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Hemispheric specialization in congenitally deaf and hearing children and adolescents.

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HEMISPHERIC SPECIALIZATION IN CONGENITALLY DEAF AND HEARING CHILDREN AND ADOLESCENTS

A Dissertation Presented

By

FARANEH VARGHA-KHADEM

Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
of the requirements for the degree of

DOCTOR OF EDUCATION

September 1979

Education

HEMISPHERIC SPECIALIZATION IN CONGENITALLY DEAF AND HEARING CHILDREN AND ADOLESCENTS

A Dissertation Presented

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This thesis is dedicated to Ramin,
Paryssa and Varqa for their love,
patience and support and to my
parents for their encouragement.

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ABSTRACT

Hemispheric Specialization in Congenitally Deaf and
Hearing Children and Adolescents

September 1979

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This thesis investigated visual and tactual laterality differences in congenitally deaf and hearing subjects. A series of four experiments is reported. In experiments I through III, American Sign Language (ASL) stimuli (in apparent motion) and English words were tachistoscopically presented to one group of deaf signers and to two groups of hearing signers and non-signers. In experiment IV, a verbal and a non-verbal tactual task was presented to congenitally deaf and hearing subjects.

Hearing signers demonstrated a right visual-field superiority in the processing of apparently moving ASL signs and English words. Hearing non-signers also demonstrated a right visual-field advantage in the processing of ASL sign sequences. However, deaf subjects, as a group, did not show significant visual-field differences in the processing of any of the stimuli employed. The absence of an overall visual-field advantage was due to individual differences which were consistent and reliable across the three visual tasks.

Deaf and hearing subjects demonstrated a right tactual-field advantage in the processing of verbal stimuli. However, neither group showed a clear tactual-field advantage in the processing of non-verbal stimuli.

It is concluded that the absence of pronounced laterality differences in deaf subjects is not due to inconsistencies in the data, but rather to reliable individual differences. These results are discussed in terms of the possible effects of early language acquisition on developmental gradients and cerebral differentiation.

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> "That the nervous system is double physically is evident enough. This is a very striking fact, but one so well known that we are in danger of ceasing to think of its significance — of ceasing to wonder at it... The nervous system, I repeat is physically double. I wish to show that it is double in function also...".
>
> Hughlings Jackson, 1874

The extent of the functional duality of the brain, which Hughlings Jackson set out to demonstrate in the late 1800's, has only become apparent within the last two decades. A brief review reveals that a wide range of functions are localized more in one hemisphere than the other. Thus the left hemisphere is specialized for the processing of such verbal stimuli as digits, words, consonant-vowel syllables (Shankweiler & Studdert-Kennedy, 1967; Darwin, 1971a) and backwards speech sounds (Kimura & Folb, 1968). In addition, the left hemisphere is more efficient than the right in the following: recognition of a speaker's voice (Doehring & Bartholomeus, 1971); in the verbal recall of visually presented objects (Levy, 1972); processing of temporal sequences of stimuli (Efron, 1963; Carmon & Naschon, 1971); production and control of motor sequences (Kimura, 1976); and perception of both alphabetical material (McKeever & Huling, 1971) and of familiar objects (Wyke & Ettlinger, 1961).

The right hemisphere, in contrast, is predominantly specialized for the processing of such non-verbal stimuli as environmental sounds (Curry, 1967; Knox & Kimura, 1970); melodies (Kimura, 1964); sonar sounds (Chaney & Webster, 1966); and pitch patterns (Darwin, 1971b). Furthermore, a wide range of visuo-spatial functions are also predominantly subserved by the right hemisphere. Thus, with appropriate viewing conditions, a left visual-field superiority indicative of right-hemisphere specialization can be demonstrated for the perception of the following: depth (Durnford & Kimura, 1971); of faces (Geffen, Bradshaw & Wallace, 1971; Rizzolatti, Umilta & Berlucchi, 1971); the location and quantity of dots (Kimura, 1966); and of the slope of lines (Durnford & Kimura, 1971; Fontenot & Benton, 1972).

Evidence for the range of functions subserved by each hemisphere has come from three sources of inquiry. One source has been studies of a small number of patients who have had surgical section of the corpus callosum for relief from generalized epilepsy (Sperry, 1975). Another source has been studies of patients who have suffered unilateral cerebral lesions (Milner, 1975). Yet another source has involved studies of normal subjects who have performed perceptual tasks in the various sense-modalities (Kimura, 1961b; Shankweiler, et al., 1967; McKeever & Huling, 1971; Witelson, 1974). In general, evidence derived from studies of normal subjects is in agreement with those provided by lesion and callosal-section studies. However, this agreement is in terms of a very general and simplified picture of left hemisphere specialization for speech and language and right hemisphere specialization for non-verbal functions. At a more specific level, many questions remain unanswered. For example, to what extent are the two hemispheres interdependent in processing information and integrating human behavior? What is the basis of hemispheric asymmetry for speech representation? What role does normal language acquisition play in the development of such hemispheric specialization? And finally, what are the factors that might contribute to a failure in the development of hemispheric asymmetry?

This thesis is primarily concerned with the last two questions. More specifically, what are the effects of auditory deprivation on the subsequent development of a normal pattern of hemispheric specialization. In the following pages an attempt will be made to investigate a number of questions pertaining to hemispheric function and language processing in congenitally deaf children and adolescents.

The review of the literature begins by examining the concept of the gestural origins of language and relating this to the development of handedness and speech representation. Normative data on the development of hemispheric specialization will be reviewed and some of the determining factors of perceptual laterality-effects will be discussed. The next section addresses the question of congenital deafness and its effects on cognitive development, information processing and language acquisition. Finally, hemispheric specialization is considered in the context of congenital deafness. The question is raised about the role of sign language and manual communication in the development of cerebral asymmetry, and existing data on perceptual asymmetries in the deaf are critically analyzed. A series of experiments is described that address some of the questions raised by previous research, while attempting to determine whether functional cerebral-asymmetry can be demonstrated in congenitally deaf subjects.

PART I

CHAPTER I

DEVELOPMENT OF HEMISPHERIC SPECIALIZATION

Gestural Language and the Origin of Language Development

It is impossible to retrace the nature of language evolution in hominids, since most theories regarding this question are based on ad hoc reasoning. However, on the basis of evidence from neurophysiological development (Campbell, 1966), increases in brain capacity and specialization (Young,1971) and tool-making abilities (Young, 1971), it may be possible to synthesize a model of how language developed (Cicourel, 1974).

One theory, dating back to the 18th century, postulates that man's first language was gestural. Proponents of this theory (Hewes, 1973; Kimura, 1976) suggest that some form of sign-gestural language existed prior to oral-language evolution. Evidence for this speculation comes from several sources.

First, whereas nearly all attempts to teach vocal language to chimpanzees have failed (Kellog, 1968), it is now evident that chimpanzees can learn complicated sign language (Gardner & Gardner, 1969; 1977; Premack, 1971). Kimura (1976) suggested that, in so far as man and chimpanzee share a common ancestry, the adeptness of the chimpanzee in learning sign language may indicate that man also went through a similar stage of development when he used manual rather than vocal communication.

Second, there is evidence suggesting that people gesture with their hands when they speak and that these gestures (free movements) are predominantly made by the right hand in right handers (Kimura, 1973). In contrast, "self-touching" movements occur at all times and may be considered non-gestural. This suggests that gestures and speech are closely-associated motor activities.

Finally, it has been proposed that the speech apparatus, in particular the vocal tract, has undergone recent adaptive changes. Thus the speech sounds produced by man today may be quite different from those produced by as late a species as the Neanderthal man (Lieberman, Crelin & Klatt, 1972; cited by Kimura, 1976). This suggests that vocal speech evolved rapidly and was not wholly dependent on the use and making of tools, as some have theorized (Marler, 1967; Washburn, 1969). Although cranial casts of fossils do not show when the speech areas of the brain developed, it can be reasonably assumed that they made their appearance during the time of most rapid expansion of the brain, i.e. between the Australopithecine stage and Homo Sapiens (Young, 1971). In contrast to vocal speech evolution, hand preference, and by inference functional brain asymmetry, dates back to Australopithecus (Dart, 1949; Young, 1971). On the basis of these reports, Kimura (1976) proposed that before the evolution of speech the functional asymmetry of the brain may have been predominantly for manual skills.

The evolutionary sequence may have begun with bipedal locomotion which freed the arms and hands for tool making. Acquisition of manual dexterity and skill in tool manipulation may then have extended to the development of a sign-gesture system of communication. With increasing organization of early human society and the need to communicate new information (Etkin, 1964), a vocal system of communication gradually evolved. (For a detailed review, see Nottebohm, 1975).

Handedness and its Relation to Speech Representation During Childhood

Preference for the use of one hand over the other appears in most children between the ages of one and two (McCarthy, 1954). Despite its early appearance, hand preference undergoes many cyclical changes until it finally becomes established around the age of eight (Gesell & Ames, 1947). It is perhaps due to these cyclical changes that the incidence of left handedness in children is about twice that in adults (Robert, 1969). Left-handedness is also more common in young than in old adults. However, estimates of its incidence are crucially dependent on methods and criterions of assessment (Newcombe, Ratcliff, Carriwick, Hiorns, Harrison & Gibson, 1975).

Although environmental and social factors play some part in the development and establishment of handedness, the process is one of maturation (Gesell & Ames, 1947). In support of the maturation hypothesis, Annett (1970) reported that the distribution of hand preference and the relative speed of the two hands in performing a skilled task remained constant during early childhood through adolescence. Furthermore, there was a linear relationship between degree of hand preference and degree of relative manual skill. Zangwill (1975) suggested that despite the preponderance of evidence indicating the genetic determination of handedness, it is only the differential preference that is innate; right handedness as such is acquired through training. Furthermore, the development of handedness may predominantly reflect bimanual coordination rather than precision or speed of performance on unimanual tasks (Oldfield, 1969).

It has been argued that lateralization of speech functions may have evolved from handedness (Corballis & Beale, 1976). In the adult, the relation between hand preference and hemispheric specialization for language is quite strong. Studies using the intracarotid sodium amytal test (Wada, 1949) have revealed that right handedness is strongly associated with left hemisphere representation for language (i.e. 92-98%) (Branch, Milner & Rasmussen, 1964). Approximately two thirds of the left handed population also have speech and language functions represented in the left hemisphere. However, the remaining one third show a right hemisphere or bilateral representation of speech (Milner, Branch & Rasmussen, 1966).

During childhood, the relationship between hand preference and speech representation is not precisely known. Ingram (1975) tested preselected, strongly right handed, groups of young children (3-5 years of age) on a dichotic-digits task (Kimura, 1963). She found that a right ear advantage was demonstrated at all age levels, except in 4 year old girls. These results suggest that children as young as age 3 have left hemisphere representation for speech functions. However, it remains to be seen whether familial left-handed children also demonstrate a right ear advantage. If so, then the relationship between right handedness and speech representation during early childhood may not be so strong.

There have been several attempts to produce models of handedness and speech representation. A genetic model proposed by Levy and Nagylaki (1972) suggested that handedness and cerebral lateralization are controlled by two genes; one of these determines hand dominance and the hemisphere involved in the processing of language; the other gene specifies whether hand dominance in contralateral or ipsilateral to the language hemisphere. Left hemisphere specialization for language and contralateral hand control are the two dominant alleles. Thus recessive homozygotes have ipsilateral control of the hand. Although this model agrees well with the filial ratios from the three types of mating (i.e. both parties right handed; both parties left handed; one left handed and one right handed), it does not allow for any differential penetrance due to chance. Yet several sources of data (Collins, 1969; Annett, 1970; 1972) indicate the necessity for partial penetrance in any model of handedness. (For a complete review, see Corballis and Beale, 1976.)

Annett (1970; 1972) proposed a model that reconciles the genetic and the chance factors of handedness. She reported that on a peg-sorting task measuring inter-manual differences, the distribution of the difference between the two hands is unimodal and appears bell shaped. She attributed the normal distribution to accidental variation. However, the distribution as a whole favours the right hand; this is labelled "the right shift" (Annett, 1972). The "right shift" is genetically determined but may be influenced by cultural factors. This implies that right handedness is inherited whereas left handedness is not. However, Annett (1974) reported that the absence of the "right shift" may also be genetically determined. Thus of the children born to 29 both-left-handed parents, only eight showed evidence of the "right shift". The remaining 45 children were divided equally with respect to preference for the left for the right hand. Annett (1974) concluded that: "...the factor biasing handedness towards dextrality is absent in these children and their laterality is determined mainly by accidental variation".(p.129). According to Zangwill (1975), this model agrees well with most findings on the relations between left handedness and hemispheric specialization for speech. However, it cannot be used to explain the phenomenon of "crossed aphasia", i.e. aphasia resulting from right hemisphere damage in dextrals with no indication of familial left handedness.

The Lateralization of Speech

Recent theories regarding the development of hemispheric specialization have been influenced by the finding that extensive injury to the left hemisphere during early childhood does not preclude the development of speech (Basser, 1962; Zangwill, 1964). Moreover, early removal of a damaged left hemisphere (hemispherectomy) rarely produces aphasic symptoms, suggesting that speech and language functions are being subserved by the intact right hemisphere. However, the transfer of language from one hemisphere to the other is not free of disadvantages. After transfer, not only language functions *per se* but also the non-verbal functions of the intact right hemisphere show mild impairments.

Recovery of language after left-hemisphere damage incurred during early childhood is relatively rapid and complete (Lenneberg, 1967; Milner, 1974). Furthermore, speech disorders are not necessarily restricted to left hemisphere damage. In some cases of early damage, aphasic symptoms may develop with right-hemisphere lesions; however, these symptoms are transient and recovery is particularly rapid (Lenneberg, 1967; Basser, 1962; Zangwill, 1964).

On the basis of lesion data, Lenneberg (1967) proposed that in the early years of life the two cerebral hemispheres are equipotential with respect to language representation. However, with maturation and exposure to environmental factors, in particular language experience, language functions become lateralized to the left hemisphere. The process of lateralization begins at the onset of language acquisition and appears to be completed by early puberty. It is assumed that neuronal plasticity underlies the development of functional lateralization. With increasing age neuronal plasticity decreases so that by adolescence or early adulthood, left hemisphere damage results in permanent impairment of language functions (Zangwill, 1975).

Although Lenneberg's (1967) theory apparently agrees well with the early lesion data, there is some evidence suggesting that it may have been overstated. It is possible that right hemisphere language that develops as a result of left cerebral insult is qualitatively different from left hemisphere language (Hécaen, 1976). In fact Dennis and Whitaker (1977) reported that two left-hemidecorticated children (with language in the isolated right hemisphere) showed a greater number of errors, compared to a right hemidecorticate, on tasks measuring the structural and syntactic aspects of auditory language. They concluded that the effects of early left-hemisphere damage on language are expressed in terms of delayed acquisition of word relationships, rather than as adult aphasic symptoms.

Furthermore, as Moscovitch (1977) pointed out, reconsideration of Basser's (1962) data suggests that there is a greater likelihood of language impairment following early left hemisphere damage. Of the 20 cases of hemiplegics who showed aphasic symptoms, 13 had left hemisphere lesions. In contrast, of the 10 cases who showed no language deficits, only two had left hemisphere lesions.

Another recent line of research has shed doubts on the concept of "developing lateralization" implied by Lenneberg's (1967) theory (Kinsbourne & Hiscock, 1977). Thus post-mortem examination of adult and infant brains showed that the left planum temporale, the auditory association cortex, is larger than the right in a significant proportion of the brains studied (Witelson & Pallie, 1973). Moreover, Wada, Clark and Hamm (1975) found that the morphological asymmetry of the planum temporale becomes measurable by the 29th week of gestation. Although anatomical asymmetry does not necessarily imply functional asymmetry, the implications of larger left than right planum temporale should not be ignored.

A number of studies involving eletrophysiological measures have indicated that functional hemispheric asymmetries may be present in neonates (Molfese, 1972; Crowell, Jones, Kapuniai & Nakagawa, 1973). Molfese (1977) reported that infants showed an asymmetric pattern of evoked potentials in response to verbal and non-verbal stimuli; thus, amplitude of evoked potentials was greater in the left hemisphere when speech sounds were presented. In contrast, non-verbal stimuli elicited larger amplitude of evoked potentials in the right hemisphere. Furthermore, this pattern was consistent with that found in children and in adults (Molfese, Freeman & Palermo, 1975). Similar results were reported by Glanville, Best and Levenson (1977) and by Best and Glanville (1978) when they used a measure of heart rate deceleration in conjunction with a dichotic-listening technique. Finally, Entus (1977) using the non-nutritive sucking paradigm in conjunction with the dichotic listening technique reported that neonates demonstrate a right-ear advantage in the perception of speech sounds and a left-ear advantage for the processing of non-verbal sounds. However, these results were not confirmed in two replication experiments carried out by Vargha-Khadem and Corballis (1979).

In addition to the electrophysiological data, there is evidence suggesting that functional hemispheric asymmetry using a behavioral response can be demonstrated in very young children. Kimura (1963) reported that children as young as four years showed a right-ear advantage in recalling dichotic digits. Nagafuchi (1970) obtained the same results with three year old children. However, despite the early appearance, the right-ear advantage does not increase with age (Geffner & Dorman, 1976; Kinsbourne & Hiscock, 1977).

Right hemisphere specialization for non-verbal processing has also been investigated in very young children. A left-ear advantage was reported with dichotic environemental and animal sounds (Knox & Kimura, 1970) and with morse-like patterns of sounds (Bakker, 1967).

The finding that anatomical and perhaps "functional" asymmetries may be present before language acquisition is inconsistent with early-lesion data and Lenneberg's (1967) theory which views the two cerebral hemispheres as equipotential and unspecialized until middle childhood. How can these two sets of data be reconciled?

Corballis and Beale (1976) proposed that the two hemispheres are indeed equipotential during early childhood; thus the right hemisphere is as capable as the left of mediating the development of language functions. However, there is a left-right maturation gradient that favors an earlier development of the left hemisphere compared to the right. As a result, the left hemisphere develops to mediate language functions because it matures slightly faster. In doing so, it gradually gains dominance over the right hemisphere with respect to language functions. However, left hemisphere dominance cannot be solely due to a developmental gradient, since the right hemisphere would be expected to eventually develop and achieve the same degree of specialization as the left hemisphere. Thus to account for the persistance of left hemisphere specialization through various developmental periods, Corballis and Beale (1976) further proposed that the left hemisphere exerts an inhibitory influence on the right during stages of language acquisition. Consequently, the right hemisphere does not develop its potential for language specialization. Should the left hemisphere then be damaged, the inhibitory influence would be removed and the right hemisphere would develop language, provided that neuronal plasticity still exists.

The process of maturation of the cerebral hemispheres may follow cyclical patterns. At different turns of the cycles, specific skills may become lateralized. The normal pattern of maturation is conceptualized as entailing a left hemisphere lead with some periods when the right hemisphere develops equally or temporarily surpasses the growth rate of the left hemisphere. During the periods of right hemisphere lead, specific skills may become lateralized to the right rather than the left.

Several implications follow from the concept of a maturational gradient favoring a particular direction of lateralization. First, in view of equal potential at the outset, the right hemisphere would be expected to have at least some language abilities. There is evidence suggesting that in fact the adult right hemisphere has language abilities equivalent to those found in five year old children (Zaidel, 1976). Second, the decline of the right hemisphere's ability to mediate language should be gradual. Thus, in case of left hemisphere damage, there would still be some linguistic base upon which further language development in the right hemisphere could be established. Third, it would be expected that, at least during the early years, there would be periods when the right hemisphere would not lag behind the left hemisphere in its language development. Thus, the dearth of reports on aphasic symptoms following early left-hemisphere lesions may in part be due to bilateral representation of some language functions (Basser, 1962; Lenneberg, 1967). Finally, in view of the maturational gradient favoring the lateralization of language functions to the left, the right hemisphere would be expected to gradually gain specialization only in those processes that can strictly be termed non-verbal. Experimental evidence to date has borne out this expectation (Broadbent, 1975). As Corballis and Beale (1976) summarize:

> "An asynchrony between the hemispheres would serve two important functions. It would permit the representation of some complex processes, such as language, to become lateralized in the brain. Second, it would allow a degree of flexibility and plasticity in the representation of lateralized skills. In particular, a right-hemisphere lag would permit this hemisphere to take over control, although perhaps at the expense of other functions, if the left hemisphere is damaged." (p. 128)

The apparent inconsistency between early-lesion data and evidence of early signs of hemispheric specialization can also be resolved if lateralization is considered as a multifaceted rather than a unitary process. Porter and Berlin (1975) suggested that different linguistic processes may become lateralized at different stages of development. Moscovitch (1977) proposed that the processes of left-hemisphere language specialization would begin with the lateralization of the phonetic-phonological system and gradually extend to the lateralization of the semantic and systactic systems. Furthermore, he argued that the majority of the developmental studies have used laterality tasks that tap only the lowest levels of linguistic processing - i.e. the phonetic level. In contrast, there are no normative studies of the development of lateralization with respect to the more complex aspects of syntax and semantics.

Infants are capable of making subtle phonetic (Eimas, Siqueland, Juscyzk & Vigorito, 1971) and rhythmic (Chang & Trehub, 1977) distinctions during the first few weeks of life. By early childhood these phonetic distinctions are predominantly made by the left hemisphere (Berlin, Hughes, Lowe-Bell & Berlin, 1973; Dorman & Geffner, 1974; Geffner & Dorman, 1976). However, during the first few years of life other language functions develop rapidly to represent much of the linguistic complexity found in adult language (Brown, 1973). It is possible that "development of lateralization " in the sense used by Lenneberg(1967) applies to the more complex linguistic aspects of syntactic and semantic relations. Thus the conclusion that cerebral dominance for language is innate (Kinsbourne & Hiscock, 1977) may only pertain to the simple phonetic levels of linguistic processing that may exist from the outset, and that have been tapped most often by conventional laterality tests.

Moscovitch (1977) proposed that during the early periods of language acquisition, at least some of the cognitive abilities involved in language are represented in the right hemisphere, although the majority are located in the left hemisphere. In some cases, the contribution of the right hemisphere to these linguistic skills is critical so that right hemisphere insult results in dysphasia or mutism (Hécaen, 1976). With further development, these cognitive abilities may either assume a peripheral role in maintaining language or they may migrate and become integrated into the already developed linguistic system of the left hemisphere.

Another alternative would be that all language functions are lateralized to the left. Thus both phonetic and sensorimotor representations, upon which semantic and syntactic systems are based, are lateralized to the left hemisphere from the very beginning, even before speech has developed (Moscovitch, 1977). Although both alternatives are plausible, there is little direct evidence to allow an unequivocal conclusion as to which, if any, is more viable.

