8709241

Prescott, Phyllis A.

DIFFERENTIAL REINFORCING VALUE OF SPEECH AND HEARTBEATS: A MEASURE OF FUNCTIONAL LATERALIZATION IN THE NEONATE

The University of North Carolina at Greensboro PH.D. 1985

University Microfilms International 300 N. Zeeb Road, Ann Arbor, MI 48106

DIFFERENTIAL REINFORCING VALUE OF SPEECH AND HEARTBEATS:

A MEASURE OF FUNCTIONAL LATERALIZATION

IN THE NEONATE

by

Phyllis A. Prescott

A Dissertation submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Greensboro
1985

Approved by

Dissertation Adviser

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of the Graduate School at the University of North Carolina at Greensboro.

Dissertation Adviser ______________________

Committee Members ______________________

____

____

____

June 28, 1985
Date of Acceptance by Committee

June 28, 1985
Date of Final Oral Examination

PRESCOTT, PHYLLIS A., Ph.D. Differential Reinforcing Value of Speech and Heartbeats: A Measure of Functional Lateralization in the Neonate. (1985)
Directed by Dr. Anthony J. DeCasper. Pp. 59.

By learning to suck on a nonnutritive nipple in temporal patterns selected by the experimenter, newborns could control whether the sounds of filtered female speech entered their left ear or their right ear. Similarly, other newborns could learn to control whether intrauterine heartbeat sounds entered one ear or the other. Infants consistently learned to suck so as to have speech sounds enter their right ear and heartbeat sounds enter their left ear. The right-ear speech preference and left-ear heartbeat preference in newborns averaging 52 hours of age indicates that auditory perception is functionally lateralized at birth and presumably, therefore, before.

ACKNOWLEDGMENTS

The author wishes to thank the infants, parents and staff of Moses Cone Hospital who played an important role in the project. I appreciate the support and advice provided by my committee members, Drs. Rosemery Nelson, Jacquelyn White, Marc Marschark and Garrett Lange. My most sincere appreciation goes to Dr. Anthony DeCasper, my thesis advisor, for his continuing guidance and support and Robin Panneton who assisted in data collection. Special thanks goes to my husband, Jim, for his encouragement and insight.

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURE

CHAPTER I

INTRODUCTION

Differences between the two cerebral hemispheres in the functions they subserve in Homo sapiens have been reported for more than a century, originating with clinical observations of brain-damaged individuals. First, Broca (1861) and Dax (1865) demonstrated that expressive speech is represented predominantly in the frontal lobe of the left cerebral hemisphere. Secondly, Wernicke (1874) located a second region in the superior posterior left temporal lobe that when damaged resulted in impairment of language comprehension. As a result of these findings, the speculation arose that the right cerebral hemisphere assumed a relatively unimportant role in language and indeed was termed the "silent hemisphere". These pioneering studies, accompanied by evidence that each hemisphere of the brain exerts primary motoric and sensory control over the contralateral half of the body, provided the foundation for examining right-left asymmetries in the cerebral cortex and their implications for functional laterality (Porac and Coren, 1981).

Historically, issues surrounding hemispheric differences were pursued primarily by neurophysiologists and those in related disciplines who observed the differential symptomatology of right as compared to left hemispheric disorders (Oppenheimer, 1977). However, technological advances during the past two decades have allowed behavioral scientists to address the functional differences between the two cerebral hemispheres.

In the early 1960's Sperry and Gazzaniga conducted studies of neurological patients who had undergone cerebral commissurotomy. By observing split-brain subjects they were able to examine the functional capabilities of each hemisphere in isolation from the other. This classic work clarified a number of differences related to vision (Gazzaniga, Bogen and Sperry, 1965), praxis (Gazzaniga, Bogen and Sperry, 1967), somatosensory representation (Gazzaniga, Bogen and Sperry, 1963), language processes (Gazzaniga and Sperry, 1967), and spatial functions (Bogen and Gazzaniga, 1965). Subsequent investigators under Sperry's direction have emphasized right-left differences in memory, transfer of training, and cognitive style (Levy and Trevarthen, 1977; Zaidel, 1976, 1978).

While substantial information has been derived from the study of unilateral brain lesions and commissurotomy patients, generalization to normal populations should be made only with considerable caution. Studies of patients with focal lesions, for example, can only provide hypotheses about the role of the undamaged hemisphere in mediating the function under study. Similarly, split-brain studies can furnish information about the independent capabilities of each hemisphere, but all the subjects involved have neurological disorders which could affect functioning and most have a history of early brain damage which might have resulted in the relocation of functions in the brain (Bryden, 1982).

Another important development was Doreen Kimura's (1961a, 1961b) introduction of the dichotic listening technique, which permits the noninvasive, behavioral assessment of cerebral specialization of auditory processes in functionally intact subjects. Kimura's technique constituted an important link between neurology and experimental psychology, and it has led to many fruitful investigations since her original work.

In dichotic listening a subject outfitted with two headphones is simultaneously presented different auditory stimuli in each ear and asked to report what he has heard. Kimura consistently found that, with verbal stimuli, subjects reported more information presented to the right ear, while there was a left ear superiority when nonverbal stimuli such as musical selections were employed (Kimura, 1964). The original technique has been refined (e.g., Hayden, Kirsten and Singh, 1979; Geffen and Caudrey, 1981) and applied to different classes of speech and nonspeech materials with comparable results. It is now commonplace to find studies in which dichotic listening performance is used as a criterion for hemisphere dominance. Superior performance or efficiency with the right ear, a right ear advantage (REA), is considered to reflect left hemisphere processing. More effective performance with the left ear, a left ear advantage (LEA), is considered evidence of right hemisphere processing.

Kimura (1967) explained her results in terms of the greater number of pathways from each ear to the contralateral hemisphere and an hypothesized ability of contralateral fibers to partially block stimulation from ipsilateral fibers at their point of overlap. Thus she proposed that the right ear/left brain connections are functionally more effective than left ear/left brain pathways in relaying information to the center for speech analysis in the left hemisphere. Speech information presented to the right ear would have an advantage because it would be more effectively transmitted to the hemisphere specialized for speech and language. A parallel explanation accounts for the left ear superiority with nonspeech stimuli. Kimura supported her hypothesis primarily by earlier evidence for a greater number of contralateral than ipsilateral auditory pathways in cats (Rosenzweig, 1951; Rosenzweig and Rosenblith, 1953) and in humans (Bocca, Calearo and Migliavacca, 1955).

Although Kimura's model can account for many of the findings of the dichotic listening literature, the test-retest reliability of ear asymmetry scores is lower than one would expect to result purely because of nervous system structure (Berlin, 1977; Teng, 1981). More recent evidence suggests that a number of nonstructural factors are also important in listening asymmetry. For example, the magnitude and direction of asymmetry can depend upon the nature of acoustic variables such as intensity, signal/noise ratio, frequency bandwidth, and temporal relationships (Berlin and Cullen, 1977). Functional lateralization can also be influenced by contextual and cognitive factors such as the context in which sound is heard (Spellacy and Blumstein, 1970), previous experience with the stimulus material (Bever and Chiarello, 1974; Johnson, 1977; Van Lanker and Fromkin, 1977), memory load (Bryden and Allard, 1981; Geffen, 1978), task difficulty (Zuriff, 1974; Hellige and Wong, 1983), attentional factors (Geffen and Wale, 1979; Hiscock and

Kinsbourne, 1980; Shadden and Peterson, 1981), and cognitive processing variables (Taylor and Heilman, 1982; Milberg, Whitman, Rourke and Glaros, 1981).

Kimura's structural explanation also has difficulty accounting for the large body of evidence which indicates that dichotic competition is unnecessary for revealing functional auditory asymmetry; laterality effects can be obtained when linguistic or nonlinguistic stimuli are presented independently to each ear (Kinsbourne, 1978). At least 105 behavioral and 14 psychophysiological studies have reported auditory asymmetry with monaural stimulation. These studies employed a wide variety of stimuli, techniques, and dependent variables and yet reached the same conclusion; there is a right ear advantage with language and a left ear advantage with nonlanguage stimuli (Henry, 1983).

In an attempt to account for these findings, Kinsbourne (1978) proposed an "orientation" model of hemispheric asymmetry. He begins with the assumption that there are innate, species- specific subcortical arousal mechanisms which engender different distributions of cortical activation based upon the acoustic characteristics of the auditory stimuli. Language sounds tend to cause activation of the left hemisphere, and nonlanguage stimuli the right, with the more active hemisphere being more efficient in processing information. Secondly, he assumes that there is a tendency for attention to shift or orient toward the side of space opposite the active hemisphere.

Kinsbourne's view does not require structurally mediated contralateral and ipsilateral interactions. He asserts that functional asymmetry is independent of structural asymmetry and conduction properties of pathways. He does acknowledge that contralateral pathways may be more efficient, but this contributes to individual variations in the degree of ear asymmetry rather than providing the basis for asymmetry itself (Kinsbourne and Hiscock, 1983).

Kinsbourne (1978) notes that differential hemispheric activation is caused by different types of physical stimuli and also results in the associated orientation to the opposite side of space. Even neonates are more likely to respond to linguistic stimulation on the right and nonlinguistic stimulation on the left. It is the differential hemispheric activation and differential attention to spatial position rather than the ear involved that is important. These attentional biases are assumed to be automatic and inflexible very early in life but gradually yield to the influence of experience and other cognitive processes. One implication is that even newborns would respond in this manner (Kinsbourne and Hiscock, 1983). Such factors as "set" and expectations in a situation become more potent as the individual accumulates experience, and the perception and processing of information become more flexible. In the adult, this flexibility in processing contributes to the imperfect relationship between stimulus characteristics and functional lateralization of auditory processes.

Language becomes functionally lateralized as the infant is exposed to speech and the repeated left brain activation facilitates the cortical aquisition of language processing functions. For Kinsbourne, it is thus unnecessary to hypothesize that the left hemisphere is structurally more suited to process language. For example, if the left brain is damaged early in life the right hemisphere becomes the more differentially activated one, and it develops as the locus of language processing (Kinsbourne and Hiscock, 1983).

