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HEMISPHERIC LATERALIZATION:

A FUNCTION OF PHYSICAL MATURITY

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "Hemispheric Lateralization: A Function of Physical Maturity," submitted by Mirna I. Vrbancic in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

Three dichotic listening tests consisting of consonant-vowel (CV) syllables and two types of pitch stimuli, simple tones (ST) and complex tones (CT) were presented to 96 normal right-lateralized males and females. The 96 individuals formed three distinct groups ie., pre-pubescent, early post-pubescent and adults (each consisting of 16 females and 16 males). The patterns of perceptual asymmetry elicited by the three different dichotic stimuli were evaluated to assess the relationship between physical maturation and hemispheric lateralization. When females and males were equated for stage of physical maturation rather than chronological age, (independent of gender) the pre-pubescent group demonstrated no significant patterns of hemispheric lateralization. However, the early post-pubescent group demonstrated the predicted asymmetries on the three dichotic listening tests. The ear advantages demonstrated by the pre-pubescent group, although not significant, were in the predicted direction. These findings suggest that the endocrinological changes asssociated with puberty may act as a catalyst to complete a pattern that has had its formation prepubertally. The adult group demonstrated no significant patterns of hemispheric lateralization for the three dichotic listening tasks.

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INTRODUCTION

There is now a substantial body of literature derived from a variety of sources indicating that the left and right cerebral hemispheres in humans process information differently. For most individuals, the left hemisphere may be described as processing in a sequential, analytic, linguistic mode, and the right hemisphere in a parallel, holistic, spatial, nonlinguistic mode (Witelsen, 1977). A further differentiation may be made with respect to functional hemispheric asymmetry. The left cerebral hemisphere is viewed as being specialized for language functions and performing learned manual tasks. In contrast, the right cerebral hemisphere is less involved in speech functions (Searleman, 1977), but more critical than the left hemisphere for the perception, construction, and recall of stimuli that are difficult to verbalize (McGlone, Within the last few years, several new strategies 1980). and procedures to study hemispheric lateralization and specialization have been developed. They have generated a considerable data base and a corresponding increase in the number of models of hemispheric specialization (Allen, 1983).

Recently, evidence has been accumulating for the possible existence of sex-related differences in

hemispheric lateralization. Males, particularly after puberty surpass females in visuospatial skill as assessed by various behavioral measures (Harris, 1978; Maccoby & Jacklin, 1974; McGee, 1979; Vandenberg & Kuse, 1979). In contrast, females appear to surpass males on speech tasks such as speed of articulation, fluency, and grammer, but not in other language tasks such as verbal reasoning (Hutt, 1972).

A number of theories and models have arisen regarding the existence of sex-related differences in the hemispheric lateralization of verbal and spatial functions. Further, speculation has centered on the inconsistent nature of these differences in childhood, relative to the consistent sex-related hemispheric difference for these functions evident in adulthood. Several authors have proposed that these differences may not be related as much to environmental factors as to the complex of genetic-hormonal interactions which underlie the basic biological differentiation between male and female (Waber, 1977; Mosley & Stan, 1984).

Within this context the following discussion will review the techniques presently available for the study of hemispheric specialization including their methodological difficulties; examine the evidence for the existence of sex-related differences in childhood and adulthood; examine

the data relating to the biological contribution to sex-related differences in hemispheric asymmetry with emphasis on hormones and development; and present the rationale for the present study.

Methods of Assessing Hemispheric Lateralization

There are a number of methods presently available to investigate hemispheric lateralization. The following is a brief overview of some of these techniques including their advantages and disadvantages.

Dichotic Listening Technique

The dichotic listening technique is frequently employed to determine which hemisphere performs what functions and to what extent one hemisphere is better than the other in the processing of certain auditory material. The dichotic listening technique involves the simultaneous presentation of two different stimuli, one to each ear and requiring the subject to report the stimuli. If the reports from one ear are more accurate than are reports from the other ear, then the hemisphere opposite the higher scoring ear is assumed to be more efficient at processing that type of material. Investigators employing the dichotic listening technique typically report a right-ear advantage (REA) for verbal material such as digits, words, and consonant-vowel (CV) syllables (Darwin, 1971; Kimura, 1961,1967; Shankweiler & Studdert-Kennedy, 1967), and a left-ear advantage (LEA) for nonverbal material (Curry, 1967; Kimura, 1964; Knox & Kimura, 1970; Spreen et al., 1970). These consistent findings suggest a left hemisphere specialization for verbal stimuli and a right hemisphere specialization for