Visual Laterality Effects

Forgays (1953) postulated that a right visual-field superiority for the perception of verbal stimuli would be demonstrated in young (2 - 6th grade) children. Furthermore, he predicted that the right visual-field advantage would increase with age, indicating a decrease in the equipotentiality of the cerebral hemispheres. Although the predicted results were obtained (in sixth graders only) and interpreted as supporting the hypothesis of decreasing equipotentiality, later research with adult subjects showed that the right visual-field advantage may have been partly caused by left-right directional scanning underlying reading habits (White, 1969; Broadbent, 1975). In order to disentangle the effects of scanning from left-hemisphere specialization for language, subsequent adult studies used unilateral rather than bilateral, and vertical rather than horizontal, arrangement of verbal stimuli (for extensive reviews, see White, 1969; 1973). Furthermore, McKeever, Suberi and Van Deventer (1972) introduced the technique of "fixation digits" in order to control for anticipatory eye movements during stimulus presentations. With these modifications in test procedures scanning effects were ruled out, and the right visual-field superiority was still consistently obtained (Hines, 1975; Hines, 1976) . In contrast, the majority of the developmental studies involving verbal material have used horizontally-arranged unilateral presentations with no fixation controls (McKeever & Huling, 1970; Miller & Turner, 1973; Marcel, Katz & Smith, 1974; Marcel & Rajan, 1975). Consequently, it is difficult to determine whether the right visual-field advantage obtained with young children indicates left hemisphere specialization, scanning habits derived from reading, or scanning habits not derived from reading, particularly in the case of pre-readers.

Kershner, Thomae and Callaway (1977) tested 5-6 year old children on a tachistoscopic task involving bilateral presentation of digits. Subjects were asked to give a verbal report of the digits seen. When a digit appeared at the fixation point to control for eye movements, a right visual-field superiority was obtained. However, when a non-verbal central fixation stimulus appeared, a left visual-field superiority in the recall of digits was demonstrated. The authors concluded that visual laterality effects are influenced by both test stimuli and experimental procedures.

Witelson (1977a) presented 6-14 year old boys with unilateral pairs of same or different letters that were arranged vertically to rule out scanning effects. Subjects were required to judge whether the letters seen were the "same" or "different". A right visual-field effect was obtained only in the 6-7 year old subgroup. Witelson (1977b) suggested that at younger ages, when children are just learning the alphabet and the visual representation of the phonetic code, substantial linguistic processing may be involved in the perception of letters. However, with increasing age and more experience with simple letters, children may simply make a "physical match" of linguistic stimuli without requiring linguistic processing (Geffen, Bradshaw & Nettleton, 1972; Cohen, 1972).

Yeni-Komshian, Isenberg and Goldberg (1975) presented 10-13 year old children with unilateral single digits and vertically-arranged words. A right visual-field superiority was not obtained for recall of either type of stimuli, even though there were no ceiling or floor effects. An ad hoc explanation of these results may be that the fairly long exposure durations (189 msecs) allowed eye movements to bring the lateralized stimuli into central vision.

There is also evidence indicating that reading experience may be related to performance on visual-laterality tasks. Thus Miller and Turner (1973) found that Stanford Reading Achievement scores of grade children correlated strongly (.60) with the demonstration of a right visual-field advantage on a words task. This correlation was maintained even when the effects of age were partialled out. Similarly, Marcel, Katz and Smith (1974) reported that good readers (between the ages of 7-9) showed a strong right visual-field effect on a verbal task, whereas poor readers showed a left visual-field advantage. Given the left visual-field preference of the poor readers, Marcel et al. (1974) concluded that one cannot assume a linear relationship between right visual-field effects and scanning tendencies that increase with improved reading skills. Phippard (1977) has suggested that visual-scanning tendencies may improve as a result of the maturational process rather than as a consequence of reading experience. Thus the correlation between right visual-field advantage and reading skills (Miller & Turner, 1973) may reflect both the development of a perceptual process and the effects of training.

In summary, these results suggest that the demonstration of right visual-field effects in young children is often hampered by methodological problems that render an unequivocal interpretation difficult. Furthermore, as Kershner et al. (1977) pointed out, the validity of the assumption that visual tachistoscopic tests reveal fixed or developmentally graded hemispheric differences is open to question.

In contrast, the interpretation of visual-field differences for the perception of non-verbal material in children is much less complicated. Since left visual-field effects cannot be due scanning tendencies associated with reading skills, right hemisphere specialization may be considered a plausible explanation of the visual-field difference. Thus, Young and Ellis (1976) tested children aged 5,7 and 11 years on a face recognition tachistoscopic task. Results indicated a left visual-field superiority at all three ages. The authors concluded that right hemisphere specialization for the processing of non-verbal visual information is present by age five.

Witelson (1977a) presented 6-13 year old children with pairs of same or different vertically-arranged pictures of human figures. Children were asked to distinguish the pictures seen as same or different. Significantly greater recognition scores were found for the stimuli presented to the left visual-field. This effect was evident across all age groups.

Similarly, Marcel and Rajan (1975) used the exposure duration necessary for correct recognition as a measure of visual-field asymmetry for unilaterally presented faces. Children ranging in age from 7-9 years were asked to recognize the stimulus from an array of two. The criterion of three consecutive correct responses was achieved at significantly lower exposure durations in the left visual-field.

Leehey (1976) reported that children from the age of ten onwards show a left visual-field advantage for the recognition of unfamiliar faces. However, when highly-familiar faces are presented, children as young as eight years (the youngest age group tested) show a left visual-field advantage. To the extent that the processing of unfamiliar faces may require more experience, it can be concluded that with maturation different aspects of right-hemisphere specialization become lateralized.

Several experiments with adult subjects have shown that a left visual-field advantage is demonstrated in the recognition of the spatial orientation of slanted lines (Fontenot & Benton, 1972; Atkinson & Egeth, 1973; Kimura & Durnford, 1976). In contrast, Reitsma (1975) reported that children (in the 6-8 year-old range) showed no visual-field differences in the recognition of slanted lines that were presented unilaterally. However, Phippard (1977) obtained a left visual-field effect with the same type of stimuli in adolescents ranging in age from 13 to 19 years.

Similarly, enumeration of a group of tachistoscopically presented dots has been found to be more accurate in the left visual-field in adult subjects (Kimura, 1966). However, a modification of this task presented to children between the ages of 6-14 showed only a tendency for greater accuracy of enumeration in the left visual-field (Witelson, 1977a).

Although there are inconsistencies in the reports of visual-field differences (for the recognition of verbal and non-verbal stimuli) in middle childhood, the adult pattern of visual-field asymmetry appears to have emerged by early adolescence (Phippard, 1977); these results suggest that functional specialization of the two hemispheres may be essentially complete by this age (c.f. Lenneberg, 1967).

Auditory Laterality Effects

Unlike visual-field differences, auditory laterality effects seem to be a more direct consequence of hemispheric specialization. Numerous studies over the past two decades have established the validity of the dichotic-listening technique (Broadbent, 1954; Kimura, 1961a; 1961b) in assessing the relationship between hemispheric specialization and auditory laterality (for reviews see Knights, 1970; Witelson, 1977b). On the basis of electrophysiological evidence (Rosenzweig, 1954) indicating that each ear has its strongest connection with the opposite hemisphere, a right ear advantage in the perception of verbal stimuli indicates left hemisphere specialization for the processing of language.

Although the early evidence for left-hemisphere language specialization in children came from studies of brain-damaged patients (Basser, 1962), the majority of subsequent research has come from dichotic -listening studies carried out with normal children. A significant right-ear advantage has been found in children as young as three years of age (Nagafuchi, 1970; Yeni-Komshian, 1973; Ingram, 1975; Kinsbourne, Hotch & Sessions, 1977) for a variety of linguistic stimuli: digits (Hiscock & Kinsbourne, 1977;Witelson, 1977c);words (Nagafuchi, 1970; Ingram, 1975; Schulman-Galambos, 1976; Piazza, 1977); CV syllables (Geffner & Dorman, 1976; Bryden, Allard & Scarpino, 1973); and words within a sentence (Ingram, 1975).

In contrast, a left-ear superiority in the perception of non-verbal sounds has been demonstrated less often in young children.However, the limited evidence in this area suggests that a left-ear advantage can be demonstrated as early as age three. Piazza (1977) presented children aged three, four and five years with a dichotic tape of environemental sounds. Half the subjects reported verbally the name of the sounds they heard, whereas the remaining half pointed to pictures that depicted the sounds. Results indicated a significant left-ear superiority in each of the three age groups, irrespective of the response mode. These results are consistent with those reported by Knox and Kimura (1970) who originally devised the environemental-sounds test. In that study, children ranging in age from five to eight years were tested with dichotic environemental and animal sounds. A significant left-ear advantage was demonstrated overall for the perception of environemental sounds; However, no overall ear difference was found for the animal sounds test.

Bakker (1967) used a monaural technique to assess ear asymmetry in the perception of Morse-like sound patterns. Each pattern consisted of three to five elements. Children, ranging in age from six to twelve, were asked to reproduce the pattern using a buzzer. Results indicated a left-ear advantage up to the age of ten. However, after age ten the left-ear advantage was attenuated.

A current issue is whether the magnitude of the right-ear advantage increases with age in young children. Although there is no reason to assume that the dichotic-listening technique is sensitive enough to demonstrate subtle changes in hemispheric specialization, there is some evidence to suggest that the magnitude of ear asymmetry and the degree of hand preference (and by implication hemispheric dominance) are correlated (Shankweiler & Studdert-Kennedy, 1975). However, as Witelson (1977d) pointed out, a major confounding factor in the interpretation of increasing ear differences is that overall accuracy is related to the size of ear asymmetry. In an effort to resolve this problem, Krashen (1972) reanalyzed earlier dichotic studies carried out with young children so as to partial out the effects of increasing overall performance due to age. He reported no change in the magnitude of ear asymmetry as a consequence of increasing age. Recent studies involving analyses that compensate for higher accuracy as a function of age have corroborated Krashen's (1972) results (Berlin, Hughes, Lowe-Bell & Berlin, 1973; Borowy & Goebel, 1976; Hynd & Obrzut, 1977; Schulman-Galambos, 1977).

There is some evidence suggesting that the early demonstration of a right-ear advantage may be related to environemental factors, in particular, socioeconomic class. Kimura (1967) presented one, two and three pairs of digits to children (aged five to eight years) from low and middle socioeconomic levels. She reported that a significant right-ear advantage was obtained in every subgroup except in five year old boys of low socioeconomic class. Similarly, Geffner and Hockberg (1971) did not find a right-ear superiority until the age of seven in their low socioeconomic sample. In contrast, children from middle socioeconomic levels demonstrated a right-ear advantage from the age of four onwards.

Although the absence of a right-ear advantage was only observed in boys of a low socioeconomic level (Kimura, 1967), there is evidence to suggest that this discrepancy is specifically related to socioeconomic status and not to sex differences (Geffner & Hockberg, 1971; Borowy & Goebel, 1976). Borowy and Goebel, (1976) assessed the effects of age, sex, race and socioeconomic level on the demonstration of a right-ear advantage. They reported that all subgroups showed a right-ear advantage; however, children from middle socioeconomic levels showed a significantly greater ear asymmetry than children from low socioeconomic levels.

Tactual Laterality Effects

Relatively little is known about hemispheric specialization for perceptual functions in the tactual modality. Until very recently, the limited evidence in this area was almost exclusively provided by studies of commissurotomized patients (Nebes, 1974) or of patients with right or left cerebral damage (Corkin, 1965; Fontenot & Benton, 1971;Milner & Taylor, 1972;Boll, 1974). However, recently a number of researchers have reported between-hand differences in the tactile perception of stimuli by normal subjects (Gardner, English, Flannery, Hartnett, McCormick & Wilhelmy, 1977;Benton, Varney & Hamsher, 1978;Dodds, 1978).

Hand asymmetries have only been obtained with non-verbal stimuli such as random forms (Gardner et al. 1977; Dodds, 1978), slanted lines (Benton et al. 1978) and nonsense Braille configurations (Rudel, Denckla & Hirsch, 1977). In all reported cases the left hand (and by implication the right hemisphere) was superior to the right hand in accuracy of recognition and in response latency.

Although the evidence is limited, the same pattern appears in children. Thus, Hermelin & O'Connor (1971) reported a significant left-hand superiority in the reading of Braille by blind children and adults. This superiority was reflected in either speed, or speed and accuracy, of Braille reading. Similarly, Rudel, Denckla and Spalten (1974) compared the performance of the two hands in tactile perception of Braille letters. Their subjects were sighted boys and girls ranging in age between seven and fourteen years, who had been trained to recognize the meaning of the Braille letters. Results indicated that by age fourteen both boys and girls showed a left-hand superiority;the preference appearing by age 11 in boys and by age 13 in girls. A later study (Rudel, Denckla & Hirsch, 1977), involving non-linguistic Braille configurations, confirmed the previous findings. This suggests that despite their linguistic characteristics, Braille stimuli are predominantly processed as spatial information.

Witelson (1974) used a dichaptic tactile-stimulation technique to investigate verbal and non-verbal perceptual functions in boys ranging in age from six to 14 years. Subjects palpated two simultaneously presented letters or random shapes and were asked to recognize them from a visual array. Since there is evidence indicating that most fine hand and finger responses are directed by the contralateral hemisphere (Berlucchi, Heron, Hyman, Rizzolatti & Umilta, 1971; Boll, 1974), gross arm movements were restricted and tactile exploration was carried out by the two index fingers. Witelson (1974) reported a significant overall left-hand superiority for the random shapes but only in the condition where this task was administered prior to the "verbal" task. The author concluded that right-hemisphere specialization for the processing of non-verbal tactile stimuli can be demonstrated as early as age six. Witelson's (1974) findings have been replicated with adult subjects (Gardner et al. 1977). However, it is not yet known whether these results are consistent in children.

It must be noted that to date there is no indication of any hand asymmetry in the perception of "linguistic" tactile stimuli. Both Witelson (1974) and LaBreche, Manning, Goble and Markman (1977) investigated whether or not a right-hand superiority could be demonstrated in the tactile perception of letter pairs. Witelson's (1974) results showed a non-significant tendency for right-hand superiority. However, LaBreche et al.'s (1977) results showed an overall right-hand superiority for the perception of nonsense shapes as well as letter pairs. In this case, the results may be attributed to right-hand dominance and not to underlying hemispheric specialization.

Finally, there is some indication that a sex difference in favor of males with respect to right hemisphere specialization may exist (for an extensive review, see Harris, 1976). In the tactile modality, the work of Rudel et al. (1974; 1977) and of Witelson (1976) lend support to this view. However, as is the case with sex differences in left hemisphere specialization, it is difficult to assess whether these differences are in fact consistent.

CHAPTER II

CONGENITAL DEAFNESS AND COGNITIVE DEVELOPMENT

Cognitive Abilities in the Deaf

Traditionally, deaf persons' inability to master the subtleties of spoken and written language was said to reflect their poor intellectual development. In fact, much of the psychological research prior to the 1960's characterized thinking in the deaf as fundamentally inferior to thinking in the hearing (cf Mykelbust, 1960). However, during the 1960's several sources of evidence indicated that non-verbal cognitive processes were closely similar in deaf and hearing subjects (for a review, see Furth, 1966). For example, despite a general linguistic deficiency, deaf children were found to perform as well as hearing children on tasks assessing rule learning (Blank & Bridger, 1966; Weigl & Metze, 1968); use of imagery in perception (Bugelski, 1970); and development and use of logical symbols (Furth, 1966; Furth & Youniss, 1965). Furthermore, despite a developmental lag, the performance of deaf children was found to be qualitatively similar to the hearing on some Piagetian tasks involving transitivity (Youniss, 1967) and formal operations (Furth & Youniss, 1969). On the basis of these results, Furth (1971; 1973) proposed that the deaf, lacking a ready-made systematized language, construct their own symbols for the development of thinking and that development of thinking and reasoning capacity is not related to linguistic competence.

In the early 1970's researchers finally realized that the deaf do indeed possess a highly structured system of communication in sign languages. The fast-accumulating research in this area clearly indicates that sign language is indeed a "true language", comparable to any other, since it is comprised of a finite set of rules which generate an infinite variety of sentences (Abbott, 1975). Furthermore, longitudinal studies of children acquiring sign language at very young ages indicate that the stages of sign language development closely resemble those of spoken language (Klima & Bellugi, 1972; Schlesinger & Meadow, 1972; Nash, 1973). Thus despite a temporal lag, development of cognitive processes and language competence (in sign language) seem to be analogous in the deaf and the hearing.

This is not to suggest, however, that differences in favor of the hearing with respect to rate and at times style of cognitive growth do not exist. Quite apart from the low standard of English language competence observed in the deaf, deficiencies are also observed in some cognitive tasks where neither language mediation nor problem conceptualization are required.

The following section analyzes differences between the deaf and the hearing that cannot be related to skills which the deaf do not possess (i.e., acoustic mediation; efficient mnemonics in short term recall). Such an analysis can provide insight into the role of various factors involved in cognitive processing.

Non-verbal perceptual tasks. Unlike vision which deals with patterns in space, audition deals primarily with patterns in time. Since deaf children are deprived of the major source of the "time sense" (Fraisse, 1963), the question arises as to how they process time-dependent phenomena such as sequential events and rhythmic patterns. Although seemingly unrelated, such phenomena are critical and necessary features of spoken and written language (Furth, 1971).

Perception of rhythmical sequences in the deaf has been investigated using the paradigms of pattern recognition and pattern reproduction. Studies involving auditory and tactile pattern-recognition have not found significant differences between deaf and hearing subjects (Rosenstein, 1957; Kracke, 1975). In contrast, studies involving pattern reproduction have revealed substantial deficits in deaf subjects (Sterrit, Camp & Lipman, 1966; Rileigh & Odom, 1972; Wolff, 1979). Furthermore, the deficits reflected a generalized central deficit not specific to the deprived modality.

Only one of these studies provided information on the language background of the deaf subjects (Wolff, 1979). If perception of rhythm and sequential patterns is indeed fundamental to decoding language, then not only relative skill in linguistic communication but also the type of communication might influence performance on sequential-rhythmical tasks. This is particularly important since the communication mode of most deaf persons (i.e., sign language) may involve different styles of perceptual processing (Klima, 1975; Stokoe, 1975). For example, sign language predominantly involves simultaneous as opposed to sequential processing. Thus deaf signers would be expected to perform poorly compared to hearing controls on tasks involving sequential processing.

Wolff (1979) provided some support for this view. He presented rhythmical patterns in the visual and tactile modalities to deaf* signers

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*Deaf subjects who participated in Wolff's (1979) studies also comprised the experimental group of the present series of experiments.

(instructed by the total communication method) and hearing controls. Subjects, ranging in age from 11 to 17 years were then required to reproduce the patterns. Deaf signers performed worse on this task than hearing controls, particularly in the visual modality. One possible interpretation is that deaf signers perform poorly on rhythmic-sequential tasks because their language is simultaneous and they therefore suffer an experiential deficit. Alternatively, their poor performance may directly reflect their sensory deficit. Whatever the explanation, it cannot be ascertained, on the basis of existing data, whether the obtained differences reflect a deficiency in central perceptual processing or a lack of sophistication of response output.

Besides perception of rhythmic sequences, other types of nonverbal perceptual tasks also differentiate between the performance of deaf and hearing subjects. However, in some cases the difference seems to reflect a developmental lag rather than a deficit as such. Thus Oleron & Gumusyan (1964), using a recognition paradigm, tested 4- to 6-year-old deaf and hearing children on an embedded-figures task. The deaf group consistently scored lower than the hearing group. However, the difference was signficant only at the younger ages. Similarly, Yashkova (1966) tested the ability of 5- to 11-year-old deaf and hearing children to produce reverse drawings of geometric figures. While older deaf children did not perform differently from hearing controls, younger deaf children performed poorly compared to controls. Deaf children spontaneously discovered a reversal technique only at 8 years, three years later than hearing children.

Memory tasks. Studies concerning short-term memory in the deaf have indicated deficits in overall span (Blair, 1957; Springer, 1973). However, overall capacity is strongly affected by various factors, notably the overall content of the stimulus set. In general, the performance of deaf subjects parallels and at times surpasses that of hearing subjects on recall tasks that are non-verbal and have spatial information in the stimulus set.

Blair (1957) compared the performance of deaf and hearing children on a sequential block tapping task (Knox Cube Task). In this task, the subject is required to reproduce, immediately after demonstration, increasingly difficult sequences of movements tapped by the experimenter. Deaf children performed better than hearing controls. Blair (1957) also compared the performance of deaf and hearing subjects on a short-term recall task involving geometric forms. Subjects were presented the forms singly for two seconds and were then required to reproduce immediately on paper the perceived figure. Once again, the deaf were superior to the hearing on this task. Finally, Fuller (1959) found that deaf children had better recall for motor mazes (Van der Lugt Test of Motor Memory) than did hearing children.

These and other similar results led to the conclusion that the deaf are more efficient compared to the hearing in recalling stimuli that are characterized by their spatial configuration (Blair, 1957; Myklebust, 1960). However, spatial information alone is not a sufficient criterion for better performance. For example, deaf children made significantly more errors compared to hearing children in recalling consecutively-presented pictures of familiar and unfamiliar objects (Rozanova, 1966;

Blair, 1957). On these tasks the spatial information contained in pictures did not particularly facilitate recall in deaf subjects. This however may have been due to consecutive presentation of the stimuli. Youniss and Furth (1966) reported that deaf children scored lower than hearing children on a task that measured recognition of temporally-ordered drawings of familiar and unfamiliar objects. Similarly, Withrow (1968) investigated recall of simultaneously and successively-ordered visual stimuli in deaf and hearing subjects. The stimuli used were geometric forms, familiar objects and random forms. Results indicated hearing children's recall was superior to the deaf when stimuli were presented successively, but there was no significant difference between groups with simultaneous presentation. In contrast to hearing subjects who found the effects of successive presentation facilitating, the deaf showed similar mean scores on both conditions. These results support the general finding that the deaf, particularly at younger ages, are hampered in recall by tasks that emphasize sequential and successive orders of stimulus presentation and recognition (Furth & Pufall, 1966). Once again, deficits in recall of sequentially-ordered stimuli have been linked to the relative linguistic inexperience of the deaf (Furth, 1971; Odom & Blanton, 1967a; O'Connor & Hermelin, 1965).

Piagetian tasks. Performance of deaf children on Piagetian tasks, particularly those pertaining to concrete operations, has attracted much attention. This is particularly due to the fact that as a "linguistically-deficient group", the deaf can provide valuable information on the role of language in cognitive development. Piaget (1954; 1966) has explicitly stated that language is subordinate to thinking and cognitive performance.

However, it is a necessary, albeit an insufficient condition, for the development of logical thought. Piaget's position is supported by a number of researchers (Oleron, 1975; Caouette, 1974) who report that the deaf lag behind the performance levels of the hearing on concrete operational tasks. The observed lags are attributed to the language deficiency of the deaf. Piaget himself (1966) seems to support the notion of minimal differences between the deaf and the hearing. However, he attributes observed developmental lags to an inability to communicate the task requirements to deaf subjects.

Another group of researchers, who also view the deaf as linguistically deficient, de-emphasize the role of language in the development of logical thought (Furth, 1966; Youniss & Robertson, 1970; Youniss, 1967). They have failed to find clear differences between the deaf and the hearing on Piagetian tasks of concrete operations (Youniss & Furth, 1965; 1966; Robertson & Youniss, 1969). When differences in favor of the hearing have been reported, they are attributed to experiential, as opposed to linguistic deficits (Furth, 1966; Furth & Youniss, 1969).

Unfortunately several problems and misconceptions have plagued the research of both groups. First, the majority of research carried out on Piagetian tasks has not differentiated between deaf subjects on the basis of method of language instruction and proficiency in sign language. If the deaf are indeed linguistically different from the hearing in both the use and processing of language then tasks should be modified to evaluate their cognitive abilities in their own language.