The extensive research and refinement of techniques during the past 20 years have both added to our knowledge of functional asymmetry and extended our conceptual framework well beyond the original notion of a rigid right-left dichotomy with a language-dominant left hemisphere and a "silent" right hemisphere. Even though language functions are still considered largely a province of the left hemisphere, the current view of hemispheric processing notes the importance of a variety of factors beyond the nature of the stimulus presented, e.g. the type of information processing required by the task or selected by the subject (Witelson, 1983). Each hemisphere is seen to have its own characteristic mode of specialized functioning : the left analyzes stimuli as discrete units, particularly in terms of their temporal arrangement, while the right integrates or synthesizes stimuli into a whole which has no temporal dimension.

The left hemisphere is better at processing stimulus elements in terms of their sequence, duration, order or rhythm, which makes it well suited for the reception or production of language, particularly in its spoken form, but also for "temporal sequences" such as complex motor movements (Bradshaw and Nettleton, 1981; Kimura and Archibald, 1974). The right hemispheric mode of processing is better suited for stimuli which derive their "meaning" from the configuration or spatial arrangement in which they occur. All forms of spatial perception (Benton, 1979), the recognition of faces (Geffen, Bradshaw and Wallace, 1971), and the identification of emotional expression (Safer and Leventhal, 1977) are normally processed in the right hemisphere.

This conception of the brain's functional organization not only accounts for most of the research data in studies of normal and neurologically impaired adults, but also is compatible with the differential hemispheric functions found in the preverbal child and, to some extent, with data from the animal literature.

This brief review has focused on the substantial body of data regarding functional lateralization of auditory functions in adults and also noted the important role assigned to experience and development. However, relatively little is known about the origin and development of the functional lateralization of auditory processing. Recent data suggest that physiological, anatomical and behavioral asymmetries, as well as functional lateralization of linguistic and nonlinguistic processes, occur at an earlier age than heretofore suspected. The purpose of this study is to further investigate the characteristics of functional auditory asymmetry at birth.

Empirical Considerations

The assumptions of cerebral equipotentiality and subsequent progressive functional lateralization of language processes have appeared in the literature since the latter half of the nineteenth century. Early psychoneurological investigators noted the apparent anatomical symmetry of the hemispheres and observed the development of language in children with left brain atrophy. They drew the reasonable inference that the strong language lateralization in adults developed from more symmetrical, simpler functioning in the neonate (Kinsbourne and Hiscock, 1983).

The first comprehensive developmental theory which encompassed these two principles of equipotentiality and progressive lateralization was proposed in Lenneberg's (1967) book, Biological Foundations of Language. His basic position was that language development and functional lateralization are governed by biological maturation which occurs in a range of typical environments and which will proceed in an orderly, predictable fashion unless markedly affected by unfavorable events. He emphasized the postnatal immaturity of brain structure and function, the notion of critical period for language aquisition, and ultimately, the complete lateralization of speech functions to the left hemisphere in adults (Wada, 1977).

Lenneberg considered the first two years of life to be a period of equipotentiality with regard to the ultimate functional laterality of language; no structural or functional laterality is present and each hemisphere is equally capable of developing the capacity for speech processing.

> ...No lateralization of the speech function seems to be present before age two or three; then there is a period that lasts to about age ten or twelve, during which cerebral lateralization for speech is gradually established but may still be put back into the right hemisphere... After puberty, lateralization is normally firmly established to the left and the right hemisphere is no further involved inthe speech function. (Lenneberg, 1967, p. 47)

The period of decreasing rate of brain development from age 2 to age 13 is thus considered a critical period for language aquisition and lateralization: during language development the right hemisphere progressively decreases its involvement in language processing, functional plasticity decreases, and at puberty the brain has achieved its mature, irrevocable level of language lateralization. Three recent lines of evidence, however, seem to require revision of this of equipotentiality and temporal course of progressive lateralization of language functions.

Early Brain Damage

Lenneberg's selection of puberty as the end of the critical period for lateralization appears rather arbitrary. There were no available studies at the time of unilateral lesions in children between the ages of six and twelve (Bryden, 1982), and Krashen (1973) actually suggested that the upper limit was more likely age 5 or 6 after his review of the evidence.

Dennis and Whitaker (1977) cite evidence that suggests less plasticity during the first two years than hypothesized by Lenneberg. Infants who had the entire left hemisphere removed later showed clear deficits in complex verbal functions compared with infants who had a right hemispherectomy. Similarly, the subjects with right brain removal were less effective than their left brain counterparts in spatial skills. Other data also suggest that language disturbances are more likely to occur when young children receive left hemisphere damage (Hecaen, 1976; Basser, 1962; Kinsbourne and Hiscock, 1977). The evidence to date indicates that the right hemisphere can assume phonological and semantic functions very well following early left brain damage, but there are particular difficulties with syntactical processing (Dennis and Whitaker, 1977; Kohn, 1980). In short, the data suggest that, following early brain lesions, there is less equipotentiality, greater complexity of recovery, and less plasticity of language functioning than Lenneberg suspected.

Developmental Asymmetry

Lenneberg's proposition that progressive lateralization occurs throughout the prepuberty period is not supported by evidence in the current literature. On the contrary, most studies suggest that the relative degree of functional lateralization remains essentially constant in normal children after age 2 or 3. Kinsbourne and Hiscock (1977) and Witelson (1977) reached much the same conclusion in their reviews of the literature, neither finding evidence of an interaction between age and degree of asymmetry.

A consistent right ear advantage for verbal stimuli in studies of dichotic listening has been reported with a wide variety of age groups, from preschoolers to college students (Bakker, Hoefkens and Vander-Vlugt, 1979; Borowy and Goebel, 1976; Bryden and Allard, 1981; Bryson, Mononen and Yu, 1980; Hiscock and Kinsbourne, 1980; Hynd and Obrzut, 1977; Piazza, 1977; Schulman-Galambos, 1977).

A few studies have utilized nonverbal stimuli or different experimental procedures in the study of asymmetry. EEG response to music and spatial stimuli (Nava and Butler, 1977), tactile identification of irregular shapes (Flanery and Balling, 1979), nonverbal environmental sounds in dichotic listening (Piazza, 1977), and response on verbal and nonverbal tasks using the unimanual finger-tapping-time-sharing technique (Piazza, 1977) all have been investigated. These data parallel those found using verbal stimuli in dichotic listening paradigms; there is left body superiority with nonlanguage sensory functions across a wide range of ages.

Infant Asymmetry

Finally, and most relevant to the purpose of this study, recent infancy data also question the view that there is no lateralization during the first two years of life. Evidence from neuroanatomical, electrophysiological, behavioral and auditory perceptual studies converge to suggest that infants have a pattern of lateralized brain structures and functions similar to that found in older children and adults.

Neuroanatomical Research. A few neuroanatomists, such as Eberstaller (1890) and Cunningham (1892) in the late nineteenth century and later Shellshear (1937) and Connolly (1950), had observed gross morphological differences between the two hemispheres in the adult brain, but these differences were largely considered incidental and of insufficient magnitude to be related to the marked functional differences between the hemispheres (e.g., Von Bonin, 1962). However, within the last decade anatomical asymmetry, particularly in the posterior temporal lobe, has been much more seriously considered as a substrate for documented differences in function.

Geschwind and Levitsky (1968) measured the planum temporale, a portion of the posterior superior surface of the first temporal gyrus, in 100 adult postmortem brain specimens. In the left hemisphere the planum is a part of Wernicke's area, important in the interpretation of speech sounds, and is adjacent to the supramarginal and angular gyri, regions known to be related to language comprehension and praxis (Bogen and Bogen, 1976; Geshwind, 1970). The authors found that the left planum was longer than the right planum in 65 % of the adult brains, and that the right hemisphere planum was longer in only 11 % of the cases. The average left planum measured 3.6 centimeters (SD = 1.0) while the average length on the right was 2.7 centimeters (SD = 1.2), a statistically reliable difference. Six subsequent studies have also reported that the average left planum is longer and greater in area than the right. A summary of the data to date (Witelson, 1983) shows that approximately 70 % of the brains studied have a larger left planum, and that the right planum, on the average, is only 63 % as large as the left.

Recent postmortem studies indicate that planum asymmetry is also present in the brain of the infant and the foetus. Wada, Clarke and Hamm (1975) were the first to demonstrate a larger left planum in the prenatal and postnatal brain. Chi, Dooling and Gilles (1977) have shown that similar differences can be observed as early as the thirty-first week of gestation. Three studies have been conducted of brains free from neurological disease. Wada, et al. (1975) employed specimens between the ages 7 months gestation and 18 months postnatal, Teszer, Tzavaras, Gruner and Hecaen (1972) studied the brains of 7 to 9 month foetuses, and Witelson and Pallie (1973) selected 1 day to 3 month old infant brains. All three studies found the mean size of the planum temporale larger in the left hemisphere than in the right.

The composite data from these investigations indicates that 66 % of the infant and foetal brains had a larger left planum, compared with the 70 % found in the adult studies, and that the average right hemisphere planum was approximately 56 % as large as the left, compared to the 63 % value found with adults. These neuroanatomical consistences support the notion that structural cerebral asymmetries, potentially relevent to language functions, exist much earlier than previously suspected.

Electrophysiological Research. A second line of research which provides evidence of physiological cerebral asymmetry in infants involves measures of the electrical activity of the two hemispheres of the brain. Even though electroencephalography has been in existence for over 50 years and is well established as a diagnostic tool in clinical neurology, only recently has the procedure been applied to the study of laterality in the normal brain.

The electroencephalogram (EEG) essentially involves the measurement of patterns of differences in electrical potential between sites on the scalp, and presumably of underlying electrical activity in the brain. Spontaneous EEG recordings of ongoing brain activity have been used by neurologists and by researchers interested in relating wave patterns to subject variables, but average evoked potentials (AEPs) have normally been used when response to a stimulus is being measured. The AEP is obtained by computer-averaging, over a number of trials, the EEG activity wave form immediately following stimulus presentation. Changes in potential related to the stimulus are enhanced as summation over trials occurs, and fluctuations independent of the stimulus are diminished (Parmelee and Sigman, 1983).

