The fact that 22 of the 90 subjects failed to exhibit an ear dominance

contrasts with the much lower number among the same subjects (seven) who failed to exhibit ear dominance for the identification of digits. The difference in numbers of subjects failing to exhibit an ear dominance on the two types of material in turn appears to be a reflection of the finding of a significant ear effect for the number of verbal, but not non-verbal, items identified. Thus, null hypotheses 11-14, outlined at the conclusion of chapter E, were all supported.

Although the present finding of no significant ear asymmetries in identification of environmental sounds is in conflict with results from the only other study with children employing environmental sounds on DL conducted prior to the data-gathering for the present study (Knox & Kimura, 1970; Piazza, 1977 appeared subsequently), detailed consideration of the data of Knox and Kimura (1970) will resolve some of the discrepancies between the results of the latter and the present studies. The first sample (experiment I) studied by Knox and Kimura (1970) was composed of 10 boys and 10 girls at each of the 5, 6, 7 and 8 yr. age levels. Separate t-tests at each age level indicated no significant ear differences in four of the eight groups, though each age-sex group did exhibit a higher left ear score). In experiment II (15 boys and 15 girls each at the 5, 6, 7 and 8 yr. level) separate t-tests were not reported. But one would surmise that ear differences in the second sample were not as pronounced as

in experiment I, since the overall ear effect in the first sample was significant at the .001 level (mean left ear score of 5.0 vs. 3.5 for the right ear), while the overall ear effect in the second sample was significant at the .05 level (mean left ear score of 3.4 vs. 2.9 for the right ear and only seven of the eight age-sex groups obtained a REA, compared to all eight groups in the first experiment). Thus it appears highly probable that if t-tests had been reported, at least four of the eight age-sex groups would again have failed to exhibit a significant difference in ear performance.

Knox and Kimura (1970) also failed to obtain a significant overall LEA in experiment II for the identification of animal sounds on DL. The animal sounds test was not administered to their first sample of 5-8 yr. olds.

Hence the marginal and non-robust nature of the overall LEA reported by Knox and Kimura (1970) is suggested by the failure of several age-sex groups to exhibit a significant REA and the failure of another type of non-verbal sound, animal sounds, to elicit an overall significant LEA.

One might speculate that the failure of the present research to obtain a significant (or even a non-significant) LEA in identification of environmental sounds may be due in part to the verbal method of report employed in the current research. There is general agreement that speech output is controlled by the left hemisphere (Dimond, 1972), and one might argue that the verbal method of report may have cancelled out any advantage that the right hemisphere may have otherwise

exhibited in the analysis of the environmental sounds. However, Knox and Kimura (1970) have observed that on verbal DL tasks (digits, words), the REA is present whether a verbal or non-verbal method of report is employed. In addition, the overall LEA for identification of non-verbal environmental sounds noted by Knox and Kimura (1970) was obtained with a verbal method of responding.¹⁶¹ "These two findings indicate that the ear difference scores resulted from asymmetries in the reception of the stimuli (input) rather than from the expression of what was perceived (output)" (Knox & Kimura, 1970, p.235).

The lack of influence of a verbal method of responding on DL of non-verbal material is also suggested by a comparison of the results of King and Kimura (1972) and Carmon and Nachshon (1973a) on DL in adults for the recognition of non-verbal human (e.g., emotional) sounds. Carmon and Nachshon (1973a) employed a completely non-verbal method of responding, yet did not obtain a larger LEA than reported by King and Kimura (1972). The latter study required subjects to verbalize the correct answer from a multiple choice presentation. Both studies reported a slight but significant LEA.

Another possible contributor to the failure to obtain significant results in the present study is the type of familiarization procedure employed. In his adult sample Curry (1967) stated that a familiarization period was provided prior to dichotic testing for environmental sounds.

Though the nature of the familiarization procedure was not described, it is possible that all sounds were presented to subjects only once or twice. Knox and Kimura did not conduct any familiarization period; instead, pretesting with children (presumably children not included in their experimental samples) was conducted to determine the difficulty of recognition of the sounds when presented dichotically. Because young children and children of very low mental age were included in the current research, each subject was presented with each sound monaurally three consecutive times and provided with the appropriate verbal label for the sound on each presentation. It has been noted earlier that the differences observed in DL studies for non-verbal material are somewhat variable and non-robust, often vacillating between a particular ear advantage that failed to reach some level of statistical significance and an ear advantage that did attain the necessary degree of significance (e.g., Knox & Kimura, 1970). Thus, perhaps the degree of familiarization with each sound precluded the appearance of differences that may have been present if the familiarization period had been less extensive.¹⁶²

However, the following observations do not support the explanation that the familiarization period obscured the appearance of ear asymmetries for environmental sound identification on the present DL task. First, according to this "familiarization" explanation, one would expect some tendency of material presented to the left ear to be more

readily recognized, even if the ear effect failed to attain significance. But in fact, any ear identification asymmetries were in the direction of REA (i.e., overall right ear score across all groups was 625 compared to a left ear score of 609). Second, extensive monaural familiarization with the material before the DL phase would presumably have a reduced effect on depressing ear asymmetries during DL when subjects were performing at relatively lower levels, i.e., at levels far removed from the ceiling (maximum possible) performance level. However, there appeared to be no tendency for non-verbal material presented to the left ear to be identified to any greater extent when performance was at such relatively lower levels (i.e., in the younger and lower IQ range groups, see summary table ABC of Table 15).

The present researcher interprets the lack of significant results in the present research with the measure designed to tap right hemisphere processing in children as a reflection of the somewhat inconsistent and non-robust nature of results obtained when the functional specialization of the right hemisphere is inferred from studies of both clinical and normal samples. For example, in normal samples it was noted earlier that Curry (1967, 1968) has reported a LEA for the identification of environmental sounds in normal adult populations, but also that Krashen (1973a) has cited a study that elicited a REA in males and no differences in females under certain conditions. Other studies employing DL for the identification of non-verbal materials have yielded

a more consistent LEA (e.g., music - Higenbottam, 1973, Kimura, 1964, 1967, King & Kimura, 1972, Schulhoff & Goodglass, 1969, Spellacy, 1970, Spreen, Spellacy & Reid, 1970; emotional and/or non-verbal expression of human voices - Carmon & Nachshon, 1973a, Haggard & Parkinson, 1971, King & Kimura, 1972; pitch recognition - Blumstein & Cooper, 1974, Curry, 1968, Darwin, 1971, H. Gordon, 1970, Spreen et. al., 1970; but negative results in one study of temporal and pitch recognition and music at a recognition interval of 12 sec. - Spellacy, 1970; and shift to REA with abrupt changes in frequency or duration of non-verbal tones - Halperin et. al., 1973). However, other experimental measures utilized to assess right hemisphere functioning have yielded more variable results (e.g., VF identification asymmetries, see literature review), and the case for right hemisphere functional specialization still encounters strong skepticism (e.g., see Bogen, 1969b; Small, 1973).

As was the case for digits, informal comparisons of the relationship between consistency of hand usage and ear dominance for environmental sounds identified did not suggest any trends.

In the groups with IQ below 61 the possibility has been discussed that the children with Down's Syndrome may possess a different pattern of hemisphere specialization for speech from the children without Down's Syndrome (on the basis of performance of the 8 and 11 yr. olds on the identification of digits on DL). It also appeared from inspection of

table 18 that ear asymmetries for identification of environmental sounds might differ for these subgroups: no ear dominance seemed to be present in the children with Down's Syndrome (if anything, perhaps a very slight LEA), while the children without Down's Syndrome seemed to be exhibiting at least a tendency toward a REA.

C. Implications For Further Research

An overall significant REA and eight of nine age-IQ groups revealing a REA (either based on number of digits identified or number of subjects showing REA, regardless of degree) were noted for number of digits identified overall and on the 1-pair sets, with two of the age-IQ groups exhibiting a significant REA and a third group approaching a significant REA for number of digits identified overall; 66% of subjects who exhibited ear dominance exhibited a REA (55 of 83), seven subjects failing to show any ear dominance. These findings for digit identification contrasted with the lack of a significant overall ear effect for identification of environmental sounds in the same subjects, absence of any trend toward ear differences in particular age-IQ groups and number of subjects showing a particular ear advantage, with 22 subjects showing no ear advantage at all for environmental sound identification. These contrasting results with material designed to tap left and right hemisphere functioning seem to be a reflection of the general status of cerebral dominance research in normal and clinical samples: such research has

more consistently implicated the left hemisphere as dominant for language reception and processing, in comparison to pre-eminence of the right hemisphere for non-language reception and processing (Bogen, 1969b; Bryden, 1976; Geffen, Bradshaw & Nettleton, 1973; Milner, 1971; Small, 1973; White, 1972).

The possible presence and course of development of hemisphere dominance for speech and language requires large scale investigation in children and adults at various levels of subaverage intelligence to establish: 1) in populations without evidence of brain damage without Down's Syndrome - the range of subaverage intellectual functioning associated with the presence of hemisphere specialization for language, its age of onset, development, extent of specialization and eventual status in the adult, compared to populations of average intelligence; 2) in Down's Syndrome populations - whether such individuals are characterized by right hemisphere specialization for language or specialization of any kind, its age of onset, development, extent of specialization and eventual status in the adult, compared to populations of average intelligence and populations matched for IQ and age, but without Down's Syndrome (e.g., since 8 and 11 yr. olds with Down's Syndrome exhibited a LEA on digit identification and 8 and 11 yr. olds with IQ < 61 without Down's Syndrome exhibited a REA, a larger, perhaps significant, REA may have appeared in this age-IQ range group on digit material if the entire group had been composed of children without Down's Syndrome, es-

pecially if large samples were studied; similarly, a larger, possibly even significant, LEA may have appeared at some point if all children with IQ<61 had been children with Down's Syndrome).

If a LEA for identification of verbal materials is found in larger samples of Down's Syndrome populations, such a finding would provide the first demonstration of a population that is characterized predominantly by right hemisphere specialization for language.¹⁶⁵

The complexity of hemisphere functioning and the pivotal role of techniques utilized to reflect such functioning may be being highlighted by the seemingly discrepant, but possibly actually complimentary, findings on the two means of reflecting ear asymmetries in the present research (e.g., concerning onset, development and extent of ear asymmetries in relation to intellectual level and Down's Syndrome vs. non-Down's Syndrome children with IQ<61). Hence detailed evaluation of the two scoring methods is suggested: a logical next step would be the conduct of a large scale validity study employing an accurate clinical measure of cerebral dominance (e.g., sodium amytal or ECT, along the lines of Kimura, 1961b, but utilizing number of subjects showing REA as well as the total scores analyzed by Kimura, 1961) to determine the degree of correlation between extent of ear advantage on DL for digit identification and contralateral hemisphere disruption on the clinical measure. Inclusion of verbal material other than digits in such a study could also address the issue of the relative sensitivity

of digits vs. other verbal materials to the presence and extent of specialization for language (see pp. 66-68 of literature review). Employment of both scoring methods on DL studies with large samples of adults and children would also provide valuable normative data.

Thus, it would also be useful if the present study was replicated utilizing both digits and other verbal materials on much larger samples, with separation of the two types of children making up the IQ below 61 groups (i.e., large samples of Down's Syndrome children matched for age and IQ with children without Down's Syndrome), and with the inclusion of older children and possibly adults as well (see below) to establish if and when a significant REA for digit identification or identification of other verbal material eventually appears in groups of subaverage IQ (as opposed to number of subjects showing REA), and to further compare the extent of the REA advantage with the number of subjects exhibiting REA, regardless of degree.

Inclusion of both methods of reflecting ear asymmetries on identification of verbal material on DL in future studies should also aid in determining the extent to which such differing methods have contributed to the discrepant results that have been obtained in regard to age of onset and general development of ear asymmetries on DL.¹⁶⁴

Since review of other studies and analysis of performance of groups on the 1-, 2- and 3-pair digit sets suggested only minimal influence of a ceiling effect in the current

and earlier DL research in children, it is not imperative to include tasks of sufficient complexity to insure that any ceiling effect does not obscure trends that may be observed. However, a variety of complexity of tasks in the same study might permit direct comparison in the same study of the performance of subjects varying even more widely in functioning level than those employed in the present study (e.g., normal and mentally retarded adults and children).

Satz et. al. (1975) employed 4-pair sets of digits in an attempt to eliminate any influence of the ceiling effect. But, as noted by Satz et. al. (1975) themselves, employment of only 4-pair sets of digits may create a "floor" effect: the task would be extremely difficult for very young children, resulting in too few, rather than too many, correct responses to material presented to both ears. Such a relatively more taxing task may thus obscure the onset and development of ear asymmetries at the younger chronological and mental age levels. Satz et. al. (1975) failed to offer any alternative to the employment of a strict 4-pair set presentation. However, as one alternative, the present researcher suggests the employment of 1-pair, 2-pair, 3-pair and 4-pair sets of digits and/or other verbal material in subjects varying widely in functional level. Comparisons could then be made among different age groups and groups at various functional levels on the task in its entirety, as well as selective comparisons of the performance of groups on portions of the task that are relatively more or less com-

plex (e.g., comparisons of performance on 4-pair sets separately, 1-pair sets separately, etc.).

Research that has employed DL and VF recognition asymmetries for verbal materials within the same adult samples (Bryden, 1965, 1973; Higenbottam, 1973; Zurif & Bryden, 1969) has suggested that each experimental technique may be measuring different aspects of left hemisphere dominance (perhaps temporal-parietal vs. occipital dominance). In this regard, speculation has also been forwarded that different aspects of speech and language may become lateralized at different ages (Bryden & Allard, 1973, in press); also that hemisphere specialization for speech perception may develop throughout life (Brown & Jaffe, 1975) and that such specialization should be viewed as varying in extent in different individuals (Shankweiler & Studdert - Kennedy, 1975). One specific hypothesis forwarded is that receptive speech specialization may mature at a later age than expressive speech specialization (Brown & Jaffe, 1975).

As suggested in the literature review, a particular experimental measure may even be tapping different aspects of left hemisphere dominance, depending upon the specific nature and complexity of the stimulus material utilized with that experimental measure (e.g., rather than digits vs. other verbal material differing in sensitivity to the presence of left hemisphere language specialization, the two types of verbal material may be reflecting slightly different aspects of left hemisphere language dominance; the speculation of Porter and Berlin, 1975, also has been referred to earlier

that DL tasks of differing difficulty may be tapping abilities that mature and become specialized at different ages).

As the present author suggested in the literature review, the fact that ear asymmetries have continued to develop in older children on the ML technique of ordered recall of digits (Bakker, 1969, 1970; Bakker et. al., 1973), in contrast to the tendency of the REA to stabilize in children as young as 5 yr. when DL of verbal materials is employed (e.g., Kimura, 1969 among many others), may also be explained by the hypothesis that the two listening techniques may be measuring different aspects of left hemisphere dominance (e.g., language vs. the temporal aspects of language) which may have their onset at different stages of development.

Thus, employment of several types of DL material (digits, syllables, words) of varying complexity (e.g., 1-, 2-, 3-, 4-pair sets of digits, syllables or words), analysis of both number of subjects exhibiting REA and amounts of material identified at each ear, and variation in reporting and listening demands (e.g., ML vs. ordered recall on DL vs. standard free recall procedure on DL), in combination with other experimental measures in the same samples of children of normal and subaverage intelligence (e.g., VF asymmetries in identification and reaction time) would help in pinpointing the critical variables. Use of such multiple measures and concomitant more powerful research designs (e.g., multivariate analysis) should provide more enlightenment than continued reliance on only one index of cerebral dominance

or one method of reflecting cerebral dominance on a particular index. Such sophisticated research may even eventually lead to findings of clinical significance, instead of the results to date that have essentially been of no more than statistical significance (e.g., see Satz & Friel, 1973, 1974, 1975; Satz et. al., 1974).

A conspicuous omission in the cerebral dominance research reviewed in chapter I utilizing DL and other experimental measures is the conduct of longitudinal, as opposed to cross-sectional, studies. All developmental studies of cerebral dominance reviewed in the current dissertation have been cross-sectional in design. Longitudinal research of any kind concerning how cerebral dominance develops is clearly required; inclusion in such longitudinal research of some of the variables suggested to this point in the discussion would be especially valuable.

In contrast to the situation revealed on the verbal measure, the non-verbal measure of the present study revealed no ear asymmetries at any level, either overall, in any particular age-IQ group or when the three groups of average IQ were compared with the groups of subaverage IQ, the only suggestion of ear asymmetries being a possible REA in the children with IQ below 61 without Down's Syndrome. The Down Syndrome children appeared to perform differently from their IQ counterparts without Down's Syndrome, but like the other eight age-IQ range groups in failing to exhibit any particular ear asymmetries on environmental sounds identification.

Given the lack of any tendency toward a LEA for identification of environmental sounds overall or in any of the age-IQ range groups studied, and given the variable and non-robust nature of results with this measure specifically in adults (Curry, 1967, 1968 vs. study referred to by Krashen, 1973a) and children (Knox & Kimura, 1970) and in regard to right hemisphere functional specialization generally (Bogen, 1969b; Bryden, 1976; Geffen Bradshaw & Nettleton, 1973; Milner, 1971; Small, 1973; White, 1972), speculation about the development or lack of development of right hemisphere specialization in the samples with IQ less than 61 included in the present study would be especially tenuous. However, in a study of specialization for speech and language with large samples of Down's Syndrome children and adults, concurrent investigation of what seems to be primarily a right hemisphere function in the normal adult, such as music (Dee, 1971; Higenbottam, 1973; Kimura, 1964, 1967; King & Kimura, 1972; Schulhoff & Goodglass, 1969; Spellacy, 1970), may prove to be worthwhile, particularly in light of the often reported adeptness of some individuals with Down's Syndrome in regard to musical abilities (Benda, 1969). In research utilizing the multiple measures of left hemisphere functioning and concomitant more powerful research designs suggested above, concurrent investigation might also be conducted in the same subjects of functions that may be mediated primarily by the right hemisphere in the normal adult.

The type of validity study suggested earlier of DL and scoring methods utilized on the DL data in clinical samples administered sodium amytal or ECT might also present non-verbal tasks in some subjects immediately after sodium amytal or ECT administration to each hemisphere to confirm the less stable nature of any hemisphere specialization for non-verbal information processing and to suggest non-verbal material that might be at least relatively sensitive to any specialization that is discovered.

Neuropsychological measures that have been discussed above may also be profitably combined with neurophysiological measures in the investigation of cerebral dominance in adults in its development in childhood. As one example, several perceptual dominance measures might be combined with several neurophysiological indicators of differential lateralized activation. It would seem particularly worthwhile to determine how the reticular activating system contributes to the differential activation of the hemispheres for the reception and the processing of language vs. non-language input and whether the "phasic" portion of the reticular system [e.g., the non-specific thalamic region and limbic system which are especially important in the "phasic" portion of the system (Luria, 1973)] may also be lateralized in terms of its activating and "dampening" influence, depending upon the type of information requiring attention.¹⁶⁶

In regard to the role of the thalamus, Vilkki and Laitinen (1974) have noted that left ventrolateral thalamotomy (but not right ventrolateral thalamotomy) was associated with

receptive and expressive verbal deterioration, while errors in matching faces increased only after right thalamotomy.

Although it is possible that other factors besides the thalamic lesion may have contributed to the alterations after thalamotomy, we are inclined to conclude from the present results that there is a functional difference between the 2 thalami, which is related to the hemispheric dominance on the cortical level. The left thalamus is more important than the right for the control of attention directed to verbal information and the continuous selection of relevant verbal responses while the right thalamus rather than the left controls the attention needed for the perception of faces. Possibly the right thalamus is also more important in other perceptual performances, in which rapid discrimination and identification of similar complex patterns without the aid of verbal cues is required (Vilkki & Laitinen, 1974, p.18).¹⁶⁷

It would also be of interest to investigate neuropsychological measures of cerebral dominance in combination with neurophysiological measures that have suggested deficits in attention in the mentally retarded (e.g., measures leading to the prestimulus arousal or attentional lag theory of Baumeister & Kellar, 1968 or the weak trace in short-term memory postulated by Ellis, 1963 to be caused by a low cortical arousal), especially if such neurophysiological measures can be tailored to reflect lateralized arousal.