Second, most Piagetian tasks of concrete operations have verbal instructions that must be rendered non-verbal in the case of deaf children.

This is essential since deaf children who are in the appropriate age range for the administration of concrete-operational tasks (between 6-8 years) are not yet efficient users of spoken and written language. In order to overcome this problem, some authors have resorted to devising non-verbal techniques for communicating task requirements to deaf children (Oleron & Herren, 1961; Furth, 1964; Caouette, 1974; Springer, 1978). Although the use of diverse non-verbal procedures has raised serious methodological problems, the efficacy of at least one of these procedures has been verified (Springer, 1977) against standard norms reported by Piaget (1952).

Despite the fact that these studies have found varying numbers of lag years depending on the type of non-verbal procedures used, they are consistent in their reports that deaf children lag behind hearing children on conservation tasks. The lag periods range from 1½ years (Furth, 1966) to 6 years (Caouette, 1974). Contrary to Piaget's (1966) suggestion, these lag years cannot be attributed to difficulties in communicating task requirements non-verbally. However, on a more speculative basis, they can be related to the relative language deficits of deaf children at the concrete-operational stage (Oleron, 1975; Caouette, 1974). Springer (1977) tested a small group of deaf native-signers on two types of conservation tasks involving non-verbal procedures. He found that whereas deaf non-signers showed lag periods of 1 to 4 years, the performance of deaf native-signers was similar to hearing children. In particular, they conserved without recourse to additional instruction. In contrast, a great percentage of deaf subjects conserved only after additional instruction. These results suggest that deaf children who are exposed to a language system early in their life have a better chance of acquiring enough experience with language skills to be able to perform on conservation tasks by the appropriate age. Those deaf children who are not taught any systematic language until they enter school do not acquire language fast enough or adequately enough to be able to perform according to normal hearing standards.

In this regard, language experience may play a large role in conservation tasks even when the procedures are rendered non-verbal. For example, hearing children who have experience with intonation, facial expressions and inflectional cues may be more sensitive to the double meaning of questions such as "Which beaker has more?". A comparison can be made on the basis of apparent volume or objective volume. It is possible that because of their extensive language experience and use of cues, hearing children readily realize the subtle distinction between apparent and objective volume. In this sense performance on non-verbal conservation tasks may still be mapped on to verbal experience. Thus deaf children who lack verbal expertise and enough experience with language to have gained sensitivity to verbal subtleties, fail to conserve according to hearing norms.

The Substitute for the Speech Code

The prominent role of the "speech code" in hearing individuals can hardly be underestimated. Quite apart from its efficient manner of information transmission and its syntactic complexities, the speech code occupies a pre-eminent role in short-term memory; according to Sperling (1960; 1967) short-term memory for language is basically auditory.

Given the limited capacity of the deaf for speech production and perception, the question naturally arises as to how linguistic items are coded in their short-term memory. It is conceivable that in the absence of the "speech code" the deaf may use orthography, dactylography, visual imagery, semantics, manual signs or combinations of these to encode linguistic items. There is some evidence indicating that each of these codes may predominate depending on task demands, relative skill of the subjects in various methods of communication, degree of hearing loss, and age of onset of deafness (Bonvillian, Nelson, & Charrow, 1976). For example, Locke (1970; Locke & Locke, 1971) presented letter pairs in a delayed-recall paradigm; letter pairs were similar either visually, phonetically or dactylically. They compared the number of errors observed with different types of letter pairs in two groups of deaf (intelligible or unintelligible oral language) and in hearing subjects. They found that hearing controls made the most errors on the basis of phonetic similarity. In contrast, the deaf groups made few errors resulting from phonetic confusion. They made frequent errors on letter pairs which were similar visually and/or dactylically. Errors of this type were somewhat less frequent in the deaf group with intelligible speech and minimal in the hearing control group. Similarly, Conrad (1970; 1972) concluded that deaf subjects who rely on the visual properties of letters in encoding them for short-term memory have poorly-developed oral language skills. Apparently, besides restricting articulatory output, profound hearing loss also results in the use of different memory codes.

If the deaf do encode the visual properties of letters in short-term memory, which code do they use in the processing of words? Of course processing of words is more complex since they possess semantic properties in addition to phonetic and orthographic properties. Studies with normal hearing children have indicated that phonetic factors retain predominance in short-term recall of words only up to a certain age (Felzen & Anisfeld, 1970; Bach & Underwood, 1970). Thus, in a recognition paradigm, young children (up to age 9) give more false-recognition responses to words that are phonetically related to words previously seen, while older children (up to age 12) give more false-recognition responses to words that are semantically related (Felzen & Anisfeld, 1970).

Frumkin and Anisfeld (1977) investigated whether the same pattern of phonetic-semantic shift characterizes short-term memory for words in deaf children. They reported that young deaf and hearing subjects showed false-recognition responses to previously-seen words that were orthographically similar (orthographic effect) and to those that were semantically similar (semantic effect). However, the semantic effect was stronger in young deaf but not hearing subjects. Older deaf subjects also showed a strong semantic effect. These results suggest that deaf children encode both the orthographic shape and the semantic content of words. Similarly, Tweney, Hoemann and Andrews (1975) found that deaf and hearing subjects organized linguistic items (such as noun words, line drawings of noun words and words referring to specific sounds) according to categories that were semantically related.

Several recent studies have addressed the question of the role of manual codes in short-term recall of the deaf (Bellugi, Klima, & Siple, 1975; Bellugi & Siple, 1974; Moulton & Beasley, 1975). According to Stokoe (1960) the following parameters govern the distinction of signs in American Sign Language: 1) hand configuration, 2) place of articulation, 3) movement and orientation. On the basis of these parameters, Bellugi and Klima (1975) have proposed a model of short-term memory in the deaf which consists of coding of signs. Deaf subjects presented with a list of signs store and recall particular primes of these four parameters. Similar to the "errors of intrusion" measure, the simplest error in this model would constitute the recall of an inappropriate prime of any one of the major parameters.

To some extent, experimental evidence supports the notion that signs may substitute for the speech code in the deaf. For example, Bellugi and Klima (1975) presented a series of ASL signs to deaf subjects born of deaf parents. These signs varied in series length from three to seven, and were delivered at the rate of one sign per second. Recall was immediate and subjects were required to write the English equivalent of the signs in the order seen. A control group of hearing students received the same task except that they were presented with English-word glosses of the signs on videotape. Analysis of errors-of-intrusion made by deaf subjects indicated that errors were similar to the original sign but differed in terms of an aspect of manual formation. Bellugi and Klima (1975) report that two-thirds of the intrusion errors of the deaf subjects differed from the corresponding original signs in only one of the three parameters. This suggests that the formational properties of signs were stored in short-term memory. Semantic similarities between errors of intrusion and the original signs were also found with the effect being greater for the deaf subjects compared to the hearing. This however, may only indicate the greater overlap between semantic similarity and formational similarity (Bellugi, Klima, & Siple, 1975). In contrast to the deaf, errors of intrusion made by hearing controls tended to be similar to the original words in terms of sound composition. Interestingly, there was no overlap between the deaf and hearing subjects in terms of patterns of errors, suggesting that in fact different strategies for encoding may be operating in each group.

The earlier work of Bellugi and Siple (1974) also provided evidence for the stability of the strategies which the deaf use in short-term recall. In a task similar to the one described above, deaf subject's responses in ASL signs and in translations into written English words were compared. In this comparison, considerable overlap was found, in terms of intrusion errors, between the two tasks. Thus the same type of intrusion errors were made when responses were made in ASL as were made in written English translation equivalent of signs.

In general, the above studies suggest that there are similarities between the role of manual signs and the role of speech in short-term memory. However, the critical characteristic of the speech code in normal hearing subjects is that it predominates even in a non-speech medium by the recoding of the stimuli into phonetic form. Such a recoding of course was not demonstrated by Bellugi et al. (1975); no recoding was necessary since subjects were presented signs presumably in the coded form.

Conlin and Paivio (1975) addressed the problem of sign coding of material presented in word form. A 20-pair list of words was shown to deaf and hearing subjects at the rate of 4 secs/pair. Subjects recalled the words after studying the list during 3 study trials. Word pairs were subcategorized into high and low imagery and high and low signability. High-signability words were those that had readily available sign equivalents`while low-signability words were those that could not be communicated readily in sign form. For both groups, more high- than low-signability words were learned but the facilitative learning effect of high-signability words was greater for the deaf than for the hearing. If there were no intrinsic difference between high- and low-signability words, then these results would provide strong evidence for the coding facility of signs. However, since hearing subjects also found recall of high-signability words easier, the objective distinguishing features of high- and low-signability words are equivocal.

At least two studies stress the semantic coding of signs in addition to the formational coding. Frumkin and Anisfeld (1977) presented a series of manual signs on videotape to deaf children. False-recognition responses were found for both semantically-similar and cherologically-similar signs (i.e., signs which are similar in their formational characteristics). Similarly, Moulton and Beasley (1975) presented severely hearing-impaired children word-pairs differing on the following dimensions: 1) similar sign, dissimilar meaning; 2) similar sign, similar meaning; 3) dissimilar sign, similar meaning and 4) dissimilar sign, dissimilar meaning. Subjects replaced the missing word of a pair after having studied all the pairs during study trials. Results showed that subjects were able to recall the information on the basis of both semantic and sign codes: however the semantic code appeared to be more efficient.

According to Frumkin and Anisfeld (1977) the test of the strength of a code lies in its ability to hold information in encoded form for long periods of time (Anisfeld, 1969; Nelson & Davis, 1972). The formational aspects of signs predominate in short-term memory over fairly long time intervals (Conlin & Paivio, 1975). However, the formational code does not seem to be operating exclusively. Evidence by Frumkin and Anisfeld (1977) suggests that the semantic code also prevails. Thus it appears that neither code possesses the power to predominate exclusively in short-term memory of the deaf the way the speech code does in hearing subjects. Alternatively, it is possible that deaf children can switch codes and use one system as opposed to another depending on the communication requirements of the situation.

Encoding Information in Sign Language

Linguists have generally thought that sign language of the deaf is largely iconic and resembles pantomime in communication. However, in recent years studies have indicated that sign language possesses many, if not all, of the features necessary to make it a natural language (Bellugi & Fisher, 1972; Stokoe, 1975; Klima, 1975). Rather than detract from the sophistication of the language, the fact that the visual-spatial mode of communication provides certain features can be considered as a definite advantage. Furthermore, the grammatical aspects of different sign languages outweigh the iconic or gestural features (Stokoe, 1975). If this were not the case, then deaf individuals would have no difficulty following the conversation of deaf persons using an unfamiliar sign language. In fact analysis of American Sign Language (ASL) has revealed that it differs from other sign languages in both sentence structure and construction of individual signs (Jordan, 1975; Jordan & Battison, 1976).

Despite its iconic features, sign language, like all vocal languages, is categorical since the meanings associated with most individual signs are arbitrary (Bonvillian, Nelson, & Charrow, 1976; Stokoe, 1975). In addition, analysis of changes over the past 100 years have indicated that the iconicity associated with signs is gradually disappearing with signs becoming conventionalized and symbolic (Frishberg, 1975).

American Sign Language differs from vocal language in several fundamental ways. First, it does not have "features" as such. In his earlier work, Stokoe (1960) had ascribed a phoneme-like status to the three aspects (cheremes) in ASL of hand configuration, place of articulation and movement and/or orientation. Somewhat later, Stokoe (1975) proposed that all signs, at least in ASL, could be constructed out of 16 "features". However sign "features" are not analogous to phonemes since they do not represent segments. Furthermore, they are not predominantly perceived sequentially like the phonemes of a syllable, but rather simultaneously. The observation that sign language does not have "features" and by implication "feature detectors" has lead some (e.g., Marler, 1975) to suggest that iconicity in sign language may be used to compensate for this deficit.

Second, sign language consists of visible activity that is organized in a spatial mode. Klima and Bellugi (1976) suggested that the visuo-spatial mode of sign language predisposes the language itself and certain aspects of communication to special characteristics not found in spoken languages. Similarly, Huttenlocher (1975) proposed that encoding spatial information in sign language might be affected by the visuo-spatial mode of signing. Evidence suggests that in normal subjects, visual imagery or spatial representation is used to solve problems that deal with spatial relations (Brooks, 1968; Shepard & Metzler, 1971; Huttenlocher & Higgins, 1971). In sign language however, the task of the decoder is simplified since information about spatial relations is delivered in decoded form. For example, instances of vertical relations between objects are described with one sign being made on top of the other (Huttenlocher, 1975). Similarly, distances among objects are conveyed by physically varying the distances among signs. Time relations are expressed in terms of the space in front of the sign, with the signs being moved back or over the shoulder to express past events (Frishberg & Gough, 1973). It is primarily this iconic effect or mapping property of space which is the advantage of the visuo-spatial mode of sign language. The use of iconic effects is not limited to expression of spatial relations. A recent study by Klima and Bellugi (1976) which analyzes art forms in ASL, reveals that the heightened form of signing (art-sign) relies on iconic representation of events and is used in poetry and songs of sign language.

The encoding of directional spatial information in sign language was investigated by Schlesinger (1971) in a group of Israeli signers. Equivalent sets of pictures illustrating grammatical relations such as agent, object and indirect object were presented to deaf signers. The task consisted of signing the message illustrated on the picture to another signer who was then required to select the picture that corresponded to what he thought the signed message was about. Results of this study indicated that the Israeli sign language did not show any word-order mechanism that could show the relations agent of, direct object of or indirect object of. There was very little concordance between partners with all possible sequences of agent, direct object and indirect object being used at least once. However, the lack of syntactic devices that clarify the direction of a relation may be quite specific to Israeli sign language as movement variation in directional verbs of ASL can be used to specify who carries out the act, who is the recipient of the action and where the action occurs (Bonvillian, Nelson, & Charrow, 1976). Furthermore, a replication of Schlesinger's (1971) experiment with ASL (Bode, 1974) revealed a very high proportion of correctly-understood messages and concordance between partners.

From a syntactical viewpoint sign language is very different from spoken language. For example, ASL does not have signs for articles, copula and some prepositions. Nor does it inflect the verb signs for tenses. Instead specific time indicators are used. Furthermore, the passive-active distinction is not made in ASL (Bellugi & Fisher, 1972). What is accomplished by word order, inflections and intonation in English is communicated in ASL by variations in speed, location in space and size of the signs produced (Fisher, 1973).

However, the rate of communication in ASL is approximately the same as that in English (Bellugi & Fisher, 1972). Since twice as many words as signs are used, the signed message seems telegraphic in comparison to speech. Furthermore, communication in ASL is marked by pauses and holds which are used to parse sentences, breaks between conjoined sentences and breaks between internal segments of sentences (Groshean & Deschamps, 1975; Grosjean & Lane, 1977).

Finally order constraints have also been found to be an important dimension. Hoemann and Florian (1976) examined the effects of structure on judgments of meaningfulness and short-term recall of anomalous ASL sequences of signs. Sign sequences, which were pre-ranked by independent judges, were presented to deaf subjects through videotape. Half the sequences presented the original structure while the remaining half were the result of the random reordering of the original sign sequences. Their results indicated that judgment of meaningfulness of sign sequences were affected by random reorderings of the original signs. Immediate recall was also affected by random reordering in the case of the longer sign sequences. Thus it appears that order constraints affect the semantic features and their processing in signed messages.

Acquisition and Development of Sign Language

Cross cultural comparisons of the form and rate of young children's acquisition of their native language have revealed many similarities. These have resulted in the concept of universal capacities underlying language development (Slobin, 1971). Such cross-cultural comparisons, however, have predominantly involved aural-vocal languages, and only recently have researchers posed the question of whether language acquisition in a different mode (e.g., sign language) reveals the same form and rate of development.

To date only a handful of longitudinal studies of sign language acquisition by deaf children (some born to deaf parents) have been carried out (Klima & Bellugi, 1972; Schlesinger & Meadow, 1972; Nash, 1973). By and large, the most remarkable feature of these studies is that stages of sign language acquisition closely parallel those of spoken language development. For deaf children born to deaf parents (three recorded cases to date) sign is the native language and its course of acquisition has been compared to the spoken language development of hearing children.

The appearance of the first signs indicates intricate control of fine motor sequences and highlights the ability of the infant to use motor sequences as symbols. It is interesting to note that the first signs of deaf children appear earlier than the first words of hearing children (Gardner & Gardner, 1977). The same onset time of signs is found in hearing children who are exposed to sign language from birth because of their parents' deafness (Schlesinger, 1978).

Similar to the first words, early signs are holophrastic with complete ideas or phrases being expressed in a single sign (Bonvillian, Nelson, & Charrow, 1976). In addition, children who learn sign as a native language, tend to overgeneralize the referential aspect of their early signs (Schlesinger, 1972).

Soon after the appearance of the first words, the child begins combining the words to form utterances. Increases in the child's grammatical ability during this period are measured through the number of word-morphemes averaged over 200 consecutive utterances - (MUL) Mean utterance length (Klima & Bellugi, 1972). Mean utterance length when plotted against chronological age reflects a quickly ascending slope (Brown, 1973). Plotting of mean utterance length, based on averaged signed-morphemes, against chronological age in deaf children also reflects the typical slope found with hearing children (Klima & Bellugi, 1972;

Schlesinger, 1978). Sign combinations also tend to make their appearance earlier than word combinations with the onset times ranging between 12 and 14 months (Stokoe, 1975).

However, the strongest evidence concerning the similarity of acquisition patterns in speech and sign is provided by the detailed analysis of the structure of early sign combinations. Analysis of early sign combinations made by deaf children born to deaf parents indicate that the two-sign combinations can be appropriately compared to the "pivot class" constructions of normal hearing children (Slobin, 1971). In these constructions "pivot words" have been found to occupy with considerable regularity the first or the last positions in the two-word utterance. Similarly, pivot signs have been found to occur rarely in combination with other pivot signs or in isolation (Bowerman, 1969). Rather, pivot signs are usually coupled with "open-class" signs.

The "word order" principle (Slobin, 1973) in vocal languages is crucial in conveying meaning. It is interesting to note that, much like hearing children, deaf children follow specific sign orders which express semantic relations following language specific rules (Schlesinger, 1971). This is remarkable since sign language can be simultaneously produced whereas words must be sequentially produced.

One of the robust indices of structural complexity is the hearing child's mastery of negatives. Not only does the method of expressing negatives change, but the change seems to reflect stages of development (Bellugi, 1967). Such changes have been reported in early sign combinations of deaf children. Thus whereas the shaking of the head was used as a primitive sign of negation, it soon got replaced by "no" or "neg"

(Klima & Bellugi, 1972) and finally by the negations of complete sentences (Schlesinger, 1978). These changes in the deaf child's acquisition of negation cover a relatively short span of time (between 2 years 7 months and 2 years 11 months) and correspond to the rapid increase in differentiation of new words for negation found in the vocabulary of hearing children.

Hearing children are helped in their acquisition of semantic and grammatical relations by the presence of regular and perceptually-salient morphological markers of adult utterances (Brown, 1973). Several variables such as stress level, phonetic structure and regular serial position affect perceptual saliency (Brown, 1973). However, at least some of these variables pertaining to acoustic-articulatory changes are not found in signing. The question then arises as to which morphological markers deaf children use to scan adult signing and which factors they find perceptually salient. Although results of research in this area are not complete to date, early indications are that visual-perceptual salience may be used as an aid in morphological marking. Schlesinger (1978) has observed the order and frequency of initial occurrence of morphemes with respect to their position, hand configuration and motion (Stokoe, 1960). She reported that some morphological features are particularly amenable to early acquisition because of their visual-perceptual saliency. For example, the articles "the" and "some" which are produced in front of the body, are acquired long before the plurals and possessives, which are produced at the shoulder. These latter categories seem to blend into the transformed sign and thus become imperceptible. Similarly, the tense markers are clearly visible with the signs being made in front of the body and then flipped over the shoulders backwards. In addition to visual clarity, the tense markers also contain semantic markers since the signing hand designates an event "behind" (past) or "in front" (future) of the signer (Schlesinger, 1978). Thus it appears that some aspects of the visual representation of morphemes may lend themselves to easy perception and be acquired at an earlier age.

Processing of English Language by the Deaf

Traditionally, the low performance of deaf persons in English language was attributed to a "developmental lag" (Bornstein & Roy, 1973; Hoemann & Ullman, 1976). However, the developmental lag is often not overcome, with deaf children maintaining their low levels of reading and writing skills. The deaf also demonstrate differences compared to the hearing in the use of English language. For example, developmental studies of free word-association in hearing children have indicated changes which correlate with stages of language development at various age levels (Ervin, 1961; Brown & Berko, 1960; Palermo & Jenkins, 1964). Normal children showed a substantial increase in the number of responses that were matched to the stimuli on the basis of syntactic class (paradigmatic responses) (Brown & Berko, 1960). In contrast, word-association patterns obtained from deaf children differed in two important respects. First, deaf subjects either failed to give any word associations or they provided far more associations than would be expected from their experience with reading material (Blanton & Nunnally, 1965; Nunnally & Blanton, 1966). Second, in sharp contrast to hearing children, deaf subjects with increasing age gave responses that were different from the syntactic class of the stimuli (syntagmatic responses) (Jacobson, 1968).

Interestingly, when given a sign-association test analogous to the word-association test, deaf children showed a developmental trend characteristic of hearing children, namely a shift from syntagmatic to paradigmatic responses (Tweney & Hoemann, 1973). These results indicate that the developmental deviations from normal hearing norms are specific to English language acquisition and do not reflect differences in general language development.

Several studies have investigated aspects of English language processing at the level of letters, words and sentences in deaf and hearing subjects. For example, Wallace (1972) compared the performance of deaf and hearing subjects on the recall of visually-presented sequences of English letters. Whereas hearing and deaf subjects trained by the oral method predominantly made use of an articulatory code, manually-trained deaf subjects relied on a visual code in recalling the stimuli. Similar results were reported by Conrad (1973). These data indicate that English letters are processed differentially in deaf subjects depending on educational skills and backgrounds. Furthermore the degree of hearing loss and the ability for articulation of speech sounds (Conrad, 1973) are important variables which affect the use of specific codes.

Despite the variations in coding strategies, important similarities in English language processing by deaf and hearing subjects are also found. For example, Cooper (1967) investigated knowledge of English morphology in deaf and hearing subjects ranging in age between seven and nine years. Using a task which combined nonsense words with English inflections (Berko, 1958), he found that the groups performed similarly with respect to their knowledge of such morphological rules as plural markers, past tense markers, etc. Although the performance of hearing subjects was significantly better overall, both groups demonstrated the same pattern of errors with respect to item difficulty.

An earlier study by the same author (Cooper, 1965) reported that deaf children acquired receptive control of morphological patterns before productive control. Further, the development of these patterns paralleled those found in samples of hearing children. Raffin, Davis, and Gilman (1978) reported that a hierarchical order exists in the acquisition of inflectional morphemes. These and another author (Anthony, 1972) suggest that deaf children who are trained by a morpheme-based sign system that accurately represents English syntax could not only acquire the inflectional morphemes earlier but would also improve their ability to read English.

Other aspects of English language processing also show similarities in deaf and hearing subjects. Tweney, Hoemann and Andrews (1975) reported that deaf subjects organize their knowledge of common English (high and low imagery) words in semantic categories which correspond to those found in hearing subjects. The recall of these categories however, was subject to different strategies in the deaf. For example, on a recall task of English words, Odom, Blanton and McIntyre (1970) found that deaf subjects were aided by those words that had accessible sign-language equivalents. Similarly, words with high visual imagery were recalled significantly more often than words with low visual imagery (Conlin & Paivio, 1975; Bonvillian, 1974; 1976).