The first study to demonstrate that electrophysiological asymmetry in response to speech vs. nonspeech sounds exists in infancy was conducted by Molfese, Freeman and Palermo (1975). The subjects included 10 adults (age 23 to 29 years), 11 children (age 4 to 11 years), and 10 infants (age 1 week to 10 months). The authors presented recorded speech syllables, words, a piano chord, and a burst of noise to each subject while recording EEG activity over the right and left temporal lobes. The resulting auditory evoked potential revealed greater activation of the left temporal area with language stimuli, and greater activation of the right temporal lobe with nonlanguage stimuli, for all three groups.

Several other studies have since found additional evidence with infants of lateralization of the electrophysiological response to various forms of speech and nonlanguage auditory stimulation. Gardiner and Walter (1977) compared the spontaneous EEG patterns of response to conversational speech vs. music, Molfese (1977) used speech syllables vs. pure tones, and Molfese and Molfese (1979, 1980) presented speech vs. analogous nonspeech sounds. All three studies reported greater left hemisphere activation with linguistic stimuli and greater right brain activation with nonlinguistic stimuli. Not all studies have obtained positive results, however, and the electrophysiological work to date has not clarified what acoustic variables result in unilateral hemispheric activation (e.g. Merryweather, 1978). Nevertheless, the more general conclusion is that there is lateralized physiological functioning associated with speech and nonspeech sounds; the nature of the lateralization is consistent with that of adults and with known anatomical asymmetries in adults and infants.

Behavioral Research. Studies of infant behavior have also cast doubts upon the view that there is little or no functional lateralization during the first two years of life. The behavioral research has focused upon asymmetries in posture, orientation, grasping, reaching behavior, and behavioral response to stimulation.

The tonic neck reflex is a characteristic posture of young infants in which the leg and arm are flexed on one side and extended on the other, with the head turned to the extended limb side. A large majority of preterm and full-term infants display either a full right tonic neck reflex or a right head turn with other elements of the position (Turkewitz, Gordon and Birch, 1965; Gardner, Lewkowicz and Turkewitz, 1977). Moreover, Michel (1981) found further support for this phenomenon in neonates, and also discovered that the preference for right or left orientation correctly predicted, in 80 % of his sample, hand preference for reaching 16 to 22 weeks later.

The Gesell and Ames (1947) observations on the development of handedness reported fluctuations in hand preference during the first year of life. Even though some subsequent studies (e.g., Cohen, 1966) have suggested an early right hand preference, problems with the use of reaching as an index of handedness have been noted (Witelson, 1977; Young, 1977). Even so, left/right postures and reaching tend to be biased toward the right from the beginning.

More consistent results have been reported in studies of grasping and strength of grip. Caplan and Kinsbourne (1976) and Hawn and Harris (1979) found that 2 to 5 month old infants held a rattle longer in the right hand, and Petrie and Peters (1980) describe a clear right hand advantage in both duration and strength of grasp measured at ages 17, 51, 82, and 108 days.

When an infant is lowered onto a flat surface so that the feet touch, there is reflexive tendency to respond with stepping movements of the legs. This stepping reflex is asymmetrical at birth. Peters and Petrie (1979) tested 24 infants on four occasions between the ages of 17 and 105 days, finding that the first step was with the right foot on 75 % of the trials. Melekian (1981) conducted a similar study of 313 neonates on their first day of life. The initial right step occurred in 88 % of the infants, and 70 % responded first with the right leg on three consecutive trials. Comparable results were obtained when the infants were tested a week later, suggesting that this bias is relatively stable.

Some tendencies toward asymmetry have been been identified in the position of the foetus prior to birth and in its presentation during birth. Normally, an infant is born head first facing the front of its mother, and usually there is a left presentation, with the infant's head turned to its left. Steel and Javert (1942) found 53 % left vs. 34 % right presentations at birth, while Kopell (1971) reported 67% left presentations. A significant relationship was found by Michel and Goodwin (1979) between left birth presentation and the later right tonic neck reflex.

Asymmetrical behavioral response has been observed to visual, tactile and auditory stimulation. When Wicklegren (1967) presented infants with visual targets they spent more time looking at those on the right. A more reliable right than left side ipsilateral response to tactile stimulation was found by Hammer and Turkewitz (1974) on the sides of the mouth, and by Weiffenbach (1972) on the tongue. Finally, Liederman and Kinsbourne (1980a, 1980b) demonstrated a bias toward a greater response to right side visual, tactile, and gustatory stimuli. The response bias was not based upon differential sensitivity and was more frequent when both parents were right-handed.

Overall, results of the behavioral research are quite consistent with the anatomical and physiological data in providing evidence of functional asymmetry in infancy.

During the past decade increasing attention has been focused upon the infant's perception of speech and nonspeech stimuli. It has been clearly established that a variety of nonspeech sounds can be discriminated, that infants as young as 3 days old can discriminate consonant and vowel (CV) contrasts in their own language, and that infants as young as 1 month of age can discriminate CV contrasts in a foreign language to which they have not been previously exposed (Butterfield and Cairns, 1974; DeCasper, Butterfield, and Cairns, 1976; Eimas, Siqueland, Jusczyk and Vigorito, 1971; Eimas, 1975; Jusczyk, 1981; Jusczyk, Pisonsi, Walley and Murray, 1980; Kuhl, 1979; Streeter, 1976). These capabilities in adults are known to be associated with functional hemispheric differences, and several researchers have conducted investigations of the possible lateralization of auditory perceptual processes in infants.

Entus (1977) combined the dichotic listening paradigm with the nonnutritive High Amplitude Sucking (HAS) procedure to study the response of 48 infants ranging in age from 22 to 140 days to CV nonsense syllables spoken by an adult male and to musical stimuli. A dichotic stimulus pair was presented, contingent upon sucking, and when habituation occurred the signal to one ear was changed. Changes in speech stimuli at the right ear produced a greater recovery of high amplitude sucking than changes at the left ear with 71% of the infants.

Greater recovery of sucking was observed for changes in musical stimuli at the left ear with 79 % of the subjects. Entus suggested that the significant difference between ears in magnitude of recovery reflected differential hemispheric processing of the stimulus materials.

Glanville, Best and Levenson (1977) obtained comparable results using the dichotic stimulation technique with cardiac dishabituation rather than nonnutritive sucking as the dependent variable. Their 3 month old subjects displayed a greater recovery of heart rate with novel speech stimuli at the right ear and with novel musical stimuli at the left.

Using a slightly different methodology, Varga-Khadam and Corballis (1979) failed to replicate the Entus (1977) results with regard to linguistic stimuli in their 3 month old subjects. However, Best, Hoffman and Glanville (1982) repeated the cardiac procedure of Glanville, et al. (1977) with a larger sample of comparable age and received confirmation of the original findings.

Other studies suggest that response asymmetries to speech and nonspeech sounds exist in even younger infants. Hammer (1977) presented speech and white noise independently to 24 hour old neonates and found significantly greater right lateral eye movements in response to speech and left eye movements in response to the white noise. The results were interpreted as evidence that the neonate processes speech sounds more effectively when presented to the right ear and white noise sounds more effectively when presented to the left.

Segalowitz and Chapman (1980) reported a reliable asymmetry of response to auditory stimuli in premature infants with a mean gestation age of 36 weeks. They made note of the fact that auditory input reduces limb tremor in premature infants, presumably because of its induction of cortical activity and the resulting greater control of limb movement, and used the reduction of unilateral limb tremor as an measure of hemispheric activation. They found that there was no differential response to orchestral music but that a taped nursery rhyme produced a greater right body side reduction in tremor, i.e., greater left hemisphere activity.

Thus, there is a substantial body of data which is inconsistent with Lenneberg's conception of initial anatomical symmetry, functional equipotentiality, and subsequent progressive lateralization beginning at about 2 years of age. Instead, the findings accumulated in studies of early brain damage, childhood developmental asymmetries, and the neuroanatomical, behavioral, electrophysiological and auditory perceptual asymmetries clearly indicate that we are asymmetrical in structure and function in our early infancy and even before.

Rationale for Study

Development has been viewed as a process involving an ongoing, interdependent, reciprocally interactive relationship between maturation and the experience of the organism (Sameroff, 1983). Specific developmental events can be understood both in relation to antecedent maturational and experiential factors and as precursors to or facilitators of subsequent development. From this point of view, the evidence that auditory structural and functional asymmetries are present during the pre- and postnatal periods raises the question of whether early lateralization could play a significant role in the process of language development.

A number of authors (Corballis, 1983; Kinsbourne and Hiscock, 1983; Turkewitz, 1977) have speculated that the various tonic (motor biases) and sensory asymmetries observed during the pre- and perinatal period reflect early species-specific asymmetrical biases in the nervous system that serve as precursors to functional lateralization. In their view, functional asymmetries in the processing of auditory stimuli result from progressive experience with speech and nonspeech stimuli superimposed upon these initial tonic responses and sensory asymmetries. It also has been suggested that a lateral difference in processing speech and nonspeech auditory stimuli could facilitate language learning, thereby providing a selective advantage in adaptation, and that the appearance of such a mechanism early in development would have a significant impact on subsequent auditory perceptual development (Turkewitz, 1977).

There have been some recent findings which support the notion that auditory functional asymmetry in the neonate is realted to interacting foetal maturational and experiential factors, and that it may possess species-specific adaptive value. A brief review of the evidence from studies of prenatal neurogenesis, prenatal auditory functioning, and the effects of prenatal experience will be presented.