The tendency of research to study the processing of material normally mediated by the left hemisphere, rather than the processing of information possibly mediated by the right hemisphere, has been noted in the literature review. The majority of research pertaining to right hemisphere functional specialization has only appeared in recent years; hopefully investigation of such relatively unknown

hemisphere functional territory will continue, and will extend itself to detailed investigation of how such territory develops whatever specialization is found to be present in the adult brain. Such research will also hopefully incorporate, whenever applicable, improvements in experimental design and procedure, methods, of measurement, etc., outlined in the current dissertation largely derived from study of information processing normally mediated by the left hemisphere.

SUMMARY AND CONCLUSIONS

Clinical and experimental research has suggested that left hemisphere language specialization, an established fact in the adult, may occur in early childhood, though the exact age of onset of such specialization and the pattern of its development are unsettled questions. The functional specialization of the right hemisphere, though not studied nearly as extensively as that of the left hemisphere, seems to involve certain types of non-language information processing. However, this latter hypothesis is not accepted by many. If the pattern of development of left hemisphere language specialization remains unclear, even less is known in regard to the development of any right hemisphere functional specialization that may be present in the adult. Hemisphere specialization research, and especially developmental research, in the intellectually subaverage, has been scarcest of all and to date has been completely inadequate. Hence, the present research investigated the presence and development of hemisphere specialization for the identification of verbal and non-verbal material on DL in children at two levels of subaverage intelligence without medical evidence of brain damage; children of average intelligence were also included for comparison purposes and because the age of onset and exact course of development of hemisphere specialization in the average child are still not definitively established.

A relative ear advantage in identifying material

dichotically presented (presentation of same general category of material simultaneously to each ear) is widely accepted as an indicator of specialized functioning of the hemisphere contralateral to that ear for the processing of that general category of information. Pre-recorded 1-pair, 2-pair and 3-pair sets of digits and common environmental sounds were employed as a means of eliciting hemisphere dominance for language and non-language input, respectively, in nine groups of children, 10 children at each of three age levels (5, 8, 11 yr.) and one of three IQ ranges (Slosson IQ > 90 selected from regular classes, 65-80 IQ selected from special classes for slow learners and IQ < 61 selected from schools for the mentally retarded).

(In the nine age - IQ range groups, an overall REA was reported for number of digits identified on 1-pair sets and on all sets combined, but no significant ear difference was noted for number of environmental sounds identified.

These results were discussed in light of the consistency of the REA on DL for identification of verbal materials and generally supportive findings in regard to left hemisphere language specialization, in contrast to the more generally less consistent reports of the LEA on DL with non-language material, as well as other experimental and clinical investigation of specialized right hemisphere functioning yielding more ambiguous results.

Further analysis suggested the importance of age and IQ range in contributing to the REA for number of digits

identified (e.g., 5 and 8 yr. olds with IQ > 90 and the 5 yr. olds with IQ 65-80 were the primary sources of the significant F-ratio for ears). Any changes in ear asymmetries with age were in the direction of a reduced REA. At the age of 5 yr., the 65-80 IQ range group exhibited a less extensive ear asymmetry (.125 significance level) than the IQ > 90 group (.05 significance level), but a more extensive asymmetry than the IQ < 61 group. The discrepancy between average and sub-average IQ groups was greatest at 8 yr. Though the REA for number of digits identified did not increase beyond the age of 5 yr., at 8 yr. number of subjects showing a REA, regardless of degree, had increased in each IQ range, relative to the number of subjects showing a REA at age 5 yr.

These results with number of digits identified as the dependent variable supported earlier DL research with verbal material suggesting the presence of left hemisphere speech specialization in children of average intelligence. Absence of significant ear asymmetries in all six groups of sub-average IQ suggested such children may possess minimal, or completely absent, hemisphere specialization for the type of left hemisphere speech specialization tapped by DL of digits. An alternate hypothesis is that some or all of the groups of subaverage IQ possess more than a negligible degree of left hemisphere specialization, but the employment of number of digits identified at each ear as the main dependent variable did not provide a test sufficiently sensitive to detect the presence of such specialization. This possibility

was supported by the fact that a majority of subjects in five of the six groups of subaverage IQ exhibited the REA (when simple presence, regardless of degree, was utilized to classify a subject as exhibiting a REA); also, in these five groups, 70% was the lowest proportion exhibiting a REA of those exhibiting ear advantage (an identical 70% figure occurred in all children without Down's Syndrome with IQ < 61; 75% of children with Down's Syndrome at age 8 and 11 yr. showed a LEA), the 70% figure being slightly higher than occurring in all 90 children or in all children with IQ above 90. The situation suggested from utilizing number of subjects showing REA, regardless of degree, as the dependent variable for ear asymmetries on digit identification is thus that 1) some degree of REA and any related left hemisphere specialization may be present in the 5 and 8 yr. olds with IQ 65-80 and the 8 and 11 yr. olds without Down Syndrome with IQ below 61; 2) some greater involvement of the right hemisphere for speech may be associated with the LEA observed in Down's Syndrome children; 3) the REA may be developing beyond the age of 5 yr, perhaps even beyond the age of 8 yr.

The different trends yielded by employment of each dependent variable to reflect ear asymmetries implicates the importance of scoring methods and also may be highlighting the necessity of introducing more sensitive, powerful research techniques and designs to detect the presence, extent and variable nature of cerebral dominance, depending upon the

type of tasks and processes being tapped.

Factors that may have obscured at an older age an increase, or at least a maintenance, of the REA observed at younger ages for digit identification, or the overall appearance of ear asymmetries for environmental sound identification, were also discussed.

Other implications of the present findings for further research were also outlined.

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APPENDIX A

Data from Child Sample of Pilot Study (N=24).

Age Range	IQ Range	N	Digits		Environ. Sounds	
			L. ear	R. ear	L. ear	R. ear
4-5 yr.	>90	6	88	105	43	35
	65-80	-	-	-	-	-
	<60	-	-	-	-	-
7-8 yr.	>90	4	104	113	42	38
	65-80	2	41	32	20	17
	<60	2*	28	31	3	3
10-11 yr.	>90	4	134	140	47	43
	65-80	4**	58	130	38	39
	<60	2*	18	31	16	20

* Data on the digit tape for this category unreliable since one of the subjects switched the earphones during dichotic testing and this fact was not discovered until the conclusion of testing.

** Headphones were not reversed for one-half of these subjects: data for this category is thus also unreliable.

Data from Adult Sample of Pilot Study
(N=7, age range - 22 to 30 yr.)

Digits Identified

L	R
31	37
20	33
30	22
17	34
16	36
21	33
16	34

Summary of 1-Way Analysis of Variance (repeated measures, Winer, 1971)

Source of Variation	SS	df	MS	F
Between people	121.00	6		
<u>Within people</u>	<u>755.00</u>	<u>7</u>		
ears	457.14	1	457.140	9.21*
res.	297.86	6	49.645	

* F.975 (1,6) = 5.99 (1-tailed)

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UNIVERSITY OF OTTAWA

OTTAWA, ONTARIO
K1N 6N5 CanadaFACULTÉ DE PSYCHOLOGIE
DEPARTEMENT DE PSYCHOLOGIE GÉNÉRALE ET
EXPÉRIMENTALEFACULTY OF PSYCHOLOGY
DEPARTMENT OF GENERAL-EXPERIMENTAL
PSYCHOLOGY

APPENDIX B

Sample Letter And Consent Form Sent to Parents

DATE

Dear

I am a graduate student in the Faculty of Psychology of the University of Ottawa, who as part of his Ph.D. thesis is conducting a study at _____ School. The study has been approved by the Research Committee of the Ottawa Board of Education (or the Research Committee of the Carleton Board of Education or the superintendent, Mr. Moore, in the case of the Ottawa R.C. Separate School Board), and your school principal, _____. I am asking your permission for your child to participate in this study.

The study involves relating general ability of children to their ability to identify numbers and other material presented simultaneously to both ears. If you grant your approval, I will administer a brief test (c. 10-15 min.) to your child on one day and on a different day, I will administer the ear recognition test (c. 38 min.).

If you are interested, I can provide you with a summary of the results of the study when it is completed. Because of the requirement of my study that children have normal hearing, I would appreciate that you inform me if your child has any hearing disorders (i.e., in either or in both ears).

I am enclosing permission forms for you to sign. The signature of either of the parents will suffice.

Thank you for your cooperation.

Yours sincerely,

Allan Anderson

Sample Letter and Consent Form Sent to Parents (cont'd).

I grant my permission for my child
_____ to participate
in the study being conducted at
_____ School by
Alan Anderson.

Mean Chronological Age, Mean Mental Age and Mean IQ
(Slosson test) for Each of the 9 Age - IQ range groups
(N=10 in each group).

Age	IQ Range	Mean CA	Mean MA	Mean IQ*
5 yr.	>90	5.34	5.53	103.6
	65-80	5.40	4.183	76.5
	<61	5.24	2.85	54.6
8 yr.	>90	8.125	8.458	104.2
	65-80	8.183	5.91	72.2
	<61	8.18	4.01	50.10
11 yr.	>90	11.208	12.233	109.0
	65-80	11.300	8.317	73.6
	<61	11.183	5.133	45.8

* Calculating mean IQ's from the mean MA's and CA's summarized here may yield slightly different mean IQ's than here reported, due to initial rounding errors in the assigning of MA, CA and IQ on the Slosson test.

Information Presented to Teachers to Guide in Selection of
Children for the Present Study.

1. The following written information was presented to kindergarten teachers to help in selecting children who would likely score in the 65 - 80 IQ Range on the SIT.

Select the 2 or 3 children in your classroom who seem to be the slowest of the entire group, children who seem to be below average in intelligence. I am seeking children who are generally slow (slow in all areas of your programme), rather than children who are having difficulties because of a specific problem, such as a child who is from a home whose first language is other than English (therefore, child just learning or only beginning to become skillful in the use of English and who you suspect is encountering school readiness problems primarily because of the language problem), a child who may have a specific learning disability (e.g., highly distractible, but child appears to learn readily when he does attend), or a child exhibiting behavioural/emotional difficulties (such a child may be experiencing readiness difficulties, but performance would probably be characterized by inconsistent performance, functioning quite adequately in some areas, very poorly in other areas).

Thus the type of child I am requesting that you identify is the child you may suspect will eventually be placed in a special class for slow learners (i.e., an opportunity class) or special resource room provided for such children.

The children you select should also employ the right hand for pencil work.

2. Teachers of regular class children were asked verbally to select "average achievers" who used their right hand for pencil work, teachers of special class children were asked to select "true slow learners" who employed their right hand for pencil work and teachers at special schools were simply asked whether the child being considered for inclusion in the study utilized the right hand for pencil work (as information on file clearly indicated the IQ's of children being considered were below 61, with the primary disability also clearly being mental retardation).

Instructions for Audiometric Examination and Sample Scoring Sheet.

You are going to hear a sound through one of these earphones. Tell me in which ear you hear a sound by pointing to that ear. If you do not hear any sound in either ear, don't point to either ear. Any questions?

	C.P.S.													
Db.	125	250	500	750	1000	1500	2000	3000	4000	6000	8000			
	L	R	L	R	L	R	L	R	L	R	L	R	L	R
110														
80														
60														
40														
20														
10														

Specific Recording Information in Construction of Digit
and Environmental Sounds DL Tape

SPECIFICATIONS:

1. The recording material: Ampex Professional G51 recording tape.
2. Equipment:
 - A) Two Ampex AG-440 two track tape deck.
 - B) One Sony 850 four track tape deck.
 - C) One MacLab 1224 mixing console.
 - D) One AKG 90E microphone.
 - E) One Dual 1219 turntable.
3. Recording speed: 7.5 ips.
4. All non-verbal sounds were from a prerecorded disc source (sound effects vol. 1 to 5).
5. All verbal sounds were recorded from the same voice.
6. All recording parameters of both verbal and non-verbal sounds were kept equal and consistent.

PROCEDURE:

1. The non-verbal sounds played on the turntable were equalized in the mixing console and recorded MONO on Tape 1. (see fig. 10)
2. The verbal sounds from the microphone were equalized in the mixing console and recorded MONO on Tape 1 following the first recording of non-verbal sounds.
3. A copy of Tape 1 was made on TAPERECORDER 2. (Special procedures were taken to insure that the copy was of the same quality as the original and contained no distinguishable characteristics from the original).
4. Using special sound recording techniques, selected sounds of Tape 1 and Tape 2 were recorded simultaneously on the left and right channels respectively of Tape 3.

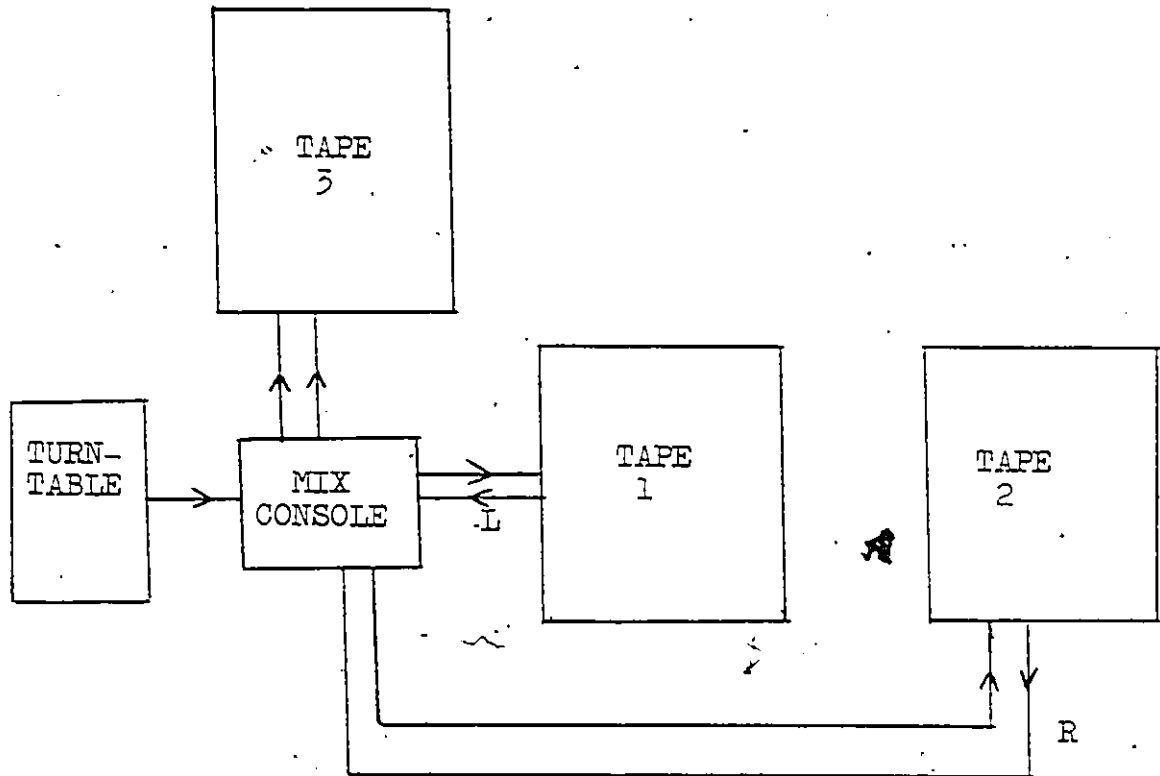


Figure 10. Arrangement of sound recording equipment employed in construction of verbal DE (digit pairs) and non-verbal (environmental sounds) DL tapes.

Procedure Employed in Analysis of Sounds Emanating from
the 2 Channels of the Sony Tape Recorder through the
Pioneer Headphone Set.

- a) take a function generator model #3300A from Hewlett Packard
- b) set function generator to 10 Hz
- c) set knob of Sony tape recorder control panel (see diagram, Appendix G) at the following:
 1. treble - mid position
 2. bass - mid position
 3. balance - mid position
 4. volume - min
 5. sp - lid
 6. mode -
 7. power amp - on
 8. noise suppress - on
 9. D/P selector - "aux"
 10. place headphone in "headphone monitor jack"
 11. L-monitor - R - "L" tape
 12. echo - off
 13. Sds - off
- d) place headphone (stereo) in monitor jack
- e) place tape reel in its proper place and make sure that your heads are cleaned and that there is good contact with tape, then tape one complete turn
- f) place counter at "000"
- g) press "L" red knob and you should hear a tone in the left side of your headphone, if not, check your knob for proper position.
- h) increase your amplitude on the function generator and "L" volume knob until you obtain 60% on your meter VV
- i) after verification start tape until you have sufficient tone to record sound measurement
- j) increase frequency to other frequency and repeat procedure
- k) after your recording is finished, it is preferable but not necessary to check all frequencies on an oscilloscope, but if no scope is available go on to your next procedure
- l) rewind tape until counter reads "0000"
- m) take an Impulse precision sound level meter (Bruel and Kjoer model #2204) and make sure batteries are good
- n) place an artificial sponge called "Windscreens VS 0082" on your meter and your headphone which will cover the entire headphone, making sure you have the LEFT channel (preferably in sound proof room)
- o) record results on graph paper
- p) repeat same procedure for "R" channel

Graphic Comparisons of the Sound Characteristics Emanating from the 2 Channels of the Sony Tape Recorder through the Pioneer Headphone Set, Data Derived from Employing Procedure as described on Previous Page. (Figure 11, analysis immediately prior to commencement of study; Figure 12, after the 43rd subject had been tested; Figure 13, at the conclusion of all testing).