The question of processing of English sentences by the deaf is somewhat complicated. Letters are processed in terms of the words they constitute; these in turn are coded into signs, finger-spelled words, visual images, shapes or articulatory (speech) forms. While hearing persons predominantly rely on the grammar of the speech code (Liberman, 1970), deaf persons may use any one or combination of the above codes. When English sentences are processed, not only must the words be coded but the overall idea of the sentences, which is defined by its grammatical structure, must be represented (Bonvillina, Nelson, & Charrow, 1976).

In marked contrast to hearing subjects, deaf subjects are not sensitive to grammatical constraints provided by phrase structure (Fremer, 1971). Deaf subjects and hearing controls learned segments of written English that varied on the diemsnions of: 1) representing phrase structure; 2) maintaining correct English word order, but not maintaining phrase structure; and 3) neither maintaining word order nor phrase structure (Odom & Blanton, 1966). All subjects then recalled correctly each learned segment. Whereas the hearing group's recall was aided by those segments that maintained phrase structure, the deaf group showed no significant difference in recall of the segments as a function of phrase structure. Similarly, Odom, Blanton and Nunnally (1967) studied the effects of grammatical structure as an aid in performing a series of "cloze" tasks. Deaf and hearing subjects filled in function words that were deleted from grammatically-correct sentences. The three test conditions consisted of a printed story with either every third word, every fourth word or every fifth word deleted. In the case of hearing subjects, readings scores correlated positively with correct prediction of function (syntactic) words. However, in the case of deaf subjects, reading scores and scores on the "cloze" task did not correlate. Furthermore, in contrast to hearing subjects, the ability of deaf subjects to predict the correct form class of syntactic words increased as a function of increasing span between deleted words. The increase in span provided more context. The authors suggested that different rules of sentence structure are used by the deaf compared to the hearing. In general syntactic (function) words are more difficult to restore than semantic (content) words. This is in keeping with the finding that semantic aspects of English language play a larger role than syntactic aspects in deaf subjects (Moulton & Beasley, 1975).

Because of these differences, some authors have suggested that the deaf may be performing in English as one would in a foreign or second language (Bonvillian, Charrow, & Nelson, 1976). In fact studies of deaf students born of deaf parents who have learned sign language from very young ages indicate that the patterns of errors made on English language tasks (e.g., Test of English as a Foreign Language) resemble closely those made by hearing foreign students (Charrow & Fletcher, 1974). These authors conclude that, at least for those deaf students who are native signers, certain aspects of English language are learned as a second language superimposed on the already existing structure of sign language.

CHAPTER III

HEMISPHERIC SPECIALIZATION IN THE CONGENITALLY DEAF

Left Hemisphere Lesions and Aphasia in the Deaf

Just as disorders of speech and language have been associated with left hemisphere damage in the hearing population, so have disorders of sign language in the deaf (Lenneberg, 1967; Critchley, 1970). As Table 1 indicates, there are eight reported cases of deaf patients who developed disorders of manual signing after left cerebral insult (Grasset, 1896; Burr, 1905; Critchley, 1938; Leischner, 1943; Tureen, Smolik, & Tritt, 1951; Douglass & Richardson, 1959; Sarno, Swisher, & Sarno, 1969; Kimura, Battison, & Lubert, 1976). All of these cases developed either transient right-sided weakness in the limbs or pronounced right hemiplegia after the onset of damage; furthermore, all eight cases developed various degrees of deficits in signing and sometimes in residual speech (Kimura, et al., 1976).

The signing deficits have been described as "aphasic errors" of substitution, omission, paraphasias and perseveration (Critchley, 1938; 1970; Battison & Padden, 1974). Critchley (1970) reported that his patient had short elegrammatic phrases instead of sentences and had slow and erratic movements of the hands when he finger-spelled. Sarno et al., (1969) reported that their patient showed little evidence of disturbance in executing basic signs, but showed pronounced deficits in the execution of complex signs. Furthermore, the deficit was limited to movements involved in signing since he had no problems imitating sequences of practiced non-meaningful movements. As Kimura et al. (1976) point out,

TABLE 1

REFERENCE	SALIENT FEATURES	CLINICAL LOCALIZING SIGNS	PROBABLE LOCUS OF LESION
Grasset, 1896	Fingerspelling affected in the right arm but not in the left.	Incoordination and weakness of right arm.	Left hemisphere
Burr, 1905	Insufficiently described general deterioration.	Right hemiplegia, hemianopia	Left hemisphere
Critchley, 1938	Non-congenitally deaf, manual signs built in speech.	Transient, right-sided paralysis	Left hemisphere
Leischner, 1943	Global loss of signing, regained some signing, extensive examination, native signer	Transient weakness of right arm and leg	Left posterior (verified by autopsy)
Tureen, Smolik, & Tritt, 1951	Signing difficulty present only in acute phase, recovered although white matter of 3rd frontal destroyed.	Left-sided craniotomy of left frontal cyst with increased intracranial pressure and hemmorrhage	Left frontal lobe and internal capsule plus pressure elsewhere
Douglass & Richardson, 1959	Basic signs most affected.	Right hemiplegia, left-sided headache	Left middle cerebral occlusion
Sarno, Swisher & Sarno, 1969	Basic signs least affected.	Right-sided weakness	Left cerebral infarct
Kimura, Battison & Lubert, 1976	Signing and speaking affected. Showed aphasic errors in signing - non-congenitally deaf	Right hemiparesis	Left middle cerebral artery occlusion

EIGHT CASES OF APHASIA IN THE DEAF

Adapted from Kimura, Battison & Lubert, (1976) and updated.

however, this patient's basic signs were not affected and it is not known how complicated a sequence of movements he could generate.

Since some of the reported cases were not congenitally deaf and developed skills of manual communication later in life (Critchley, 1938), it is possible that their sign language ability was superimposed on to an already established vocal system. As a result, it is difficult to interpret the implications of signing deficits in terms of the functions affected. A particularly informative case is one reported by Grasset (1896). This deaf-mute patient developed evidence of cerebral softening and gradually lost the ability to comprehend finger-spelling in others. He could not fingerspell with his right hand. However, with his left hand he could fingerspell printed words and the alphabet correctly. This suggests that language functions were not impaired even though their manifestation in terms of the motor output of the right hand were. Another case that provides useful information on this question is one reported by Reiden (1941; In Critchley, 1970). This patient was a 32-year-old hearing man who was a native signer because of his mother's congenital deafness. This man developed severe seizures and over a short period of time showed dysphasic symptoms. His ability to communicate by signs however, was rather well preserved, although he made some mistakes in fingerspelling. With rapid deterioration of his disease, he became aphasic but up to the time of his death he maintained his ability to communicate by sign language. This case study suggests that signing and speaking may have different neural substrates, even though their manifestations overlap in terms of sequential-motor output. Thus the "manual aphasia" observed in deaf patients may represent as much a loss of motor skills as of language ability.

Of the eight cases of deaf patients reported, there is only one where the locus of lesion responsible for the demonstration of signing deficit was clearly identified. Leischner's (1943) patient was congenitally deaf and was born and reared in a deaf family. He was a native signer who did not develop any vocal speech until the age of 8. His deficits in signing were at first global, but later he gained some ability to express himself in sign language. Following death, the patient's brain became available for extensive pathological examination. The massive lesion that had been associated with his signing impairment was located in the left hemisphere in the region of the angular and supramarginal gyri, extending to the white matter underneath. On the whole, as Table 1 indicates, the majority of the reported cases showed transient right-sided weakness, suggesting that the lesions producing the deficits were predominantly in the posterior regions of the left cerebral hemisphere.

On the basis of these eight cases, it can be concluded that deaf patients show evidence of disorders in manual communication skills after left hemisphere damage. However, it is not known whether the disorder reflects a language deficit, a motor control impairment or a combination of both. Furthermore, the incidence of manual aphasia, or the absence of it, following right hemisphere lesions in the deaf, has not yet been investigated. It is therefore not possible at this time to determine whether the deaf have left hemisphere localization for language functions.

The Apraxias and their Relation to Sign Language Expression

According to Dejerine (1914), it is perhaps easier to describe what apraxia is not than to explain what it is. Traditionally, apraxic patients were defined as those who manifested a disturbance in the performance of gestural activity even though their motor apparatus was intact and they showed no signs of global intellectual deficiencies (Hécaen, 1975). Although this general definition has not changed since the early 1900's when Liepmann (1908) reported a case of motor apraxia, several other clinical types and classifications of apraxias have been documented and reported.

Indeomotor apraxia. Described by Liepmann (1900) as motor apraxia, this disability affects the imitation and production, on demand, of simple gestures. The ideational level of the acts remain itact. Hécaen (1975) classified the gestures that demonstrate this apraxia as follows: 1) symbolic expressive gestures; 2) imitation of meaningless gestures; 3) production of conventional symbolic gestures; and 4) production of gestures miming the use of an absent object.

Ideational apraxia. This type of apraxia consists of an inability to produce a complex act even though the elements of this act can be produced in isolation (Hécaen, 1969) It is primarily a disturbance in the production of an integrated sequence of actions. Patients with this disorder do not possess the representation of a complex act as a whole; they lack the ability to organize the temporal and spatial elements of a complex movement sequence. Ideational apraxia never occurs as an isolated deficit and is often encountered in the context of severe aphasic syndromes (De Ajuraiguerra & Tissot, 1969).

Baillarger (1890) and Jackson (1932) proposed a principle that is applicable to the two types of apraxias described so far: the greater the voluntary nature of, and the less automatic, a gesture, the more pronounced will be the deficit. Both ideomotor and ideational apraxia result most often from bilateral uncircumscribed lesions in the posterior-parietal regions of the cerebral hemispheres (De Ajuriaguerra & Tissot, 1969). Ideomotor apraxia may sometimes result from unilateral lesions, in which case the left hemisphere will be the locus of the damage (Hécaen, 1969).

Constructional apraxia. This is the most frequent form of apraxia named by Straus (1924) and Kleist (1934). Constructional apraxia results from either left or right hemisphere lesions, but the frequency of occurrence and degree of severity is greater with right hemisphere lesions (McFie, Piercy & Zangwill, 1950; Hécaen, De Ajuriaguerra, & Massonnet, 1951). With right hemisphere lesions, the deficit becomes apparent in all tasks involving the use and representation of objective or Euclidean space (De Ajuriguerra & Tissot, 1969). With left hemisphere lesions, constructional apraxia becomes an "executive disorder" (Hécaen, 1975).

Aphasia and apraxia. As early as 1905, Liepmann reported that ideomotor apraxia and aphasia were frequently associated symptoms of cerebral insult. Since then the role of left hemisphere lesions in producing indeomotor apraxia has been repeatedly confirmed (De Renzi, Pieczulo, & Vignolo, 1968; Goodglass & Kaplan, 1963). However, it is still not known whether the relation between aphasia and apraxia is due to the anatomical proximity of motor areas involved in language and gesture production or to a global disturbance of linguistic and paralinguistic behavior. Goodglass and Kaplan (1963) found that aphasic patients showed more severe gestural defects compared to non-aphasic control patients. However, there was no relation between the intensity of gestural deficit and the severity of aphasic symptoms. These results suggest that gestural deficits primarily reflect praxic disorders and not impairments of global language.

Kimura (1976) also viewed ideomotor and ideational apraxia as a defect in motor control and not attributable to language mediation. Furthermore, she reported that in patients with left hemisphere damage, apraxic disorders were demonstrated not only with familiar and meaningful movements, but also with unfamiliar and meaningless sequences of movements (Kimura & Archibald, 1974). These results suggest that a distinction should be made between the symbolic language and sequential motor-control functions of the left hemisphere. Kimura (1973) also reported that the left hemisphere is primarily involved in the control of hand gestures that accompany oral speech in normal hearing subjects. On the basis of these and other related findings (Kimura & Vanderwolf, 1970), Kimura (1974) proposed that in fact the left hemisphere's specialized functions were primarily related to the control of complex motor-sequences and not to language. Although the lesions that produce disturbances in either or both language and motor functions appear to overlap extensively, the association of aphasic with apraxic symptoms may be explained by the proximity of the structures affected.

Traditionally, disturbances of sign language in deaf patients with left cerebral damage were interpreted as disorders of symbolic language function (see Critchley, 1970 for a review). This interpretation was strengthened by reports of aphasia (language apraxia) in the absence of non-language apraxia (Critchley, 1938; Tureen, Smolik, & Tritt, 1951;

Sarno, Swisher, & Sarno, 1969). However, a case study of a deaf aphasic showed a clear non-linguistic impairment but no deficits on the traditional apraxia tasks (Kimura, Battison, & Lubert, 1976). Since the distinction between meaningful and meaningless sequences of complex movements was not clearly made in earlier studies of deaf aphasics, it is difficult to assess whether the language-apraxia was due to a motor control or to a sign language disorder.

Laterality Effects in the Sense Modalities

In the absence of clear data from neurological case studies of deaf patients, a number of researchers over the past ten years have conducted studies on neurologically intact deaf individuals (Ling, 1971; McKeever, Hoemann, Florian, & Vandeventer, 1976; Phippard, 1977; Manning, Goble, Markman, & LaBreche, 1977; Neville, 1976). The primary goal of these studies was to determine whether laterality effects analogous to those found in normal subjects could be demonstrated in the congenitally deaf. In general, these studies failed to find a clear pattern of cerebral asymmetry. When laterality effects were found, they reflected a reversed pattern of hemispheric advantage (Neville, 1976; Phippard, 1977).

Ling (1971) presented monoaural and dichotic digits tasks to deaf and hearing children in order to determine speech laterality. Whereas in the dichotic condition the right-ear score was significantly superior to the left in the case of hearing children, there was no significant difference between the ear scores of deaf children. However, the non-significant trend for the deaf group was caused by intersubject variation with individuals showing either a marked right or left ear superiority. Deaf children rarely reported both inputs of a dichotic pair, with one input being suppressed or masked by the other. Ling (1971) suggested that deaf children have "a dominant ear" by may suppress sounds arriving at the non-dominant ear rather than integrating them as do normal hearing subjects. However, this interpretation may be premature on the basis of the above data, since it was not known whether the intersubject variability was consistent.

In one sense, if the deaf were to demonstrate laterality effects analogous to normal subjects, one would expect that they would be manifested in the visual modality, since it is primarily through vision that the deaf receive, code, store and retrieve cognitive information. However, much the same pattern of results as those reported by Ling (1971) has been obtained with studies carried out in the visual modality.

McKeever, Hoemann, Florian and Vandeventer (1976) tachistoscopically presented unilateral letters and English words and bilateral English words and line drawings of ASL letters and static signs to congenitally deaf and hearing college students. On the unilaterally presented English-words task, deaf and hearing subjects demonstrated a significant right visual field advantage; however, on the bilateral English-words task, the deaf, in contrast to the hearing, showed no significant differences between the two visual fields. Hearing subjects showed a significant left visual field advantage in the perception of bilateral ASL signs whereas deaf subjects showed a nonsignificant tendency for left visual field superiority.

Almost identical results were obtained by Manning et al. (1977) with bilateral presentation of English words and pictures of static ASL signs. However, in a test condition where word-sign combinations were presented in order to bias attention towards language processing, deaf subjects showed a nonsignificant tendency for right visual field superiority.

McKeever et al. (1976) attributed the lack of pronounced visual-field asymmetries in the deaf to bilaterality of information-processing functions. Assuming that the basis of lateral language-dominance is auditory (Liberman, 1974), they suggested that the deaf fail to develop normal lateralization of visual-language functions.

Phippard (1977) tested congenitally-deaf subjects trained by either the oral or total communication method of instruction. She presented subjects (total communication group) with English letters, finger-spelled hand positions, slanted lines and human faces. In contrast to hearing subjects who showed the double-dissociation effect on these tasks, deaf subjects showed no visual field differences on any of the tasks. The orally-trained deaf group was tested on English letters and slanted lines. These subjects showed a left visual field superiority on both the verbal and the non-verbal task. Phippard (1977) suggested that the brief duration of stimulus presentation may have encouraged visual rather than linguistic processing. This implies that in the orally-trained deaf subjects, language functions were lateralized but would have only been tapped by tasks that encouraged a linguistic rather than a visual coding system.

Interpretation of the lack of pronounced visual-field differences in deaf signers is somewhat more complicated. Once again it is possible that deaf signers developed bilateral representation of language functions because of early auditory linguistic deprivation (Phippard, 1974). Alternatively, perhaps deaf signers did not process English words and letters as strictly "verbal" material. Since the deaf acquire English language predominantly through the visual modality, it is possible that they process the visuo-spatial as well as the "verbal" features of English stimuli.

In addition, as Phippard (1977) pointed out, the use of the recognition paradigm (Phippard, 1977; Manning et al., 1977) may have encouraged the strategy of making a physical rather than a linguistic match between the stimuli. Such physical matches involve visual-spatial processing and are more efficiently performed by the right hemisphere (Cohen, 1972). In view of the differences found between deaf and hearing subjects in coding and representation of English stimuli (Conrad, 1973), it is possible that in deaf signers "verbal" and "spatial" components were confounded, resulting in the absence of a clear visual-field asymmetry.

Much the same interpretation may apply to the processing of ASL signs. Sign-language communication is a dynamic process involving changes in hand configuration, ocaltion and, even more important, movement (Stokoe, 1975). The two ASL tasks involved statis signs (McKeever, et al., 1976; Manning, et al., 1977). It is possible that in the absence of sequential movement, signs became predominantly visuo-spatial configurations. Thus their linguistic aspect may have been undermined. Once again, the linguistic and spatial aspects may have been confounded. This would explain the lack of a pronounced visual-field asymmetry.

Neville (1976) conducted a study on congenitally-deaf and hearing children using an evoked potential measure. Subjects were shown line drawings of objects projected to the left or right visual fields. For a

2-sec. period after the projection of the stimuli, evoked potentials were recorded. Analysis of visual evoked potentials showed larger amplitudes and earlier latencies in the right hemisphere, but only in the hearing group. The visual evoked potentials for the left and right hemispheres were not significantly different in deaf subjects.

When the deaf group was subdivided into signers and non-signers, a left hemisphere advantage, in terms of amplitude, was found in deaf signers. Deaf non-signers showed no asymmetries. Neville (1676) concluded that deaf signers acquired verbal language, "with left-hemisphere specialization playing a role:". Whereas hearing children showed a right hemisphere effect for spatial tasks, deaf signers demonstrated a left hemisphere effect. Neville (1976) argued that because sign language "may be characterized as visual-spatial, 'spatial' tasks in which normal children show right hemisphere specialization may be mediated by the left, or spatial-language, hemisphere in signing children" (p. 129).

It is difficult to reconcile these findings and their interpretation with the results reported by McKeever et al., (1976), Manning, et al., (1977) and Phippard (1977). The difficulty is compounded by the fact that Neville's (1976) study involved non-verbal rather than sign-language stimuli and an electrophysiological rather than a behavioral response. Consequently, direct comparisons between the non-verbal tasks used by Phippard (1977) and Neville (1976) cannot be made. However, in very general terms, there is a suggestion that different processes underlie hemispheric function in congenitally-deaf signers and non-signers (Phippard, 1977; Neville, 1976).

Finally, a group a researchers (LaBreche, Manning, Goble, &

Markman, 1977) attempted to investigate hemispheric specialization for linguistic and non-linguistic tactual stimuli in deaf and hearing subjects. However, they did not find the double-dissociation effect in either the hearing or the deaf. Consequently, the lack of tactual asymmetry in deaf subjects could have been as much attributed to the particular tasks used as to the consequences of auditory deprivation.

Based on the data reviewed so far, it is difficult to reach an unequivocal conclusion regarding hemispheric specialization in the congenitally deaf. It has been argued that at least some of the ambiguity may be attributed to the choice of stimuli and tasks which were termed "linguistic". Stimuli that may require language processing in hearing subjects may not necessarity do so in deaf subjects. In addition, there are no data to confirm whether the lack of asymmetry found in deaf signers is reliable. In the absence of this type of evidence, it cannot be concluded whether the deaf have "a dominant hemisphere" for language processing (Ling, 1971) or have bilateral representation of language (McKeever, et al., 1976).

The following series of experiments were designed to address some of the above issues. In all, four experiments were carried out. The first three experiments involved tachistoscopic presentation of lateralized stimuli. Experiment I was designed to investigate the role of apparent movement in sign language perception. Experiment II was carried out in order to determine whether or not laterality effects could be consistently demonstrated across individual deaf subjects. The third experiment, a replication of McKeever et al.'s (1976) Bilateral Words study, was carried out to provide a standard against which performance on the first two experiments could be evaluated and interpreted. Finally, the fourth experiment, consisting of a verbal and a non-verbal task, was conducted in the tactual modality. It sought to investigate whether laterality effects could be demonstrated in the tactual modality and to determine if these effects correlated with the ones found in the visual modality.

PART II

CHAPTER I

GENERAL METHOD

Subjects

One group of prelingually-deaf children and adolescents and three groups of hearing control subjects participated in the four experments described below. The experimental group (Group E) consisted of 19 deaf students (9 female, 10 male) who were attending a combined residential and day school for the deaf (Mackay Institute for Deaf and Crippled Children) in Montreal. The method of instruction at the school for the deaf concentrates on total communication, i.e., a mixture of American Sign Language, finger-spelled English, speech, and speech reading. Although much of the instruction in classrooms consists of simultaneous speech and sign language, the social communication among the students is predominantly manual. These students represent a heterogeneous group with respect to country of origin, language used in the home environment, and number of years of sign-language education. Deaf subjects were selected on the basis of prelingually-diagnosed central deafness, freedom from any physical handicap or neurological damage, and a measured hearing loss of at least 80 db. in the better ear, averaged over the pure tone range of frequency (500, 1000, and 2000 Hz). All deaf subjects were required to have at least 4 years of sign language instruction (mean = 7 years, range = 4 to 13 years). Subjects ranged in age from 12 to 17 years, with a mean age of 14 years 7 months. For each experiment, different sub-groups of 16 were selected randomly to form the subject group.

As a basis for selection of an appropriate matched control group for the deaf subjects, a non-verbal test of intelligence (Raven's Progressive Matrices) was administered to the group. Since deaf subjects generally perform poorly with respect to their chronological age and normal hearing counterparts on verbal tests of intelligence (Hoemann & Ullman, 1976; Bonvillian, Charrow, & Nelson, 1973), it was felt that a non-verbal test would be more appropriate as a basis for selection of the control group. Of the 19 deaf subjects to whom the intelligence test was administered, 9 (6 females and 3 males) obtained scores between the 75th and 95th percentiles. The remaining 10 subjects (3 females and 7 males) obtained scores between the 10th and 35th percentiles.

The first control group (C1) of 16 normal hearing subjects (8 females and 8 males) was selected from the grades 7, 8 and 11 of a public secondary school (West Hill High School) in Montreal. The subjects ranged between 14 years 3 months and 16 years 9 months, with a mean age of 14 years 2 months. The Raven's Progressive Matrices test was administered to all the subjects in this group. Of the subjects tested, 7 (4 female and 3 male) obtained scores between 30th to 50th percentiles. The remaining 9 subjects (4 females and 5 males) obtained scores between 75th and 95th percentiles. Subjects comprising group C1 participated in the tactual experiments.