Prenatal Neurogenesis

The human auditory pathways become bilaterally organized at an early stage in prenatal development (Bindman & Lippold, 1981). Golgi and Nissl staining techniques have revealed myelinated fibers in the trapezoid body and lateral lemniscus around the 21st week of gestation. The myellogenetic cycle is completed up to collicular level and a few myelinated fibers are beginning to appear in the medial lemniscus at the 34th feetal week (Lecours, 1975). More recently, Kostivic, Kelovic, Nemanic and Krmpotic-Memanic (1980) using histochemical methodology (AChE staining) to examine afferent fiber ingrowth to the auditory cortex observed extensive vertical columnar organizational patering in prospective layer IV as early as 28 weeks gestation. Moreover, Golgi and Nissl analyses have shown the presence of dendrites, axons and synapses in the auditory cortex as early as 11-13.5 weeks gestation; mature synapses are present by the 35th week, one month before term (Krmpotic-Nemanic, Kostovic, Nemanic & Kelovic, 1979). These researchers have suggested that early prenatal development of myelogenesis, neuronal connections with the prospective auditory cortex, and afferent input to the developing cortical layers are indications that prenatal maturation of the auditory system assumes a significant role in the functional organization of the brain.

Prenatal Auditory Function

Recent studies that measured the ambient noise level in the intrauterine environment of pregnant women near term found intensity recordings of about 85 dB with an inverse relationship between intensity and frequency; intensity decreases as frequency increases (Querleu and Renard, 1981; Querleu, Renard and Crepin, 1981; Walker, Grimwald, and Wood, 1971). The maternal heartbeat was the source of the more intense, lower frequencies (Querleu and Renard, 1981; Querleu, Renard and Crepin, 1981). Further investigation revealed that maternal speech is audible and intelligible within the pregnant uterus while other extrauterine speech sounds are not so intense, e.g., male speech, because they are probably masked by intrauterine sounds and/or attenuated by maternal tissue (Querleu and Renard, 1981). Since it has also been demonstrated that the foetus can hear and is reliably responsive to sound around the 28th week of gestation, it is clearly possible that prenatal auditory stimulation could influence the functional development of the central auditory system in the human foetus (Birnholz and Benacerraf, 1983).

An example from the animal literature illustrates this phenomenon. Rubel and Ryals (1983) and Lippe and Rubel (1983) manipulated changes in acoustic stimuli (differential frequencies) with chick embryos and found significant changes both in the tonotopic organization of auditory brainstem nuclei and locus of hair cell damage in the cochlea as a function of differential prenatal auditory stimulation. The inference derived from these studies was that structural changes in the central nervous system were induced by differential sounds experienced during the prenatal period.

Prenatal Auditory Experience

It is clear that neonates are active listeners in their environment and within 24 hours after birth exhibit orderly auditory preferences. The earliest voice preferences can be ranked as follows: maternal voice > female voices > paternal voice = male voices (DeCasper and Fifer, 1980; DeCasper and Prescott, 1984). Although newborns do not prefer their father's voice to that of another male, discrimination between male voices has been shown (DeCasper and Prescott, 1984). Furthermore, newborns prefer intrauterine heartbeat sounds to that of a male voice (Panneton and DeCasper, 1984).

The order of these preferences suggest that they are influenced by earlier, prenatal exposure with maternal voices and heartbeat sounds. This hypothesis was directly tested in a recent study which indicated that newborns prefer the sounds of a nursery rhyme that was read aloud by their mother during the last month of pregnancy more than the sounds of a novel rhyme she had never recited (DeCasper and Spence, 1984). A direct implication of these data is that during the last trimester there is a biological substrate adequate for functional hearing and differential perception that was influenced by prenatal auditory experience.

A second significant finding revealed in the DeCasper and Spence (1984) experiment was that while the neonates preferred the story read to them by their mother during the last trimester, the presence of maternal voice cues was unnecessary for the expression of preference for the familiar rhyme. In one condition, the familiar and novel nursery rhymes were presented to the infant by an unfamiliar female speaker and a significant preference for the familiar nursery rhyme was exhibited. A possible implication of this finding is that the perceptual salience or reinforcing value of the speech sounds was related to their general species-specific communication value. This view is consistent with recent analyses of the infant speech perception literature. A number of authors have speculated that the relevant characteristic of speech cues in the perception of speech as speech is more related to their functional significance as species-specific communication cues rather than their acoustic characteristics as human speech sounds (e.g., Studdert-Kennedy, 1981).

A recent study tested this assumption with Japanese macaques and two other species of monkeys. The experiment was designed to examine whether the functional auditory lateralization of vocal perception resulted from the acoustic properties of the calls or their communicative significance. The auditory signals were presented monaurally, and the discrimination performance of the two ears was compared. For all the Japanese macaques, discrimination of the calls was more accurate with the right ear than the left suggesting, by analogy with human studies of speech perception mechanisms, that the left cerebral hemisphere was superior in processing the calls. Moreover, although comparison monkeys of different species could make the requisite discrimination, they failed to show functionally lateralized differences in discrimination; i.e., differential responding between the right and left ear was not observed. These researchers suggested that a lateralized network was activated when species-specific calls were presented to the Japanese macaques thereby facilitating neural activation and auditory processing. Furthermore, the communicative valence of the signals was the critical factor in determining species differences in functional lateralization effects rather than their purely acoustic nature. This finding suggests that the processing of acoustic stimuli may not depend solely on the physical structure of the signals in question but primarily upon the nature of the listener's previous experience with the auditory signals and their species-specific communication value (Petersen, Zoloth, Beecher, Green, Marler, Moody and Stebbins, 1984).

When the presented evidence is considered in aggregate, it suggests that there is, at birth, functionally lateralized processing of speech and nonspeech sounds. The primary purpose of this study will be to test the hypothesis that newborns less than 3 days of age display lateralized perceptual processing of a female voice reading a story (speech stimulus) and an intrauterine heartbeat (nonspeech stimulus). More specifically, the study will test whether the reinforcing value of the speech is greater when the speech reinforcer is presented to the right ear and whether the reinforcing value of heartbeats is greater when they are presented to the left ear.

There is some preliminary evidence for this hypothesis. A pilot study conducted in our lab revealed that the neonate preferred to listen to intrauterine heartbeat sounds in their left ear when it was available to either ear. An opposite right ear preference for speech could not be advanced because of methodological problems. The data were clear, however, in indicating that speech was not differentially preferred in the left ear.

Predicted results would provide direct evidence that, in adddition to behavioral and physiological differential reactivity to speech and nonspeech stimuli, differential perceptual processing of speech and nonspeech is present shortly after birth. This outcome would also be consistent with the view that functional auditory asymmetry is related to prenatal experience, which could play a significant role in the development of language.

CHAPTER II

METHOD

Subjects

Subjects were 12 male and 12 female neonates randomly selected from among all neonates who met the following criteria: a) uncomplicated gestation and an uncomplicated vaginal or cesarian delivery in the LOA (left occipital anterior) or ROA (right occipital anterior) vertex postion, b) birthweight between 2500 and 4000 grams, c) Apgar score of at least 8 at 1 and 5 minutes after birth, d) a birth record and neonatal examination indicating full-term birth with no neurological or skeletal- muscular anomalies; and, e) age at testing was between 1 and 3 days. Males were tested before or at least 12 hours after circumcisions. In addition, both parents of the neonate were classified as right-handed. Classification of hand preferences was ascertained by positive right hand responses to all manual tasks on the standardized Bryden Hand Preference Questionnaire (1977). Parents with a history of switched hand preference were excluded. Informed consent was obtained from the mothers and the parents were invited to observe the experimental session.

Twenty-six neonates were eliminated from the study during the experimental phase of the session; 13 for excessive crying, 10 who had either two consecutive minutes or two one-minute intervals of not sucking and three neonates failed to maintain appropriate sucking criteria.

Apparatus and Stimuli

The neonates wore padded, calibrated earphones (Phonic Ear TDH-39-4) that were adjusted to fit comfortably for binaural listening. Sterilized nonnutritive nipples were attached to a Statham P23AA Pressure Transducer by 30-cm surgical tubing. The Pressure Transducer was connected to a Grass ploygraph which recorded sucking pressure and to solid state recording (Marantz PMD stereo tape recorder) and programming equipment (BRS / LVE / Colburn logic devices).

One of the two reinforcing stimuli utilized was a lowpass filtered tape recording of an unfamiliar female speaker reading a short story, The Sleeping Princess. The speech signal had all its acoustic energy between the speaker's fundamental frequency and 1000 Hz. The speaker recorded the story in a manner typical of adult-directed speech, and not as if directed at an infant or child. This control was instituted to maximize attention to the species-specific language cues and to minimize attention to voice recognition cues; e.g., maternal voice cues (c.f., DeCasper and Spence, 1984). In addition, Saxby and Bryden (1984) found that children as young as 5 years of age showed a LEA for processing verbal material that was emotionally intonated. When the verbal material was presented in a normal speaking manner, the children showed the general finding of a REA for speech material. These results suggest right hemispheric processing for the perception of emotion. Therefore, the use of an unfamiliar female voice, rather than the maternal voice, reciting adult-like speech should both maximize the probability that the neonate's attention will be directed toward the acoustic cues of speech per se and minimize attention being directed toward the affective cues of speech material.

The other stimulus used was an intrauterine heartbeat recording obtained from a commercially available record (Murooka, 1974). Murooka made the record by placing a microphone in the uterus near the head of an 8 month old foetus. Each stimulus recording was taped on both tracks of a cassette tape using a Technics M22 tape recorder. Tape recordings were equated for perceived intensity by two adult observers. Their peak intensities measured on the C-scale of a sound level meter coupled to the earphones did not exceed 70 dB SPL at each ear.

Procedure

Experimental sessions were conducted approximately 2.5 hours after a scheduled feeding in a quiet, dimly lit room adjacent to the nursery. At that time, infants were gently coaxed into a state of quiet alertness. Any infant that could not be coaxed into the quiet, alert, eye-open state was returned to the nursery and brought back after the next feeding if possible. The neonate was placed supine in his/her bassinet, the earphones were positioned, and the nipple was placed in the neonate's mouth by an experimenter who could not be seen by the infant and who was blind to the experimental condition. A second experimenter monitored the recording equipment. The infant was given a 2 minute adjustment period during which sucks of at least 20-mm Hg negative pressure had to be emitted in order to begin testing.