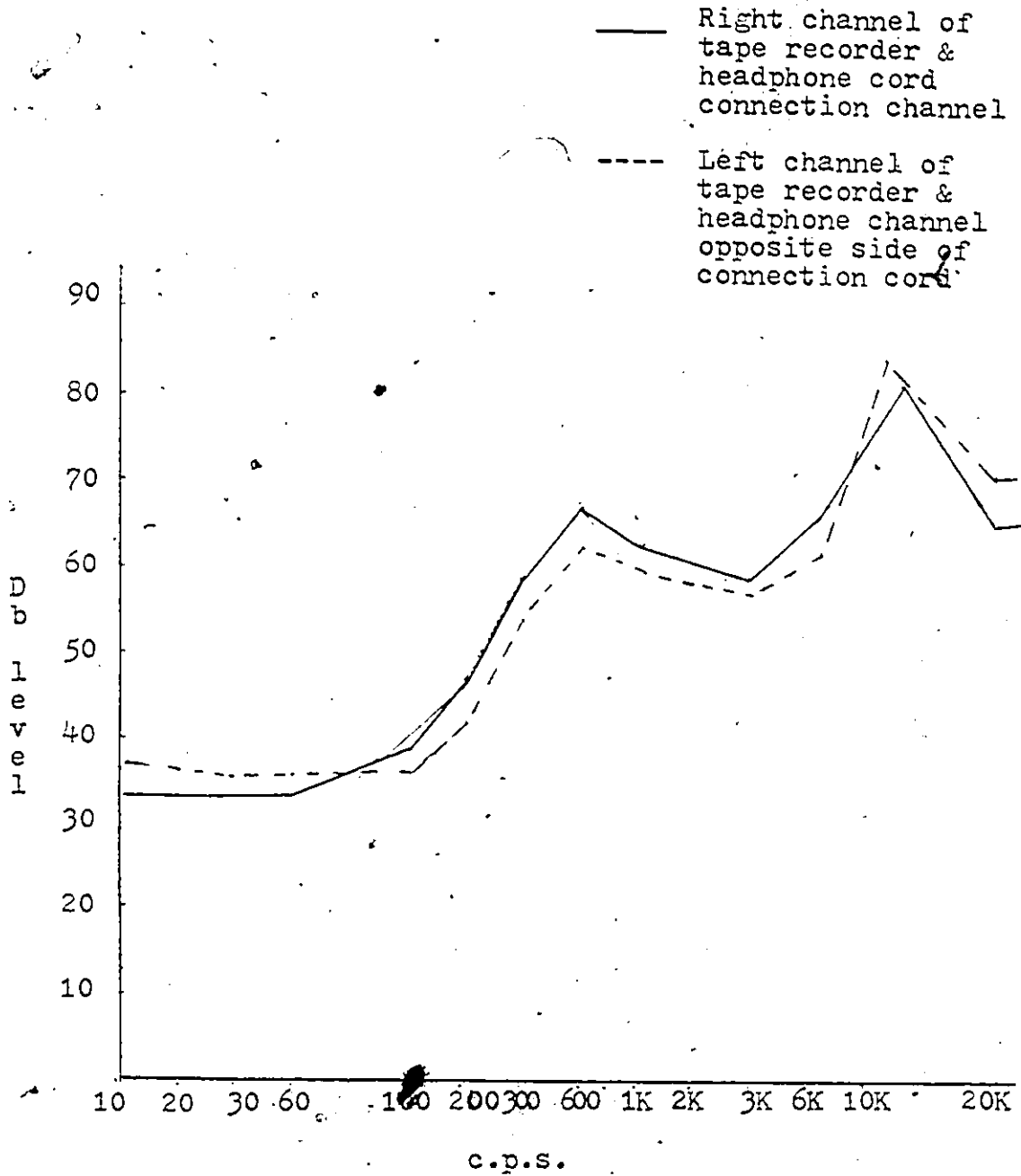


Figure 11

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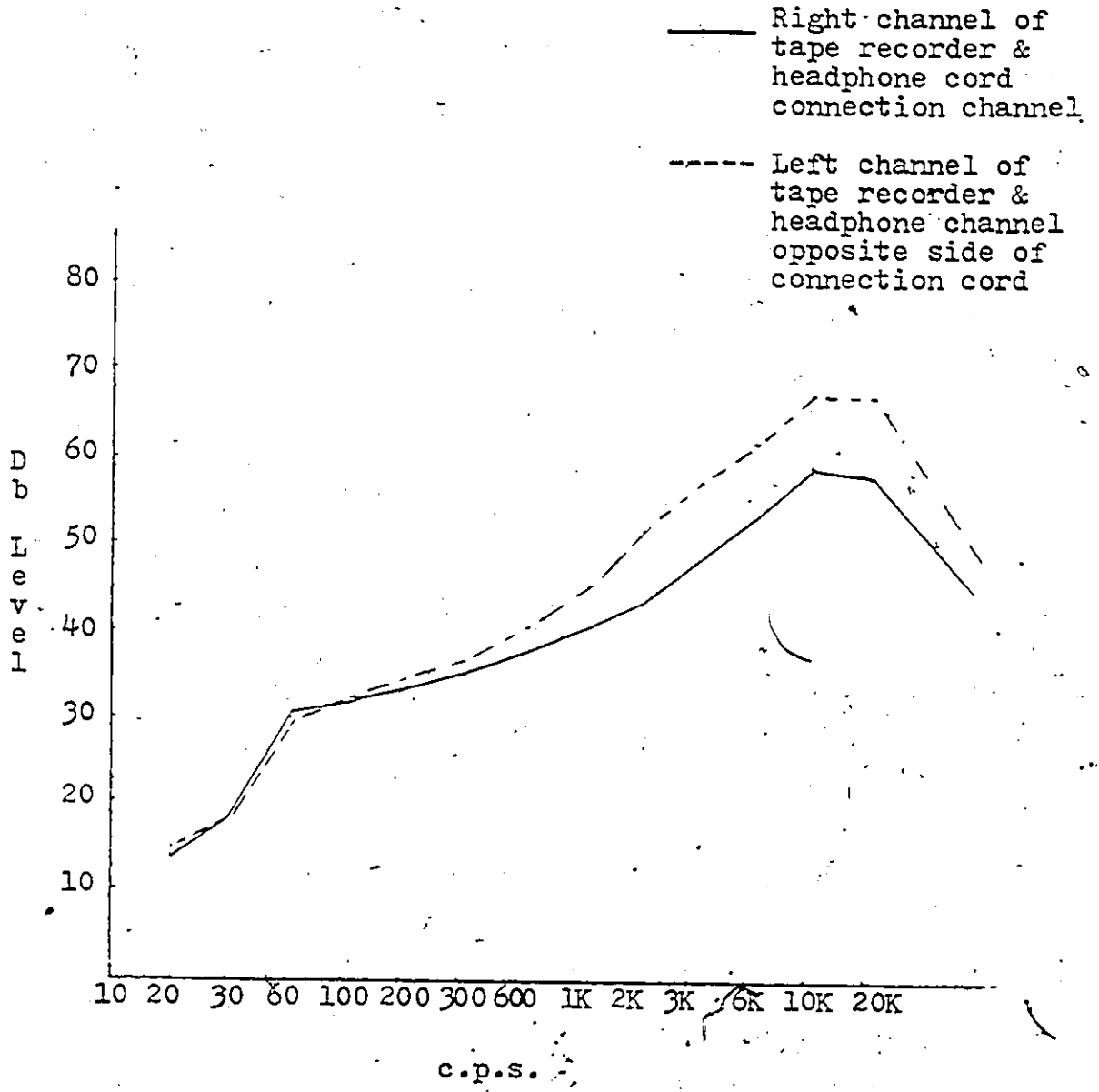


Figure 12

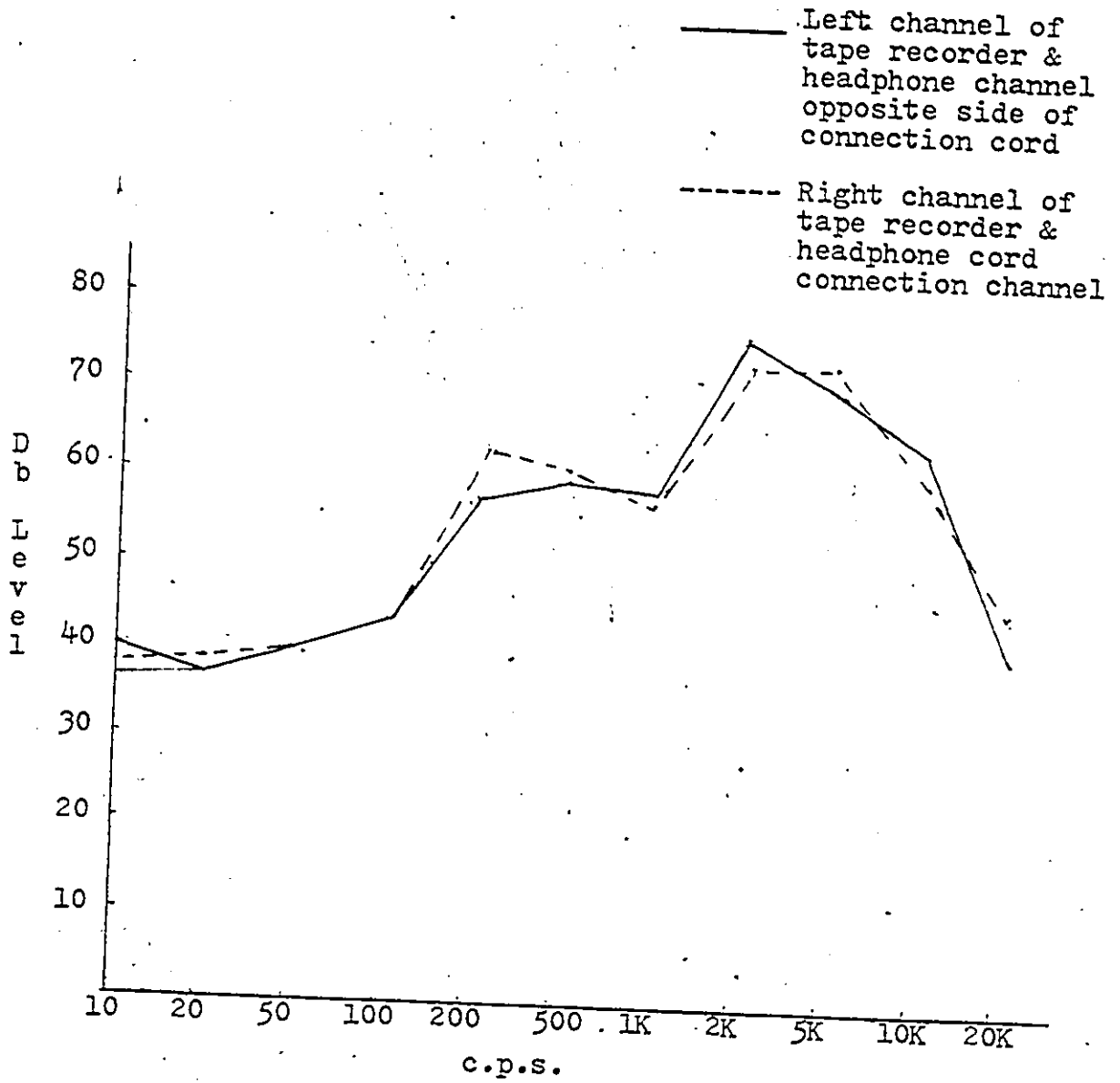


Figure 13

DIAGRAMS OF SONY TAPE RECORDER

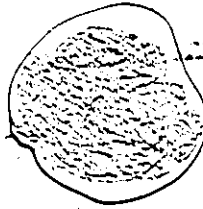
Canada Model

E Model

USA Model

AEP Model

UK Model



STEREO TAPE RECORDER

SPECIFICATIONS

Power Requirements:	85W (100 VA), 117 volts (USA, Canada Model) 85W, 100, 110, 117, 125, 220 & 240 volts (E, AEP, UK Model) (Voltage selector provided in the set) AC 60Hz (USA, Canada Model) AC 50 or 60Hz (E, AEP, UK Model) (Convertible with power frequency selector and capstan sleeve)	Outputs:	Line outputs: 0 dB (0.775V), Load impedance 100k Ω Speaker outputs (for external): Load impedance 8 Ω Speaker outputs (for lid): Load impedance 16 Ω Headphone outputs (for monitoring): Load impedance 8 Ω Headphone outputs (for listening): Load impedance 8 Ω
Tape Speeds:	19 cm/s, 9.5 cm/s and 4.8 cm/s 7 $\frac{1}{2}$ ips, 3 $\frac{3}{4}$ ips and 1 $\frac{7}{8}$ ips	Recording Time: (with 1,800 ft tape)	4-track stereo 1.5 hrs at 19cm/s, 7 $\frac{1}{2}$ ips 3 hrs at 9.5cm/s, 3 $\frac{3}{4}$ ips 6 hrs at 4.8cm/s, 1 $\frac{7}{8}$ ips
Reel Size:	7 inches or smaller		4-track mono 3 hrs at 19cm/s, 7 $\frac{1}{2}$ ips 6 hrs at 9.5cm/s, 3 $\frac{3}{4}$ ips 12 hrs at 4.8cm/s, 1 $\frac{7}{8}$ ips
Track System:	4-track stereophonic or monophonic	Semiconductors:	Transistor: 40 pcs. Diode: 7 pcs.
Frequency Response: (NAB)	30~22,000 Hz at 19cm/s, 7 $\frac{1}{2}$ ips 30~13,000 Hz at 9.5cm/s, 3 $\frac{3}{4}$ ips 30~10,000 Hz at 4.8cm/s, 1 $\frac{7}{8}$ ips	Heads:	Record: PP 30-2902A PP 102-2902 (Serial No. 124701 and later) Playback: RP30-2902 RP102-2902 (Serial No. 124701 and later) Erase: EF18-2902A
Wow and Flutter: (NAB)	Less than 0.09% at 19cm/s, 7 $\frac{1}{2}$ ips Less than 0.12% at 9.5cm/s, 3 $\frac{3}{4}$ ips Less than 0.16% at 4.8cm/s, 1 $\frac{7}{8}$ ips		Dimensions: 454(w) x 506 (h) x 294 (d) mm 17 $\frac{7}{8}$ (w) x 20 (h) x 11 $\frac{1}{4}$ (d) inches
Power Output:	15W (maximum) per channel 40W (dynamic power) with both channels	Weight:	21 kg, 46 lb 3 oz
Signal-to-Noise Ratio	Better than 50 dB		
Harmonic Distortion:	Less than 1.2% (at normal recording level) Less than 0.5% (in working as an amplifier)		
Recording Level Indication:	Two VU meters		
Tone Controls:	Two separate controls for bass and treble		
Inputs:	Low impedance microphone inputs: -72 dB (0.2 mV) High impedance auxiliary inputs: -22 dB (0.06V) High impedance tuner inputs: -22 dB (0.06V) Phonograph inputs: -52 dB (2 mV)		

SONY

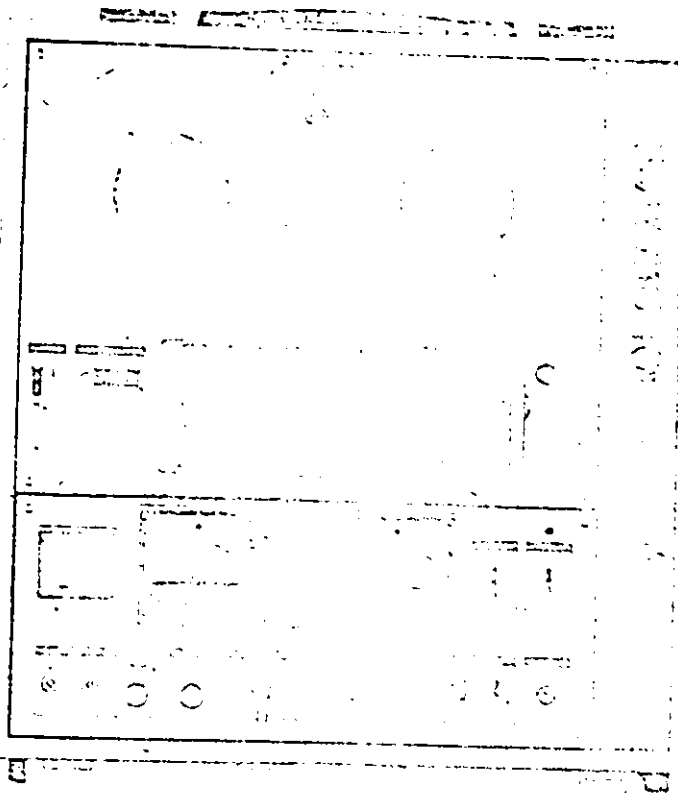
SERVICE MANUAL

1000

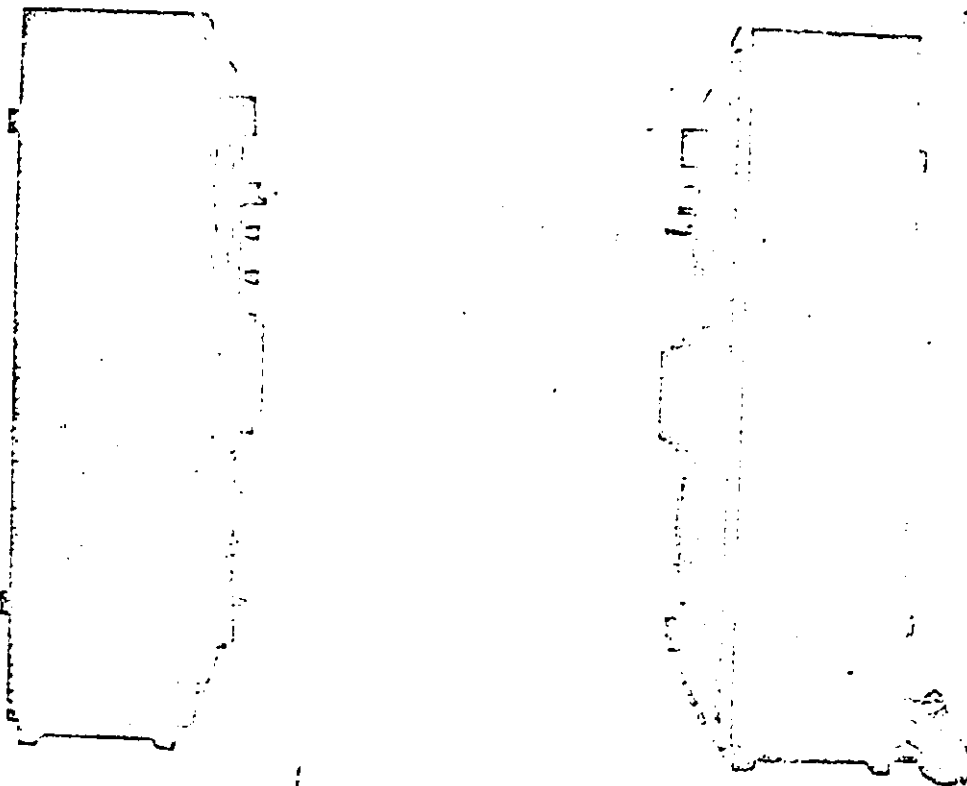
APPENDIX H
DIAGRAMS OF SONY TAPE RECORDER (CONT'D)

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1-2. CABINET TOP VIEW



1-3. CABINET SIDE VIEWS (AEP, UK)



Analysis of Variance Tables for the 1-Way Analysis of
Variance for Digit Identification Conducted for Each of
the 9 Age-IQ Range Groups

5 yr. Olds				
IQ > 90				
Source of Variation	Ss	df	MS	F
Between people	124.800	9		
Within people	416.000	10		
ears	115.200	1	115.200	3.447**
res.	300.800	9	33.422	
IQ: 65-80				
Source of Variation	Ss	df	MS	F
Between people	299.200	9		
Within people	139.000	10		
ears	33.800	1	33.800	2.8916*
res.	105.200	9	11.688	
IQ < 61				
Source of Variation	Ss	df	MS	F
Between people	316.000	9		
Within people	237.000	10		
ears	5.000	1	5.000	-
res.	232.00	9	25.777	
* p .125 F.875 (1,9) = 1.54 (1-tailed)				
** p .05 F.95 (1,9) = 3.36 (1-tailed)				
p .025 F.975 (1,9) = 5.12 (1-tailed)				

Analysis of Variance Tables for the 1-way Analysis of Variance for Digit Identification Conducted for Each of the 9 Age-IQ Range Groups (Cont'd)

8 yr. Olds

Source of Variation	IQ > 90 Ss	df	MS	F
Between people	139.050	9		
Within people	151.500	10		
ears	42.450	1	42.450	3.4906**
res.	109.450	9	12.161	

Source of Variation	IQ: 65-80 Ss	df	MS	F
Between people	249.250	9		
Within people	322.500	10		
ears	2.450	1	2.45	-
res.	320.050	9	35.561	

Source of Variation	IQ < 61 Ss	df	MS	F
Between people	476.450	9		
Within people	144.500	10		
ears	4.500	1	4.050	-
res.	140.450	9	15.606	

* p .125 F.875 (1,9) = 1.54 (1-tailed)

** p .05 F.95 (1,9) = 3.36 (1-tailed)

p .025 F.975 (1,9) = 5.12 (1-tailed)

Analysis of Variance Tables for the 1-Way Analysis of
 Variance for Digit Identification Conducted For Each of
 the 9 Age-IQ Range Groups (Cont'd)

11 Yr. Olds					
IQ > 90					
Source of Variation	Ss	df	MS	F	
Between people	77.800	9			
Within people	60.000	10			
ears	.800	1	.80	-	
res.	59.200	9	6.578		
IQ: 65-80					
Source of Variation	Ss	df	MS	F	
Between people	255.200	9			
Within people	83.000	10			
ears	5.000	1	5.000	-	
res.	78.000	9	8.667		
IQ < 61					
Source of Variation	Ss	df	MS	F	
Between people	331.000	9			
Within people	222.000	10			
ears	3.200	1	3.200	-	
res.	218.800	9	24.222		

Number of Children in Each Age-IQ Group Not Completely Employing Right Hand on the 6 Handedness Tests (3R, 4R, 5R = consistently employed right hand on 3, 4 and 5 of the handedness tests, respectively)

	IQ RANGE		
	>90	65-80	<61
5 yr.	2(1-3R, 1-4R)	2(1-4R, 1-5R)	2(1-4R, 1-5R)
8 yr.	1(1-3R)	2(1-4R, 1-5R)	4(2-3R, 2-4R)
11 yr.	2 (1-4R, 1-5)	2(2-3R)	2(1-5R, 1-5R)

In Groups Whose IQ < 61, Raw Data for Performance of Children With (N=12) and Without Down's Syndrome (N=18) on the DL Digit Tape and Summary Table for 3-Way Analysis of Variance on Raw Data

	Down's Syndrome		Other	
	L	R	L	R
5 yr.	9	10	12	19
	2	15	3	4
	1	1	4	4
	4	8	9	6
	<u>16</u>	<u>34</u>	19	4
		7	9	
		<u>54</u>	<u>46</u>	
8 yr.	3	9	7	5
	21	14	2	5
	12	2	0	2
	11	3	7	12
	<u>47</u>	<u>28</u>	8	13
		13	19	
		<u>57</u>	<u>56</u>	
11 yr.	11	20	8	9
	17	14	19	13
	21	11	15	17
	13	9	15	18
	<u>62</u>	<u>54</u>	11	22
		6	4	
		<u>74</u>	<u>83</u>	
		<u>125</u>	<u>116</u>	
		<u>165</u>	<u>185</u>	

Raw Data for Number of Environmental Sounds Identified At
Each Ear in the 3 Age Groups with IQ < 61.