The second control group (C2) consisted of 16 normal hearing women selected mainly from two classes of a community junior college (Vanier CEGEP). They ranged in age from 13 to 19 with a mean of 17 years. All subjects in this group had received between 10 months and 3 years of sign language instruction, as part of their curriculum or, in some cases, as an elective course. Group C2 participated in two of the visual experiments.

The third control group (C3) consisted of 16 normal hearing subjects (8 females, 8 males) who answered a posted call for subjects. They ranged in age between 13 and 20 with a mean age of 16 years and 5 months. These subjects participated in the sign-sequences experiment only.

All subjects in both the experimental and the control groups were required to be free of uncorrected visual problems, and to be strongly right-handed. Subjects were defined as right-handed if they obtained a score of 8/8 on the Edinburgh Handedness Inventory (Oldfield, 1971) and if there were no left-handers among their parents or siblings. A copy of the handedness inventory is shown in Appendix A.

Apparatus and Procedures: Visual Tasks

A 3-channel Scientific Prototype Tachistoscope (Model GB) was used. Pairs of stimuli were presented simultaneously, one in the left and one in the right visual fields. In the three visual experiments, stimuli were presented bilaterally. All stimuli were mounted on black cards (12.7 x 17.8 cm). For each experiment, a number of pre-test trials were carried out to determine whether subjects could report the stimuli without the aid of recognition displays. Since performance of the deaf subjects on the pre-test trials was particularly low, appropriate recognition cards were prepared for each test.

Pre-test trials were administered before each experiment to familiarize subjects with tachistoscopic viewing. On actual test trials, subjects were required to look at a fixation stimulus (a dot or circle) and, in the case of hearing subjects, await the signal, "one, two, three, go", or in the case of deaf subjects, await a signal of four light taps on the shoulder. At the count of four, two stimuli would be presented briefly to either side of the fixation stimulus. Subjects were then required to look at a recognition card and select the two stimuli they had seen.

Apparatus and Procedures: Tactual Task

A schematic diagram of the testing situation is presented in Fig. 1. Subjects were seated at a table opposite the experimenter. A large wooden box with two openings for the hands faced the subject on the table. Subjects were instructed to insert their hands into the openings of the box until their wrists were aligned with the horizontal plane of the box edge. The two sliding bars were then lowered to restrict gross movements of the wrists and arms. Tactile exploration was carried out with only the index and third fingers. Since cerebral control of the extremities has been found to be contralaterally represented (Gazzaniga & Ledoux, 1978; Brinkman & Kuypers, 1972) it was thought that restriction of gross arm and wrist movements and exploration by the whole hand would limit feedback through the ipsilateral motor pathways.

Once the subject's hands were positioned, a pair of stimuli stuck to a bristol board were slid underneath the raised fingers of the subject. The experimenter then guided the fingers of the subject to the stimuli. Subjects were instructed and pre-trained to explore the stimuli through simultaneous movement of the fingers of the two hands. On trials where any pause in exploration was observed, the test trial was interrupted and readministered according to a random schedule of trial presentation.

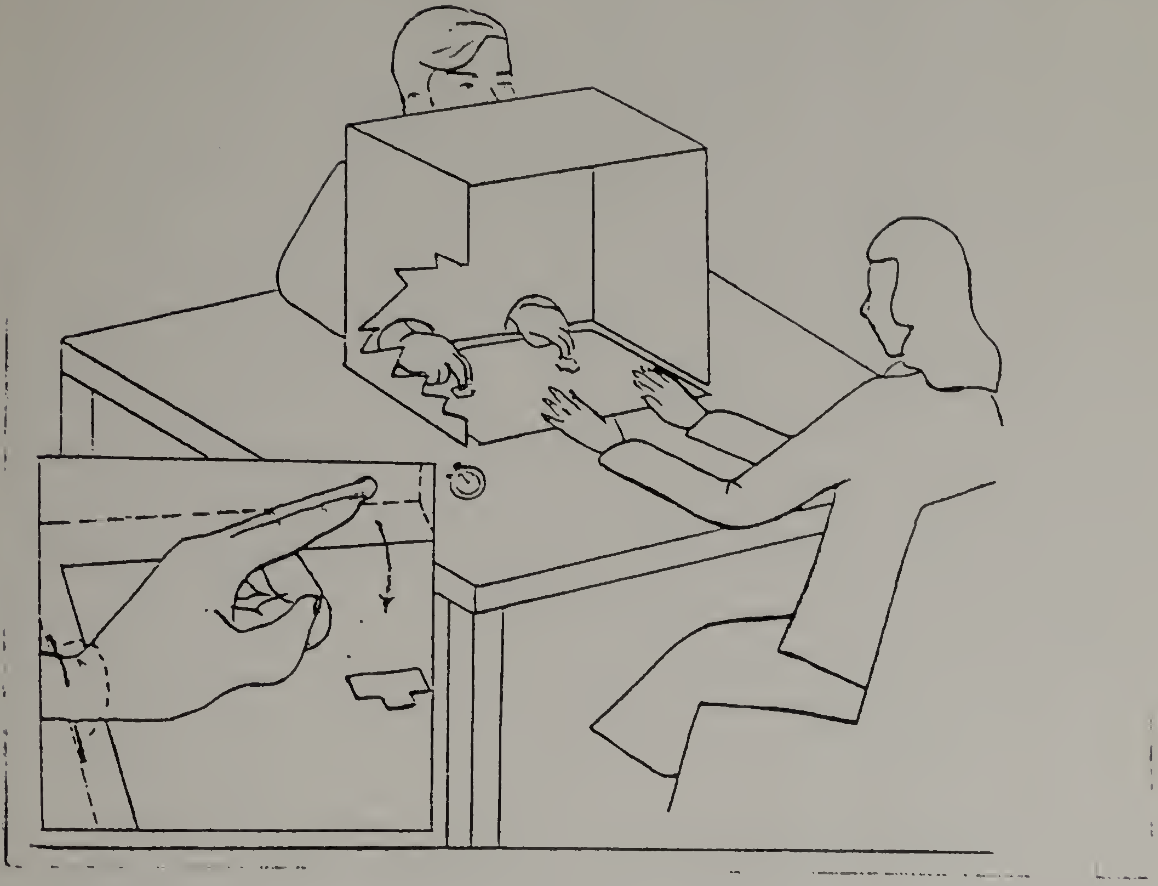

Fig. 1. Diagram of test situation for the tactual verbal and non-verbal tasks.

Following a timed period of tactile exploration, the bristol board was withdrawn and one hand was freed to choose the stimuli from a recognition display. Half the subjects pointed with their left hand on the first block of test trials and with the right hand on the second block of test trials; for the remaining half of the subjects, the order was reversed. The non-verbal shapes test was always administered before the letter sequences test. Following a number of pre-test trials, the first block of each test was administered. After a 2-week delay, the second block of each test was administered with the left-right position of the stimulus pairs being counterbalanced. Thus each stimulus was presented twice, once to the left hand and once to the right hand. Subjects were not given any feedback on their performance on the tests.

In all experiments, instructions to deaf subjects were given in sign language. All signed instructions, and the recording of signed responses (where applicable) were carried out by a certified translator for the deaf.

CHAPTER II

EXPERIMENT I

The first experiment was designed to determine whether or not deaf and hearing subjects would display visual field asymmetries when recognizing ASL sign sequences represented in apparent movement. Two previous studies (McKeever, Hoemann, Florian, & Vandeventer, 1976; and Manning, Goble, Markman, & LaBreche, 1977) did not find clear visual asymmetries in the deaf when static hand drawings and pictures of ASL signs were tachistoscopically presented. However, as mentioned earluer, the static presentation may have been responsible for the lack of clear asymmetries. Since signs are rarely encountered in static form, incorporation of movement should render them more realistic. This in turn should aid recognition.

Since there are no normative data on the processing of dynamic sign-sequences, no hypotheses concerning the performance of the deaf group were formulated. Nevertheless, specifiable types of processing might be involved in the task. Dynamic signs contain substantial elements of spatial organization. Should these characteristics predominate, a right hemisphere superiority would be expected. Alternatively, dynamic signs are linguistic stimuli delivered in a temporal sequence, the order of which must be followed for correct recognition. If these aspects of the signs predominate, a left hemisphere superiority would be anticipated.

Since both deaf and hearing subjects were competent signers, it was expected that they would demonstrate comparable overall performance.

Method

Subjects. Two groups of subjects participated in this experiment. Group (E) consisted of 16 deaf subjects (8 boys and 8 girls). The age range was between 12 years 1 month and 17 years 3 months, with a mean age of 14 years 6 months. Group (C2), hearing signers, consisted of 16 women ranging in age from 13 years to 19 years with a mean age of 17 years.

Stimuli and procedures. Twenty-two ASL signs were selected from the common vocabulary of the deaf group. The process of selection was carried out in collaboration with two teachers of the deaf group who ensured that all the subjects knew the signs and could both recognize and reproduce them on demand. All the signs selected contained movement. Furthermore, the movement involved in making each sign usually covered a large space in front of the signer. Thus most signs would begin at the level of the face and terminate at the centre of the body. Each sign was divided into three frames, one depicting the starting point, one the mid point and one the terminal point. A proficient signer and certified translator for the deaf modelled each sign and posed for each frame. Photographs were taken such that distance from the camera and the position of the head and body remained unchanged. Only the position of the hands and arms varied from one frame to another. Figure 2 illustrates the sign "learn" and the division of the sign into three frames.

Of the 22 signs, five were symmetrical in that both hands made the same motion. The remaining 17 signs were asymmetrical with one hand carrying out most of the movement in relation to the other hand. A complete list of all the signs used and their respective photographs is

Fig. 2. Sign for "learn" used as stimulus on the sign sequences task.

included in Appendix B.

The 22 signs were randomly paired to yield 11 bilateral trials, constituting one block. Each subject received four blocks. In blocks 1 and 3 the position of the bilateral sign-sequences were counterbalanced. In blocks 2 and 4 the asymmetrical signs made predominantly with one hand were counterbalanced such that a sign made with the right hand in block 2 would be made with the left hand in block 4.

Each subject received a total of 44 trials. The exposure duration for each trial was 150 msec; 50 msecs per frame with no inter-stimulus interval. The luminances of the three tachistoscopic fields were set at 4.0 fL. Each frame measured 5½ x 7 cms. At a viewing distance of 125 cms the inner edge of the frame was 1° while the outer edge was 3° from a fixation point.

Following each trial, subjects were presented with a recognition card depicting six signs. All signs were line drawings similar to the Hoemann and Hoemann Sign Language Flashcards (1973). On these drawings movements and their directions were depicted using arrows. Of the six signs featured on the recognition card, two represented the target stimuli, while the remaining four were distractors. Each sign had two distractors that were associated with the target on the basis of similarity of movement. Figure 3 illustrates the signs "learn" and "birthday" and the distractors "eat", "again", "new" and "arrive". A complete list of all distractors and the targets to which they related is included in Appendix C.

In order to ensure that all subjects were familiar with the meaning and the movements involved in the signs, two training sessions were given a week in advance of testing. On two separate days, for a period of

Fig. 3. An example of a recognition display used on the sign sequences task.

1 hour, each subject was asked to read, describe the meaning and produce each sign on demand. Following these training sessions, subjects were given three practice trials in order to familiarize them with the testing procedures. All instructions, given in sign language to deaf subjects, were clearly specified at the start of the test session. Remainders to fixate were repeated before each trial. Following each trial the experimenter presented an appropriate recognition card. Subjects responded by pointing to the appropriate signs and their choices were recorded by the experimenter.

Results and Discussion

Table 2 shows the mean visual-field recognition scores (in percentages) and their standard deviations for each group. A two-way analysis of variance was performed on the accuracy scores to determine the effects of groups and visual fields. The results of this analysis are summarized in Table 3. The main effect of visual fields was significant ($P < 0.03$) with the accuracy better in the right visual field than the left for both groups. However, a test of simple effects was made to determine whether visual field differences appeared within any one group. The results of this comparison test are summarized in Table 4. Also shown in Table 4 is the number of subjects showing visual field asymmetries. As can be seen only hearing signers demonstrated significant (RVF) advantage ($P < 0.05$). The difference between the two visual fields in the case of deaf signers did not reach conventional levels of significance.

Hearing signers showed a significant right visual field (RVF) effect. This finding is opposite to that found by McKeever, Hoemann,

TABLE 2

GROUP	LEFT VISUAL FIELD		RIGHT VISUAL FIELD	
	MEAN	SD	MEAN	SD
Group E	46.87	9.756	50.18	9.593
Group C	46.00	8.610	53.56	9.245

MEANS AND STANDARD DEVIATIONS FOR ACCURACY SCORES (%)

ON THE SIGN SEQUENCES TASK

TABLE 3

SOURCE	dF	MEAN SQUARE	F	P
Groups	1	25.000	0.3555	NS
Visual field	1	473.063	4.6368	0.03
Groups Visual fields	1	72.250	0.708	NS
S	30	70.314		
S x visual fields	30	102.023		

ANALYSIS OF VARIANCE OF ACCURACY SCORES (%) ON THE

SIGN SEQUENCES TASK

TABLE 4

GROUPS	LVF SUPERIOR	EQUAL	RVF SUPERIOR	t	dF	P
Group E	8	-	8	0.927	30	NS
Group C_2	3	3	10	2.11	30	0.05

NUMBER OF SUBJECTS DEMONSTRATING VISUAL FIELD ASYMMETRY
AND RESULTS OF TESTS OF SIMPLE EFFECTS
ON SIGN SEQUENCES TASK

Florian and Vandeventer (1976) where hearing signers had a left visual field (LVF) advantage with static ASL signs. McKeever et al. (1976) attributed their finding to the spatial characteristics of signs predominating over the semantic or "verbal" components. This discrepancy between the present results and those of McKeever et al. (1976) may be due to the fact that dynamic sequences were used in the present study while McKeever et al. (1976) presented static displays.

A number of researchers (Huttenlocher, 1975; Stokoe, 1975) have commented on the fact that sign language communication is simultaneous, in contrast to vocal communication, which is sequential. To the extent that static signs are produced by a particular hand configuration located at a specific point on or near the body, they can be considered simultaneous. However, moving signs are sequential in that the movements are ordered in time. Such a distinction would explain why static signs require the specialized spatial functions of the right hemisphere whereas moving signs would primarily require the sequential processing capacities of the left hemisphere.

Based on the results of the present experiment, it cannot be determined whether the RVF superiority shown by hearing signers was due to the sequential movement component or the linguistic component of the signs. Since both sequential processing and language processing are specialized functions of the left hemisphere (Kimura, 1976), either one could have contributed to the demonstration of a RVF advantage. Experiment II will be, in part, addressed to resolving this question.

Contrary to expectations, deaf subjects did not show a RVF advantage, a finding that can be interpreted in at least two ways. Both

McKeever et al. (1976) and Phippard (1977) have suggested that the lack of pronounced visual-field asymmetry found in deaf subjects may indicate bilateral representaion of language. Since congenitally deaf subjects do not possess auditory language experience, which may be necessary for the development of left hemisphere specialization, they do not demonstrate functional cerebral asymmetry. This implies that deaf subjects would not show an asymmetry in the processing of verbal or non-verbal stimuli; and that they would maintain this pattern of performance when laterality tests are administered in different modalities. Indeed deaf signers have not shown visual field asymmetry in the processing of static signs and English words (McKeever et al., 1976), finger-spelled hand configurations and faces (Phippard, 1977), and now moving sign sequences; but at present, there are no data to verify whether this pattern of performance is maintained in other modalities. Experiment IV in this series will address this question.

An alternative interpretation of the performance of deaf subjects on the sign-sequences task is that language functions are specialized in one hemisphere of individual subjects, but the asymmetry can favour either the left or the right side. Since there is great individual variation in the demonstration of visual-field asymmetry, the overall group effect is one of no clear laterality. Deaf subjects were equally divided with respect to those who showed a LVF effect and those who showed a RVF superiority. Manning, Markmann, Goble and LabBreche (1977) also found that of 16 congenitally deaf subjects tested on static signs, seven obtained a LVF advantage while another seven showed a right visual field superiority. Similarly, Long (1971) reported that hearing-impaired children did not show a right ear advantage in the perception of dichotic digits because of excessive variability of right ear versus left ear scores. Since there are no data to establish whether these individual variations are consistent, it cannot be concluded decisively if deaf subjects have a specialized hemisphere (either the left or the right) for the processing of language stimuli. Experiments II and III in this series will attempt to resolve this question.

CHAPTER III

EXPERIMENT II

The purpose of the second experiment was twofold. First, it sought to determine whether the right visual-field superiority (RVF) found in hearing signers is related to the sequential movement component or the language component of sign sequences. If the language component of signs is the salient feature requiring left hemisphere processing, then hearing non-signers should not demonstrate a (RVF) advantage on the sign sequences task. However, if the sequential movement of signs is the salient feature, then hearing non-signers should show the same pattern of results as hearing signers.

The second purpose of this experiment was to determine whether the performance of deaf signers was affected by the response paradigm used in Experiment I. In that experiment, subjects attempted to recognize two previously seen signs among six line drawings. This type of drawing had been used as an instructional aid for teaching hearing signers; hence their acquisition of sign language was based on graphic representation of signs. In contrast, deaf signers did not have as much experience with such drawings, since their knowledge of sign language was predominantly acquired through interaction with other signers. Because of this experiential difference, recognition of signs from line drawings possibly involved different processes in the deaf and the hearing. Therefore, signs in the recognition array in this study were demonstrated by a fluent signer for subjects. If deaf subjects were to maintain their pattern of performance, it could be concluded that processing of sign sequences is not related to the recognition paradigm. Alternatively, if their pattern of performance changes, then it could be concluded that the test procedures influence the recognition of signs. Specifically, when signs are recognized from an array of line drawings, subjects can make errors of recognition. However, when signs are demonstrated, subject's performance indicates errors of perception.

Method

Subjects. Two groups of subjects participated in this experiment:1) group E from experiment I and 2) group C3, consisting of 16 normal hearing subjects (eight males and eight females) ranging in age from 13 to 20 with a mean age of 16 years. Subjects in group C3 did not know sign language. There was an interval of three months between testing of deaf subjects in experiments I and II.

Stimuli and procedures. The stimuli and their order of presentation were identical to those in experiment I. However, the recognition procedure differed. After each trial, a certified translator for the deaf (the same person who appeared on the photographs) demonstrated four signs, two targets and two distractors. The distractors were selected from the list of distractors used in experiment I. In the case of asymmetrical signs, half were demonstrated by the right hand while the remaining half were performed by the left hand. In order to facilitate selection, each sign was numbered from one to four. Subjects responded by selecting the two numbers that corresponded to the signs they had seen.

Results and Discussion

Table 5 shows the mean visual-field recognition scores (in percentages) and their standard deviations for each group. A three-way analysis of variance was performed on the accuracy scores to determine the effects of groups, sex and visual fields. The results of this analysis are summarized in Table 6. The main effect of visual fields approached significance ($P < 0.06$) with accuracy better in the RVF than the LVF for both groups. There was also a significant groups-by-visual-field interaction ($P < 0.03$). In order to determine whether visual-field differences appeared within either group, a test of simple effects was carried out. The results of this test are presented in Table 7. There was no significant difference in accuracy of recognition between left and right visual fields in the case of deaf signers. However, subjects in group C3 showed a significant ($P < 0.05$) right visual-field superiority.

In order to determine whether deaf signers were consistent with respect to the direction of field differences across the two different recognition procedures, the subjects were classified according to a two-by-two contingency table, shown in Table 8. A chi-square test revealed that the contingency was significantly greater than chance ($P < 0.05$), indicating a high degree of consistency. In fact, 12 subjects showed the same direction under the two procedures (six showed a RVF advantage, and six a LVF advantage), while only four showed differences in the opposite direction.

Since subjects in group C3 were not familiar with sign language, their right visual-field advantage cannot reflect language specialization

TABLE 5

GROUP	LEFT VISUAL FIELD Mean	LEFT VISUAL FIELD SD	RIGHT VISUAL FIELD Mean	RIGHT VISUAL FIELD SD
Group (E)	61.56	10.52	60.93	12.09
Group (C3)	55.25	7.78	65.06	8.98

MEANS AND STANDARD DEVIATIONS FOR
ACCURACY SCORES (%) ON THE SIGN
SEQUENCES TASK (DEMONSTRATED)

TABLE 6

SOURCE	dF	MEAN SQUARE	F	P
Groups	1	19.14	0.166	NS
Sex	1	0.15	0.135	NS
Visual Fields	1	337.641	3.710	0.06
Groups and Sex	1	74.390	0.647	NS
Visual Fields and Groups	1	435.766	4.788	0.03
Sex and Visual Fields	1	21.390	0.235	NS
Groups and Sex	1	107.641	1.182	NS
Visual Fields	1	114.975		
Subjects	28			

ANALYSIS OF VARIANCE OF ACCURACY SCORES ON THE SIGN SEQUENCES
TASK (DEMONSTRATED)

TABLE 7

GROUPS	t	dF	P
Group (E)	0.187	28	NS
Group (C3)	2.91	28	0.05

TEST OF SIMPLE EFFECTS ON THE SIGN SEQUENCES TASK (DEMONSTRATED)

TABLE 8

		SIGN SEQUENCES (EXPERIMENT I)	
		RIGHT VISUAL FIELD	LEFT VISUAL FIELD
SIGN SEQUENCES (EXPERIMENT II)	RIGHT VISUAL FIELD	6	1
	LEFT VISUAL FIELD	3	6

$(X^2_1 = 4.37, \quad P < 0.05)$

CHI-SQUARE ANALYSIS ON THE SIGN SEQUENCES TASKS OF EXPERIMENT I AND EXPERIMENT II of the left hemisphere. However, their visual-field difference may be related to the left hemisphere's specialization for processing of sequential information.

A number of researchers (Efron, 1963;McGlone, 1970; Carmon & Naschon, 1971) have suggested that the left hemisphere mediates the processing of temporal sequences perceived in visual and auditory stimuli. Further, Kimura (1976) has proposed that the basis of left hemisphere specialization lies in the control of motor sequences, both vocal and manual. Evidence, in support of this theory, suggests that production of non-linguistic sequences of movements are impaired following left hemisphere insult (Kimura, Battison & Lubert, 1976). However, impairment does not occur when single isolated movements are produced. Moreover, individual and paired finger flexions are more easily performed by the left hand in right handers. But when individual movements are coordinated and organized into a sequence, the right hand becomes considerably more efficient than the left (Kimura & Vanderwolf, 1970). Of course these data bear directly on sequence production and not perception. However, to the extent that sequential ordering characterizes the processing style of the left hemisphere, it should affect both production and perception of information.

Consistent with their performance in experiment I, deaf signers as a group did not demonstrate a visual-field asymmetry. Once again, the group was almost equally divided between those who demonstrated a LVF effect and those who showed a RVF superiority. However, despite the group variability, individual subjects were consistent in showing visual-field differences. Twelve of the 16 subjects demonstrated the same visual-field asymmetry as in experiment I. Thus deaf signers seem to demonstrate reliable hemispheric asymmetry. Further support for this notion would be provided if deaf signers were consistently found to maintain their pattern of asymmetry when other types of verbal stimuli were presented. Experiment III addresses this question.