Testing began with 5 minutes of baseline sucking during which no reinforcing stimulus was presented over the earphones (approximately 22 sucking bursts). The time elapsing between the end of one sucking burst and the next, the interburst interval (IBI), was recorded and the frequency distribution of IBIs was used to calculate the median interburst interval (MIBI). The MIBI was then used to determine the reinforcement criterion for each infant during the reinforcement phase of the session. A sucking burst was defined as a series of individual sucks separated from one another by less than 2 seconds. Bursts terminate when 2 seconds elapse without a suck.

The research design is shown in Figure 1. Six infants in the Speech Group (3 males and 3 females) were reinforced in the left ear with the speech stimulus when a sucking burst terminated a response latency equal to or greater than the baseline median (=> T). Bursts terminating latencies less than the baseline median (< T) were reinforced in the right ear with the speech stimulus. The response contingency was reversed for the remaining 6 infants in the Speech Group.

For 6 infants (3 males and 3 females) in the Heartbeat Group, reinforcement in the left ear with the heartbeat stimulus occured when a sucking burst terminated a response latency equal to or greater than the baseline MIBI. Bursts terminating a response latency less than the baseline MIBI were reinforced in the right ear with the heartbeat stimulus. The response contingency was reversed for the other 6 infants in the Heartbeat Group.

	REINFORCER			
	HEARTBEAT GROUP		FILTERED FEMALE VOICE GROUP	
CONTINGENCY				
	M	=>LE <RE	M	=>RE <LE
EQUAL OR	M	=>LE <RE	M	=>RE <LE
GREATER	M	=>LE <RE	M	=>RE <LE
THAN T	F	=>LE <RE	F	=>RE <LE
	F	=>LE <RE	F	=>RE <LE
	F	=>LE <RE	F	=>RE <LE
	M	<LE =>RE	M	<RE =>LE
	M	<LE =>RE	M	<RE =>LE
LESS THAN	M	<LE =>RE	M	<RE =>LE
T	F	<LE =>RE	F	<RE =>LE
	F	<LE =>RE	F	<RE =>LE
	F	<LE =>RE	F	<RE =>LE

Figure 1. Research design showing reinforcer, contingency, sex of subjects and ear presentation for each group.

Each stimulus presentation continued as long as the sucking burst which produced it continued. The reinforcement phase lasted a minimum of 10 minutes, but if the infant failed to suck during one 2 minute period or two 1 minute periods the session was terminated and the data were not analyzed. contingency was reversed for the other 6 infants in the Heartbeat Group.

Each stimulus presentation continued as long as the sucking burst which produced it continued. The reinforcement phase lasted a minimum of 10 minutes, but if the infant failed to suck during one 2 minute period or two 1 minute periods the session was terminated and the data were not analyzed.

CHAPTER III

RESULTS

The reinforcement ratio for REA (right ear advantage) represented the primary dependent variable. This ratio was computed by dividing the proportion of interburst intervals which produced a reinforcer presentation to the right ear during the reinforcement phase by the proportion of IBIs during the baseline phase which would have produced the right ear presentation. Table 1 presents a summary of individual subject data.

A three-factor Analysis of Variance with Reinforcer (Speech vs. Heartbeat), Contingency (Greater than or equal to $\bar{I}$ vs. Less than $\bar{I}$), and Sex (Male vs. Female) as factors indicated a robust effect of Reinforcer. Right ear proportions were significantly larger for the Speech Group, $F\ (1,\ 16) = 38.3$, $p < .001$. There were no other effects, and all other F values were less than 1.0.

In addition, right ear ratios were greater than 1.0 for 11 of 12 infants in the Speech group, $p = .006$ by the binomial test, and the mean ratio was greater than 1.0, $t\ (11) = 4.72$, $p < .0005$. All twelve infants in the Heartbeat group had ratios less than 1.0, $p = .001$ by the binomial test, and the mean was less than 1.0, $t\ (11) = 6.87$, $p < .0005$. Thus, the results indicated that neonates took advantage of a greater proportion of opportunities to place the Speech stimulus in the right ear and a greater proportion of opportunities to place the Heartbeat

Table 1.

Baseline phase proportions, reinforcement phase proportions and reinforcement ratios for all subjects.

Stimulus	Sex	Age (hrs)	Right-ear Criterion	Baseline N	Baseline prop	Reinf N	Reinf prop	REA Ratio
Speech	M	48	<3	21	.33	65	.60	1.82
	F	84	<3	22	.54	52	.63	1.17
	M	62	=>3	22	.41	37	.73	1.78
	M	82	=>3	21	.67	47	.79	1.18
	F	42	=>3	22	.48	54	.74	1.54
	M	55	<4	21	.52	48	.42	.81
	F	71	<4	22	.54	55	.74	1.37
	F	39	=>4	22	.50	40	.62	1.24
	M	54	<5	21	.43	45	.69	1.60
	F	51	=>5	22	.45	46	.70	1.56
	F	41	<6	22	.36	51	.74	2.05
	M	34	=>6	21	.57	29	.86	1.51
Mean		55.25	=>4.0, <4.1		.48		.69	1.47
SD					.09		.11	.33
Heartbeat	M	59	<3	21	.48	25	.20	.42
	M	72	<3	21	.48	54	.35	.73
	F	56	<3	21	.57	28	.29	.51
	M	53	=>3	21	.48	45	.31	.65
	F	53	=>3	22	.50	73	.36	.72
	F	39	<4	22	.41	40	.30	.73
	M	38	=>4	21	.48	63	.35	.73
	F	35	=>4	22	.54	47	.43	.80
	M	41	<6	22	.50	40	.42	.84
	F	48	<6	22	.50	34	.38	.76
	F	50	=>6	22	.59	43	.42	.71
	M	48	=>8	21	.52	32	.50	.96
Mean		49.33	=>4.6, <4.1		.50		.36	.71
SD					.05		.08	.14

stimulus in the left ear.

CHAPTER IV

DISCUSSION

The present study clearly indicated a significant left ear preference when the nonspeech sound was available to either ear and a significant right ear preference when speech was available to either ear. This finding is consistent with the anatomical asymmetries, the tonic behavioral and physiological asymmetries and sensory sensitivities found in pre- and postnatal infants, and with the functionally lateralized auditory perception in older infants, children and adults. In contrast to these earlier studies with neonates in which infants only passively responded, the use of an active operant choice task in which the infants displayed a consistent ear preference is considered strong evidence of the differential perceptual processing of speech and nonspeech sounds at birth.

Experimental Controls

The specific control conditions employed in this study were designed to both isolate lateralization effects and eliminate or minimize the plausibility of alternative explanations. Controls were exercised over three types of variables: (1) Subject variables, (2) Stimulus variables, and (3) Procedural variables.

Subject variables. First, both parents of the randomly selected infants were evaluated on the Bryden Hand Preference Questionaire to ascertain whether they used their right or left hand to perform five specific tasks (writing a message, drawing a picture, using a toothbrush, throwing a ball and using a pair of scissors). Considering their reliability, validity and loading on a common factor of handedness, these five items currently represent the best available behavioral evidence for assessing hand preference. When either parent revealed a weak right hand preference, ambilaterality, or a history of hand reversal, the infant was excluded from the study.

While the genetic basis of handedness remains somewhat controversal, the incidence of left handed offspring as a function of parental handedness is significantly less when both parents are right handed (Annette, 1973). In addition, the development of the sodium amytal technique for the assessment of speech lateralization (Wada and Rasemussen, 1960) has made it possible to obtain data on the relation between handedness and speech lateralization from large samples of subjects. Recent data (Rasmussen and Milner, 1977) indicate that 96% of right handers and 70% of left handers show left hemispheric speech lateralization. The incidence of right-hemispheric speech is much higher in the sinistrals than in the dextrals, and bilateral speech representation is a characteristic almost wholly associated with left-handedness. Thus, if genetic functions play a significant role in handedness or lateralization, the parental screening procedure increased the probability of obtaining a subject who would possess the normative left-right asymmetry.

Secondly, foetal head position 3-4 weeks prior to delivery and at delivery had to be in the vertex postion. The eventual birth position of the foetal head is achieved some 3-4 weeks before delivery and is maintained with restricted mobility during the remaining prenatal period. All of the neonates selected for the study were born vaginally in the vertex postion or the head was engaged in this position prior to a cesarian section. This control was introduced to maximize the foetus' accessibility to and duration of exposure to sounds which were present when the fetal hearing apparatus was functional. If the infant's hospital records indicated the posibility of a preterm birth the infant was not included in the study.

Thirdly, optimal neurobehavioral organization of the infants was assured by accepting only those who had APGAR scores of at least eight at one and five minutes following birth and who were termed normal after the pediatrician's examination. Evidence of any neurological anomalies resulted in exclusion from the study.

Stimulus variables. First, filtered female speech was selected as the speech stimulus and intrauterine heartbeat was selected as the nonspeech stimulus because they are known reinforcers for newborns. Moreover, both stimuli are approximately equivalent simulations of the speech and heartbeat sounds available in utero. The two stimuli possess all their acoustic energy below 1000 Hz, the frequency level known to be available prenatally. The possibility of differential dialect (prosodic) effects between white and nonwhite female speaking voices on ear preferences was obviated by having both a white and a nonwhite tape recording available.

The filtered speech of an unfamiliar female was used because data from our laboratory has demonstrated that maternal speech is a prepotent postnatal reinforcer due to its voice-specific features rather than its more general speech characteristics. In adults, voice recognition cues are processed in the right hemisphere. Since one of the major objectives of this study was to test whether lateralized auditory perceptual processing of speech and nonspeech was present at birth, the a priori reinforcing value of speech sounds per se was maximized and the a priori reinforcing value of voice sounds per se was minimized by selecting a stimulus which was more likely to be processed by the left hemisphere.

Differential intensity effects were controlled by equating the intensity of each stimulus at each earphone, by a sound level meter, at 70 dB SPL. On two random occasions the physical location of the earphones was reversed. The earphones were checked daily for appropriate right and left ear presentations and the position of the earphones on the baby was examined prior to and following each session. In addition, the same apparatus configuration was used to test infants from each group.