Age	Down's Syndrome		Other	
	L	R	L	R
5 Yr.	3	2	3	2
	1	8	0	2
	1	1	0	1
	1	1	1	0
	<u>1</u>	<u>1</u>	2	2
	6	12	2	4
			<u>8</u>	<u>11</u>
8 Yr.	2	1	4	4
	7	7	4	4
	5	5	0	0
	0	2	5	10
	<u>0</u>	<u>2</u>	2	1
	14	15	6	6
			<u>21</u>	<u>25</u>
11 Yr.	8	4	4	4
	10	7	10	11
	7	4	8	8
	2	3	8	4
	<u>2</u>	<u>3</u>	7	9
	27	18	1	6
			<u>38</u>	<u>38</u>
	<u>47</u>	<u>45</u>	<u>67</u>	<u>78</u>

NOTES

1 Aphasia has been defined by Morgan (1965) and Geschwind (1970) as a disorder of language resulting from injury to the brain. The psychiatric dictionary (4th. ed., Hinselwood & Campbell, 1970) added the qualification that the language disorder cannot be the result of faulty innervation of the speech muscles, involvement of the organs of articulation or general intellectual deficiency. Distinctions between "acquired," "congenital" and "developmental" aphasia have been offered by Chase (1972).

It is beyond the scope of this review to provide a detailed account of the history of the study of aphasia and other brain-behaviour relationships. In addition to Benton (1964a), such accounts have been presented by Critchley (1966, 1972), Giannitrapani (1967), and Joynt (1964). A recent review of aphasia has been provided by Luria and Hutton (1977).

2 However, Geschwind (1970) credited Broca in 1861 as providing the first demonstration that aphasia is associated with specific lesions occurring predominantly in the left hemisphere. The difference of opinion may be because Dax did not publish until 1865, though he had reported his observation in written, but unpublished form in 1836 (Benton, 1964a) and had conceived the possibility as early as 1811 (Goodglass & Quadfasel, 1954).

3. Many authors (e.g., Sinclair, 1968, 1971) have utilized the tendency to employ a particular limb consistently in a free-choice situation as an indication of the "dominance" of that limb for that activity, and have used the term "preference" and "dominance" interchangeably. However, the limb that is preferred may not be the more skilful or efficient when that limb's performance is compared with the non-preferred limb (Dimond, 1972, cited 4 references). In such cases, limb skilfulness may be a more meaningful way of defining "dominance" (Pick & Pick, 1970). The present writer believes that the term "preference" (e.g., motor or limb preference, or perceptual preference, such as eye or ear) should be utilized only in a free-choice situation. The term "dominance" should be restricted to situations in which the particular motor or perceptual function is being compared in terms of lateralized skilfulness (e.g., skill of a hand or foot compared to the second limb, right vs. left visual field performance in tachistoscopic recognition, right vs. left ear on dichotic listening). The clinical neuropsychologist may note any discrepancies in performance on various behavioural tests between preference and dominance as presently defined in attempting to detect the presence of lateralized brain damage (Goldstein, 1974; Smith & Phillipus, 1969).

4. Goodglass and Quadfasel (1954) also cited earlier unpublished research that questioned the classical view (e.g., Wepman, J. Recovery from Aphasia. New York, 1951; Milner, B.

/continued ...

4 (cont'd)

Intellectual effects of temporal lobe damage in man. Doctoral dissertation, McGill University, 1952).

5. Sodium amytal is an anesthetic that can be injected at the neck into the right or left carotid artery, cerebral arteries that supply the right and left hemisphere, respectively. The degree of speech disruption caused by anesthetization of a particular hemisphere determines the extent that hemisphere is dominant for speech. Wada and Rasmussen (1960) stated that the technique was introduced by Wada, J. [A new method for the determination of the side of cerebral speech dominance; a preliminary report on the intracarotid injection of Sodium Amytal in man. Igaku to Seibutsugaku (Japanese), 1949, 14, 221-222].

6. In an updated review of the use of sodium amytal at the Montreal Neurological Institute to determine lateralization of cerebral speech functions, Rasmussen and Milner (1975) reported: in the 371 patients tested to that date, sodium amytal had been accurate in every case in its identification of side of speech specialization, as indicated by lack of speech deficiency after surgical intervention in the hemisphere indicated not to be the speech-dominant hemisphere.

7. Bogen, DeZure, Tenhouten and Marsh (1972) cited 12 additional references that provide EEG evidence of differential hemispheric participation in different activities.

8. The prevalence of this conceptualization of cerebral dominance seems to be reflected by the fact that a psychiatric dictionary has described cerebral dominance in exactly these terms: "The tendency for certain functions of the brain to be concentrated on a single side of the brain. In right-handed persons, such functions tend to be concentrated in the left cerebral hemisphere". (Hinsie & Campbell, 1970, p. 225).

9. Hemispherectomized patients are people who have undergone surgical removal of one of their cerebral hemispheres due to intractable brain damage (Dimond, 1972). More precisely, decortication occurs in that the whole of the hemisphere is not removed and parts of the thalamus and basal ganglia may remain (Dimond, 1972).

10. This model actually has some similarity to the first conceptualization described, the view that Zangwill (1962) and Shankweiler (1964) claimed has received no direct support. The "functional localization model" specifies that the hemisphere dominant for language, "controls" verbal functioning of the non-dominant hemisphere, though such control is not thought to extend to any other functions of the non-dominant hemisphere.

11 Later discussion will reveal that this model also has some affinity to the suggestion of Milner (1969) that language specialization will not be transferred to the right hemisphere in childhood after a left hemisphere lesion unless the lesion includes significant areas (e.g., the posterior language zones). The major difference seems to lie in the fact that the functional localization model emphasizes that the verbal capacities of the right hemisphere are quite extensive in the adult, while Milner (1969, 1974, 1975) seems to be arguing that in adulthood the right hemisphere no longer possesses very extensive verbal capacities or very extensive potential to acquire (or re-acquire) such capacities.

12. Reviews of research data on clinical samples concerning the specialization of the hemispheres have been provided by Blakemore, Iversen and Zangwill (1972) and Milner (1971, 1974), among others.

13. It is beyond the scope of the present review to outline the contribution of clinical research to our knowledge of brain-behaviour relationships (e.g., research that implicates or fails to implicate a specific critical area as the main site for the processing of a particular type of input or the main site for a specific modality or a main functional connecting link between brain areas, e.g., see Brown, 1975b and Geschwind, 1965 for discussion of the "isolation" syndrome), unless such research has relevance specifically to the topic of cerebral dominance. See Reitan (1976) and Reitan and Davison (1974) for reviews of knowledge of brain-behaviour relationships derived from lesion studies.

14 Throughout this paper the terms "major", "dominant" and left hemisphere will be used interchangeably to refer to the hemisphere that is dominant for speech and language; the term "minor", "non-dominant" and right hemisphere will refer to the hemisphere not dominant for speech and language. When the major hemisphere under discussion is not the left hemisphere, such a fact will be clearly stated in the main text.

15 Bogen (1969) and Matarazzo (1972) both listed 12 other studies that have noted greater deficits in verbal tests in persons with dominant hemisphere lesions, and greater deficits in non-verbal or performance tests in persons with nondominant hemisphere lesion. Attempts to link the laterality of a lesion to performance on other tests have met with clearly negative or mixed results (e.g., the Minnesota Multiphasic Personality Inventory, see Dikman & Reitan, 1974; for review of studies of the usefulness of the MMPI in detecting brain damage, see Reitan, 1976).

16 Excellent reviews are provided by Sperry (1968), Gazzaniga (1970) and Nebes (1974). Behavioural observation of split-brain patients has provided speculation concerning the role of the forebrain commissures (especially the largest of these commissures, the corpus callosum) in the intact brain. For detailed consideration of the role of the corpus callosum in brain functioning, refer to Dennis (1976), Dimond (1972), Ferriss and Dorsen (1974), Gazzaniga (1969, 1970), Geschwind (1965), Joynt (1974), Kinsbourne (1974b), Netley (in press) and Selnes (1974).

17 Carmon and Nachshon (1971) cited three earlier supportive studies with brain-damaged subjects and three earlier supportive studies with normal subjects. There also have been reports of disorders of temporal perception in aphasic children and adults (Krashen, 1973b; Papcun, Krashen, Terbeek, Remington & Harshman, 1974).

18 Milner (1971, 1974) described data gathered by her student, Corsi - findings of a greater deficit in the temporal ordering of events (recency) for verbal material (words) after left vs. right frontal lobectomy; however a greater deficit in the temporal ordering of non-verbal material (abstract paintings) was noted after right frontal lobectomy.

19 Left hemisphere lesion patients performed poorer than a right hemisphere lesion group when a fast tapping pace was required; however under slow and moderate tapping requirements, a reversed trend was observed.

20 As reported by Dimond (1972). Dimond (1972) specifically cited the following findings: Wyke, 1966 - left-sided lesions produced contralateral limb impairment on a task of maintaining extended arm position in the absence of vision, while right-sided lesions were associated only with contralateral impairment; Wyke, 1967 - alternating repetitive single arm movements were faster with the right arm in normal subjects, left-sided lesions reducing both contralateral and ipsilateral arm movement speed, right-sided lesions slowing only the contralateral arm (especially with parietal lesion); Wyke, 1967 - right arm significantly better in normal subjects on a pursuit rotor, with impaired performance in ipsilateral and contralateral limbs occurring with unilateral lesions (but removal of subjects with visual field defects yielded only contralateral limb performance impairment with right-sided lesions, bilateral impairment with left-sided lesions). Dimond (1972, p.143) concluded: "This reflects the greater proficiency of the right hand over the left for the performance of various tasks by right-handed subjects. It has also the implication that the left hemisphere plays a greater overall part in performance control than the right..."

21 Dee and Van Allen (1973) suggested that subjects with left hemisphere disease show relatively greater impairment in speed of decision-making in situations of increased complexity in comparison to patients with right hemisphere injury.

22 Not in agreement with this interpretation are the results of Milner (1962, 1971, 1974) and Chase (1967) who reported evidence for a right hemisphere dominance for some of these functions (Dobrokhotova & Braghina, 1974, also concluded from their literature review that the right hemisphere may be specialized for time perception); and the fact that ear dominance for verbal materials on dichotic listening occurs earlier in development (e.g., Kimura, 1967) than ear dominance for verbal material monaurally presented that must be reported in the order presented (e.g., Bakker, Smink & Reitsma, 1973 - see dichotic listening research described in literature review section entitled "The Development of Cerebral Dominance").

23 Kimura (1973) referred to reports of deaf mutes (no reference cited) who utilized hand movements to communicate and who displayed deficits in these hand movements after left-hemisphere damage; Kimura (1973) herself found left-sided damage to be associated with difficulty copying a series of hand movements, meaningful or not. "That the left hemisphere has a special control over some aspects of manual behaviours is further suggested by the fact that most people use their right hand for many skilled acts. Although the relation between speech lateralization and hand preference is not perfect, the high incidence of both left hemisphere control of speech and right hand preference is probably not coincidental... [concerning hand gestures hardly ever appearing except during speech] - the free movements during speech are made primarily by the hand opposite the hemisphere that controls speech (as determined by means of the dichotic verbal method). If speech is controlled by the left hemisphere, as it is in most people, the right hand makes more of the free movements, whereas if speech is controlled by the right hemisphere, the left hand makes more of the free movements. Curiously, this asymmetry is restricted to free movements; it does not appear in self-touching movements. These findings and the clinical findings I have mentioned suggest that there is indeed some overlap between the speaking system in a hemisphere and the system controlling certain kinds of manual activity. It may be that the left hemisphere is particularly well adapted not for the symbolic function in itself but for the execution of some categories of motor activity that happen to lend themselves readily to communication" (Kimura, 1973, pp. 77-78).

24 See the experimental studies on dichotic listening reviewed later in this section for further discussion of what basic elements may underlie the left hemisphere dominance for speech.

25 The disagreement may be related to the confounding of the ability to calculate with language and visual spatial abilities. Benson and Weir (1972) and Hécaen (1962) distinguished between aphasic acalculia (where number language is disturbed), visuospatial acalculia (where alignment and place-holding values are disturbed), and anarithmetia (a disturbance of the ability to perform computations). Dimond and Beaumont (1972) suggested that the left hemisphere-calculation link may have obtained wide acceptance because of the tendency to test calculation ability through verbal responding; a left hemisphere lesion may act over a wide area to dissociate the right hemisphere calculation mechanism from the speech output system in the left hemisphere.

Besides the possibility that the left hemisphere may be mistakenly thought to be dominant for calculation because of testing through expressive speech (a left hemisphere function), another possible source of misinterpretation is the assessment of calculation skill by requiring receptive speech (e.g., verbal instructions). In this regard, Gardner, Strub and Albert (1975) have described the case of a 41 year old who had suffered a left hemisphere stroke 11 years earlier who performed calculation presented in non-linguistic, but not linguistic (e.g., oral) form. Sperry (1968) also noted at least some right hemisphere calculation ability when tested through non-verbal response.

26 Jasper, H. A laboratory study of diagnostic indices of bilateral neuromuscular organization in stutterers and normal speakers. Psychological Monographs, 1932, 43, no. 1

27 Jasper, H. & Raney, E. The phi test of lateral dominance. American Journal of Psychology, 1937, 49, 450-457.

28 McFie, J. Cerebral dominance in cases of reading disability. Journal of Neurology, Neurosurgery and Psychiatry, 1952, 15, 195-199.

29 Ettliger, G. & Jackson, C. Organic factors in developmental dyslexia. Proceedings of the Royal Society of Medicine, 1955, 48, 998-1000.

30 Carter, D. A further demonstration of phi movement cerebral dominance. Journal of Psychology, 1953, 36, 229-309.

31 White (1969, 1972) has provided an extensive review of the relevant research literature and a critique of methodologies employed. Review covering the 1967-1975 period has been provided by Holcomb and Arnold (1976).

32 It is interesting to speculate about the interaction of the more general models of cerebral dominance (e.g., those presented earlier in the subsection entitled "Conceptualizations of Cerebral Dominance") and these more specific postulates. If one were a strict localizationist the visual field asymmetry results would force one to adopt the first hypothesis outlined above. For if the strict localizationist adopted the second hypothesis, he would expect a complete absence of analysis of material presented to the visual field that projects directly to the hemisphere non-dominant for that type of functioning. But the visual field asymmetry studies in fact reveal a high degree of analysis of such material, the difference between the two visual fields in fact being slight, though consistently found to be significant. The visual field asymmetry studies would provide no basis for the split brain model to opt for either hypothesis; because one would expect only a relatively better performance in the visual field directly projecting to the relatively more dominant hemisphere, whether material from the second visual field was shunted across to the relatively more dominant hemisphere for processing or whether the processing occurred in the relatively less dominant hemisphere.

33 Berlin, Lowe-Bell, Cullen, Thompson and Loovis (1973) have demonstrated that stimulus delay effects on DL are complex.

34 Several studies have attempted to pinpoint critical variables affecting the right ear effect for speech on dichotic listening (Berlin, Lowe-Bell, Cullen, Thompson & Loovis, 1973 - temporal onset variables; Berlin, Lowe-Bell, Cullen, Thompson & Stafford, 1972, Cullen, Thompson, Hughes, Berlin & Samson, 1974, Thompson, Stafford, Cullen, Hughes, Lowe-Bell & Berlin, 1972 - intensity; Cullen et. al., 1974 - signal-to-noise ratio and bandwidth; Godfrey, 1974 - white noise, vowel duration and acoustic vowel phonetic distinctness in vowel recognition; Blumstein, 1974 - distinctive linguistic features; Pisoni & McNabb, 1974 - feature sharing and lag effects), phonetic vs. non-phonetic features (Callen, Berlin & Tobey, 1976). Many of these studies are included in an edition of the journal, Brain and Language (Oct., 1974), devoted exclusively to DL research. In addition to the references cited in the main text, the articles in this special edition have referred to many earlier references that have investigated specific aspects of speech and language sounds that contribute to the REA on DL. A second issue of Brain and Language (Apr., 1975) has also devoted itself exclusively to DL.

35 Another variation is the use of pursuit auditory tracking of dichotically presented tones: a target tone varying randomly in frequency and amplitude is presented to one ear,

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35 (cont'd) while the subject produces a second variable tone to his second ear by continuous movement of a body part (e.g., tongue movement). The task is to control the motor system so that the tone controlled matches the frequency change of the target tone (Sussman & MacNeilage, 1975abc; Sussman, MacNeilage & Lumbley, 1975). Sussman and MacNeilage have argued that this task involves speech production in contrast to the speech perception tapped by conventional dichotic listening. A visual analogue of pursuit auditory tracking has also been investigated (MacNeilage, Sussman & Stolz, 1975).

36 Results that seem to run counter to this trend of a particular differential reaction to material unilaterally presented to each ear depending upon the verbal vs. non-verbal nature of the material have also appeared in the literature. For example, in right handers a faster right ear reaction was noted during the monaural presentation of a presumably non-verbal stimulus, a 1000 Hz tone (Provins & Jeeves, 1975; Simon, 1967), or else differences seemed to be unrelated to any verbal-non-verbal division of the material (Karp & Birch, 1969).

37 Two other EEG studies measuring auditory evoked potentials were cited by Haaland (1974), and one study measuring visual evoked potentials and two recording EEG activity in the left hemisphere for speech and language behaviour were cited by Lenneberg (1973), though Haaland (1974) and Lenneberg (1973) were not completely explicit concerning the specific results. Neither author discussed the studies individually.