The interpretations for these results are based on two claims about the structure of the auditory system. First, that there exists a greater number of contralateral ear-to-hemisphere connections than ipsilateral connections (Hall & Goldstein, 1968); and second, that the ipsilateral input from one ear is suppressed by the contralateral input from the other ear (Cullen et al., 1974; Kimura, 1961). However, a number of studies have provided evidence from a number of sources that dichotic stimulation may contribute to substantial ear differences, but is not a necessary condition to produce an ear advantage (Phillips & Gates, 1982; Wale, 1984; Bradshaw, Farrelly, & Taylor, 1981). These findings argue against the assumption of ipsilateral pathway suppression. A more parsimonious explanation has been proposed by Geffen and Quinn (1984). Due to the indirect nature of the transcollosal route and the weak

ipsilateral sensory route, verbal dichotic stimulation will produce a poor report of left-ear stimuli. In addition, verbal material presented to the right-ear occurring in the dominant sound field will be perceived and reported first, further imposing a delay in recognizing the simultaneously presented left-ear input. Bradshaw et al. (1981), have further proposed that if the information-processing demands of monaural and dichotic stimulation were matched, the magnitude of the REA for verbal stimulation should be similar with both types of presentation.

There are a number of factors that further complicate the interpretation of dichotic listening data. First, it has been demonstrated that the REA for verbal material is extremely fragile. The REA is very sensitive to variation in acoustic features such as time of onset and intensity of signal (Berlin & Cullen, 1977). Since the magnitude of REA or LEA is dependent on acoustic variables, the measure of degree of laterality is automatically confounded with the particular test stimuli used. However, even when stimulus tapes are carefully produced, the dichotic listening test does not always produce consistent findings, suggesting the involvment of other influential factors.

The finding that about twenty per cent of right-handed individuals demonstrate a LEA for verbal stimuli, whereas estimates of the percentage of the right-handed population

with language lateralized to the right hemisphere varies from between zero and five per cent, as determined by the sodium amytal injection (Wada Test) technique (Springer & Deutsch, 1981), raises a concern for the dichotic listening data. Further, Blumstein, Goodglass and Tartter (1975) in testing and retesting subjects one week later on three dichotic tapes consisting of consonants, vowels, and music, found the expected results for the first session, but on the second session a substantial percentage of subjects had switched ear advantages.

One possible explanation that may account for these unstable results focuses on ipsilateral input. Gruber and Segalowitz (1977) have pointed to the possibility that the occlusion of ipsilateral input is not complete and that the contralateral signal may simply have an advantage in dichotomous stimulation. This explanation appears highly probable in light of the evidence presented by Geffen and Quinn (1984) discounting the suppression of information on the ipsilateral pathways by the contralateral pathways. Α second possible explanation is that psychological variables may be as critical as acoustic variables. Spellacy and Blumstein (1970) found a REA for vowels when embedded in a series of English words and a LEA for these same vowels when embedded in a series of melodies with sound effects. These data were interpreted as a change in the expectancy

of the psychological set which presumably influenced how the subjects perceived the stimuli.

Kinsbourne (1975) has proposed that the REA usually observed in dichotic listening is due to preferential attention allocated to the left (language) hemisphere. In this case, the context in which a listener hears competing speech stimuli affects the magnitude of the ear asymmetry. This interpretation is supported by Morais and Landeray (1977), who demonstrated a decrease in the REA for dichotically presented CV syllables when the subject was required to hold in memory a short musical passage presented immediately before each syllable pair. The musical passage was assumed to activate the right hemisphere, consequently producing an attentional left-field bias and attenuating the expected right-field advantage created by the verbal stimuli that were subsequently presented.

It is apparent that not only are acoustic variables important but that task demands can and, in many cases, do interact to produce the perceptual asymmetries observed in research employing the dichotic listening technique. Memory load has been proposed as a critical factor (Harshman et al., 1974), as has the meaningfulness or type of stimulus used (eg. CV syllables vs familiar words; Gazzaniga et al., 1975; Springer & Gazzaniga, 1975).

Researchers should be cautious in their interpretations, a perceptual asymmetry does not necessarily imply a structural hemispheric difference.

Visual Half Field Technique

This technique capitalizes on the physiological structure of the human visual system. The visual cortex of each hemisphere receives input from only the contralateral visual half field. Tachistoscopic (rapid) presentation of a visual stimulus to only one visual half field, will ensure reception of that stimulus by the contralateral hemisphere.

It is imperative that stimulus exposure duration is less than 100 ms to prevent voluntary eye movements (scanning). In addition, the visual angle of presentation must be sufficiently large to prevent the target from falling within the foveal region (Gruber & Segalowitz, 1977). These constraints are the major drawbacks of this technique. However, only then can it be reasonably assumed that the stimulus is restricted to one visual half field, and is thereby transmitted directly to the contralateral hemisphere. Using the dichoptic presentation (simultaneous presentation of different stimuli in each visual half field) of words (Obler, et al., 1984), a significant right-visual half field superiority was obtained, while a left-visual half field superiority was demonstrated for nonverbal visuospatial stimuli (Berrini, et al., 1982). These findings reflect the processing superiority of the right hemisphere for nonverbal stimuli, and the left hemisphere processing superiority for verbal stimuli.