CHAPTER IV

EXPERIMENT III

A replication of McKeever, Hoemann, Florian and VanDeventer's (1976) experiment with bilateral English words was carried out in order to determine whether deaf subjects would maintain their pattern of visual-field asymmetry when language stimuli other than ASL signs are used. Results of Experiments I and II raised the possibility that each deaf subject may demonstrate a consistent RVF or LVF supriority in the processing of different language-related tasks. Should this possibility be verified, then it can no longer be concluded that deaf subjects as a group have bilateral representation of language. If, however, no consistent patterns of visual-field asymmetry emerge, then bilateral representation of language would indeed be the most likely explanation of hemispheric organization in the deaf.

Method

Subjects. Two groups of subjects participated in this experiment: 1) Group E of Experiments I and II, and 2) Group C2 (N=14) of Experiment I. Subjects in Group C2 ranged in age from 17 to 19 with a mean age of 18 years.

Stimuli and procedures. The stimuli consisted of 20 four-letter English nouns (McKeever et al., 1976) that were paired and counterbalanced to give 20 bilateral trials. The maximum possible accuracy score for each visual field was 20. Subjects saw each word once in the RVF and once in the LVF. On each trial fixation digits appeared simultaneously with the lateralized words (McKeever, Suberi & VanDeventer, 1972). Fixation digits appeared within a white circle which served as the fixation point. (A list of the words and their pairings, and fixation digits is presented in Appendix D.)

At a viewing distance of 125 cm, the inner edge of each word was 1.6° from the fixation point while the outer edge was 2.6° from fixation. All exposure durations were 85 msec. Following each trial, a recognition card depicting all the 20 words and the 9 fixation digits was presented. (A copy of the recognition card is included in Appendix E.) Subjects were required to point to the correct fixation-digit first and then to the two stimuli they had seen. To familiarize the subjects with the procedures of the test, several practice trials, some with only fixation digits and others with bilateral words plus fixation digits, were presented prior to the test session.

Results and Discussion

Table 9 shows the mean visual-field recognition scores (in percentages) and their standard deviations for each group. A two-way analysis of variance was performed on the accuracy scores to determine the effects of groups and visual-fields. The results of this analysis are summarized in Table 10. The main effect of groups was significant ($p < 0.00001$) indicating that hearing signers recognized the stimuli more accurately than deaf signers. The main effect of visual fields was also significant ($p < 0.02$). A test of simple effects was carried out to determine whether visual field differences appeared within either group. Results of this test and the number of subjects showing visual field asymmetries are presented in Table 11. Once again only hearing signers showed a significant RVF

TABLE 9

GROUPS	LEFT VISUAL FIELD Mean	LEFT VISUAL FIELD SD	RIGHT VISUAL FIELD Mean	RIGHT VISUAL FIELD SD
Group E	27.18	19.06	32.50	26.33
Group C2	56.07	24.74	76.42	22.74

MEANS AND STANDARD DEVIATIONS FOR
ACCURACY SCORES (%) ON THE BILATERAL
ENGLISH WORDS TASK

TABLE 10

SOURCE	dF	MEAN SQUARE	F	P
Groups	1	19792.9	29.70	0.000
Visual Fields	1	2281.67	5.380	0.0279
Groups and Fields	1	345.00	1.992	NS
Subjects	28	666.267		

ANALYSIS OF VARIANCE OF ACCURACY SCORES ON THE
BILATERAL WORDS TASK

TABLE 11

				SUBJECTS SUPERIOR		
GROUPS	t	dF	P	LVF	EQUAL	RVF
Group E	0.73	28	NS	8	1	7
Group C2	2.61	28	0.05	3	0	11

TEST OF SIMPLE EFFECTS AND NUMBER OF SUBJECTS DEMONSTRATING VISUAL FIELD ASYMMETRIES ON THE BILATERAL WORDS TASK

TABLE 12

		SIGN SEQUENCES TASK	
		RIGHT VISUAL FIELD	LEFT VISUAL FIELD
BILATERAL WORDS TASK	RIGHT VISUAL FIELD	6	1
	LEFT VISUAL FIELD	2	6

$(X^{2}_{1} = 5.14, p < 0.025)$

CHI SQUARE ANALYSIS ON THE SIGN SEQUENCES AND BILATERAL WORDS TASKS advantage over the LVF ($p < 0.05$). The difference between visual fields in deaf signers did not reach significance.

A chi-square test was conducted to determine whether the performance of deaf signers was consistent across the sign sequences (Experiment I) and the bilateral words tasks. The results of this test, summarized in Table 12, was significant ($p < 0.025$); of the 15* deaf subjects, six demonstrated a consistent RVF superiority while another six showed a reliable LVF advantage on both tasks. The remaining three subjects showed a RVF advantage on one task and a LVF superiority on the other.

This result suggests that the deaf typically do not have equal, bilateral representation of language in the two cerebral hemispheres. Rather, each deaf subject appears to have processed the language stimuli predominantly in one hemisphere - the left in approximately half the subjects and the right in the remaining half.

Further strength for this explanation would be provided if deaf subjects were to show double-dissociation of function in the processing of a verbal and a non-verbal task. An experiment on the perception of chimeric faces with deaf signers is presently in progress to determine if the pattern of visual-field asymmetry obtained with language stimuli reverses in the case of non-verbal stimuli.

The finding of a main group effect in favor of hearing signers is consistent with previous results (Bonvillian, Charrow & Nelson, 1973; Hoemann & Ullman, 1976) indicating the lack of proficiency of deaf subjects in the processing of the English language.

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*One subject who showed no visual field asymmetry on the bilateral words task was excluded from the sample for the Chi-Square test.

CHAPTER V

EXPERIMENT IV

Although a left tactual field (LTF) superiority in normal subjects has been obtained with simultaneous presentation of nonsense shapes (Witelson, 1974), a corresponding right tactual field (RTF) effect for the perception of dichaptic letter pairs has not been found (Witelson, 1974; LaBreche, Manning, Goble & Markman, 1977). This may be related to the fact that letter pairs explored tactually involve spatial as well as verbal processing. Although letter pairs are simple and familiar linguistic stimuli, they are not usually perceived through the tactual modality. With tactual presentation, therefore, the spatial aspects of the stimuli may become more salient. Alternatively, the task of individual letter-pair recognition may be so simple that either no sophiticated linguistic processing is required or the information may be transferred to the left hemisphere with no significant loss during callosal transmission. This implies that perceptual asymmetries can be demonstrated only if task demands are sufficiently complex to require the specialized processing system of a particular hemisphere. Thus, it is conceivable that a complex linguistic task would overide the initial tactuo-spatial analysis and require the involvement of the language centres of the left hemisphere for effective processing.

In view of the above, Experiment IV was designed to address two questions. First, it sought to determine whether the double-dissociation of function between the two hemispheres could be demonstrated in normal subjects using a complex verbal and a non-verbal task in the tactual modality. Second, it investigated whether deaf subjects would maintain their consistent pattern of hemispheric specialization in the tactual modality and individually show the double-dissociation effect.

Methods

Subjects. The experimental group consisted of a sub-group of 16 subjects (8 females - 8 males) selected randomly from group E. Control group C1 consisted of 16 normal hearing subjects (8 females - 8 males). The age range in both groups was from 12 to 17 years, with a mean of 14 years 11 months for group E and a mean of 15 years 2 months for group C1. The two groups were further subdivided into two age groups ranging from 12 to 14 years and from 15 to 17 years. Both groups completed a non-verbal I.Q. test. (For details, refer to the GENERAL METHODS section.)

Stimuli and procedures. For the verbal test, 20 abstract three letter nouns were selected and randomly paired to give 20 counterbalanced pairs. Twelve pairs were used on test trials and 8 on practice trials. Word pairs were mounted by letter pairs on 3 bristol boards. Each trial consisted of presenting three letter-pairs in succession with minimum inter-pair interval. Subjects were allowed up to 5 seconds to explore each stimulus pair. Following this timed interval, the stimuli were withdrawn and the appropriate recognition card was presented. Figure 4 illustrates the words "TAX" and "JOY" and the presentation order of each letter pair.

For each trial a separate recognition card was prepared featuring 6 words, two target stimuli and four distractors.

Two distractors were chosen for each target word, one beginning and one ending with the same letter as the target stimulus. In order to discourage any type of systematic scanning, the words on the recognition

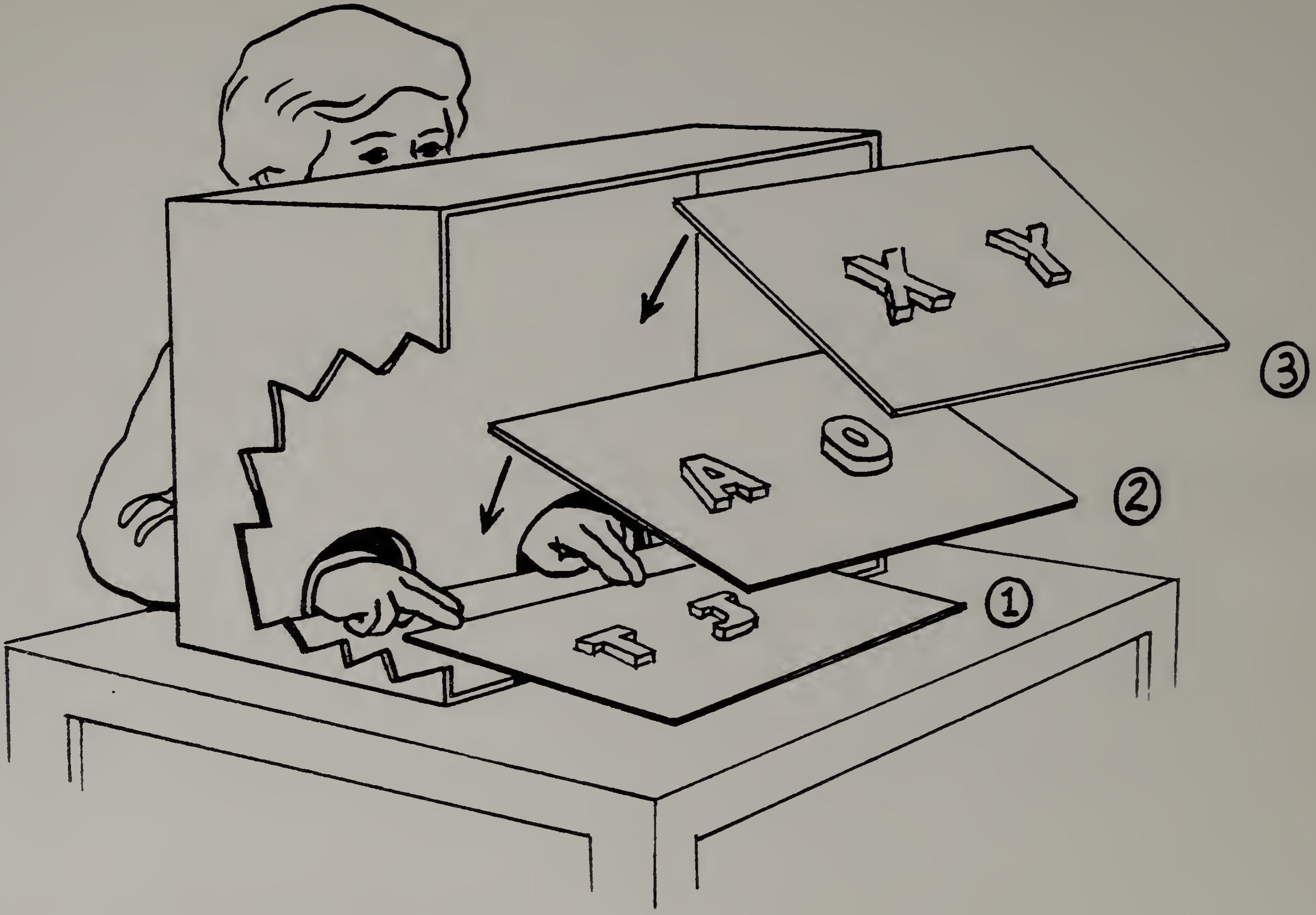

Fig. 4. An example of the word stimuli used on the verbal tactual task.

displays were arranged in a circle. Subjects were required to point to the two words they had palpated. A complete list of all words used as stimuli and their distractors is included in Appendix F.

The stimuli used in the non-verbal shapes test was identical to those used by Witelson (1974). Sixteen pairs of nonsense shapes were cut out of plywood. Of these, 10 were used on test trials and 6 on practice trials. Each pair of stimuli was presented for 8 seconds. The pointing hand was then freed to choose the two stimuli from a recognition display.

Separate recognition cards were prepared for each trial. Each card featured 6 items, 2 targets, 2 distractors and 2 other distractors that appeared on other trials as targets. A list of non-verbal stimuli and distractors is included in Appendix G. The non-verbal shapes test was always administered before the letter sequences test.

Results and Discussion

In order to allow comparison between the two tests, which differed on the maximum obtainable score, percentage scores were calculated. Table 13 shows mean tactual-field recognition scores (in percentages) and their standard deviations for each group. An analysis of variance was performed on the accuracy scores to determine the effects of groups, sex, age, I.Q., task and tactual-field. The results of this analysis are summarized in Table 14.

The main effect of groups was significant ($p < 0.01$) indicating that deaf subjects obtained lower overall scores on both tasks compared to hearing control-subjects. The main effect of tactual-fields was also significant ($p < 0.02$) and the means showed that the right tactual-field

TABLE 13

GROUPS	VERBAL TASK				NON-VERBAL TASK			
	(LTF)		(RTF)		(LTF)		(RTF)	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
GROUP E	58.31	20.5	78.70	14.6	69.92	16.4	73.20	11.3
GROUP C1	81.17	18.7	88.43	10.5	76.43	15.4	78.72	13.8

MEANS AND STANDARD DEVIATIONS FOR ACCURACY SCORES (%) ON THE VERBAL AND NON-VERBAL TACTUAL TASKS

TABLE 14

SOURCE	df	MEAN SQUARE	F	P
Groups	1	3101.04	8.36	0.01
Sex	1	104.77	0.28	NS
Age	1	228.03	2.29	NS
Tasks	1	108.10	0.74	NS
Tactual Fields	1	1716.50	6.28	0.02
Groups x Tasks	1	657.73	4.55	0.04
Tasks x Tactual Fields	1	758.63	5.41	0.03
Age x I.Q. x Sex	1	735.90	5.09	0.03
Groups x Tasks x Tactual Fields	1	229.45	1.63	NS
S	16	370.72		
S x Tasks	16	144.39		
S x Tactual Fields	16	272.98		
S x Tactual Fields x Tasks	16	140.10		

ANALYSIS OF VARIANCE OF ACCURACY SCORES ON

THE VERBAL AND NON-VERBAL TACTUAL TASKS

accuracy across all other indices was greater than the left tactual-field accuracy.

The interaction of groups and tasks, illustrated in Figure 5, was significant ($p < 0.04$). Means showed that deaf subjects obtained greater accuracy scores on the non-verbal than on the verbal task, whereas control subjects performed better on the verbal than on the non-verbal task. In order to determine whether significant differences within tasks and groups appeared, an analysis of simple effects was carried out. Results of this analysis are presented in Table 15. Means indicated that groups differed significantly with respect to performance on the verbal task. However, the difference between groups on the non-verbal task was not significant. The comparison of tasks revealed that the control group's performance differed significantly on the verbal and the non-verbal tasks. However, the difference in the case of the experimental group did not reach significance.

Another significant effect, illustrated in Figure 6 was the interaction of tasks by tactual-fields ($p < 0.03$). Means indicated that the RTF accuracy was greater compared to the LTF on both tasks, though to a lesser extent on the non-verbal task. Post-hoc analysis was carried out to determine whether significant differences appeared within tactual-fields and tasks. Results of the analysis of simple effects are shown in Table 16. As can be seen, the RTF accuracy differed significantly on the verbal and the non-verbal tasks. In contrast, LTF accuracy was not significantly different on the two tasks. Comparison of tactual-fields indicated that the means differed significantly on the verbal task.

Finally, the interaction of age-by-sex-by-I.Q. was significant ($p < 0.03$). The means of this interaction, illustrated in Figure 7,

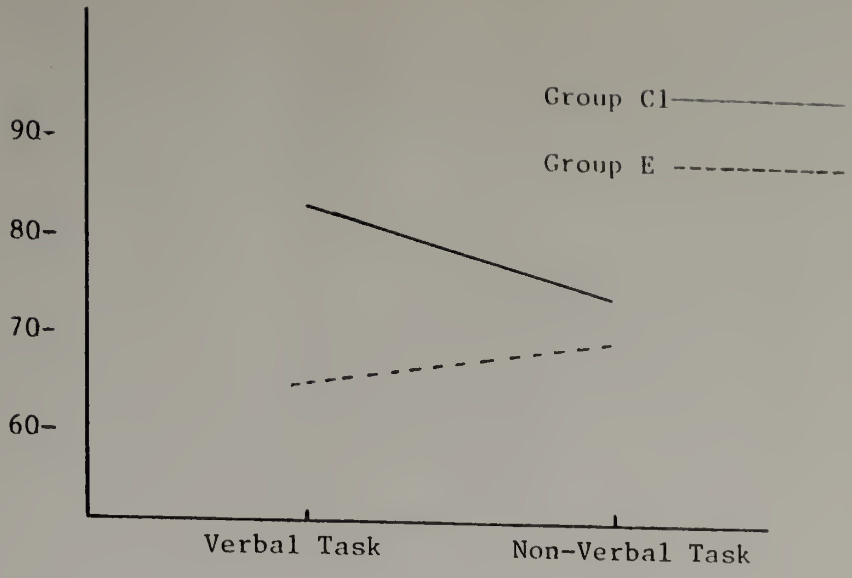

Fig. 5. Task by group interaction.

TABLE 15

SOURCE	df	MEAN SQUARE	F	P
Groups (T_1 - Verbal)	1	4251.04	16.37	0.01
Groups (T_2 - Non-Verbal)	1	577.92	2.24	NS
Tasks (Group C1)	1	2176.97	15.08	0.01
Tasks (Group E)	1	149.82	1.04	NS

ANALYSIS OF SIMPLE EFFECTS ON THE TASK

BY GROUP INTERACTION

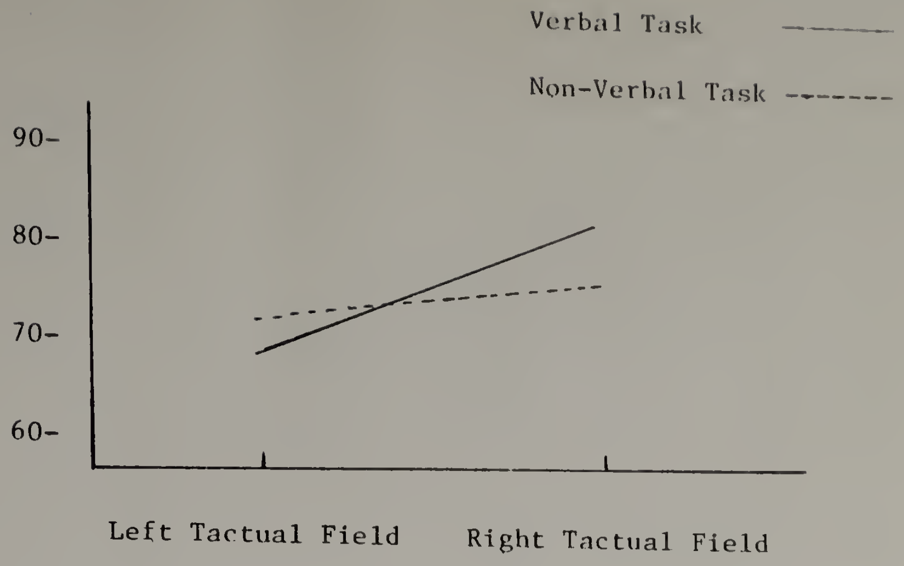

Fig. 6. Task by tactual field interaction.

TABLE 16

SOURCE	df	MEAN SQUARE	F	p
Tasks (Tactual Field$_1$ -R)	1	924.16	4.47	0.05
Tasks (Tactual Field$_2$ -L)	1	189.34	0.91	NS
Tactual Fields (Verbal)	1	3055.8	21.48	0.01
Tactual Fields (Non-Verbal)	1	1237.0	10.87	NS

ANALYSIS OF SIMPLE EFFECTS ON THE TASK BY

TACTUAL FIELDS INTERACTION

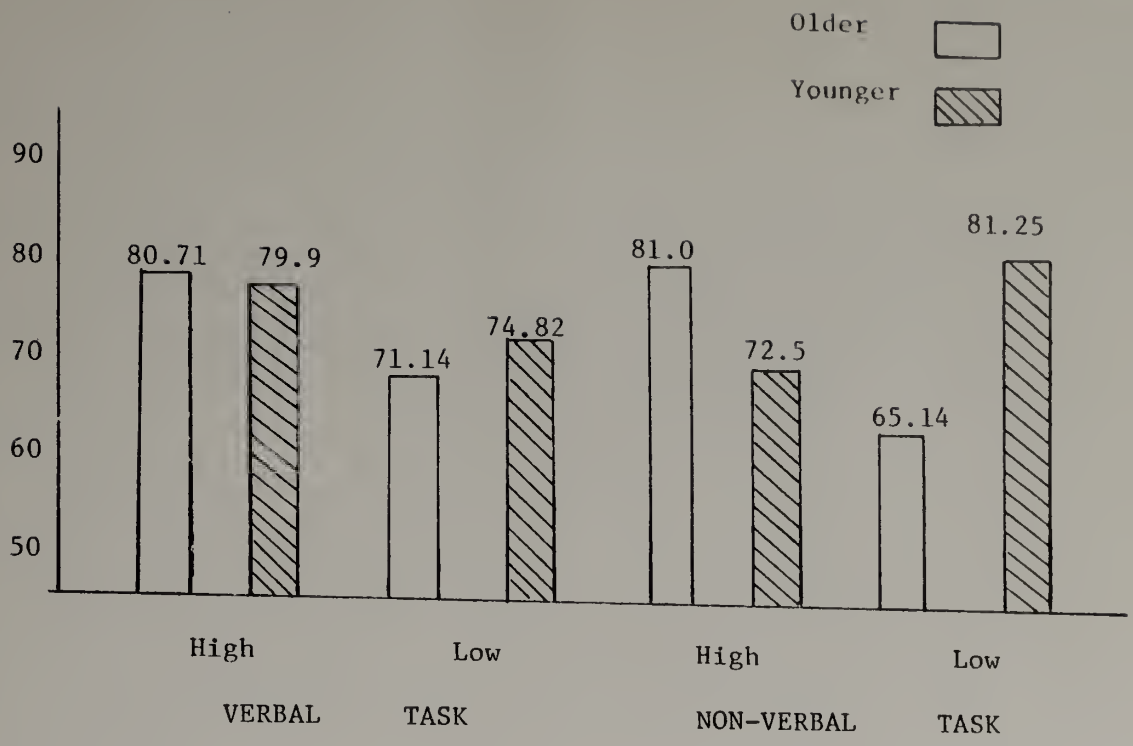

Fig. 7. Task by age by I.Q. interaction.