38 Weitan & Etaugh (1974) cited two studies that found specifically that right-movers obtained higher scores on the Mathematics section of the Scholastic Aptitude Test than did left-movers (Bakan, 1971; Weitan, W. & Etaugh, C. Lateral eye-movement as related to verbal and perceptual-motor skills and values. Perceptual and Motor Skills, 1973, 36, 423-428).

39 But the dominance of the right hemisphere seems to extend to only certain classes of non-verbal spatial materials or at least is not consistently present. For example, Warrington and Rabin (1970) did not find significant deficit in the right parietal group on the cube analysis (from Stanford-Binet) or block design test (from Wechsler Adult Intelligence Scale). Experimental studies of right hemisphere functioning (e.g., Kimura, 1966, 1969, Kimura & Durnford, 1974, see relevant section of this review) have also failed to obtain evidence for hemisphere differences on many types of tasks. Determination of the extent of right hemisphere dominance for spatial processing may be complicated by the possible important involvement of the left hemisphere, especi-

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39(Cont'd) ally the left parietal lobe in spatial functioning (see Critchley, 1969, Dimond, 1972, Luria, 1973; Milner, 1971 also cites three studies).

40 But recall that Milner (1971, 1974) also described data that indicated a larger deficit in the temporal ordering of verbal material after left, in contrast to right frontal lobectomy or controls.

41 Such results were noted by Corkin (1965) to be identical to those found on visually guided mazes (Milner, 1965, 1967).

42 One earlier supportive study cited by Fontinot and Benton (1971): Carmon, A. & Benton, A. Tactile perception of direction and number in patients with unilateral cerebral disease. Neurology, 1969, 19, 525-532.

43 The possibility that any right hemisphere specialization extends only to certain types of complex tactual sensitivity is suggested from three non-supportive lesion studies cited by Blakemore, Iverson & Zanguill, 1972).

44 As cited in an earlier note, Bogen (1969) and Matarazzo (1972) have listed twelve other studies that have noted greater deficits on non-verbal tests in persons with non-dominant hemisphere lesions, and greater verbal deficits on verbal tests in persons with dominant hemisphere lesions.

45 See also the next section on experimental research with DL for additional evidence of the relatively greater importance of the right hemisphere in the perception of the environment, including the perception of the emotional environment (Carmon & Nachshon, 1973a; Curry, 1967, 1968; Haggard & Parkinson, 1971; King & Kimura, 1972).

46 Dimond (1972) and Gazzaniga (1967) have likewise stressed that the right hemisphere is not word blind or word deaf, but exhibits linguistic capacities if abilities are tested through means other than expressive speech. Moscovitch (1973) has labelled the conceptualization of hemispheric functioning derived from split-brain studies as the split-brain model. As discussed elsewhere in this paper in detail, one also has to consider the possibility that the presence of the hemisphere dominant for language is inhibiting the release of linguistic capacities of the hemisphere non-dominant for language so that this hemisphere in subjects with intact hemispheres (and even the hemisphere non-dominant for language in dominant hemisphere lesion patients whose lesion spares the critical part of the left hemisphere producing the inhibition) may not even exhibit the non-speech linguistic capacities of the split-brain patients which has been freed from the control of the dominant hemisphere (Moscovitch, 1973, 1976).

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46 (Cont'd) The inhibitory presence of the left hemisphere and an analogous inhibiting influence emanating from the right hemisphere depending on the function in question may also explain other paradoxical results noted by Kinsbourne (1974) " ... the function of the whole appears to be less than the sum of the parts. Focal lesions within a lobe result in deficits that are not observed after hemispherectomy. Left occipital disease results in colour agnosia (Kinsbourne & Warrington, 1964), but left hemispherectomy does not (Smith, 1966). Right occipital disease results in prosopagnosia (defective recognition of faces, Hecaen & Angelergues, 1962), but right hemispherectomy does not (Smith, 1969). Unilateral parietal disease may cause gross neglect of contralateral space (Gainotti, 1972), but bilateral parietal disease does not (at least in that gross form)." (p.260).

The hypothesis that the right hemisphere possesses receptive speech capacities that are inhibited or masked by the presence of the left hemisphere is supported by reports of the presence of a fair degree of verbal comprehension immediately after removal of the left hemisphere for tumour in adults (Smith, 1972, 1976; Moscovitch, 1973). Much less clearly supportive evidence came from a study of split-brain patients (Gazzaniga & Hillyard, 1971).

Authors have even observed expressive speech and writing possibly emanating from the right hemisphere of adult split-brain (Butler & Norsell, 1968; Levy, Nebes & Sperry, 1971; Nebes & Sperry, 1971) and aphasic (Kinsbourne, 1974) patients.

Detailed reviews and discussion of the linguistic limitations of the right hemisphere of split-brain patients (and speculation concerning right hemisphere function in the intact brain) have been provided by Gazzaniga (1967), Gazzaniga and Hillyard (1971), Levy, Nebes and Sperry (1971), Nebes (1974), Sperry (1968) and Springer and Gazzaniga (1975). Dimond (1972) has also argued on behalf of the involvement of the right hemisphere in language functioning.

47 Less consistent findings (Bryden, 1976) or complete failure to replicate results on dot localization (Bryden, 1973; Pohl, Butters and Goodglass, 1972) have also been reported.

48 When hemispheric functioning was assessed by comparing the hands in terms of tactile perception of direction in normal subjects, a left hand (and presumably a right hemisphere) superiority was noted (Benton et. al., 1973).

49 A summary of the work of Kimura and her co-workers in regard to right hemisphere functioning is provided by Kimura (1973) and Kimura and Durnford (1974).

50 Kimura and Durnford (1974) reported that Durnford (1971) failed to obtain VF differences for identification of block designs. Also refer to note 39.

51 But a RVF superiority was reported by Hannay, Rogers and Durant (1976) on a similar task.

52 White and Barr-Brown (1972) attempted to replicate the McKeever and Huling (1970) finding using symmetrical dotted figures and what they termed a more objective scoring procedure. They failed to observe any visual field differences in the reproduction of dotted, broken line or solid line figures. It was concluded that absolutely no support was provided for the McKeever & Huling (1970) contention that the right hemisphere is dominant in dot perception. However, it should be pointed out that the White and Barr-Brown (1972) study differed in one very significant aspect from that of McKeever and Huling, 1970 (besides the fact that White and Barr-Brown, 1972 attempted to control for any bias created by asymmetrical figures and subjective scoring criteria). Exposure duration of figures in the latter study was 100 msec., while McKeever and Huling (1970) employed exposure times of 15, 20, 25, and 30 msec. The grossly different exposure duration of 100 msec. was utilized in the replication despite the fact that it was White (1969) himself in a lengthy review of tachistoscopic recognition studies of visual field differences who emphasized the importance of a variable such as exposure duration in producing the disparate results reported in the literature concerning tachistoscopic recognition. White (1969) specifically referred to two general categories (exposure well above threshold, 50-150 msec. range, and exposure at threshold duration level), and postulated that cerebral dominance was only elicited when material was presented at threshold exposure levels.

53 Gilbert and Bakan (1973) demonstrated experimentally that the tendency of the right side of the human face to be more prominent in the sense that it appears to more closely resemble the whole face may be explained in the light of asymmetrical LVF bias rather than inherent facial qualities.

54 Krashen (1973a) has cited a recent study by Krashen and Spitz (no reference provided) which obtained a REA in males for identification of environmental sounds under certain conditions, and no ear differences for females.

55 Detailed investigation of ear dominance for pitch contained in dichotic chords has been conducted by Efron and Yund (1974, 1975, 1976), Efron, Tanis and Yund (1977), Efron, Dennis and Yund (1977), Efron, Bogen and Yund (1977) and Yund and Efron (1975, 1976, 1977), a phenomenon that may involve a mechanism separate from that responsible for the REA for music processing (Yund & Efron, 1977; Efron, Dennis & Yund, 1977).

56 Weinstein and Sersen (1961) cited supportive research (Seemes, J., Weinstein, S.; Ghent, L. & Teuber, H. Somatosensory Changes after Penetrating Brain Wounds in Man. Cambridge: Harvard U. Press, 1960), as did Witelson, 1974 (Weinstein, S. Intensive and extensive aspects of tactile sensitivity as a function of body part, sex and laterality. In D. Kenshalo [ed.], The Skin Senses. Springfield, Ill.: Chas. C. Thomas, 1968).

57 Benton (1965) also pointed out that widespread left hemisphere injury often produces aphasia serious enough to render the subject untestable, while no such limitation in regard to lesion extent is applicable to the right hemisphere case.

58 This and earlier qualifications are not intended to deny the importance of the study of persons with damaged brains in contributing to our knowledge of hemispheric specialization; the statement simply sounds a note of caution. Luria (1973) similarly noted after his cautionary preamble that the study of the injured brain, carefully executed, can be one of the most important sources of knowledge of cerebral organization of mental activity.

59 White (1972) review: 15 of 25 VF studies yielded no VF identification differences with unilateral presentation of non-language material vs. four of 12 studies failing to obtain a RVF superiority for identification of language material.

60 Schmit and Davis (1974) and Seamon (1974), among others, have continued to argue that hemisphere specialization is modality specific, that such specialization is based on verbal vs. visually coded information processing, despite the abundant research evidence cited in the present review that argues for a much broader distinction.

61 Jackson, J. Selected Writings of John Hughlings Jackson, J. Taylor (Ed.), New York: Basic Books, 1958.

62 Bogen (1969) presented a table with 14 different pairs of labels that have been suggested by various writers to summarize the left hemisphere - right hemisphere functional dichotomy.

63 In split-brain patients Levy-Agresti and Sperry (1968) demonstrated a left-hand-right hemisphere superiority for matching spatial forms (tactual-visual spatial matches). The low correlation that was observed between the pattern of accuracy on the different stimuli led Levy-Agresti and Sperry (1968, p.1151) to propose that the two hemispheres were following different perceptual approaches to solve the task.

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63 (Cont'd) "The data indicate that the mute, minor hemisphere is specialized for Gestalt perception, being primarily a synthesist in dealing with information input. The speaking, major hemisphere, in contrast, seems to operate in a more logical, analytic computer-like fashion. Its language is inadequate for the rapid complex synthesis achieved by the minor hemisphere: the findings suggest that a possible reason for cerebral lateralization in man is basic incompatibility of language functions on the one hand and synthetic perceptual functions on the other."

This hypothesis is described in greater detail (and additional split-brain data cited) by Levy (1972).

Thus observations from split-brain studies have given rise to the view that a second type of consciousness residing in the minor hemisphere may very well exist alongside the more dominant field of consciousness residing in the major hemisphere (Sperry, 1968).

In addition to the 14 pairs of words different authors have formulated to describe left-right hemispheric functional differences (see note 62), Bogen (1969) presented 19 other pairs of terms forwarded by various writers to describe two modes of thought without specific reference to hemisphere lateralization. Bogen (1969) speculated that the prevalence of such discussions of the two modes of thought is a direct reflection of left-right hemispheric functional specialization in terms of propositional-appositional operations. One dichotomy, the successive vs. simultaneous of Sechenov and Luria (organization into simultaneous and primarily spatial vs. temporally organized successive groups) caused Bogen (1969, p.160) to make a special comment. "Although the distinction (Sechenov-Luria) suggests no lateralization, it implies what may well be the most important distinction between the left and the right hemisphere modes, that is, the extent to which a linear concept of time participates in the ordering of thought."

Cohen (1972) has argued the case for parallel processing by the right hemisphere. Dimond and Beaumont (1974) referred to this view of Cohen (1972), the observation of Levy-Agresti and Sperry (1968) and their own data in stating that the left hemisphere analyses in sequence (processes serially), while the right hemisphere analyses in parallel (processes simultaneously). (The position of Papcun et. al., 1974, has been stated earlier. Papcun et. al. (1974) speculated specifically that the left hemisphere is specialized for processing the sequential subparts that comprise the stimuli and that language is lateralized to the left hemisphere because of the emphasis of language on segmental subparts).

Ornstein (1972, 1973) also linked the specialized nature of the left hemisphere, especially verbal and mathematical functioning (however, recall the ambiguity concerning hemisphere

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specialization for calculation noted earlier in this review), to analytical and logical thinking and the attendant primarily linear mode of operation. At the same time, the right hemisphere is primarily responsible for "holistic mentation" (i.e., orientation in space, artistic activities, body image, recognition of faces), dreaming and creativity in general (Bakan, 1971; Dimond & Beaumont, 1974; Ornstein, 1972, 1973) and possesses limited language ability. "It processes information more diffusely than does the left hemisphere and its responsibilities demand a ready integration of many inputs at once. If the left hemisphere can be termed predominantly analytic and sequential in its operation, than the right hemisphere is more holistic and relational, and more simultaneous in its mode of operation," (Ornstein, 1972, pp. 52-53).

It will be recalled that Semmes (1968) postulated a different physiological organization in the two hemispheres: the left seems to be more discretely specialized, the right more diffusely organized. Ornstein (1972) concluded from this paper (Semmes, 1968) that the left hemisphere is anatomically more specialized for the focal information processes that underlie logic, and the right hemisphere's diffuse anatomic organization would provide the basis for the processing of spatial orientation and other input requiring the simultaneous integration of many inputs. Paired dichotomies for the two modes of consciousness (many of the dichotomies excerpted from Bogen; 1969) were also presented and discussed by Ornstein (1972).

The work of Nebes (1971a, 1972, 1973), Levy, Trevarthen and Sperry (1972), and Zaidel and Sperry (1973) have been briefly referred to in the main text. These authors have also tended to interpret their findings as supportive of a concept of a right hemisphere basis for "holistic mentation". Refer to Nebes (1974) for a review and further discussion of this concept.

After discussing the work of Levy et. al. (1972) and Levy and Trevarthen (Hemispheric specialization tested by simultaneous rivalry for mental association, in preparation), Levy (1974) suggested that the right hemisphere may be specialized for imagistic encoding, the left hemisphere for linguistic encoding. (Dacko, 1973, obtained data that supported the hypothesis that imagery differences were dependent upon hemisphere specialization - high imagers coded pictures and concrete material tachistoscopically presented more effectively with the right hemisphere, while low imagers tended to code correctly more pictorial material and words with the left hemisphere. A glaring weakness of this study was the employment of a 700 msec. exposure time, which would permit several eye movements to occur during a single presentation, which in turn would permit exposure to both hemispheres, see White, 1969).

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Basso, Bisiach and Faglioni (1974) studied linear length discrimination and susceptibility to the Muller-Lyer illusion in persons with unilateral brain damage. Their findings were also discussed in terms of analytic vs. wholistic processing of pattern. Basso, Bisiach and Faglioni (1974) also questioned whether the nature of the tasks employed by Levy-Agresti and Sperry (1968) and Nebes (1971b) can be interpreted in terms of the analytic vs. wholistic issue.

Bryden and Allard (1976) concluded that the analytic (left hemisphere) vs. integrative (right hemisphere) distinction may be the most valid. Bryden and Allard (1976) p. 199) also stated: "Perhaps the most general distinction is that given by Broadbent (1974), who suggests that the left hemisphere is concerned with categorizing changes in the environment, while the right hemisphere is concerned with sustaining the continuing representation of the environment."

It has also been suggested that television may engage right hemisphere processes primarily (Emery and Emery, 1975; McLuhan, 1977).

64 Strich (1969, p.385) noted two complications in comparison of the effects of infantile and late human brain lesions: "subcortical involvement is very common and strictly unilateral lesions are rare."

65 Some writers would question the statement that full recovery from aphasia never occurs when the aphasia results from left hemisphere lesions in adults: full recovery has occasionally been reported (see Kinsbourne, 1974b) and a figure of 33% of adults showing left hemisphere dominance who show no aphasia or a complete recovery after a left hemisphere lesion has also been quoted (Levy, 1974). Hecaen (1976) has also reported excellent language recovery in three 14 yr. olds and full recovery in a 16 and 17 yr. old after left hemisphere lesion.

66 The complexity of the study of brain functioning and inference of brain functioning on the basis of clinical and experimental data is further illustrated by the fact that few statements can be expressed without qualification (as evidenced by the frequency of notes throughout this review). In this case it should be added that if language disruption does occur in young patients, recovery of functioning may not be complete (Annett, 1973; Griffiths & Davidson, 1966). Annett (1973) suggested that the laterality of the lesion occurring early in life may be relevant to the motor production of speech, but not to the development of higher language functioning and general intelligence.

Levy and Nagylaki (1972) argued that the capacity to develop right hemisphere language is genetically determined. Individuals possessing the homozygote LL do not have the capability of

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66 (Cont'd) recovering from aphasia after a left hemisphere lesion, while the heterozygote rL does possess the potential to develop right hemisphere language. An argument against this genetic explanation is the fact that close to 100% of children recover completely from aphasia (or show no aphasia) after a left hemisphere lesion (as noted in main text and as also noted by Levy, 1974). Levy (1974) utilized the Levy and Nagylaki (1972) explanation to account for the 33% she cited as recovering or failing to exhibit aphasia after left hemisphere lesion - they have the rL genetic pattern and 67% do not. However, Levy (1974) does not deal with the question raised by a statement she herself made that close to 100% of children either recover from language disturbance following left hemisphere lesion or show no aphasic disturbance. Levy and Nagylaki (1972, p.126) themselves dismissed the fact that "should the dominant hemisphere be damaged, the younger the child, even if purely dextral, the greater is his capacity to utilize either hemisphere for speech" by stating that "it seems to us that the capacity of children to develop language in either hemisphere is simply another example of the general physiological plasticity observed in all developing systems." How such recovery (plasticity) is dependent upon the presence of the heterozygote rL, in adulthood but not in childhood, is not dealt with by Levy and Nagylaki (1972) or Levy (1974): e.g., how is it possible that close to 100% of children exhibit plasticity, but only a much smaller percentage, i.e., 33%, possess the heterozygote rL enabling the right hemisphere to assume language functioning?

67 See Dimond (1972) and Smith (1972) for reviews of hemispherectomy studies in relation to information about cerebral dominance.

68 If even some minor speech specialization in the left hemisphere had begun before the age of first speech, one would expect the left hemisphere lesion group whose first speech had been acquired after a lesion had been sustained to exhibit some slight delays in speech onset compared to the comparable right hemisphere group. (An alternate explanation might be that the left hemisphere had begun to specialize, but that the right hemisphere and/or remaining intact portions of the left hemisphere were completely "plastic" in ability to acquire speech at this young an age). If no hemispheric speech specialization had occurred after the age of 1 yr. in the groups acquiring the right and left hemisphere damage after first speech had been acquired, one would expect an equal proportion of speech disturbance in the groups. The fact that left hemisphere speech specialization was not complete by the age of 5 yr. is suggested by the fact that 47% of the right hemisphere group exhibited speech disturbances (the oldest child in this group exhibiting speech disturbance being five years old). In an adult population one would expect

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68 (Cont'd). speech disturbances to occur in no more than 4 to 5% of any group sustaining right hemisphere lesions, since the percentage of adults whose right hemisphere is dominant for language has been estimated to be less than 5% (Basser, 1962; Geschwind, 1970, 1972; Geschwind & Levitsky, 1968; Lenneberg, 1967; Russell & Espir, 1961).

69 Teuber (1972) discussed the effects of cerebral lesions as a function of age specifically in reference to the frontal cortex. Luria (1973) also stated that lesions in childhood may have more serious lasting effects - in young children, lesion of a cortical sensory area results invariably in imperfect development of the higher structure imposed on it; in adults, lesions here are not as crucial since higher structures have been formed and now control the organization of such simpler (i.e., sensory) forms of activity.