<u>Procedural variables</u>. A number of procedural factors are known to influence the presence and/or magnitude of an observed laterality effect in children and adults. Memory load, difficulty of the task and priming effects were the factors which seemed to be particularly relevant to testing laterality effects in the neonatal population. Therefore, the

operant choice procedure was selected because it has been found to be robust in demonstrating the differential reinforcing value of stimuli presented to newborn subjects as young as 24 hours. This procedure uses temporal discriminative stimuli, thus eliminating the possibility of priming effects which could potentially be a factor if auditory discriminative stimuli were used. Hiscock and Bergstrom (1982) have demonstrated that the order of presentation of speech and nonspeech sounds to children can alter the direction of auditory perceptual asymmetries. They attribute this finding to the introduction of a degree of imbalance between the hemispheres created by an attentional bias associated with the class (speech vs. nonspeech) of the initially presented stimulus. Secondly, the between subjects design eliminated the likelihood of asymmetrical priming effects. Lastly, movement of the head was restricted by the earphones to rule out gross changes in head position associated with the right turning bias as a mediator of differential ear preference.

While the extent of the controls over subject, stimulus and procedural factors undoubtedly contributed to the isolation of the lateralization phenomenon, it also may raise the issue of generalizability of the results. The question of whether asymmetry of auditory processing exists under other experimental conditions with other subjects and with other auditory stimuli is essentially an empirical one, but several factors should be noted which are related to the question of generalizability.

The criteria for subject inclusion did not result in a highly selected infant group. Neonates who have right hended parents, APGAR scores of eight or more, the vertex head position prior to birth and a full term birth are considered healthy, normal infants and are clearly in the majority. Approximately 50% of the subjects in the initial sample were subsequently excluded because of their failure to suck consistently during the reinforcement phase of the study. Virtually all of these infants, however, appeared to stop sucking because they went to sleep or cried for a period which met the termination criterion, behavior which was also commonly observed in the retained infants at other times. Although not meeting the criterion for exclusion, onset of sleep was the aparent reason why one subject did not display a lateralization effect (even though other factors such as hemispheric dominance cannot be ruled out). Both sexes, both White and Black infants, and parents representing a range of socio-economic status were all included, and the overall number of subjects lost was relatively small compared with that typically reported in studies with neonates.

To some extent, a similar position may be taken with regard to the representativeness of the stimuli and the procedural conditions employed, but these do appear to put greater limits on generalizability. The dependent measure used was instrumental sucking behavior, a response qualitatively quite different from some other accepted indices of asymmetry such as EEG activity and reflexive behavioral responses. Also, the limited frequency range of the stimuli, their controlled reinforcement value, and the heterogeneity of the populations of speech and nonspeech sounds itself implies that generalization should be made only with additional data.

Theoretical Implications

This study provides additional counterevidence against Lenneberg's (1967) two basic theoretical tenets: (1) Equipotentiality is present at birth and, (2) Functional auditory lateralization does not exist until the central nervous system reaches a general level of maturation at the age of two. The current results clearly add to the body of evidence inconsistent with his position.

Another implication of the present study has to do with the time of onset of language development. Studdert-Kennedy (1981) has suggested that the appearance of speech sensitivity should be considered the beginning of the development. He argues that prespeech lip and tongue movements entrained with a mother's behavior (Trevarthen, 1976), cooing, intonation, babbling and first word utterances can be considered a part of the progression toward speech behavior, and that the developmental sequence starts a few weeks after birth.

An even earlier onset is espoused by Kinsbourne and Hiscock (1983). They take the position that early auditory asymmetry represents an innate mechanism which activates one hemisphere of the brain more than the other in response to particular categories of auditory stimulation. Infants are more likely to respond to linguistic stimuli on the right side and to nonlinguistic stimuli on the left, and this differential sensitivity forms the basis for later lateralization of language functions. Language development thus has begun at birth, but its form at this stage is reflexive, genetically determined and independent of experience.

The results of this research imply that asymmetrical auditory processing, an important aspect of language development, is present at birth and possibly prior to birth.

The nature of the functional lateralization demonstrated in the study is also considered to have important implications. The infants were presented an operant task requiring them to learn a time discrimination in order to direct speech sounds to the right ear and nonspeech sounds to the left. The acquisition of preferences was apparent within the first five minutes and was typical of the performance of neonates in prior studies when a potent reinforcer was used. It is difficult to characterize this behavior as automatic and inflexible, or as a genetically determined asymmetry, in accordance with Kinsbourne's explanation. It seems more plausable to hypothesize that the infant's ear choice was based upon more efficient processing of the auditory stimulus in the contralateral hemisphere.

Lastly, because of the nature of the stimuli involved in the experiment, it is possible that prenatal speech and nonspeech available to the foetus during the last trimester could influence the development of functional auditory processing. If this is the case, the timetable for the onset of a sensitive phase for language development could be extended to include prenatal auditory events accessible to the foetus. It seems unduly conservative to apply a strict predetermined epigenetic view when the foetus is capable of some form of learning and when the auditory apparatus is functional.

This viewpoint would be consistent both with our previous lab results, which have clearly demonstrated postnatal effects of prenatal experience with auditory stimuli, as well as with the results of animal studies employing similar paradigms (c.f., Petersen, et. al., 1984). Animal studies have also demonstrated that prenatal experience with auditory stimuli during a sensitive period directly affects the development of the biological substrate for auditory perceptual development (c.f., Rubel and Ryals, 1983).

The current findings thus appear to add to the point of view that there is a reciprocal interaction between prenatal auditory stimulation and prenatal maturational factors which has a significant influence upon the differential auditory processing of speech and nonspeech sounds.

Research Implications

One area of research which seems particularly important is that of specifying the characteristics of prenatal experiential factors which influence later auditory processing. For example, is the lateralization seen in neonates dependent upon or influenced by prior experience with the reinforcing stimulus, or is it independent of experience? We know that neonates can discriminate between speech and nonspeech stimuli with which they have had no experience, but we do not know if they will display an ear preference for such stimuli. Similarily, what is the relationship between reinforcement value and lateralized processing; e. g., does the valence of stimuli influence the observation of auditory lateralization at birth? Clarification of issues such as these will assist in isolating the possible effects of prenatal experience upon the development of speech and nonspeech perception.

Additional questions may be raised about the factors influencing auditory asymmetry during the postnatal course of development. In listening research with older children and adults there is usually a lower percentage of subjects who display lateralization than would be predicted based upon known hemispheric dominance. In contrast, 96 % of the subjects in this study displayed an ear preference in the predicted direction. Kinsbourne (1978) accounts for the discrepancy in the adult data in terms of cognitive flexibility and selective attention which accompany an advanced level of development. If this is true, the current results may represent a more "pure" phenomenon which becomes partially obscured as the child acquires cognitive abilities during development. Another possible explanation is in terms of the neonate's incompletely myelinated corpus callosum. Without the oportunity for interhemispheric transfer, one would expect a more consistent lateralization effect.

A possibly fruitful area of investigation would therefore be to examine the influence of both physiological and cognitive changes during development upon auditory asymmetry. There is virtually no data regarding auditory lateralization for the period from birth to age two, and afterwards functional asymmetry appears relatively constant. The course of development of speech and nonspeech perceptual processing during this period, in relation to other aspects of development, seems particularly important in view of the robust results of the present study.

A final question is related to handedness. In this study the selection of infants with right-handed parents presumably resulted in left hemisphere dominant subjects and a predictable ear preference for speech and nonspeech stimuli. Infants with left-handed parents should not show the same strong, consistent lateralization. Assuming that auditory lateralization at birth is consistent with later measures of hemispheric specialization, these infants should display a combination of left ear preference for speech, mixed or no ear preference, and the currently found right ear speech preference.

BIBLIOGRAPHY

Annett, M. (1973). Handedness in families. Annals in Human Genetics, 37, 93-105.

Bakker, D. J., Hoefkens, M., & Vander-Vlugt, H. (1979). Hemispheric specialization in children as reflected in the longitudinal development of ear asymmetry. Cortex, 15, 619-625.

Basser, L. (1962). Hemiplegia of early onset and the faculty of speech with special reference to the effects of hemispherectomy. Brain, 85, 427-460.

Benton, A. (1979). Visuoperceptive, visuospatial, and visuoconstructive disorders. In K. M. Heilman and E. Valenstein (Eds.), Clinical neuropsychology. Oxford: Oxford Press.

Berlin, C. (1977). Hemispheric asymmetry in auditory tasks. In S. Harnad, R. W. Doty, L. Goldstein, J. Jaynes, and G. Krauthamer (Eds.), Lateralization in the nervous system. New York: Academic Press.

Berlin, C., & Cullen, J. (1977). Acoustic problems in dichotic listening tasks. In S. J. Segalowitz and F. A. Gruber (Eds.), Language development and neurological theory. New York: Academic Press.

Best, C., Hoffman, H., & Glanville, B. (1982). Development of infant ear asymmetries for speech and music. Perception and Psychophysics, 31, 75-85.

Bever, T., & Chiarello, R. (1974). Cerebral dominance in musicians and nonmusicians. Science, 185, 537-539.

Bindman, L., & Lippold, O. (1981). The neurophysiology of the cerebral cortex. Austin: University of Texas Press.

Birnholz, J. C., & Benacerraf, B. (1983). The development of human fetal hearing. Science, 222, 517-519.

Bocca, E., Calearo V., & Migliavacca, F. (1955). Testing cortical hearing in temporal lobe tumours. Acta Otolaryngdica, 45, 289-304.

Bogen, J., & Bogen, G. (1976). Wernicke's region--Where is it? Annals of the New York Academy of Sciences, 280, 834-843.

Bogen, J., & Gazzaniga, M. (1965). Cerebral commisurotomy in man: Minor hemisphere dominance for certain visual-spatial functions. Journal of Neurosurgery, 23, 394-399.

Borowy, T., & Goebel R. (1976). Cerebral lateralization of speech: The effects of age, sex, race and socioeconomic class. Neuropsychologia, 14, 363-370.

Bradshaw, J., & Nettleton N. (1981). The nature of hemispheric specialization in man. Behavioral and Brain Sciences, 51-91.