TABLE 17

SOURCE	df	MEAN SQUARE	F	p
I.Q. x AGE (Tasks - verbal)	1	56.84	0.220	NS
I.Q. x AGE (Tasks - non-verbal)	1	2741.82	10.64	0.01
AGE (Verbal Task - Low I.Q.)	1	53.32	0.20	NS
AGE (Non-Verbal Task - Low I.Q.)	1	1234.98	4.79	0.05
I.Q. (Younger Age - Non-Verbal Task)	1	275.63	1.07	NS
I.Q. (Older Age - Non-Verbal Task)	1	1255.28	4.87	0.05

ANALYSIS OF SIMPLE EFFECTS ON THE

AGE BY I.Q. BY TASK INTERACTION

indicated that older subjects of high I.Q. did not show any differences in accuracy scores between the two tasks; older subjects of low I.Q. demonstrated greater accuracy scores on the verbal than on the non-verbal task, as did younger subjects of high I.Q. However, the reverse of this was true for younger subjects of low I.Q.

In order to determine whether significant differences appeared within the tasks-by-age-I.Q. interaction, an analysis of simple effects and simple interactions was carried out. Results of this analysis are presented in Table 17. Pooled error terms and Satterthwaite approximation of df were used where appropriate. Means indicated that in the low I.Q. group the performance of older subjects differed significantly from younger subjects on the non-verbal task ($p < 0.05$). In the older group, the difference in performance on the non-verbal task between the high and low I.Q. groups was significant ($p < 0.05$).

The findings of a group difference in favour of hearing controls is consistent with earlier reports of poor performance by deaf subjects on language-related tasks (Nisbet, 1953; Bereiter & Engelmen, 1966; Hoemann & Ullman, 1976). Several authors have suggested that differences between deaf and hearing subjects are specific to language tasks and that deaf subjects demonstrate equal if not superior performance on non-verbal tasks (Meyerson, 1963; Furth, 1971; Sattler, 1974). The interaction of groups-by-tasks in this experiment lends support to this suggestion. Significant differences between groups were found on the verbal tasks only.

The significant difference between groups on the verbal task may be attributable to inadequate rehearsal strategies on the part of deaf subjects. It is possible that the deaf group could not use an effective method to categorize, form, and store in short term memory, simultaneously-occurring paris of words. In fact deficiency in verbal rehearsal on short-term memory tasks has been implicated as one of the factors contributing to lower performance scores of deaf subjects (Hoemann & Ullman, 1976). Although it cannot be ascertained whether performance on the verbal task was achieved through letter by letter rather than whole word processing, it is possible that some type of verbal rehearsal aided recognition, particularly since stimuli were presented in a temporal sequence.

Although there was an overall RTF superiority, this cannot be attributed solely to hand dominance, since the difference between fields depended on the task. There was a significant RTF advantage only on the verbal task, and although there was also a RTF superiority on the non-verbal task this was not significant. This interaction suggests that field differences are indeed sensitive to the differential processing capacities of the two cerebral hemispheres.

On the basis of these results, it cannot be ascertained whether the right tactual-field advantage shown on the verbal task was due to the semantic aspect of the stimuli or to the fact that each word was processed as three consecutive letters presented in a temporal sequence. In order to clarify this question, a variation of this experiment is presently in progress. Thus, to determine the effects of word meaning, tactual stimuli are presented in a backwards sequence. For example, the words TAX and JOY are presented as XAT and YOJ. Should subjects maintain their right-tactual field advantage, then it can be concluded that the semantic aspect of the stimuli is relatively insignificant in the demonstration of left hemisphere specialization.

As Table 13 indicates, the tactual-field asymmetry demonstrated by deaf subjects on the verbal task was stronger than that shown by hearing subjects. It is interesting to note that this was the only task wherein deaf subjects as a group showed a tendency for left hemisphere specialization. However, it should be pointed out that the interaction of tasks, groups and tactual-fields was not statistically significant (Table 14).

Results of the non-verbal task do not give strong support to the notion that the right hemisphere is superior to the left in the performance of this type of spatial task. In this respect, the results do not support Witelson's (1974) finding of a significant overall left tactual-field superiority, and are more in line with the results of LaBreche et al. (1977). The fact that the subjects in this experiment were older than those in Witelson's sample may have contributed to the discrepancy. Mean accuracy scores for both the left and the right tactual-fields in this experiment were considerably higher than those found by Witelson (1974). Thus, for older subjects, the tactual task may not have been sufficiently complex to demonstrate clearly the underlying specialization of the right hemisphere.

Significant interactions with age and I.Q. groups appeared only on the non-verbal task. The fact that older subjects of high I.Q. performed better than older subjects of low I.Q. suggests that the non-verbal task was sufficiently complex to differentiate between I.Q. groups. Younger subjects of low I.Q. performed better compared to older subjects of low I.Q. This tendency, which was also demonstrated on the verbal task, is somewhat puzzling. It would be expected that with increasing age, subject's performance would be aided by experience and availability of different strategies. Since the high I.Q. group showed the expected tendency of better performance by older subjects compared to younger subjects, the reversed tendency observed in the case of the low I.Q. group cannot be attributed to the non-verbal task as a whole. However, it is possible that for the low I.Q. group some aspects of the non-verbal task were particularly salient, thereby facilitating effective processing.

PART III

CHAPTER I

GENERAL RESULTS

In order to determine the patterning of the variation within the set of independent and dependent variables used in all of the previous experiments, a principal components analysis was carried out. Results of this analysis are presented in Table 18. The correlation matrix in complete form is presented in Appendix O. Six factors, each with eigenvalue greater than one, emerged from the analysis performed on the 14 measures obtained from 19 deaf subjects. Before varimax rotation, Factor 1 accounted for 24.4% of the variance and the six factors together accounted for 86.9% of the total variation. Variables with an absolute factor loading larger than 0.50 were considered to have a "high" loading.

After rotation, variables with a high positive loading on Factor 1 included I.Q., right visual-field --sign sequences task and right visual-field -- bilateral words task. The correlation coefficient for sign sequences task (RVF) and bilateral words task (RVF) was 0.72 and for sign sequences task and I.Q. it was 0.58. Since these three measures, in particular the two visual tasks, were designed to tap the underlying logical-analytical skills of the left hemisphere, the clustering of these variables was referred to as a "left hemisphere" factor.

Variables with high loadings on Factor 2 were age, left tactual-field -- verbal task and left visual-field -- bilateral words task. The correlation coefficient of verbal task (LTF) with bilateral words task (LVF) was 0.53 and the coefficient of verbal task with age was -0.54. The clustering of the two variables of tactual and visual verbal tasks --left visual fields -- may reflect the fact that the two tasks were tapping the same capacity in two different modalities. Although the three variables loaded high on Factor 2 in the positive direction, both verbal tasks had a negative correlation with age. The clustering of the verbal tasks with age cannot be interpreted in terms of the earlier experimental results. For purposes of identification, this clustering was referred to as a "modality" factor.

Number of years of sign language experience (negative loading) and performance of the right visual-field on the sign sequences task (demonstrated) loaded on Factor 3. The correlation coefficient for these two variables was -0.70. Since both variables reflected sign language processing, this clustering was referred to as the "sign language" factor.

The variables with high positive loadings on Factor 4 were those of right tactual-field -- verbal task and left visual-field -- sign sequences task. The correlation coefficient for these variables was 0.59. Once again for ease of identification this clustering was referred to as a "task" factor.

The variables of right tactual-field -- non-verbal task and left tactual-field -- non-verbal task loaded highly and positively on Factor 5. The variable of left visual-field -- sign sequences task (demonstrated) loaded highly and negatively on Factor 5. The correlation coefficient for right and left tactual-fields -- non-verbal task was 0.18, while for right tactual-field -- non-verbal task and left visual-field -- sign sequences task it was 0.40. Since the tactual non-verbal task was designed to measure right hemisphere functions and performance

TABLE 18

VARIABLES						
1. Sex	0.05	0.03	0.10	0.03	0.01	0.95
2. Age	-0.06	-0.73*	0.06	0.10	0.41	0.25
3. I.Q.	0.61*	0.25	0.11	0.32	-0.01	-0.58*
4. Tactual Verbal Task (RTF)	0.08	0.05	0.18	0.89*	0.05	0.18
5. Tactual Verbal Task (LTF)	0.30	0.83*	-0.35	0.02	0.18	-0.04
6. Tactual Non-Verbal Task(RTF)	-0.01	0.08	-0.21	0.24	0.72*	0.08
7. Tactual Non-Verbal Task(LTF)	0.48	-0.01	0.02	-0.14	0.63*	-0.33
8. Sign Sequences Task (RVF)	0.90*	0.09	0.14	-0.05	-0.00	-0.13
9. Sign Sequences Task (LVF)	-0.30	0.03	-0.17	0.84*	0.00	0.19
10. Sign Sequences Task (RVF) (Demonstrated)	0.14	0.17	0.86*	0.33	-0.15	0.13
11. Sign Sequences Task (LVF) (Demonstrated)	0.46	0.24	-0.16	0.22	-0.74*	-0.05
12. Bilateral Words Task (RVF)	0.88*	0.12	0.08	-0.18	-0.10	0.26
13. Bilateral Words Task (LVF)	0.02	0.76*	0.34	0.22	0.03	0.24
14. Number of Years of Sign Language Experience	-0.12	0.18	-0.91*	0.21	-0.03	0.01
% TOTAL VARIATION	24.4	16.4	15.5	12.8	10.6	7.8

* LOADINGS ≥ 0.50

FACTOR LOADINGS AFTER VARIMAX ROTATION FOR

FOURTEEN MEASURES OF THE DEAF GROUP

on the sign sequences task (demonstrated) showed a slight overall left visual-field effect, this clustering of variables was referred to as a "right hemisphere" factor.

Finally, the variables with high negative loadings on Factor 6 were sex and I.Q. with correlation coefficient of -0.45.

CHAPTER II

GENERAL DISCUSSION

The series of experiments described was designed to obtain new information about sign- and English-language processing in the visual and tactual modalities in congenitally-deaf subjects. These data were then evaluated against normative performance measures obtained from three different hearing control groups. Table 19 summarizes the performance of deaf and hearing subjects on the visual and tactual tasks.

The control groups' performance on the two visual laterality tasks involving sign language showed a right visual-field superiority. This suggests that the left hemisphere was predominantly involved in the processing of these stimuli. Since the right visual-field effect was also shown by control subjects who were not familiar with sign language, it can be concluded that the right visual-field advantage was not directly related to the "linguistic" characteristics of sign sequences. Rather, it appears that the demonstration of a right visual-field effect was primarily related to the perception of sequential apparent-movement.

There is some indication that the left hemisphere may subserve the sequential and temporal aspects of auditory (Halperin, Nachshon & Carmon, 1973), visual (Carmon, 1975) and tactile (Zaidel & Sperry, 1973) perceptual information. Thus, Efron (1963) found that comparison of two temporally-ordered sensory stimuli is predominantly carried out by the left hemisphere. Similarly, Carmon and Nachshon (1971) reported that patients with left hemisphere lesions showed deficits in identifying the order of audio-visual stimuli delivered in a sequence. On the basis of

TABLE 19

TASKS	DEAF EXPERIMENTAL		HEARING CONTROL	
	LVF	RVF	LVF	RVF
Sign Sequences Task	46.87	50.18	46.00	53.56 *
Sign Sequences Task (Demonstrated)	61.56	60.93	55.25	65.06 *
Bilateral Words Task	27.18	32.50	56.07	76.42 *
Verbal Tactual Task	58.31	78.70	81.17	88.43
Non-Verbal Tactual Task	69.92	73.20	76.43	78.72

* $P < 0.05$

SUMMARY OF THE PERFORMANCE OF DEAF AND HEARING SUBJECTS ON THE VISUAL AND TACTUAL TASKS (ACCURACY SCORES IN PERCENTAGE) .

evidence indicating that the left hemisphere is dominant for the processing of the sequential aspects of verbal acoustic input, Albert (1972) reported that hemispheric asymmetry is based upon auditory sequencing. Finally, whereas the left hand is superior to the right on tasks such as finger spacing and hand postures (Ingram, 1975; Kimura, 1976), the right hand is superior to the left on tasks that involve sequential movement (Lomas & Kimura, 1976). Although these results are from tests of perceptual and motor skills in different sense modalities, they are consistent in implying the involvement of the left hemisphere for the processing of sequential events.

Laterality effects found for the hearing subjects on the bilateral-words task was identical to that reported by McKeever et al. (1976). Recognition scores for word stimuli presented in the right visual-field were significantly higher than for those presented in the left visual-field. Thus, the three visual experiments involving language stimuli predominantly required left-hemisphere processing in hearing subjects.

Performance on the verbal-tactile task indicated an asymmetry in favor of the right hand in the case of hearing subjects. Although there was a significant main effect of right hand superiority, the advantage was most pronounced in the case of deaf subjects. The trend towards a right hand superiority in hearing controls can be explained by the fact that 38% of the population performed at ceiling level. This may have concealed the underlying hand asymmetry. Two previous attempts at demonstrating a right hand superiority for the perception of tactile letter pairs gave equivocal results (Witelson, 1974; LaBreche et al., 1977). As has been argued earlier in this thesis, in order for left hemisphere processing to be demonstrated with tactile stimuli the task requirements have to be sufficiently complex to ensure that a subject cannot use a pattern-matching strategy, because that would favor the processing of the stimuli by the right hemisphere.

Performance of hearing subjects on the non-verbal tactile task also showed a right hand superiority. It is argued that this finding could not be attributed solely to hand dominance, since the magnitude of the left-right hand difference on the non-verbal task was greatly reduced compared to the left-right difference on the verbal task. These results do not fully support the findings of Witelson (1974) or of Gardner et al., (1977). As was mentioned earlier, the overall performance of hearing subjects on the non-verbal task was considerably higher than that found by Witelson (1974). This difference may have contributed to the discrepancy between the present results and those obtained by Witelson (1974) on the same task.

In contrast to hearing subjects, congenitally deaf subjects did not show a left-hemisphere superiority for the processing of sign sequences or bilateral English words. Moreover, they did not show a pronounced visual field asymmetry even when response measures were altered so as to aid the recognition of the signs. However, despite the lack of an overall visual-field difference, 80% of the deaf subjects individually showed a consistent visual-field superiority for the processing of each of the three visual tasks. Thus, it appears that consistent individual variation resulted in the lack of an overall visual-field asymmetry. Consequently, the absence of pronounced laterality differences in deaf subjects cannot be due to inconsistencies in the data, but rather to reliable individual differences.

The performance of deaf subjects with respect to visual-field differences on the bilateral-words task was almost identical to that reported by McKeever et al. (1976) for his deaf group. However, overall performance of his subjects was superior to that found in the bilateral words experiment of this series.

The performance of deaf subjects with respect to hand differences on the tactual tasks was consistent with that found in hearing subjects. A strong right hand superiority was obtained on the verbal task and a tendency for a right hand advantage on the non-verbal task. Once again, the magnitude of the right hand advantage on the verbal task was greatly reduced compared to the right hand advantage on the non-verbal task. Consistent with previous reports of low performance by deaf subjects on verbal tasks (Hoemann & Ullman, 1976), an overall group difference in favor of the hearing was also obtained.

How can the marked difference between deaf and hearing subjects on the visual tasks and the tactual tasks be explained? An examination of the linguistic and educational background of the deaf subjects may be useful in the interpretation of the observed differences. Although all of the deaf subjects had several years of sign language experience and were proficient at signing, there was wide individual variation with respect to the time at which they acquired this skill. For example, some subjects were born into families where they learned sign language from older deaf siblings. Others were not exposed to any sign language until they entered school. Still others were previously trained by the 'oral' method of instruction and as a result had acquired skills in speech and speech reading before signing. Consequently, some subjects had well developed skills in speech reading and speech production whereas others relied predominantly on sign language for communication.

Although there were large individual variations in the use of the English language, interpersonal communication among deaf subjects was exclusively in sign language. It is possible that, depending on the amount of experience in signing, deaf subjects also varied with respect to how correctly and efficiently they produced and processed sign language. Unfortunately, in the absence of standardized tests in American Sign Language, it is difficult to assess the existence and the extent of such individual variations. Whatever the implications of these variations may be, it can be concluded that all deaf subjects studied in these experiments have been exposed to a language system from early childhood.

With this background in mind, the question arises as to why the deaf did not show the same pattern of hemispheric specialization as did the hearing. The main problem in answering this question is that the basis of hemispheric specialization for language functions is not known. However, several factors have been implicated as playing an essential role in the development of functional specialization of the left hemisphere.

Kimura (1973; Kimura & Archibald, 1974) suggested that the left hemisphere is particularly involved in the sequential organization of different types of motor behavior. Since language is a sequential activity, it is subserved by the left hemisphere. The left hemisphere is "...adapted, not for symbolic function per se, but for the execution of some categories of motor activity which happen to lend themselves readily to communication" (Kimura, 1976, p. 154). Thus, the symbolic language functions of the left hemisphere are viewed as a secondary consequence of specialization for motor functions. In support of this view, there is evidence indicating that left hemisphere lesions lead to apraxia for both meaningful (Kimura & Archibald, 1974) and non-meaningful movement sequences (Kimura, et al. 1976). Furthermore, there is a strong, though not necessary, association between aphasia and apraxia (DeRenzi, Pieczuro & Vignolo, 1966). Lastly, studies of normal subjects have indicated that the right hand of right handed persons is predominantly involved in gestural movements made during speaking (Kimura, 1973). An implication of Kimura's motor sequencing theory is that sign language and finger spelling which involve sequential movement as well as symbolic meaning are primarily represented in the left hemisphere.

A number of researchers (Albert, 1972;McKeever et al. 1976) have suggested that the basis of left hemisphere specialization for language may be auditory. Kimura (1961a) proposed that the left temporal lobe is particularly important for the auditory perception of verbal material. There is also anatomical evidence indicating that the left planum temporale (auditory association cortex) is significantly larger than the right in both adult and infant brains (Geschwind & Levitsky, 1968; Witelson & Pallie, 1973). Furthermore, studies of infants involving the presentation of verbal auditory stimuli have indicated that the left hemisphere may be specialized for the processing of elementary speech sounds early in life (Glanville & Best, 1976; Best et al., 1978). This specialization is not necessarily for meaningful speech sounds, rather it is for those sounds that are potentially articulable by the human vocal cords (Kimura & Folb, 1968). If in fact hemispheric specialization is strongly associated with the auditory nature of human language, then it can be argued that in the absence of auditory experience, left hemisphere specialization for language does not develop (McKeever et al., 1976).

Liberman (1970; 1975) proposed that the dominance of the left hemisphere for the processing of verbal material may rest on the ability to manipulate the sequential aspects of auditory stimuli. The involvement of the left hemisphere in the perception and processing of temporally-ordered auditory, visual and tactile stimuli has already been noted (Carmon & Nachshon, 1971; Carmon, 1975; Zaidel & Sperry, 1973).

During the course of language development, hearing children normally gain considerable experience with temporal sequencing through acoustic reception and vocal production. Later, through educational training, they also gain experience with sequencing of visual verbal stimuli. In contrast, deaf children are deprived of the stimulation provided by acoustic input and often vocal output. As a result, they are poor at reproduction of both auditory and visual temporal patterns (Rileigh & Odom, 1972; Wolff, 1979). O'Connor and Hermelin (1973) reported that deaf children process visually presented stimuli in a spatial, as opposed to a temporal pattern, suggesting that for these subjects spatial aspects of stimuli may be more salient. In any case if cerebral lateralization of language functions is based on temporal-sequential analysis, then it would be expected that the deaf, as a result of reduced experience with temporally-ordered stimuli, would not demonstrate a strong left hemisphere specialization for language functions.

Lenneberg's (1967; 1969) theory of the development of hemispheric specialization emphasizes the role of language experience as a critical factor. Furthermore, he emphasizes that there is a 'critical period' for language learning. This 'critical period' ranges from two years of age to early adolescence, and is concurrent with the development of hemispheric specialization. Although Lenneberg (1967) subscribes to the view that those deaf persons who have adequate language skills have left hemisphere specialization for language functions, he also implies that in the absence of language acquisition, normal hemispheric asymmetry may not develop. Very few deaf persons can be said to have no language skills; however, the great majority do acquire primary language skills late and, to some extent, in an incomplete form.

There is some evidence indicating that the development of a normal pattern of hemispheric asymmetry may also be related to a 'critical period'. Thus, recent reports on Genie, a girl isolated from social interaction until the age of thirteen, indicate that her slowly acquired language skills are predominantly represented in the right hemisphere (Fromkin, Kreshen, Curtiss, Rigler & Rigler, 1974; Curtiss, 1978). Although there is not enough evidence in this area to draw firm conclusions, it may be possible to speculate on the implications of these findings for hemispheric specialization in the deaf. Since normal language acquisition is definitely retarded and to some extent incomplete in the great majority of congenitally deaf persons, it is possible that hemispheric specialization is also not as well developed. This would imply that, depending on the amount of language deficits, deaf subjects would either show bilateral representation of language or only weak tendencies for left hemisphere language processing.

The problem inherent in evaluating the theories of the basis of hemispheric specialization is that each theory pertains to only one feature of the language system. Although sequential motor control, acoustic input and vocal output, temporal-patterning and language experience represent different aspects of language processing, none fully captures the symbolic and representational aspects of language. As Poeck and Huber (1977) aptly pointed out, the language code has many complexities only some of which have been isolated and experimentally investigated. Since the extent and the dimensions of the mechanisms underlying hemispheric specialization and language processing are unknown, the interpretation of the performance of deaf subjects in these experiments is compounded.

One possible explanation of a lack of visual-field asymmetry in the deaf may be that the use of the recognition paradigm encouraged a pattern-matching strategy favoring the right hemisphere (Posner & Mitchell, 1967; Geffen, Bradshaw & Nettleton, 1972). Thus, language processing was confounded with the strategy of spatial processing, resulting in no overall difference between the visual-fields. However, in the sign sequences task, subjects matched an apparently moving sign to a two dimensional static drawing. Given that subjects had to perform a 'transformation' on the stimuli, it is unlikely that they could have used a pattern matching strategy. The probability of pattern matching on the variation of the sign sequences task was also unlikely, since the perceived signs were presented at a much faster rate than the demonstrated signs. However, pattern-matching could have been used in the processing of words, since the words on the recognition display were identical to those presented tachistoscopically. If such a strategy was used, then deaf subjects' performance on the words task would be expected to be inconsistent with that shown on the sign sequences task. In fact, the opposite was found. Performance of deaf subjects was consistent across the sign sequences and the words task. Thus, the processing strategy used by deaf subjects appears to have been the same on the two tasks involving different language stimuli.

Alternatively, the absence of an overall right-visual field superiority in the deaf may be explained by the fact that opposite visual-field directional tendencies may have cancelled one another out. On the two tasks involving sign sequences and English words, approximately half the subjects showed a right visual-field advantage while the remaining half showed a left-visual field superiority. The direction of the visual-field advantage was consistent across subjects and tasks. Furthermore, the magnitude of the consistent asymmetries shown by all twelve deaf subjects ranged from 0 - 20% across the two tasks. Thus, it appears that the absence of an overall significant field difference was in fact the result of opposite directional tendencies being cancelled out.