70 Lenneberg (1967), in agreement with Dimond (1972), stated that the earlier in life the lesion occurs, the more favourable the prognosis for language.

71 Reference cited: Bryan, E. & Brown, M. A method for differential diagnosis of brain damage in adolescents. Journal of Nervous and Mental Disease, 1957, 125, 69-72. This view appears to differ from that of Luria (1973), as outlined in note 69.

72 Reference cited: Hebb, D. The effect of early and late brain injury upon test scores, and the nature of normal adult intelligence. Proceedings of the American Philosophical Society, 1942, 85, 275-292.

73 Matarazzo (1972) listed 12 studies in which adults sustaining damage to the left hemisphere tended to obtain a lower Wechsler Verbal IQ compared to a Wechsler Performance IQ, while right hemisphere damage tended to be associated with lower Wechsler Performance IQ relative to Wechsler Verbal IQ. Some of the studies cited by Bogen (1969) utilized the Wechsler scales and found similar results.

74 Moscovitch (1973) labelled such an explanation the neurological reorganization hypothesis. As earlier noted, Moscovitch (1973) suggested that, in regard to a left hemisphere lesion and reorganization of language processing in the right hemisphere, the damage would have to include the area that would ordinarily inhibit the right hemisphere from assuming responsibility for language processing. Milner (1969) similarly stated in terms of transfer of language functioning to the right hemisphere, left hemisphere damage would have to occur in a critical area (e.g., posterior language area lesion).

75 But even this more precise formulation of brain-behaviour relationships in terms of the effects of lateralized brain trauma and its severity and extent at different ages for such types of information processing does not exhaust critical variables. Matarazzo (1972) listed other important characteristics: site of the lesion within a hemisphere, factors that created the lesion, time interval between the occurrence of injury and testing, specific interventions attempted (e.g., medication, effects of neurosurgical procedures), lateral motor and cerebral functional dominance, and acuteness vs. chronicity of the lesion.

76 Gazzaniga (1974) later postulated that initially both hemispheres are involved in language and cognitive functioning of all kinds (e.g., up to age 8 or so), but that with lateralization then occurring (e.g., left hemisphere language specialization), an inhibitory mechanism arises from the left hemisphere and restricts the cognitive functioning of the right hemisphere. "Taken together this data would suggest that as dominance is established in the left hemisphere, inhibitory processes develop which suppress the upper cognitive level and decision-making capacity of the right hemisphere. When the brain is entirely split, these functions are realized with greater force on the right side than when a lesion of the left hemisphere alone is present. In the lesion case, of course, the vast majority of the interhemispheric connections are present and remain active and functional with their inhibitory influence" (Gazzaniga, 1974, p.377).

77 If such conceptualizations are a fair reflection of the actual state of affairs, a possible remedial technique in the rehabilitation of aphasic patients would be the development of the dormant verbal capacity of the minor hemisphere. Gazzaniga (1972) and Glass and Gazzaniga (undated) have tried teaching such patients via picture-symbol language that has been utilized for language learning in chimpanzees. The potential inherent in this approach is reflected in the fact that subjects have been able to comprehend and manipulate such artificial language symbols.

78 Zangwill, O. The current status of cerebral dominance. Research in Public Assistance and Research in Nervous and Mental Disease, 1964, 4, 103.

79 Bogen (1969) seemed to be suggesting that major hemisphere specialization may be a prerequisite for full specialization of minor hemisphere capacities and that optimal development may be characterized by establishment of major hemisphere specialization before minor hemisphere specialization, though he doesn't make an explicit statement to that effect. But Moscovitch (1973, 1976) did offer such a hypothesis. Goldman (1972) also argued that the left hemisphere matures earlier

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79 (Cont'd). than the right hemisphere. On the other hand, Carmon and Nachshon (1973a) suggested that the right hemisphere may mature earlier than the left hemisphere and may be more involved in the earliest stages of learning. The latter authors found a LEA in adults on DL for the perception of non-verbal emotional human voices. However young children were not studied. Fromkin, Krashen, Curtiss, Rigler and Rigler (1974) noted the hypothesis that the right hemisphere is the first to develop. They interpreted as supportive of the hypothesis their finding of a normal right hemisphere specialization for non-verbal information processing in contrast to an abnormal specialization for language (right hemisphere specialization inferred from DL performance) in Genie, a 16 yr. old girl who had experienced extreme environmental deprivation. Brown and Jaffe (1975) have also speculated that the right hemisphere may be dominant during the prelinguistic period, while the left hemisphere may assume its dominance pattern only as speech and linguistic skills develop; and although he states that maturational processes eventually favour language elaboration, Sperry (1974) has postulated that right hemisphere perceptual functions begin to develop before language.

Despite these speculations, very little experimental research has been conducted pertaining to the development of right hemisphere specialization. The present reviewer is not aware of any research employing reasonably well-validated measures of verbal vs. non-verbal hemisphere dominance that have suggested different ages for the appearance of verbal vs. non-verbal hemispheric specialization. See the next subsection in the main text dealing with research in normal child populations.

80 This explanation may also aid in explaining the apparent discrepancy between the presence of verbal-non-verbal differences in this study and the studies described earlier in which the usual verbal-non-verbal performance differential so often noted in adults who acquire lateralized brain injury has not been found in children (e.g., Annett, 1973; Pennington et.al., 1965; Reed & Reitan, 1969). The latter studies probably investigated children whose lateralized brain damage was extensive enough to cause the second hemisphere to assume the functions of the damaged hemisphere: the result is an equal reduction in the abilities originally being mediated by that hemisphere and the abilities which now are mediated in the same hemisphere. The children described by Rudel et. al. (1974) may not have received damage encroaching on the critical language zones (and non-language area in the case of right hemisphere injury). The result is a "surprisingly adult-like pattern," the pattern in this instance pertaining to verbal-non-verbal performance differences. A similar explanation seems applicable to the study that did obtain verbal-performance (Wechsler) differences in lateralized lesion groups
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80 (Cont'd). of children that followed the adult pattern. Fedio and Mirsky (1969) employed the presence of lateralized epileptiform focus to classify lateralized brain damage groups. Such a classification criterion in all probability produced groups of children whose brain damage was less extensive than those included by many of the other studies.

As pointed out earlier, Milner (1974) has suggested that the critical variable in these situations is not extent, but location, of brain insult: early left hemisphere lesions outside the two critical speech zones of the left hemisphere (Broca's area and primary speech area of the temporal lobe) do not alter development of left hemisphere lateralization, but lesions within these zones produce right hemisphere dominance for speech (or more rarely, a bilateral representation). Milner (1974 pp. 86-87) stated: "The intellectual consequences of these 2 types of early lesions are quite different. Damage outside the primary speech areas is associated with highly specific defects which reflect the specialization of the hemisphere and the site of the lesion. Thus regardless of whether the lesion occurs early or late in life, left anterior temporal damage is likely to cause a specific impairment of verbal memory but no general intellectual loss. With an early injury so located that speech has to develop on the other side, the situation is radically different, because there is always an intellectual price to pay for such plasticity. As both Sperry and Teuber have indicated, people with most of their cognitive abilities 'crowded' into one hemisphere are likely to be lower in general intelligence than the normal population (Hebb, 1942; Basser, 1962; Lansdell, 1969). Again both Sperry and Teuber emphasize that verbal skills tend to develop at the expense of non-verbal ones in this kind of intrahemispheric competition; but the fact remains that both are low." Milner (1975) and Smith (1972) argued likewise that language functioning appears to take precedence over non-language functioning in such a situation.

In discussing his functional localization model, Moscovitch (1976) stated that lateralization of language to the left hemisphere may result in potentially linguistic structures in the right hemisphere instead specializing for non-language functions. "It also predicts, as some investigators have already found (Levy, 1973), that if language develops on the right it may take over some structures that would normally mediate nonverbal function and, thereby, lower the person's performance on nonverbal tasks" (Moscovitch, 1976, p.67).

81 Results of additional studies cited by Hécaen, 1976 (Lansdell, 1962, 1969; McFie, 1961; Wood & Teuber, 1973) and his own data fit this explanation, as does the IQ data of Dennis and Kohn (1975) on five left hemidecorticates and four right hemidecorticates.

McFie (1969, p.384) emphasized the possibility of major reorganization of cerebral function following early cortical lesion and offered three points concerning focal lesion.

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cognitive deficits occurring at different ages. "1. After hemispherectomy, children with severe neonatal lesions show cognitive defects which are not related to the side of the lesion. 2. Cerebral lesions occurring after infancy but during childhood provoke intellectual disabilities which are related to both the side and the intra-hemispheric locus of the lesion but this relationship appears to be less marked than in adults. 3. Certain deficits in brain injured children appear not to be related to the locus of the lesion. Dr. McFie regarded this as a manifestation of the principle of mass action."

S2 Followup 15 and 21 years later of a 5½ yr. old boy who had undergone a left hemispherectomy for seizures (Smith & Sugar, 1975) revealed development of superior language and intellectual abilities in contrast to those reports that suggested that the plasticity of the nervous system may have been overrated (e.g., Rudel et.al., 1974), reports which describe restricted development of language functioning after left and non-language function after right hemispherectomy for perinatal lateralized brain lesion. The explanation offered in the main text and note 80 concerning the conflict of the Rudel et.al. (1974) data and hemispherectomy studies (e.g., Basser, 1962) applies only to a point: the subject described by Smith and Sugar (1975) obviously lost the use of the classical language zone of the left hemisphere (either through the initial lesion or the subsequent hemispherectomy); therefore language and non-language functions "crowded" into the right hemisphere. However the crowding was associated not only with verbal and language skill precedence, but also with the development of superior language and average non-language functioning. Smith and Sugar (1975) explained this anomalous finding (the usual pattern being below average verbal and non-verbal skill development, even if verbal skills are superior to non-verbal skills) by suggesting that the right hemisphere of their subject possessed the required "substrate" for such development, while subjects in other studies whose verbal and non-verbal functioning was below average following hemispherectomy did not possess the necessary integrity or intactness of the remaining hemisphere.

An alternate explanation to that forwarded by Smith and Sugar (1975) that would fit speculations of Rudel et. al. (1974), Milner (1974) and Sperry is that this individual may have developed to an even higher intellectual level without the brain lesion and subsequent transfer of all functions to the right hemisphere (i.e., without the lesion, the individual may have attained a very superior, perhaps genius intellectual level), so that the "crowding" in fact did reduce overall intellectual development.

83 J. Wada. Paper presented at the 9th. International Congress of Neurology, New York, 1969. It has also been reported that Wada even noted such asymmetries in fetuses as young as 20 weeks post-conception (Milner, 1974; Geschwind, 1974).

84 Wada, J., Clarke, R., and Hamm, A. (Cerebral hemispheric asymmetries in humans. Archives of Neurology, 1975, 32, 239-246) reportedly found only 12 of 100 fetal and only 10 of 100 adult brains showing reversed asymmetry.

85 Teszner, D., Tsavaras, G. and Hécaen, H. L'asymetrie droite-gauche du planum temporale: a propos de l'étude anatomique de 100 cerveaux. Revue Neurologique, 1972, 126, 444-449.

86 Dichero, G. Angiographic patterns of cerebral convexity veins and superficial dural sinuses. American Journal of Roentgenology, 1962, 87, 308-321; Dichero, G. Venous patterns of cerebral dominance: New England Journal of Medicine, 1972, 287, 933-934.

87 LeMay, M. & Culebras, A. Human brain: morphological differences in the hemispheres demonstrable by carotid arteriography. New England Journal of Medicine, 1972, 287, 168-170; Carmon, A., Harishanu, Y., Lowinger, E. & Lavy, S. Asymmetries in hemispheric blood volume and cerebral dominance. Behavioural Biology, 1972, 7, 853-859.

88 Hansen, S., Perry, T. & Wada, J. Amino acid analysis of speech areas in human brain: absence of left-right asymmetry: Brain Research, 1972, 45, 318-320.

89 McRae, Branch and Milner (1968) found the left occipital horn of the lateral ventricle in living subjects (noted by pneumoencephalography) to be longer than the right occipital horn. Geschwind (1974) has found that a longer occipital horn on one side in post-mortem material has predictive value concerning the size of the temporal plane; it was felt that if such results were replicated, diagnostic pneumoencephalography may predict the presence of a larger temporal plane on one side. However, Milner (1974) cited the data of McRae et. al. (1968) in speculating about anatomical asymmetries favouring the right hemisphere since it was felt results could mean the mass of brain tissue in the posterior of the hemisphere is greater on the right.

90 It is interesting to speculate about the relative contribution of constitutional and genetic factors vs. environmental influences upon the development of hemisphere specialization. The studies just cited obviously provide evidence for a constitutional basis to hemispheric asymmetries. Bogen (1969) stated that the degree to which both appositional and proposi-

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90 (Cont'd). tional ability develop is dependent upon environmental exposure. Bogen and Bogen (1969) opined that the origin of such asymmetries is genetic and that the two modes of thought would arise even if the individual were not exposed to language. Bogen et.al. (1972) again stressed the importance of heredity for these asymmetries. But the contribution of the environment was also stressed in developing both sides of the cortex (Bogen & Bogen 1969); reliance on one hemisphere may be due to early cultural experience (Bogen, et.al. 1972). The lack of correlation of ear performance between siblings noted by Bryden and Allard (1973) and Bryden (1975) on DL led the authors to suggest that those aspects of speech lateralization measured by DL may be environmentally determined. Also, belief in the importance of environmental factors in affecting hemispheric dominance is reflected in the speculation that Western thought is very left-hemisphere dominant (e.g., verbal, mathematical), while Eastern thought is believed to be primarily right hemisphere dominant (McLuhan, 1977; Ornstein, 1972).

An indication of the left hemisphere bias of our Western culture may well be the frequency with which Western psychological science has endeavoured to experimentally investigate left hemisphere, compared to right hemisphere, functioning. An overwhelming majority of studies of hemisphere functioning uncovered by the present reviewer (i.e., the number of studies reviewed in the literature review sections on left and right hemisphere functioning) have investigated processes mediated by the left, rather than right hemisphere. Anatomical studies also reflect this bias: 6 studies have been cited that investigated anatomical differences in the planum temporale of each hemisphere, in contrast to one study exploring anatomical asymmetries in non-speech regions. (McRae et. al., 1968). In fact this latter study that might have implications for non-language dominance has instead been linked to left hemisphere planum temporale size (Geschwind, 1974), and no consideration was made of this finding in terms of right hemisphere specialization.

The fact that experimental investigation of left hemisphere functioning has more consistently suggested a left hemisphere dominance for the processing of verbal material than a right hemisphere superiority for non-verbal material (see relevant sections of current review) may also be a reflection of the left hemisphere emphasis in our culture: the right hemisphere may in fact not be as specialized in its functioning than the left hemisphere, and this situation may in turn be a product of a relative de-emphasis of functions mediated predominantly by the right hemisphere. If the environment does play a major role in influencing the degree of hemispheric specialization, one might speculate that individuals engaged in occupations that emphasize skills mediated by the left hemisphere may differ in their degree of hemisphere specialization from individuals whose occupations emphasize right hemisphere functions (of course one could still argue that a constitutional factor promoting left /continued ...

90 (Cont'd). For right hemisphere specialization would predispose an individual to select an occupation that emphasizes the relevant left or right hemisphere skills). In this regard Dumas and Morgan (1975) did not find any differences in EEG activity in artists (assumed to be right hemisphere users) vs. engineers (assumed to be left hemisphere users).

The left hemisphere bias is also apparent in the early clinical research pertaining to cerebral dominance. A great deal of effort was directed toward validating the suggestions of Dax and Broca that language was primarily a left hemisphere function (see references to history of the study of brain-behaviour relationships cited in the introduction and notes). The successful demonstration that such was the case led to theories of left hemisphere dominance for all cognitive processing. Even when it was recognized that the right hemisphere may be specialized to handle certain types of non-verbal information, the fact that the left hemisphere has been established as the hemisphere dominant for language processing continues to cause writers to refer to this hemisphere as the "major" hemisphere, the hemisphere non-dominant for language (but possibly dominant for non-verbal functioning) as the "minor" hemisphere (e.g., Lezak, 1976; Moscovitch, 1973). The present reviewer in fact has adopted the conventional terminology by employing the terms "major" and "dominant" for the hemisphere dominant for the processing of language.

Perhaps the tendency to select the right ear in a free choice listening situation (e.g., when either ear can be selected to listen to sounds - Groden, 1969; Sinclair, 1968, 1971) is also related to greater dependence on left hemisphere functioning in our society. The right ear has a greater representation of auditory fibers in the left (language dominant) hemisphere compared to the ipsilateral hemisphere (Rosenzeig, 1951, see later main text section on DL as a measure of cerebral dominance). Thus the right ear may tend to be more readily selected because a greater number of its auditory fibers has more immediate access to the left hemisphere than does the left ear.

Lenneberg (1969) also discussed the environment-heredity interaction in language development.

91 As implied earlier (e.g., see notes 65 and 79), some authors even believe that the right hemisphere possesses considerable potential to assume language functioning beyond this age (e.g., Fromkin et al., 1974; Gazzaniga, 1974; Krashen, 1973a, in press; Moscovitch, 1973).

92 Brown and Jaffe (1975) and Kinsbourne (1974) suggested that receptive speech lateralization may develop at a slower pace than expressive speech lateralization, and may even continue to increase throughout life. Evidence interpreted as unfavourable to the hypothesis has been offered by Blumstein et al. (1975) and Cooper and Lauritsen (1974). Also, if this

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92 (Cont'd). hypothesis were true, one would expect expressive speech to appear before receptive speech in development, a prediction that is not supported by what actually occurs in development. Besides arguing that receptive language specialization may increase throughout life, Brown and Jaffe (1975, and Brown & Hecaen, 1976 as well) also suggested that general specialization within the left hemisphere may continue to develop throughout much of the life span.

93 Bryden and Allard (in press) reported another study finding a REA on DL for digits in 6 - 15 yr. olds (Ling, A. Dichotic listening in hearing impaired children. Journal of Speech and Hearing Research, 1971, 14, 793-803).

94 Dorman and Geffner (1974) also reported that a REA in all groups was found in a study of 5 yr. and 7 yr. black and white children (Sadick, T. Dept. of Behavioural Sciences, U. of Connecticut, doctoral dissertation in preparation). Berlin and Cullen (in press) cited findings of a REA in 7 - 15 yr. olds even if the right ear input is delayed (Mirabile, P. Dichotic lag effect and right ear advantage in children 7 to 15. Master's thesis, U. of Orleans, Dept. of Psychology, New Orleans, La., 1975).

95 According to Brunt and Goetzinger (1968), this finding was noted in unpublished studies by Brunt and Myrick on the Katz dichotic words (SSW) test.

96. Bryden and Allard (in press) cited a study (Bever, T. The nature of cerebral dominance in speech behavior of the child and adult. In R. Huxley & E. Ingram, Eds., Language Acquisition: Models and Methods. London: Academic Press, 1971) that found a REA in a sample of 195 2½ - 5½ yr. old children. Witelson (1975) cited findings of ear asymmetries even in infancy on an adaptation of DL (Entus, A. Hemisphere asymmetries for processing of dichotically presented speech and non-speech sounds by infants. Abstract presented at the Society for Research in Child Development, Denver, Apr., 1975). Levy (in press) described a study employing dishabituation of nonnutritive sucking as a behavioural measure of discrimination which found that very young babies discriminated consonant-vowel syllables better with their right ears and musical melodies better with their left ears, also on an adaptation of DL (Entus, A. & Corballis, M. Hemispheric asymmetry in processing of speech and nonspeech sounds by infants, submitted for publication).

97 Sobotka, K. Neuropsychological and neurophysiological correlates of reading disability. Unpublished master's thesis (Psychology), University of New Orleans, New Orleans, La., 1974.