Broca, P. (1861). Nouvelle observation d'aphemie produite par une lesion de la moite posterieure dex deuxieme et troisieme circonvolutions frontales. Bulletin de la Society Anatomique de Paris, 36, 398-407.

Bryden, M. (1977). Measuring handedness with questionnaires. Neuropsychologia, 15, 617-624.

Bryden, M., & Allard, F. Do auditory perceptual asymmetries develop? Cortex, 17, 313-318.

Bryson, S., Mononen, L., & Yu, L. (1980). Procedural constraints on the measurement of laterality in young children. Neuropsychologia, 18, 243-246.

Butterfield, E., & Cairns, G. (1974). Whether infants perceive linguistically is uncertain, and if they did, its practical importance would be equivocal. In R. L. Schiefelbusch and L. L. Lloyd (Eds.), Language perspectives: acquistion, retardation and intervention. Baltimore: University Park Press.

Caplan, P., & Kinsbourne, M. (1976). Baby drops the rattle: Asymmetry of duration of grasp by infants. Child Development, 47, 532-534.

Chi, J., Dolling, E., & Gilles, F. Left-right asymmetries of the human fetus. Archives of Neurology, 34, 346-348.

Cohen, A. (1966). Hand preference and developmental status of infants. Journal of Genetic Psychology, 108, 337-345.

Connolly, C. (1950). External morphology of the primate brain. Springfield, Illinois: Charles C. Thomas.

Corballis, M. C. (1983). Human laterality. New York: Academic Press.

Cunningham, D. (1892). Contribution to the surface anatomy of the cerebral hemispheres. Cunningham Memoirs No. VII. Dublin: Royal Irish Academy.

Dax, M. (1865). Lesions de la moitie de l'encephale coincident avec l'oubli des signes de la pensee. Gazette Bebdom, 11, 259-260.

DeCasper, A., Butterfield, E., & Cairns, G. (1976). The role of contingency relations in speech discrimination by newborns. Paper presented at the Fourth Biennial Conference on Human Development, Nashville, Tenn.

DeCasper, A., & Fifer, W. (1980). Of human bonding: Newborns prefer their mother's voices. Science, 208, 1174-1176.

DeCasper, A., & Prescott, P. (1984). Human newborns' perception of male voices: Preference, discrimination and reinforcing value. Developmental Psychobiology, 17, 481-491.

DeCasper, A., & Spence, M. Prenatal maternal speech influences newborns' perception of speech sounds. Manuscript in preparation.

Dennis, M., & Whitaker, H. A. (1977). Hemispheric equipotentiality and language acquistion. In S. J. Segalowitz and F. A. Gruber (Eds.), Language development and neurological theory. New York: Academic Press.

Eberstaller, O. (1890). Das Stirnhirn. wein and Leipzig. Urban and Schwarqenberg.

Eimas, P. (1975). Auditory and phonetic coding of the cues for speech: Discrimination of the (r-l) distinction by young infants. Perception and psychophysics, 18, 341-347.

Eimas, P., Siqueland, E., Jusczyk, P., & Vigorito, J. (1975). Speech perception in infants. Science, 171, 303-306.

Entus, A. K. (1977). Hemispheric asymmetry in processing of dichotic presented speech and nonspeech stimuli by infants. In S. J. Segalowitz and F. A. Gruber (Eds.), Language development and neurological theory. New York: Acacemic Press.

Flanery, R., & Balling, J. Developmental changes in hemispheric specialization for tactile spatial ability. Developmental Psychology, 15, 364-372.

Gardner, J., Lewkowicz, E., & Turkewitz, G. (1977). Development of postural asymmetry in premature infants. Developmental Psychology, 10, 471-480.

Gardner, M., & Walter, D. (1977). Evidence of hemispheric specialization from infant EEG. In S. Harnad, R. Doty, L. Goldstein, J. Jaynes, and G. Krauthamer (Eds.), Lateralization in the nervous system. New York: Academic Press.

Gazzaniga, M., Bogen, J., & Sperry, R. (1963). Laterality effects in somesthesis following cerebral commisurotomy in man. *Neuropsychologia*, *1*, 209-215.

Gazzaniga, M., Bogen, J., & Sperry, R. (1965). Observations of visual perception after disconnexion of the cerebral hemispheres in man. *Brain*, *88*, 221-230.

Gazzaniga, M., Bogen, J., & Sperry, R. (1967). Dyspraxia following division of the cerebral commissures. *Archives of Neurology*, *16*, 606-612.

Gazzaniga, M., & Sperry, R. (1967). Language after section of the cerebral commissures. *Brain*, *90*, 131-138.

Geffen, G. (1978). The development of the right ear advantage in dichotic listening with focused attention. *Cortex*, *14*, 11-17.

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

Geffen, G., & Caudrey, D. (1981). Reliability and Validity of the dichotic monitoring test for language laterality. *Neuropsychologia*, *19*, 413-424.

Geffen, G., & Wale, J. (1979). Development of selective listening and hemispheric asymmetry. *Developmental Psychology*, *15*, 138-146.

Geschwind, N. (1970). The organization of language and the brain. *Science*, *170*, 940-944.

Geschwind, N., & Levitsky, W. (1968). Human brain: Left-right asymmetries in temporal speech region. *Science*, *161*, 186-187.

Gesell, A., & Ames, L. (1947). The development of handedness. *Journal of Genetic Psychology*, *70*, 155-175.

Glanville, B., Best, C., & Levenson, R. (1977). A cardiac measure of cerebral asymmetries in infant auditory perception. *Developmental Psychology*, *13*, 55-59.

Hammer, M. (1977). Lateral differences in the newborn infant's response to speech and noise stimuli. Unpublished Ph.D. dissertation New York University. *Dissertation Abstracts International*, 38 (2), 1439-B.

Hammer, M., & Turkewitz, G. (1974). A sensory bias for the lateral difference in the newborn infant's response to somesthetic stimulation. *Journal of Experimental Child Psychology*, *18*, 304-312.

Hawn, P., & Harris, L. J. Hand asymmetries in grasp duration and reaching in two- and five-month old infants. Paper presented at Annual Meeting of the International Neuro- psychology Society, New York, February, 1979.

Hayden, M., Kirsten, E., & Singh, S. (1979). Role of distinctive features in dichotic perception of 21 English consonants. Journal of the Acoustical Society of America, 65, 1039-1046.

Hecaen, H. (1976). Acquired aphasia in children and the ontogenesis of of hemispheric functional specialization. Brain and Language, 3, 114-134.

Hellige, J., & Wong, T. (1983). Hemispheric-specific interference in dichotic listening: Task variables and individual differences. Journal of Experimental Psychology: General, 112, 218-239.

Henry, R. G. (1983). Monaural studies eliciting an hemispheric asymmetry: A bibliography II. Perceptual and Motor Skills, 56, 915-918.

Hiscock, M., & Kinsbourne, M. (1980). Asymmetries of selective Listening and attention switching in children. Developmental Psychology, 16, 70-82.

Hynd, G., & Obrzut, J. (1977). Effects of grade level and sex on the magnitude of the dichotic ear advantage. Neuropsychologia, 15, 689-692.

Johnson, P. (1977). Dichotically stimulated ear differences in musicians nonmusicians. Cortex, 13, 385-389.

Jusczyk, P. (1981). Infant speech perception: A critical appraisal. In P. D. Eimas and J. L. Miller (Eds.), Perspectives on the study of speech. Hillsdale N.J.: Erlbaum.

Jusczyk, P., Pisoni, D., Walley A., & Murray, J. (1981). Discrimination of relative onset time of two-component tones by infants. Journal of the Acoustical Society of America, 67, 262-270.

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

Kimura, D. (1961). Some effects of temporal lobe damage on auditory perception. Canadian Journal of Psychology, 15, 156- 165. (b)

Kimura, D. (1964). Left-right differences in the perception of melodies. Quarterly Journal of Psychology, 16, 355-358.

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

Kimura, D., & Archibald, Y. (1974). Motor functions of the left hemisphere. Brain, 97, 337-350.

Kinsbourne, M. (1978). Asymmetrical function of the brain. New York: Cambridge University Press.

Kinsbourne, M., & Hiscock, M. (1977). Does cerebral dominance develop? In S. J. Segalowitz and F. A. Gruber (Eds.), Language development and neurological theory. New York: Academic Press.

Kinsbourne, M., & Hiscock, M. (1983). Development of functional lateralization of the brain. In P. H. Mussen (Ed.), Handbook of child psychology: Infancy and developmental psychobiology. Vol. II. New York: John Wiley.

Kohn, B. (1980). Right hemisphere speech representation and comprehension of syntax after left cerebral injury. Brain and Language, 9, 350-361.

Kopell, H. K. (1971). Letter in Scientific American, 224 (June), 9.

Kostovic, I., Kelovic Z., Nemanic, D., & Krmpotic-Nemanic, J. (1980). Development of AChE staining in human fetal cortex. Acta Otolaryngdica, 89, 388-392.

Krashen, S. (1973). Lateralization, language learning, and the critical period: Some new evidence. Language Learning, 23, 63-74.

Krmpotic-Nemanic, J., Kostovic, I., Nemanic, D., & Kelovic, Z. (1979). The laminar organization of prospective auditory cortex in the human fetus. Acta Otolaryngdica, 87, 241-246.

Kuhl, P. K. (1979). The perception of speech in early infancy. In N. J. Lass (Ed.), Speech and language: Advances in basic research and practice. (Vol. I). New York: Academic Press.

Lecours, A. R. (1975). Myelogenetic correlates of the development of speech and language. In E. H. Lenneberg and E. Lenneberg (Eds.), Foundations of language development. (Vol. I). New York: Academic Press.

Lenneberg, E. (1967). Biological foundations of language. New York: Wiley.

Levy, J., & Trevarthen, C. (1977). Perceptual, semantic and phonetic aspects of elementary language processes in split-brain patients. Brain, 100, 105-118.