In view of the lack of visual-field effects for the processing of language stimuli, both McKeever et al (1976) and Phippard (1977) suggested that language skills may be bilaterally represented in congenitally deaf subjects. Two points may be raised against this view. First, as mentioned earlier in this thesis, the 'verbal' stimuli used in the

McKeever et al. (1976) and Phippard's (1977) studies may not necessarily have been processed as language material. Finger spelled letters, static signs and English words are not representative of the language of the deaf. Furthermore, since a written symbol system correlated with sign language is not yet available, examination of natural signs may provide the only way of assessing language processing in the deaf. Second, if the deaf have bilateral representation of language, they would not be expected to show a strong degree or direction of visual-field asymmetry. However, the results of the present series of experiments contradict this prediction. Language functions appear to be represented in one hemisphere in individual subjects but the asymmetry can favor either the right or the left. Since there is great individual variation in the demonstration of such an asymmetry, the overall result is one of no laterality effects. Two previous reports (Ling, 1971; Manning, Markman, Goble & LaBreche, 1977) had also found no overall asymmetry in the deaf due to excessive individual variation. However, in the absence of data, to that date, indicating whether these individual variations were consistent, it was not possible to determine whether deaf subjects had bilateral representation of language or language represented in a single specialized hemisphere (either left or right). The results of the present series of experiments lend support to this latter alternative.

The question can now be raised as to why some deaf subjects show left hemisphere specialization for the processing of language stimuli whereas others demonstrate a right hemisphere advantage. Although any explanation of this question will necessarily be ad hoc, it may guide the formulation of further research in this area. Non-parametric analyses of variables which were thought to be related to individual variations in performance (e.g. number of years of sign language experience, early vs. late acquisition of sign language, speech vs. no speech training) did not reveal any specific trends. However, one factor that seems to relate to the demonstration of a right or left hemisphere specialization, is whether or not speech, both intelligible and unintelligible, is produced while signing. All six subjects who showed a consistent right hemisphere superiority on the language tasks, have poor speech and rely exclusively on sign language for communication. In contrast, of the six subjects who showed a left hemisphere superiority, five have good skills in speech production and always attempt to speak while signing. Although the exact nature of this apparent relation needs further research for clarification, on a speculative basis, it can be suggested that ability and experience in speech production aids a left hemisphere processing strategy which is perhaps analogous to that found in hearing subjects.

The performance of deaf subjects on the tactual tasks, in particular the verbal task, cannot be readily explained. Of the eleven subjects who showed consistent asymmetries on the visual tasks and also participated in the tactual experiment, six subjects maintained the direction of asymmetry shown on the visual tasks whereas the remaining five subjects reversed their pattern of asymmetry. If, as the significant interaction of tasks by tactual fields indicates, the verbal tactual task reflects underlying hemispheric specialization, then deaf subjects show a pronounced degree of hand difference, and by implication hemispheric asymmetry (refer to Table 13).

The question may be raised as to whether or not the tactual modality in the deaf, in contrast to the visual modality, is particularly appropriate for revealing perceptual differences. There is no direct experimental evidence to answer this question; however, Wolff (1979) found that deaf signers performed poorly compared to hearing controls on rhythm reproduction tasks. Comparison of the visual and tactual modalities indicated that performance was somewhat improved when stimuli were presented in the tactual modality.

To the extent that visual laterality tests are not completely independent of extraneous variables (such as scanning and processing strategies) the tactual modality may be less complex. However, laterality tests in the tactual modality also have disadvantages (such as the possibility of ipsilateral feedback and transmission across the corpus callosum) which make unequivocal interpretation of data equally difficult.

Predictably the results of the factor analysis did not show strong correlations between the visual and tactual measures. In fact, only the 'modality factor' indicated a correlation between a visual and a tactual performance measure. Although this correlation was between the left visual and tactual fields of the words task, it is possible that the two measures were tapping the same type of verbal processing in the two modalities.

The 'left hemisphere' factor revealed a predictable and interesting clustering. As would be expected there was a strong correlation between the right visual-field scores on the sign sequences and bilateral words tasks. In addition, there was a correlation between performances on the sign sequences task and on the non-verbal I.Q. test (Raven's Progressive Matrices). Even though the I.Q. test was non-verbal and involved predominantly spatial arrangements of various geometrical forms, it may have required a 'logical or analytic' (Levy, Agresti & Sperry, 1968) style of cognitive processing which is characteristic of the left hemisphere. Evidence from callosum-sectioned patients indicates that this test can be performed by either the left or the right hemisphere, but the two hemispheres may use different modes of central processing (Zaidel & Sperry, 1973).

Contrary to expectations, the 'sign language' factor indicated a negative correlation between number of years of sign language experience and performance on the sign sequences task (demonstrated) for stimuli presented in the right visual-field. However, a closer examination of individual performances can explain this negative correlation. The majority of the subjects with many years of sign language experience showed a left visual-field advantage, and therefore a low right visual-field recognition score, on the sign sequences task. Thus, the less experience with sign language, the greater the chance of processing sign sequences predominantly in the left hemisphere.

In conclusion, the main finding of this series of experiments is that deaf subjects individually demonstrate a reliable pattern of hemispheric specialization. However, as a group, the direction of laterlization is not consistent. It is possible that the group inconsistency is related to the age of onset of language development. Left cerebral dominance is presumably dependent on early and normal language development (Lenneberg, 1967; 1969), while right cerebral dominance is more likely the product of late or abnormal language development (Curtiss, 1978). Thus, those deaf individuals who learn a language during the normal period of language acquisition may develop left hemisphere specialization whereas those deaf persons whose language acquisition is delayed and incomplete may develop right hemisphere specialization.

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APPENDIX A

MODIFIED VERSION OF THE EDINBURGH HAND PREFERENCE INVENTORY

(Oldfield, 1971)

HAND PREFERENCE INVENTORY

Name: ______________________ Age: ______________________

Date of birth: ______________ Sex: ______________________

Group: ______________

	LEFT	RIGHT	EITHER
1. Hand preference of S's monther:			
2. Hand preference of S's father:			
3. Hand preference of S for:			
a) writing			
b) drawing			
c) throwing a ball			
d) brushing teeth			
e) combing hair			
f) cutting with a knife			
g) striking a match			
h) opening a jar			

APPENDIX B

LIST OF ASL SIGNS USED AS STIMULI ON THE SIGN SEQUENCES TASK (EXPERIMENTS I & II)

1.	learn	birthday
2.	program	college
3.	develop	daughter
4.	picture	free
5.	boyfriend	never
6.	grow	deaf
7.	storm	teacher
8.	remember	star
9.	jump	brother
10.	year	room
11.	group	president

APPENDIX C

LIST OF DISTRACTOR AND TARGET ASL SIGNS USED ON THE SIGN SEQUENCES TASK (EXPERIMENTS I & II)

TRIALS	TARGETS	DISTRACTORS
1.	learn-birthday	new - eat - again - arrive
2.	program-college	count - under - both - trouble
3.	develop-daughter	proud - later - morning - night
4.	picture-free	tall - shy - spread - disappear
5.	boyfriend-never	will - why - letter - pound
6.	deaf-grow	tree - decide - fire - don't care
7.	teacher-storm	now - walk - leave - surprise
8.	remember-star	believe - hide - sign - people
9.	jump-brother	stupid - final - middle - defeat
10.	room-year	coffee - when - keep - help
11.	group-president	smart - happen - cat - to

APPENDIX D

LIST OF STIMULI AND FIXATION DIGITS USED ON THE BILATERAL WORDS TASK (EXPERIMENT III)

TRIALS	LVF	FIXATION DIGIT	RVF
1.	farm	9	cold
2.	belt	3	comb
3.	nose	4	desk
4.	hair	7	dove
5.	road	8	snow
6.	hand	6	rain
7.	lamp	3	hair
8.	dove	2	knob
9.	bear	9	mask
10.	rain	8	nose
11.	post	8	farm
12.	snow	6	lamp
13.	cold	4	road
14.	comb	2	hand
15.	desk	5	belt
16.	cake	7	post
17.	tape	3	bear
18.	mask	5	lane
19.	knob	6	tape
20.	lane	3	cake

APPENDIX E

RECOGNITION CARD FOR BILATERAL WORDS TASK (EXPERIMENT III)

MASK
KNOB LANE
SNOW 1 POST
2
LAMP 3 RAIN
4
COMB 5 COLD
6
FARM 7 TAPE
8
NOSE 9 DOVE
HAIR HAND
ROAD BELT
DESK BEAR
CAKE

APPENDIX F

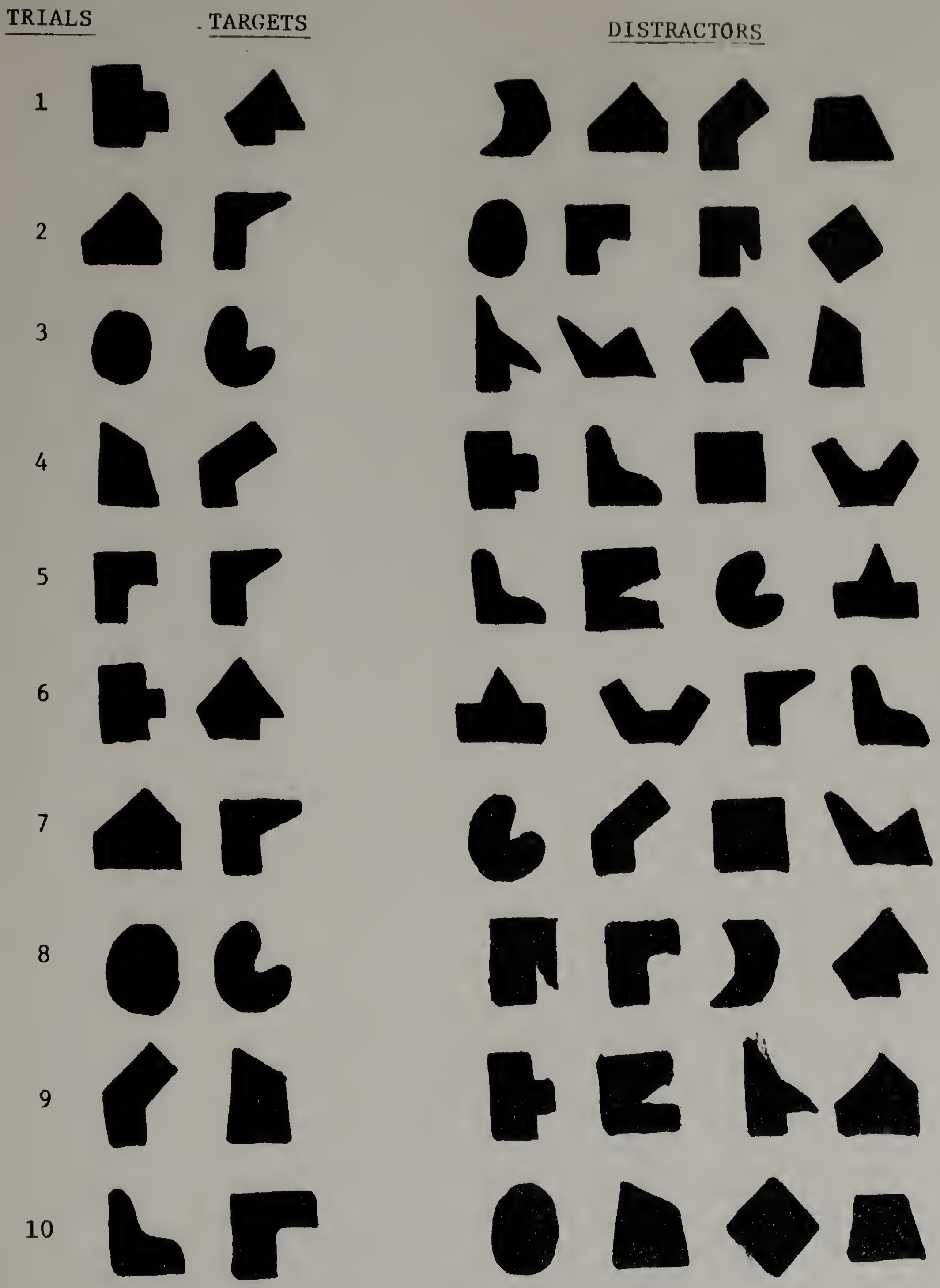
LIST OF STIMULI AND DISTRACTORS
USED ON VERBAL TACTUAL TASK
(EXPERIMENT IV)

TRIALS	TARGETS	DISTRACTORS
1	YET - MAD	YES - PET - PAD - MOP
2	TAX - JOY	TOY - SIX - TIN - JAR
3	FAD - ART	HAT - AXE - LID - FIT
4	FUN - SIN	SET - FAR - PAN - MAN
5	KIN - LAW	ROW - LIP - KIT - PIN
6	EGO - AIR	EAR - APE - CAR - PRO
7	JOY - AIR	JAR - FAR - EAR - TOY
8	MAD - KIN	GOD - MIT - KIT - PAN
9	FUN - EGO	PRO - SUN - FAT - EAT
10	ART - LAW	LID - ANT - CAT - SAW
11	SIN - YET	MAT - SON - PAN - YES
12	FAD - TAX	SIX - TIP - POD - FAR

APPENDIX G

STIMULI AND DISTRACTORS USED ON NON-VERBAL TACTUAL TASK

(EXPERIMENT IV)


TRIALS
TARGETS
DISTRACTORS
1
2
3
4
5
6
7
8
9
10

APPENDIX H

RAVEN'S PROGRESSIVE MATRICES I.Q. SCORES OF SUBJECTS IN GROUP E

SUBJECT	I.Q. (PERCENTILES)
1 C.L.	90
2 I.D.	90
3 E.C.	30
4 G.W.	75
5 C.A.	25
6 O.P.	25
7 F.C.	80
8 R.L.	90
9 H.D.	98
10 V.O.	30
11 M.L.	25
12 M.R.	25
13 S.L.	75
14 D.H.	75
15 M.L.	75
16 S.R.	35
17 G.F.	25
18 P.P.	20
19 S.A.	25

APPENDIX I

PERSONAL DATA ON SUBJECTS OF GROUP E

SUBJECT	SEX	AGE	DB LOSS	No. OF YEARS OF ASL
1	F	12	100	5
2	F	12	100	4
3	F	14	100	10
4	F	15	105	6
5	F	16	100	9
6	F	15	108	5
7	F	17	80	4
8	F	17	110	6
9	F	17	103	8
10	M	12	103	4
11	M	13	98	8
12	M	14	98	4
13	M	15	100	12
14	M	15	100	6
15	M	15	100	4
16	M	16	93	11
17	M	14	97	6
18	M	17	103	6
19	M	14	98	

APPENDIX J

EXPERIMENT I: PERCENT ACCURACY OF RECOGNITION IN LEFT AND RIGHT VISUAL FIELDS

ASL SIGN SEQUENCES TASK

(N = 44 Trials)

TABLE 20

(GROUP E) SUBJECT	LVF	RVF	(GROUP C2) SUBJECT	LVF	RVF
1 C.L.	57	45	1	59	41
2 I.D.	45	66	2	50	50
3 E.C.	59	43	3	36	64
4 G.W.	20	61	4	30	57
5 C.A.	48	43	5	45	52
6 O.P.	39	52	6	48	61
7 F.C.	43	55	7	50	50
8 R.L.	50	41	8	50	50
9 V.O.	39	48	9	45	59
10 M.L.	55	43	10	32	43
11 N.R.	41	48	11	48	59
12 S.L.	52	68	12	52	61
13 D.H.	57	52	13	57	45
14 N.L.	45	61	14	34	36
15 G.F.	45	40	15	50	59
16 P.P.	55	37	16	50	70
TOTAL	750	803		736	857

PERCENT ACCURACY OF RECOGNITION

IN LEFT AND RIGHT VISUAL FIELDS

ASL SIGN SEQUENCES TASK

APPENDIX K

EXPERIMENT II: PERCENT ACCURACY OF RECOGNITION IN LEFT AND RIGHT VISUAL FIELDS ASL SIGN SEQUENCES TASK (DEMONSTRATED)

(N = 44 Trials)

TABLE 21

(GROUP E) SUBJECTS	LVF	RVF	(GROUP C3) SUBJECTS	LVF	RVF
1 C.L.	59	57	1	48	66
2 I.D.	75	66	2	57	50
3 E.C.	50	41	3	65	63
4 G.D.	52	59	4	45	59
5 C.A.	70	43	5	55	61
6 O.P.	59	68	6	50	84
7 F.C.	66	82	7	55	57
8 R.L.	61	55	8	64	66
9 V.O.	48	59	9	43	55
10 M.L.	68	64	10	56	75
11 M.R.	57	66	11	68	64
12 S.L.	64	70	12	61	66
13 D.R.	70	84	13	57	68
14 M.L.	77	48	14	64	69
15 G.F.	36	59	15	45	80
16 P.P.	66	61	16	51	58
TOTAL	985	975		884	1041

PERCENT ACCURACY OF RECOGNITION IN

LEFT AND RIGHT VISUAL FIELDS

ASL SIGN SEQUENCES TASK (DEMONSTRATED)

APPENDIX L

EXPERIMENT III: PERCENT ACCURACY OF RECOGNITION IN LEFT AND RIGHT VISUAL FIELDS

BILATERAL ENGLISH WORDS TASK

(N = 20 Trials)

TABLE 22

(GROUP E) SUBJECTS	LVF	RVF	(GROUP C2) SUBJECTS	LVF	RVF
1 C.L.	30	15	1	80	65
2 I.D.	5	60	2	95	90
3 E.C.	30	0	3	65	25
4 G.W.	15	75	4	60	90
5 C.A.	20	20	5	55	95
6 O.P.	15	5	6	20	80
7 F.C.	55	15	7	80	90
8 R.L.	15	10	8	65	90
9 V.O.	10	20	9	40	50
10 M.L.	10	25	10	45	90
11 M.R.	50	70	11	35	100
12 S.L.	25	60	12	70	80
13 D.H.	65	55	13	5	40
14 M.L.	40	65	14	70	85
15 G.F.	20	15			
16 P.P.	30	10			
TOTAL	435	420		785	1070

PERCENT ACCURACY OF RECOGNITION

IN LEFT AND RIGHT VISUAL FIELDS

BILATERAL ENGLISH WORDS TASK

APPENDIX M

EXPERIMENT IV: PERCENT ACCURACY OF RECOGNITION IN LEFT AND RIGHT TACTUAL FIELDS

VERBAL TASK

(N = 12 Trials)

TABLE 23

(GROUP E)	LTF	RTF	(GROUP C1)	LTF	RTF
SUBJECTS			SUBJECTS		
1 C.L.	50	90	1	100	100
2 I.D.	33	83	2	58	83
3 E.C.	66	75	3	92	100
4 G.W.	54	63	4	92	92
5 C.A.	45	63	5	58	92
6 H.D.	100	100	6	67	75
7 V.O.	55	55	7	83	83
8 M.L.	45	73	8	92	83
9 M.R.	54	64	9	100	100
10 S.R.	75	50	10	50	67
11 S.L.	58	92	11	50	83
12 D.H.	66	91	12	75	83
13 M.L.	100	75	13	50	92
14 G.F.	36	91	14	92	92
15 P.P.	45	82	15	92	92
16 S.A.	33	83	16	83	67
TOTAL	915	1230		1234	1384

PERCENT ACCURACY OF RECOGNITION

IN LEFT AND RIGHT TACTUAL FIELDS

VERBAL TASK

APPENDIX N

EXPERIMENT IV: PERCENT ACCURACY FOR RECOGNITION IN LEFT AND RIGHT TACTUAL FIELDS

NON-VERBAL TASK

(N = 10 Trials)

TABLE 24

(GROUP E)		LTF	RTF	(GROUP C1)	LTF	RTF
SUBJECTS				SUBJECTS		
1	C.L.	100	60	1	70	100
2	I.D.	70	70	2	60	70
3	E.C.	80	100	3	80	90
4	G.W.	80	70	4	80	80
5	C.A.	55	55	5	70	70
6	H.D.	70	80	6	90	80
7	V.O.	70	80	7	100	100
8	M.L.	50	80	8	80	90
9	M.R.	90	70	9	70	80
10	S.R.	70	70	10	60	80
11	S.L.	90	90	11	56	78
12	D.H.	50	70	12	80	80
13	M.L.	80	70	13	70	50
14	G.F.	67	78	14	80	60
15	P.P.	60	70	15	100	78
16	S.A.	60	60	16	70	60
TOTAL		1142	1173		1196	1246

PERCENT ACCURACY OF RECOGNITION

IN LEFT AND RIGHT TACTUAL FIELDS

NON-VERBAL TASK

APPENDIX O

CORRELATION MATRIX OF FOURTEEN
MEASURES FOR DEAF GROUP

TABLE 25

		SEX	AGE	IQ	(RTF) TVR	(LTF) TRL	(RTF) TNR	(LTF) TNL	(RVF) SSR	(LVF) SSL	(RVF) SSDR	(LVF) SSDL	(RVF) BR	(LVF) BL	YEARS
1.	Sex (F=1, M=2)		0.16	0.44	0.10	0.03	0.05	0.27	0.06	0.18	0.25	0.07	0.29	0.24	0.07
2.	Age	0.16		0.31	0.00	0.53*	0.13	0.20	0.24	0.17	0.15	0.46	0.11	0.26	0.20
3.	I.Q.	0.4	0.31		0.48	0.42	0.02	0.42	0.57*	0.03	0.23	0.42	0.37	0.15	0.09
4.	Tactual Verbal Task (RTF) -- (TVR)	0.10	0.00	0.48		0.02	0.14	0.01	0.08	0.58*	0.46	0.07	0.07	0.25	0.10
5.	Tactual Verbal Task (LTF) -- (TVL)	0.03	0.53*	0.42	0.02		0.25	0.22	0.29	0.03	0.18	0.28	0.30	0.52	0.34
6.	Tactual non-Verbal Task (RTF) -- (TNR)	0.05	0.13	0.02	0.14	0.25		0.17	0.07	0.20	0.01	0.40	0.17	0.11	0.25
7.	Tactual non-Verbal Task (LTF) -- (TNL)	0.27	0.20	0.42	0.01	0.22	0.17		0.42	0.22	0.19	0.23	0.30	0.04	0.15
8.	Sign Sequences Task (RVF) -- (SSR)	0.06	0.24	0.57*	0.08	0.29	0.07	0.42		0.39	0.28	0.43	0.72*	0.02	0.24
9.	Sign Sequences Task (LVF) -- (SSL)	0.18	0.17	0.03	0.58*	0.03	0.20	0.22	0.39		0.05	0.14	0.41	0.24	0.28
10.	Sign Sequences Task (Demonstrated) (RVF) -- (SSDR)	0.25	0.15	0.23	0.46	0.18	0.01	0.19	0.28	0.05		0.18	0.17	0.45	0.70*
11.	Sign Sequences Task (Demonstrated) (LVF) -- (SSDL)	0.07	0.46	0.42	0.07	0.28	0.40	0.23	0.43	0.16	0.18		0.39	0.18	0.19
12.	Bilateral Words Task (RVF) -- (BR)	0.29	0.11	0.37	0.07	0.30	0.17	0.30	0.72*	0.41	0.17	0.39		0.20	0.16
13.	Bilateral Words Task (LVF) -- (BL)	0.24	0.26	0.15	0.25	0.52	0.11	0.04	0.02	0.24	0.45	0.18	0.20		0.09
14.	No. of Years of Sign Language (Years)	0.07	0.20	0.09	0.10	0.39	0.25	0.15	0.24	0.28	0.70*	0.19	0.16	0.09	

* Factors with "high" loading.

CORRELATION MATRIX OF FOURTEEN MEASURES