98 For a general discussion of the relationship between handedness and hemisphere functioning, refer to Beaumont (1974) and Levy (1974). Genetic models of handedness have been formulated by Levy (1969), Levy & Nagylaki (1972) and Annett (1964). A discussion of pathological handedness is offered by Satz (1972, 1973).

99 Close inspection of the age curves presented by Bryden (1970) suggested that the adult pattern was not achieved in either sex group until grade 6. At grade 2, figure 1 of the Bryden (1970) article suggested that c. 63% of right-handed girls identified more digits presented to the right ear compared to c. 57% of the boys; at grade 4, the number of girls exhibiting a REA declined to 53% while the number of grade 4 boys exhibiting a REA increased (c. 63%) and surpassed the percentage exhibited in grade 4 girls. By grade 6 both sex groups exhibited REA at a high percentage level (c. 73% for both groups). Statistical analysis suggested an overall REA for both the right handed boys and girls, but Bryden (1970) did not report further statistical analysis of the percentage of subjects exhibiting ear superiorities at each age level, either for all right-handed subjects or for boys and girls separately (failure to do so makes it necessary for the reader to resort to visual inspection of his figure 1 to detect age trends in differential performance of the 2 ears in boys and girls). Although Bryden (1970) left the point completely unclear (e.g., in his discussion, Bryden, 1970, referred to figure 1, which dealt with data uncorrected for ear order of report and made no specific reference to the data corrected for order of report he presented in an earlier section), one can only surmise that Bryden (1970) arrived at the statement quoted in the main text on the basis of his data corrected for ear order of report (calculation of mean score for each ear for those trials where all numbers were reported from a particular ear before any numbers were reported from the second ear; an average of these means was determined for each ear to supply ear score independent of ear order of report). Using this method, Bryden (1970) stated that 73% of right-handed girls in grades 4 and 6 were right ear dominant, while 65% of the right-handed boys in grades 4 and 6 exhibited such a pattern. Again Bryden (1970) failed to report more specific data (e.g., specific percentages at grade 4 vs. grade 6 for boys and girls) nor any additional statistical analysis to determine the extent of the difference at the two age levels. The omission becomes even more serious as one realizes that Bryden (1970) attempted to reconcile his findings with the data of Kimura (1963) in terms of the different scoring methods employed (i.e., Kimura, 1963, utilized mean number of digits identified in each ear for all subjects of a particular age and sex group; Bryden, 1970 used number of subjects exhibiting a REA or LEA).

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99 (Cont'd) A REA was noted by Kimura (1963) at age 4, with little variation in the older groups (5-9 yr.). Any change that did occur was in the direction of a smaller REA for older grade levels. Bryden (1970) noted that overall performance, and particularly performance on the second ear reported, increased with age (see Inglis & Sykes, 1967). Bryden (1970) implied that Kimura (1963) failed to demonstrate an increasing ear dominance with age because of the tendency of the second ear to improve with age. Presumably, Bryden (1970) believed that his method of classifying his data (percentage of subjects showing a particular ear dominance) remains relatively unaffected by such tendencies and is a better barometer of the development of ear asymmetries in children of different age levels. Kimura (1963) provided an analogous explanation for the decrease she observed in ear differences in the older child: she suggested this pattern was a result of a ceiling effect, the higher total score achieved providing less opportunity for differences between ears to continue to manifest themselves. This factor presumably would explain the fact that in older children the second ear tended to reduce the difference in performance between itself and the first ear reported. Geffner and Hochberg (1971) have also noted that the degree of REA on a dichotic digit task was greatest in 4 year olds and seemed to decrease with age until it levelled off at age 7 (but see discussion in Chapter IV of this data and the findings of Knox and Kimura, 1970)

Possible age changes in the performance of the second ear reported (the left ear in this case) and its possible effect on overall asymmetries, as well as the two methods of measuring ear differences, have been closely examined because of the effects such age changes and scoring procedures may have in reconciling the discrepancies between the data of Bryden (1970) and those of Kimura (1963, 1967) and Knox and Kimura (1970).

In regard to the age trend, Brunt and Goetzinger (1968) also cited unpublished studies (Brunt, 1962; Myrick, 1965) which revealed a REA for dichotic recognition of words in 6 - 10 year old children, but which also showed that by age 12 and older, only a very slight laterality effect was observed.

In regard to the measurement procedure employed, it is of interest to note that one could draw different conclusions from the DL data of Berlin et. al. (1973) and Witelson and Rabinovitch (1972) in children and from the data of Bryden and Allard (1976) in adults on tachistoscopic recognition of letters presented in varying typeface, depending upon whether one chose to emphasize group mean number of items correctly identified per ear or total number of subjects exhibiting a REA. On a single syllable identification task, Berlin et. al. (1973) focused on the mean number of items identified and concluded that the REA was present and essentially permanently established by 5 years of age. However, brief reference was also made to the number of subjects

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99 (Cont'd). exhibiting a REA. If one chose to emphasize the pattern suggested by this latter data, one might conclude that the REA continued to become more pronounced until perhaps 9 years of age (since 16 of 30 5 yr. olds, 21 of 30 7 yr. olds and 23 of 30 9 yr. olds exhibited a right ear score of at least two items greater than that exhibited by the left ear). Though only a non-significant REA appeared in the 9 - 11 yr. olds studied by Witelson and Rabinovitch (1972) on 2- and 3-pair digit sets presented at three different presentation rates, significantly more subjects identified more digits presented at the right vs. left ear (17 vs. 7). Bryden and Allard (1976) also noted significantly more subjects exhibiting a RVF vs. LVF advantage (17 vs. 6), despite analysis of variance yielding no significant visual field effects for number of items identified.

Other ways of treating data obtained on DL have been suggested by Harshman and Krashen (1972), Kuhn (1973), Marshall, Caplan and Holmes (1975), Richardson (1976) and Studdert-Kennedy and Shankweiler (1970).

100 Darby, R. & Satz, P. Developmental dyslexia, a possible lag mechanism. Unpublished Master's thesis, University of Florida, 1973.

101 Gardiner, M. Paper presented at the Lateralization Symposium for Neurosciences, New Jersey Chapter, Rutgers Medical School, 1975 (to be published in S. Harnad, R. Doby, L. Golstein, J. Jaynes & G. Krauthaner (Eds.), Lateralization in the Nervous System. New York: Academic Press, 1977); Molfese, D., Freeman, R. & Palermo, D. The ontogeny of brain lateralization for speech and non-speech stimuli. Brain & Language, 1975, 2, 356-368.

102 Molfese, D. Cerebral asymmetry in infants, children and adults: auditory evoked responses to speech and noise stimuli. An abstract of a thesis in psychology, Pennsylvania State University, 1972.

103 Some writers argue that the hypothesis that, in comparison to females, males possess a left hemisphere more extensively specialized for speech and language, should continue to be entertained (Bryden 1976b, 1978; Lake & Bryden, 1976; McGlone, in press). The data cited by Bryden to support this argument is drawn for the most part from research not employing DL (research in adults has found no sex effect in adults on DL, e.g., McGlone & Davidson, 1973). Examples of evidence of possibly greater left hemisphere language specialization in adult males include LEM (Bakan, 1971; Weitan & Etaugh 1974a), VF (Hannay & Malone 1976ab; Marcel, Katz & Smith, 1974), and distribution of handedness (Thompson & Marsh, 1976) studies, but other research has been contradictory and ambiguous (e.g.,

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Hannay, 1976). Most cerebral dominance research in normal populations has either utilized only male or female samples, or else has combined such data for further analysis because of preliminary analysis yielding similar results in males and females (e.g., Bryden, 1965).

104. One study that Knox and Kimura (1970) cited in their discussion (Ghent, 1961) did report a sex difference (greater left thumb pressure sensitivity at age 6 in females, but not until age 11 in males), as did Kimura, 1963 (9 yr. old females, but not males, show superior left thumb sensitivity) and Kimura (1963) raised the possibility that this sensitivity may indicate the presence of right hemisphere dominance by this age. However, the data of Ghent (1961) and the supportive evidence of Kimura (1963) suggested that this type of function attains specialization in the right hemisphere earlier for girls, while Knox & Kimura (1970) suggested that right hemisphere specialization for environmental sounds may appear at an earlier age for boys.

This contradiction is resolvable by referring to the first experiment of Knox and Kimura (1970) where girls actually exhibited a LEA for non-verbal (environmental) sound identification at an earlier age than boys. Unfortunately the resolution of this contradiction creates another conflict: the interpretation that girls exhibit right hemisphere specialization earlier than boys (at least for non-verbal auditory information) does not accord with data about to be cited in the main text and the next note that suggested that males exhibit a left hand tactual identification superiority at an earlier age than females, or that the adult male performs more efficiently on visuo-spatial tasks (since visuo-spatial analysis seems to be predominantly a right hemisphere mediated function in the adult), unless one wishes to argue that in later childhood and adulthood males catch up to and surpass females in degree of right hemisphere specialization for visuo-spatial material or that visual-spatial and non-verbal auditory processes engage separate aspects of hemisphere specialization.

A distinction should be made between age of onset of lateralization and degree of lateralization (see Lake & Bryden, 1976). Thus lateralization may or may not begin to occur at different ages in each sex, but degree of lateralization in adulthood may be unrelated to the time of onset in childhood (e.g., degree of lateralization for either sex may not differ once lateralization is fully established in each sex).

105 Cerebral dominance research in normal (reaction time Bowers & Heilman, 1976; Bryden, 1976a; Harshman & Remington, submitted; Kimura, 1969; McGlone & Davidson, 1973) and brain-damaged individuals (Harshman & Remington, submitted; Lansdell, 1968; McGlone, in press; McGlone & Kertesz, 1973) has lead to the suggestion right hemisphere specialization for visual-spatial information may be greater in males than females. Such

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results support the hypothesis that both hemispheres of females are less lateralized than males (Harshman and Remington, submitted), an hypothesis Levy (1972) adopted to explain the fact that females perform significantly poorer than males on a variety of spatial tests (Levy, 1972 cited Porteus, 1967 and Smith, 1967). It should be noted though that no sex differences have occurred in EEG hemisphere activity on verbal vs. non-verbal tasks (Morgan et. al., 1974) and that results with evoked potentials have been contradictory (Dustman et.al., 1975).

However, the purported male superiority on visual-spatial tasks has also been attributed to a completely opposite neuropsychological organization. Marshall (1973) outlined the Buffery-Gray hypothesis (Buffery, A. & Gray, J. Sex differences in the development of spatial and linguistic skills. In C. Ounsted & D. Taylor (Eds.), Gender Differences: their Ontogeny and Significance. Edinburgh: Churchill Livingstone, 1972) as follows: in contrast to females, males possess a relatively bilateral representation for visuo-spatial abilities; the male's superiority on visuo-spatial tasks is explained in terms of the bilateral representation providing the most efficient neurological organization for high level visuo-spatial skills.

Additional evidence for sex differences in skills that may be related to sex differences in cerebral dominance has been cited by Buffery, 1974 (e.g., Buffery & Gray, 1972; Hutt, 1972; Taylor, 1969).

106 Chalfant and Scheffelin (1969) have prepared an extensive review of research relevant to an understanding of language behaviour and language disorders in children.

107 Mach, E. The Analysis of Sensations (Trans. by C. Williams, revised by S. Waterlow) London: Open Court, 1914.

108 Money (1962) described developmental dyslexia as a term applicable to a child who is unable to learn to read at a normal rate despite normal intelligence, intact senses, proper instruction and normal motivation: a history of brain injury is seldom present. Post-traumatic dyslexia is applicable in situations where disruption of an acquired ability to read occurs after brain damage (Money, 1962; Benton, 1962).

Although the exact etiology of developmental dyslexia is not known, its possible constitutional basis is reflected in the 1968 World Federation of Neurology definition: "a disorder manifested by difficulty in learning to read despite conventional instruction, adequate intelligence and socio-cultural opportunity. It is dependent upon fundamental cognitive disabilities which are frequently of constitutional origin" (Critchley, 1972, p.11).

9

109 The present review of the literature does provide some support for the theory that the hemisphere dominant for language "controls" the minor hemisphere in so far as it may inhibit the language functioning of the minor hemisphere (see Bogen, 1969; Gazzaniga, 1967; Geschwind, 1968; Moscovitch, 1973). However the view that the left hemisphere controls or directs all functioning of the right hemisphere clearly finds no support in the present review.

110 No reference for these two findings was provided by Critchley (1966, 1972), but the two references presumably are the ones in notes 28 and 29 of the earlier discussion of the phi test.

111 Goody, W. & Reinhold, M. Congenital dyslexia and asymmetry of cerebral function. Brain, 1961, 84, 231-242.

112 As stated by Luessenhop, Boggs, La Borwit & Walle, 1973 (Orton, S. A physiological theory of reading disability and stuttering in children. New England Journal of Medicine, 1928, 199, 1050 - 1052).

113 Taylor, L. Perception of digits presented to right and left ears in children with reading difficulties. Paper read at meeting of Canadian Psychological Association, Hamilton, Ont., 1962.

114 Witelson, S. Perception of auditory stimuli in children with learning problems. Unpublished M.Sc. (applied) project, McGill U., 1962.

115 Dermody, P. Auditory processing factors in a dichotic CV task. Journal of the Acoustical Society of America, 1976, 59, suppl.1, 56.

116 Satz and his coworkers (Satz & Friel, 1973, 1974, 1975; Satz, Friel & Rudegeair, 1974) have provided longitudinal review (1, 2, 3 and 4 yr. follow-ups) on one sample and 3 yr. cross-validated follow-up on a different sample of children in terms of the validity of a developmental neuropsychological test battery to forecast reading disability. The test battery was derived on the basis of their theory of left hemisphere developmental lag. Performance on DL was only one of several predictor variables employed; DL might be profitably combined with other predictor variables as well (e.g., measures employed by Rourke & Orr, 1977).

117 In addition to the articles cited in the main text, detailed discussion of reading ability, laterality and neurological asymmetry has been provided by Kershner and Kershner (1973), Kershner (1975) and Kinsbourne (1975, 1976).

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A research program described by Rourke (1975), utilizing a wide variety of measures and based on a model of brain-behaviour relationships described by Reitan (1966), has implicated the role of impaired cerebral functioning in learning disabilities. (Rourke, 1976ab; Rourke & Telegdy, 1971; Rourke, Young & Flewelling, 1971; Rourke, Yanni, MacDonald & Young, 1975; Rourke & Finlayson, 1975, in press).

118 Bakker et. al. (1975) also referred to a study that revealed a two yr. lag in the development of this pattern of ear asymmetries in 9 - 10 and 11 - 13 yr. old dyslexics: such children revealed an ear asymmetry pattern very similar to the 7 - 8 and 9 - 11 yr. olds respectively of the study of Bakker et. al., 1975 (Bakker, D. Hemispheric specialization and stages in the learning to read process. Bulletin of the Orton Society, 1975, in press).

119 Milner (1971) cited clinical data from her student (Corsi) that suggested a left hemisphere dominance for retention of digit sequences: in four subgroups differing in extent of hippocampus removed, greater deficit occurred on Hebb's digit sequence task after left, compared to right, temporal lobectomy, with the deficit being proportional to the extent of hippocampus removed (no differences among the subgroups on ordinary digit span or on non-recurring digit sequence).

120 i.e., the right ear would have more direct access to the left hemisphere, the hemisphere dominant for language and temporal analysis.

121 As noted previously, Kimura (1967) reported that monaural presentation of digits without any requirement of reporting in proper sequence failed to elicit significant ear differences, even when digits were rapidly alternated between the ears. The model offered by Kimura (1967) to explain ear asymmetries on DL considered the direct competition of the two auditory input fibers that results from simultaneous presentation of input to both ears as crucial in contributing to ear asymmetries (see later section in main text on DL).

122 Even younger if the results in 3 yr. olds (Ingram, 1975; Nagafuchi, 1970; Piazza, 1977) and infants (Entus, 1975; Entus & Corballis, in press - see note 96) and certain interpretations of clinical observations (e.g., Annett, 1973; Rudel et. al., 1974) are accepted.

123 In this vein, employment of VF and DL techniques in the same populations have lead to the suggestion that these two measures are tapping different aspects of cerebral dominance (Bryden, 1965; 1973; Higenbottam, 1973; Zurif & Bryden, 1969) because of the low correlation noted between the two tests. In contrast Hines and Satz (1974) have reported a significant correlation between the tests. One might also wish to refer to later discussion of the hypotheses of different experimental measures, and even different DL tasks, measuring different aspects of cerebral dominance (Brown & Jaffe, 1975; Porter & Berlin, 1975), and that even a particular method of reflecting ear asymmetries may be reflecting a slightly different aspect of a particular type of left hemisphere dominance.

124 Dichotic and monaural tasks were administered to the same subjects in one of the experiments (7 yr. olds) reported by Bakker et. al. (1973). Though low ear asymmetries on DL were felt to be associated with high reading scores, reading skills did not differ significantly for subjects exhibiting low vs. larger ear asymmetries. DL was not employed in the second (8 - 9 yr. olds) or third (7 - 11 yr. olds) experiment. Hence developmental comparisons of performance on the two tasks was not possible. The DL task also consisted of presentation of digits at the rate of one pair per sec., which differs from the rate of presentation of one pair of digits per 1/2/sec. in the majority of the studies reporting ear differences at relatively young age levels. Hence even comparison of the performance of the 7 yr. olds in the Bakker et. al. (1973) study on the two listening tasks would permit statements pertaining only to DL performance with one sec. presentation rates in relation to the Bakker type of ML task.

125 Zurif and Carson (1970) have noted that dyslexics (grade 4 age level) were poorer in the analysis of auditory temporal information than were normal readers. It was suggested that an explanation of developmental dyslexia in relation to difficulties in temporal analysis within a given sense modality is more parsimonious than an explanation in terms of a maturational lag in the capacity to assimilate multimodal information (Birch & Belmont, 1964). The implication is that left hemisphere specialization for language may occur in the young child before the temporal aspects of language become important; the explanation would conflict with the hypothesis that the basis for left hemisphere language specialization is specialization for temporal analysis (as suggested by Bosshardt & Hormann, 1975; Halperin et. al., 1973; Papcun et. al., 1974; Robinson & Solomon, 1974).

126 Sussman and MacNeilage (1975b) also have cited research that showed an absence in stutterers of the normal REA on DL for speech input (Perrin, K. An examination of ear preference for speech and non-speech stimuli in a stuttering population. Ph.D. thesis, Stanford University, 1969).

127 Gruber and Powell (1974) noted that both normal and stutterer groups failed to exhibit an ear asymmetry.

128 Dorman and Porter (1975) also noted a study that found no differences between adult stutterers and controls on DL (Quinn, P. Stuttering, cerebral dominance and the dichotic word test. Medical Journal of Australia, 1972, 2, 639-643).

129 Clinical observations of cerebral dominance in stutterers assessed by sodium amytal injection are also contradictory. Support for the hypothesis that cerebral dominance for speech is not well established in stutterers is provided by Jones (1966). Carotid amytal injection in either hemisphere induced an equal degree of dysphasia in four patients prior to intracranial surgery for a tumour or aneurysm. Following surgical intervention the stuttering ceased in all four cases. At the same time, dysphasia now tended to occur to a much greater extent during amytal injection to the hemisphere opposite the lesion (three subjects - lesion on left, one subject - lesion on right). Thus the results of this study suggested that cerebral dominance for speech may not be well established and that the establishment of a greater degree of dominance is associated with a cessation of stuttering. Chase (1972) has also cited a reference that has described various attempts to relate stuttering to language laterality as assessed by handedness (Bloodstein, O. A Handbook on Stuttering for Professional Workers. Chicago: National Society for Crippled Children and Adults, 1959).