Liederman, J., & Kinsbourne, M. (1980). The mechanism of neonatal rightward turning bias: A sensory or motor asymmetry? Infant Behavior and Development, 3, 223-238. (a)

Liederman, J., & Kinsbourne, M. (1980). Rightward motor bias in newborns depends upon parent right-handedness. Neuropsychologia, 18, 579-584. (b)

Lippe, W., & Rubel, E. (1983). Development of the place principle: Tonotopic organization. Science, 219, 514-516.

Melekian, B. (1981). Lateralization in the human newborn at birth: Asymmetry of the stepping reflex. Neuropsychologia, 19, 707-711.

Merryweather, J. (1978). The development of hemispheric specialization in infants and young children. Unpublished Ph.D. dissertation, University of Denver. Dissertation Abstracts International, 39 (2), 1016-B.

Micnel, G. (1981). Right-handedness: A consequence of infant supine head-orientation preference? Science, 212, 685-687.

Michel, G., & Goodwin, R. (1979). Intrauterine birth position predicts newborn supine head position preferences. Infant Behavior and Development, 2, 29-38.

Milberg, W., Whitman R., Rourke, D., & Glaros, A. (1981). Role of subvocal activity in dichotic speech perception and selective attention. Journal of Experimental Psychology: Human Perception and Performance, 7, 231-239.

Molfese, D. (1977). Infant cerebral asymmetry. In S. J. Segalowitz and F. A. Gruber (Eds.), Language development and neurological theory. New York: Academic Press.

Molfese, D., Freeman, R., & Palermo, D. (1975). The ontogeny of brain lateralization for speech and nonspeech stimuli. Brain and Language, 2, 356-368.

Molfese, D., & Molfese V. J. (1979). Hemisphere and stimulus differences as reflected in the cortical responses of newborn infants to speech stimuli. Developmental Psychology, 15, 505-511.

Molfese, D., & Molfese, V. J. (1980). Cortical responses of preterm infants to phonetic and nonphonetic speech stimuli. Developmental Psychology, 16, 574-581.

Murooka, H. (1974). Sound of the main artery of the mother (side 1, band 1). Lullaby from the womb. Capitol Records.

Nava, P., & Butler, S. (1977). Development of cerebral dominance motivated by asymmetries in the alpha rhythm. Electroencephalography and Clinical Neurophysiology, 43, 582.

Oppenheimer, J. (1977). Studies of brain asymmetry: Historical perspective. In S. J. Dimond and D. A. Blizard (Eds.), Evolution and lateralization of the brain. New York: New York Academy of Sciences.

Panneton, R., & DeCasper, A. Newborns prefer intrauterine heartbeat sounds to male voices. Paper presented at the In- ternational Conference on Infant Studies, New York, April, 1984.

Parmelee, A., & Sigman, M. (1983). Perinatal brain development and behavior. In P. Mussen (Ed.), Handbook of child psychology: Infancy and developmental psychobiology. (Vol. II). New York: John Wiley.

Peters, M., & Petrie, B. F. (1979). Functional asymmetries of the stepping reflex of human neonates. Canadian Journal of Psychology, 33, 198-200.

Petersen, M., Zoloth, S., Beecher, M., Green, S., Marler, P., Moody, D., & Stebbins, W. (1984). Neural lateralization of vocalizations by Japanese macaques: Communicative sig- nificance is more important than acoustic structure. Behavioral Neuroscience, 98, 779-790.

Petrie, B. F., & Peters, M. (1980). Handedness: Left/right differences in intensity of grasp response and duration of rattle holding in infants. Infant Behavior and Development, 3, 215-221.

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

Porac, C., & Coren, S. (1981). Lateral preferences and human behavior. New York: Springer-Verlag.

Querleu, D., & Renard, K. (1981). Les perceptions auditives du foetus humain. Medicine and Hygiene, 39, 2102-2110.

Querleu, D., Renard, K., & Crepin G. (1981). Perception auditive et reactivite foetale aux stimulations sonores. Journal of Gynecology, Obstetrics and Biological Reproduction, 10, 307-314.

Rasmussen, T., & Milner, B. (1977). The role of left-brain injury in determining lateralization of cerebral speech dominance. Annals of the New York Academy of Sciences, 299, 355-369.

Rosenzweig, M. (1951). Representations of the two ears at the auditory cortex. American Journal of Physiology, 167, 147- 214.

Rosenzweig, M., & Rosenblith, W. (1953). Responses to auditory stimuli at the cochlea and the auditory cortex. Psychological Monograph. 67, 1-26.

Rubel, E., & Ryals, B. (1983). Development of the place principle: Acoustic trauma. Science, 219, 512-514.

Safer, M., & Leventhal, H. (1977). Ear differences in evaluating emotional tones of voice and verbal content. Journal of Experimental Psychology: Human Perception and Performance, 3, 75-82.

Sameroff, A. (1983). Developmental systems: Contexts and evolution. In P. H. Mussen (Ed.), Handbook of child psychology: History, theory, and methods. (Vol. I). New York: John Wiley.

Saxby, L., & Bryden, M. (1984). Left-ear superiority in children for processing auditory emotional material. Developmental Psychology, 20, 72-80.

Schulman-Galambos, C. (1977). Dichotic listening performance in elementary and college students. Neuropsychologia, 15, 577-584.

Segalowitz, S. J., & Chapman J. (1980). Cerebral asymmetry for speech in neonates: A behavioral measure. Brain and Language, 9, 281-288.

Shadden, B., & Peterson, H. (1981). Ear differences in simple reaction time: The influence of attentional factors. Brain and Language, 14, 181-189.

Shellshear, J. (1937). The brain of the aboriginal australian: A study in cerebral morphology. Royal Society of London, Serial B, 227, 293-409.

Spellacy, F., & Blumstein, S. (1970). The influence of language set on ear preference in phoneme recognition. Cortex, 6, 430-439.

Steel, K., & Javert, C. (1942). Mechanisms of labor for transverse positions of the vertex. Surgical Gynecology and Obstetrics, 75, 477-480.

Streeter, L. A. (1976). Language perception of 2-month-old infants shows effects of both innate mechanisms and experience. Nature, 259, 39-41.

Studdert-Kennedy, M. (1981). The beginnings of speech. In K. Immelmann, G. Barlow, L. Petrinovich and M. Main (Eds.), Behavioral development. Cambridge: Cambridge University Press.

Taylor, H., & Heilman, K. (1982). Monaural recall and the right ear advantage. Brain and Language, 15, 334-339.

Teng, E. (1981). Dichotic ear difference is a poor index for the functional asymmetry between the cerebral hemispheres. Neuropsychologia, 19, 235-240.

Teszner, D., Tzavaras, A., Gruner, J., and Hecaen, H. (1972). L'asymetrie droite-gauche du planum temporale: a propos de l'etude anatomique de 100 cerveaux. Revue Neurologique, 126, 444-449.

Trevarthen, C. P. (1975). Les activites innees du nourisson. La Rechaerche, 56, 447-458.

Tukewitz, G. (1977). The development of lateral differentiation in the human infant. In S. J. Dimond and D. A. Blizard (Eds.), Evolution and lateralization of the brain. New York: New York Academy of Sciences.

Turkewitz, G., Gordon, E., & Birch, H. (1965). Head-turning in the human neonate: Effect of prandial condition and lateral preference. Journal of Comparative and PHysiological Psychology, 59, 189-192.

Van Lanker, D., & Fromkin, V. (1977). Hemispheric specialization of pitch and tone. Evidence from Thai. Journal of Phonetics, 1, 101-109.

Vargha-Khadem, F., & Corballis, M. (1979). Cerebral asymmetry in infants. Brain and Language, 8, 1-9.

Von Bonin, G. (1962). Anatomical asymmetries of the cerebral hemispheres. In JV. B. Moutcastle (Ed.), Interhemispheric relations and cerebral dominance. Baltimore: John Hopkins University Press.

Wada, J. (1977). Prelanguage and fudamental asymmetry of the infant brain. In S. J. Diamond and D. A. Blizard (Eds.), Evolution and lateralization of the brain. New York: New York Academy of Sciences.

Wada, J., Clark, R., & Hamm, A. (1975). Cerebral hemisphere asymmetry in humans. Archives of Neurology, 32, 239-246.

Wada, J., & Rasmussen, T. (1960). Intercarotid injection of sodium amytal for the lateralization of cerebral speech dominance. Journal of Neurosurgery, 17, 266-282.

Walker, D., Grimwade, J., & Wood, C. (1971). Intrauterine noise: A component of the fetal environment. American Journal of Obstetrics and Gynecology, 109, 91-95.

Weiffenbach, J. (1972). Discrete elicited motions of the newborn's tongue. In J. W. Bosma (Ed.), Third symposium on oral sensation and perception. Springfield: Charles Thomas.

Wernicke, C. (1874). Der aphasische symptomen complex. Breslau: Max Cohn and Weigert.

Wickelgren, L. W. (1967). Convergence in the human newborn. *Journal of Experimental Child Psychology*, *5*, 74-85.

Witelson, S. (1977). Early hemisphere specialization and interhemispheric plasticity: An empirical and theoretical review. In S. J. Segalowitz and F. A. Gruber (Eds.), *Language development and neurological theory*. New York: Academic Press.

Witelson, S. (1983). Bumps on the brain. In S. J. Segalowitz (Ed.), *Language functions and brain organization*. New York: Academic Press.

Witelson, S., & Pallie, W. (1973). Left hemisphere specialization for language in the newborn: Neuroanatomical evidence of asymmetry. *Brain*, *96*, 641-646.

Young, G. (1977). Manual specialization in infancy: Implications for lateralization of brain function. In S. J. Segalowitz and F. A. Gruber (Eds.), *Language development and neurological theory*. New York: Academic Press.

Zaidel, E. (1976). Auditory vocabulary of the right hemisphere following brain bisection or hemicortication. *Cortex*, *12*, 191-211.

Zaidel, E. (1978). Lexical organization in the right hemisphere. In P. A. Buser and A. Rougeul-Buser (Eds.), *Cerebral correlates of conscious experience*. Amsterdam: Elsevier/North Holland.

Zurif, E. B. (1974). Auditory lateralization: Prosodic and syntactic factors. *Brain and Language*, *1*, 391-404.