However, the hypothesis was not supported in the publication of Luessenhop et. al (1973). Sodium amytal testing in three chronic stutterers revealed left hemisphere dominance for language. These researchers also cited a study involving four stutterers that also revealed unilateral hemisphere dominance for speech (Andrews, G., Quinn, P. & Sorby, W. Stuttering: an investigation into cerebral dominance for speech. Journal of Neurological and Neurosurgical Psychiatry, 1972, 35, 414-418). Luessenhop et. al. (1973) concluded that mixed speech dominance is not uniformly present in adult stutterers.

130 One might also be critical of an experimental procedure that expects stutterers to identify material verbally because of their problem in expressive speech. It is generally agreed that in a normal population expressive

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130 (Cont'd). speech is controlled by the left hemisphere and that the verbal identification of material presented to either ear would have to occur through the left hemisphere, regardless of the main site of reception and analysis of speech input; hence any differences in ear asymmetries on DL in normal population samples revealed through a verbal identification procedure is attributable to factors other than the verbal identification requirement of the task. However, any assumption of the presence of a normal left hemisphere specialization for expressive speech would be too tenuous an assumption in a population whose specific difficulty lies in expressive speech. Hence the DL studies with stutterers cited in the main text can be criticized for failing to utilize a recognition procedure instead of (or in addition to) the identification procedure employed, the failure thereby confounding receptive vs. expressive speech site abnormality variables in stutterers.

131 Sussman and MacNeilage (1975b) cited eight early EEG studies that provided some support to the hypothesis of mixed cerebral dominance in stutterer populations.

132 Although this study was obviously poorly designed, Jones and Spreen (1967) is cited here because of the paucity of studies in the literature investigating cerebral dominance in these types of children. Another weakness of this particular piece of research is the failure to administer a standard IQ test to all children investigated. The IQ tests administered were not specified, and one would strongly suspect that IQ data was obtained from any of a variety of IQ tests administered independently of the research by several different testers.

133 A paper appeared (Briggs & Nebes, 1976) after the data for the present research was gathered that speculated that, in view of the fact that intellectual deficits are associated with left-handedness (paper in preparation by Briggs, Nebes & Kinsbourne cited), a relationship may exist between ear differences on DL and intellectual level (presumably also considering their finding of a non-significant REA in left-handers for identification of digits on DL vs. a significant REA for right- and mixed-handed subjects).

134 After the data had been gathered for the current thesis research, three studies appeared that failed to obtain differences in degree of ear asymmetries on DL (syllables) in young children from different socio-economic levels. Significant REA of equal magnitude was found in 6 yr. old black and white children (Dorman & Geffner, 1974), 4 yr. old males (Geffner & Dorman, 1976) from either middle or low socio-economic classes, and 3-5 yr. olds from mainly non-professional backgrounds (Ingram, 1975). One study that appeared subsequent to data-gathering that did find differences

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134 (Cont'd). was Borowy, 1974 (significantly less extensive REA in 5 - 11 yr. olds from "lower" class).

135 See Richardson and Knights (1970) for an extensive bibliography of DL publications.

136 Bocca, E., Calaero, C. Cassinari, Y. & Migliavasca, F. Testing "cortical" hearing in temporal lobe tumours. Acta Oto-laryngology, 1955, 15, 289-304.

137 Singha, F. The role of the temporal lobe in hearing. Master's thesis, McGill University, 1959.

138 The percentages of left and right handers exhibiting REA were roughly equivalent in the study of Satz et. al., 1965 (88.5% of the right handers, 73.2% of the left handers). However the percentages reported by Bryden (1965) seemed to deviate significantly from the percentages noted by Branch et. al. (1964): 65% of the right handers (13 of 20) and 35% of the left handers (7 of 20) identified more digits presented to the right ear than digits presented to the left ear.

Although Bryden and Allard (in press) and Bryden (1975) have also stated that many studies have found the percentage of right handed adults exhibiting a REA to fall in the 80's, many of the studies reviewed by the present author have yielded much lower percentages (see discussion in Chapter IV).

139 Kimura (1961) actually found left hemisphere lesions to depress scores on both ears, right hemisphere lesions to impair performance only at the contralateral ear.

140 As indicated by the suppression on DL of the ear contralateral to the site of damage in temporal lesion patients and "release from suppression" in hemispherectomies (Berlin et. al., 1973b stated that hemispherectomized subjects show almost 100% correct performance in the ipsilateral ear). Such refinements may provide a means of integrating these models of DL performance and the functional lateralization model of Moscovitch (1973) and related speculations by Geschwind (1968, 1969) and Bogen (1969), among others.

An alternate explanation offered by Kinsbourne (1974) for performance on DL after hemisphere lesions is an attentional shift to the receptive field contralateral to the intact hemisphere (see subsection 3 of section E of literature review).

141 The models being considered here have been formulated specifically to explain performance on DL. In regard to reaction time differences to material presented to each ear, the observation of Gordon (1975) of faster verbal reaction time to simple words presented to the right ear (monaurally)

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141 (Cont'd). of callossectomized subjects (therefore, performance of the right and left ear reflected performance by contralateral and ipsilateral pathways, respectively) led him to question an explanation of such ear performance asymmetries in terms of callosal transmission time.

142 Berlin and Cullen (in press) have discussed the influence of the following factors on DL performance with speech material: acoustic variables (intensity, signal-to-noise ratio, frequency, bandwidth, time relationships, phase, phonetic effects), subject variables (reliability with a particular subject, age, sex, performance of clinical samples) and stimulus variables (syllables vs. digits, synthetic vs. natural syllables, scoring of data).

143 Bartz et. al (1967ab); Bryden (1965) and Satz, et.al. (1967), all referred to earlier in this section; in addition - Bartz, W., Satz, P. & Fennell, Proceeding of the American Psychological Association, 1966; Broadbent, D. & Gregory, M. Quarterly Journal of Experimental Psychology, 1964, 16, 309; Cooper, A., Achenbach, K., Satz, P. & Levy, M., Psychonomic Science, 1967, 24, 97. Unpublished work of K. Achenbach was also cited by Satz (1968).

144 The present reviewer has not been able to uncover any direct reference by Kimura herself to the nature of the prediction of degree of ear asymmetries with increasing S-R time delay that would be provided by her own perceptual model. However, a third prediction seems as plausible to the present reviewer than either of the two predictions just cited in the main text: if decreases in ear performance are identical in the two ears whatever the time delays, one might very well expect an increase in relative performance advantage of the right ear with greater time delays. Because optimal performance levels of both ears would be expected for the 0 sec. delay condition with a monotonic reduction in the performance of both ears with increasing time delays, the REA may assume an even greater degree of statistical significance as the lower levels of performance are approached (i.e., one might expect a REA of five in the context of a large total score to perhaps assume a lower degree of statistical significance than a REA of five in the context of a lower or very low total score). Scoring procedures that consider differences in overall accuracy have been suggested (e.g., Harshman & Krashen, 1972; Studdert-Kennedy & Shankweiler, 1970). Certainly further development of some sort of statistical model that would provide for any different variance estimators that might be required in the context of significantly different total scores will contribute to a better formulation of such predictions.

Although the present reviewer has not found any direct reference by Kimura herself to the nature of the prediction

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144 (Cont'd). of degree of ear asymmetries with increasing S-R time delay that would be provided by her own perceptual model, she does make direct reference to results expected with more difficult DL conditions. Thus Kimura (1962) stated that "the hypothesis [presumably that outlined in her 1961a paper] implies that any factor which makes the task more difficult will affect most severely those digits reported last, that is, that it will affect the non-dominant channel in Inglis' terminology" (p.19). Therefore increasing S-R time delays would affect those digits presented to the left ear to a greater extent when the left ear channel is the non-dominant channel, in the sense of left channel digits being reported after digits are reported from the right channel (Bartz et. al., 1967ab; Bryden, 1963).

Another difficulty in making predictions of the effect of time delay on pattern of ear asymmetries for dichotically presented verbal (Nachshon & Carmon, 1973a, utilized digits) and non-verbal (Spellacy, 1970 and Spreen et. al., 1970 used music) material is the differing nature of the memory tasks often employed with verbal vs. non-verbal input (i.e., DL of digits is usually followed by a recall procedure, while DL of music typically utilizes a recognition procedure). In fact it would appear that the "ear order of report" issue has relevance only to tasks that employ recall rather than recognition procedures.

145 By stating that VF asymmetries are due to more direct access by a particular VF to the contralateral hemisphere, Kimura (1966) implied that input to a particular VF would have to reach the ipsilateral hemisphere indirectly via the contralateral hemisphere and across the corpus callosum, although this was not made explicit. However, in other articles discussing auditory asymmetries, Kimura (1961ab, 1967) made no reference to corpus callosum transmission of information and does not include such transmission pathways in her model to explain such asymmetries (as pointed out by Sparks & Geschwind, 1968 and Sparks, Goodglass & Nickel, 1970ab as part of their criticism of the Kimura model).

146 The concept of attention is obviously the common element in the positions of Inglis, Oxbury, Treisman and Kinsbourne. However, the difference lies in the explanation of the level where attention is crucial. For Inglis and Oxbury, attention affects reproduction and retrieval, not reception or perception; for Treisman and Kinsbourne, attention operates on incoming stimuli, and therefore affects reception and perception of material.

147 Kimura and Durnford (1974) dismissed the hypothesis of Kinsbourne (1970) by noting the contradiction of an explanation that ascribes differences in human perceptual fields to

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147 (Cont'd.) attentional processes rather than functional differences between the hemispheres, but then attributes the attentional bias to hemisphere differences (as indicated in the main text, the same sort of tautological reasoning criticism applies to the explanation of Triesman & Geffen, 1968). However, Kimura and Durnford (1974) failed to address their rebuttal to another aspect of the position taken by Kinsbourne (1970): his rejection of the explanation of the effects in terms of more efficient information transmission by the shorter pathway.

148 Levy (1974) cited evidence she felt supported the Kinsbourne (1970) position. However the data cited supports a prediction that is clearly opposite to any Kinsbourne (1970) would make. "Such a mechanism would predict that reaction time differences for verbal stimuli projected to the left and right hemispheres would disappear if the left hemisphere were already aroused and attentive prior to stimulus presentation" (Levy, 1974; p. 149).

149 Most DL studies have employed a recall procedure with verbal material and a recognition procedure with non-verbal material; any task requirement that can be known only during or after the presentation of the stimulus either to recognize (for non-verbal material) or identify (for verbal material) would impose a different task demand than involved in the DL studies conducted to date. Such a change in task demand would provide some difficulty in terms of interpretation.

150 Dirks (1964) had earlier reported a REA with his own materials (competing words) and with the Kimura digit test. Brunt and Goetzinger (1968) noted this fact in their introduction, but in their discussion of their results they failed to refer to the discrepancy between the data of Dirks (1964) and their own findings.

151 Satz (1977) has pointed out that the error rate in classifying individuals as left or right hemisphere dominant for verbal materials on the basis of ear performance is extremely high only when a LEA is utilized to classify individuals as right hemisphere dominant for the analysis of that verbal material.

152 One should recall that non-supportive results do not necessarily indicate an insensitive instrument, but perhaps that the left hemisphere dominance for that material may not be firmly established by that age.

153 Although there is very little speculation in this regard in the literature (which also seems to be a reflection of the language and left hemisphere bias of research, which in turn was related in an earlier note to a possible emphasis

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153 (cont'd.) or over-emphasis of left hemisphere mediated activities in our Western society), focal right hemisphere damage to a critical area may also cause a transfer of the site of information-processing to the left hemisphere. However if the hypothesis of Semmes (1968) is accepted, the relatively more diffuse physiological and functional organization of the right hemisphere would often require a relatively more extensive lesion to effect a transfer of functioning from right to left hemisphere, in comparison to a transfer of left hemisphere functions to the right side. Recall also the earlier speculation that if the brain damage is not extensive enough or not in an area that would result in transfer of the function to the opposite hemisphere, a specific verbal or non-verbal intellectual deficit may be the result; also that overall intellectual deficits may occur if language and non-language functioning are "crowded" into the same hemisphere (i.e., if the damage is extensive enough or strategically located so that transfer to the opposite hemisphere does occur.)

154 If the primary purpose had been to definitively establish the development of the REA (and possibly other perceptual asymmetries) and relate such asymmetries to left hemisphere specialization (possibly of various kinds), the study would have utilized much larger age samples and would have utilized several types of auditory material (e.g., digits, words and syllables, monaurally and dichotically presented, and possibly other perceptual measures); the environmental sounds test in all probability would have been omitted.

155 Until the data for the current study was gathered, only two other developmental studies had been uncovered, both utilizing the mode of touch, that investigated information-processing possibly mediated primarily by the right hemisphere (Ghent, 1961; Kimura, 1963). Since the selection of DL for the present study, studies have appeared employing DL (Geffen, 1976; Piazza, 1977), the mode of touch (Witelson, 1974, 1975, 1976, in press) and the visual modality (Witelson, 1975).

156 The appropriateness of the SIT with children of sub-average intelligence has been demonstrated by Delapa (1968) and Hammill (1969).

157 The 5 yr. old children whose Slosson IQ fell in the 65-80 range were especially difficult to locate. Children whom the teacher expected would score in this IQ range but who obtained IQ's on the Slosson above 80 accounted for 17 of these 19 children. It was necessary to visit 14 different kindergarten classes in order to obtain the 10 children required to fill this particular cell, despite the written

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157 (Cont'd.) guidelines described in appendix D presented to kindergarten teachers to guide them in their selection of possible candidates. Four other children from special schools (whose IQ's presumably fell below 61) did not exhibit any speech during conversation or during administration of the Slosson. These latter children were also eliminated from the study.

158 Audiometric testing was highly unreliable in the groups of children with Slosson IQ's below 61. In the 11 yr. olds at this IQ range three of these children seemed to be responding in a manner unrelated to the ear in which a particular sound appeared; in the 8 yr. old group, six children similarly seemed to be responding in an essentially random manner; and in the 5 yr. old group, nine of the 10 children were responding in such a manner. Members of all other IQ groups responded appropriately.

The erratic test performers on audiometric testing were retained because all children were initially screened for absence of hearing deficits; their erratic performance was presumably a result of their IQ level rather than because of the presence of hearing deficits; exclusion of such children would have left only one 5 yr. old, four 8 yr. olds and seven 11 yr. olds with IQ below 61, with little possibility of finding more appropriate subjects as all local resources had been tapped to gather as many subjects as were studied. The present researcher would suggest that any undetected hearing deficits present in the erratic responders would likely have minimal effects on differences between age-IQ range groups and especially on overall ear asymmetries because any hearing deficits might be bilateral and equal in a particular subject, or, if unilateral, likely equally distributed between the ears across subjects in a particular age-IQ range groups, and especially across the entire 90 children.

159 During the monaural familiarization phase, each subject included in the study repeated the name of each environmental sound on at least two of the three occasions that the verbal label of the sound was supplied by the experimenter.

160 Nachshon and Carmon (1973b) have reported a higher negative correlation between overall accuracy and degree of ear asymmetry on more complex 4- and 5-pair digit strings compared to 3-pair digit strings. Thus, the less complex (3-pair) task produced greater ear asymmetries as accuracy increased (in other words, as the distance from ceiling performance level decreased) than did the more complex tasks.

161 Curry (1967, 1968) similarly utilized a verbal method of indicating identification of environmental sounds dichotically presented to adults; both studies also noted a significant LEA.

162 The fact that the more extensive familiarization period employed in the present study did influence overall performance is suggested by comparison of the mean performance of the 5 yr. olds in the present study with Slosson IQ above 90 (mean left ear score of 6.7 vs. 7.0 for right ear) with the lower mean performance scores in the 5 yr. old sample of experiment I of Knox and Kimura, 1970 (mean left ear score of 5.6 vs. 5.25 for right ear). Performance might be expected to be slightly higher in the present research because 15 test pairs were employed, compared to 12 test pairs utilized by Knox & Kimura (1970); however this latter difference would only account for a small portion of the higher performance of the 5 yr. olds (Slosson IQ > 90) in the present study.

163 It was pointed out in the literature review that abnormal states of hemisphere specialization for speech and language have been posited for several groups (e.g., dyslexics, stutterers), but that the evidence pertaining to the possibility has been either ambiguous and contradictory or pertaining to abnormal states of left hemisphere dominance for language or right hemisphere dominance for non-language (e.g., dyslexia). The present researcher has been informed in a personal communication (Moscovitch, 1977) that C. Rinehart has gathered evidence to support the hypothesis of right hemisphere language specialization in Down's Syndrome individuals (in a paper presented at the annual meeting of the Canadian Psychological Association, 1976).

164 Bryden and Allard (in press) have argued that both measures are required for clear assessment of the processes involved. However, in an apparently contemporaneously written article, Bryden (1975) utilized only mean number of digits identified. Other methods of deriving and analysing DL scores have been suggested (see note 99).

165 Variations on the free recall procedure might also be included to control for different strategies that subjects may adopt on DL and on other laterality measures (see Bryden, 1972, 1977 for discussion of subject strategy effects in the assessment of hemisphere asymmetries).

166 Recall the positions of Inglis (1965), Kinsbourne (1970), Oxbury et. al. (1967) and Treisman and Geffen (1968) concerning the involvement of attention in contributing to the ear effect on DL. Levy (1974) referred specifically to the possibility that laterality differences may be determined by the time required for a stimulus going to a hemisphere not dominant for that type of input to alert the lower brain center to arouse the competent hemispheres, rather than by the time required to shift the stimulus to the dominant hemisphere.

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It has also been suggested that the two hemispheres may differ in basal arousal level (Bakan, 1971), or that attention becomes focussed in one hemisphere because of differential lateral connections in the subcortical thalamic-brainstem attentional mechanisms (Sperry, 1974). Any such lateral differences in turn may perhaps be related to any hemisphere differences in fatigability (Dimond, 1972) and emotional reaction (e.g., as described by Lezak, 1976). "Shock also may have differential effects. Murphy and Venables (1969) in their study showed that the performance of the right and left ear does not differ when clicks are presented alone. However, the presentation of a short electric shock before a click is due results in a considerable decrement in right ear performance but little change in left ear performance. Murphy and Venables suggest that the hemispheres may differ in their lability or in cortico-reticular interactions and the results are in line with the investigations of the interfering effects of an additional response on a previously operating response of the hands (Dimond, 1970d). Shock, as measured by GSR can be suppressed more effectively by on-going verbal activity if this occurs in the right as opposed to the left ear (Bever et. al., 1968). The response to shock is less during the beginning of a clause than at its end, but this effect is magnified to speech presented through the right ear" (Dimond, 1972, p. 158).

Concerning the role of the thalamus on auditory input (e.g., ML, DL), Calaero, 1975 (in a review of verbal tests for diagnosis of central deafness) noted monaural test evidence of the influence of the reticular formation on auditory stimulation and the crossing of the auditory pathways.

167 Disruption in performance on a simple mental arithmetic task after right (Ojemann, 1974), and disruption of object naming (Fedio & Van Buren, 1975; Ojemann, 1975) and elicitation of spontaneous speech (Schaltenbrand, 1975) during left, thalamus stimulation have also been noted.

Brown (1975) discussed the involvement of the thalamus and speculated concerning its relationship to the cortex in the development of language and its lateralization. Riklan and Cooper (1975) and Ojemann (1975) related the role of the thalamus in language specifically to arousal and attention. However, Van Buren (1975) concluded from his review of the functional effects of thalamic stimulation and thalamic lesions that caution is necessary in suggesting any more than a minor role to the dominant thalamus in speech processes. In his review of the role of the thalamus, Reitan (1976, p.204) similarly concluded that, though research suggests thalamus specialization includes lateral specialization similar to the corresponding hemisphere, its role "... is not as prominent as is the role of the cortex."

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