This technique has been useful in a large number of investigations of hemispheric specialization (Klein, 1976), and is especially useful for determining the abilities of each hemisphere in split-brain patients. Because the corpus callosum and/or the anterior commissures have been sectioned in these patients, information fed to one hemisphere cannot cross to the other hemisphere. Thus, we can be sure which hemisphere is doing the processing. A recently devised apparatus by Zaidel (1975), considerably extends the usefulness of the visual half field technique by allowing continous visual projection to only one hemisphere.

Cortical Activity-Averaged Evoked Response (AER)

A rough measure of lateralized cortical activity in a general area of the cerebral cortex is the EEG evoked potential. In general, the technique involves placement of

electrodes on the scalp over particular areas of the left and right cerebral hemispheres. Changes in electrical potential are recorded during certain kinds of stimulation or cognitive activity. Using this technique Callaway and Harris (1974) have found greater left-hemisphere activity for verbal stimuli and greater right-hemisphere activity for visual non-verbal stimuli. Similarly, bilateral EEG recordings from right-handed subjects (Doyle, Orhstein & Galin, 1974; Scwartz, Davidson, Maer & Bromfield, 1974) have revealed significant asymmetries during verbal tasks (decreased alpha in the left-hemisphere, or greater activation for that hemisphere) as well as during spatial and musical tasks (decreased alpha in the right-hemisphere).

The advantage of the AER and EEG techniques over other performance measures is that an immediate cortical response is obtained, leading to fewer inferences about neurophysiological processes. However, a severe drawback specifically pretaining to the AER technique is the limitation on stimulus presentations. The stimuli must have relatively discrete onset and duration times, the response must be quick (ie., within one second), and must be effective over a number of presentations (Gruber & Segalowitz, 1977). Notwithstanding these limitations, this

technique is useful as a direct assessment of hemispheric differences in performance.

Manual Dexterity

Manual dexterity has also been used to assess asymmetries of hemispheric function. The preferred hand for writing has been assumed to be superior for other types of activities. However, studies assessing proficiency of the hands, such as, sequential finger tapping (Wolf & Hurwitz, 1976), dowel balancing (Hicks, 1975) and tactile perception (Witelson, 1975) have demonstrated that the writing hand is not always superior. The nonwriting hand has been found to be superior for tasks such as mirror tracing (Long, 1977) and tactile perception (Witelson, 1975). This asymmetry of manual skill is inferred to reflect differences in the processing capabilities of the cerebral hemisphere contralateral to each hand. Dual task performance and the extent to which concurrent verbalization or other activity interferes with unilateral motor performance (eg. tapping) have also been taken as measures of lateralization for particular types of cognitive functioning (Hicks, 1975).

Levy and Reid (1978) have further proposed that hand posture during writing is a reliable indicator of hemispheric specialization for verbal and non-verbal spatial thinking. They found that subjects who held the hand below the line, with the pen or pencil pointing toward the top of the page when writing, ordinarily had language functions represented in the hemisphere opposite the writing hand, and non-verbal spatial functions represented on the same side as the writing hand. This writing posture is present in the majority of subjects. Subjects who write with the hand above the line and the pen or pencil pointed toward the bottom of the page had language represented in the ipsilateral cerebral hemisphere and non-verbal spatial representation in the contralateral hemisphere.

It is now apparant that manual performance and reflected hemispheric differences cannot be assumed directly from Questionaire data which indicate direction and strength of manual asymmetry for a number of tasks (eg. writing hand, throwing a ball, brushing one's teeth). Individuals vary along a continous dimension in hand preference for various tasks, and the questionaire data do not supply us with a measure of proficiency on these tasks (Carter-Saltzman, 1979). What is required are behavioral measures of manual performance.

The Wada Test

The aforementioned techniques employed in the study of hemispheric lateralization are noninvasive in nature. The following technique is invasive.

The Wada test, a technique devised by Wada and Rasmussen (1960) is used clinically (eg., administered prior to brain surgery to assess language localization). The technique involves injecting sodium amytal into a single cerebral hemisphere through the ipsilateral carotid artery. The patient will demonstrate aphasic symptoms when the hemisphere primarily involved in linguistic functioning is injected. If the other hemisphere is injected, aphasic symptoms last for only a few seconds (Springer & Deutsch, 1981). Milner (1974) in utilizing this technique on over 200 patients for neurological reasons found that 92% of right-handed patients had language functions represented in the left hemisphere. Of the patients who had not undergone early childhood damage to the left hemisphere, 69% demonstrated left hemisphere speech representation. Of this 69%, only 1% of the right-handers, and approximately 15% of the left-handers, showed aphasic symptoms after sodium amytal injection into either hemisphere. These results support the findings that right-handedness is strongly associated with left hemisphere verbal

functioning, while left-handedness may be associated with left, right, or bilateral verbal hemispheric representation.

A major shortcoming of the Wada Test is its limitation to clinical populations. It may not be reliable to generalize from clinical populations to neurologically intact individuals. Due to early cerebral damage, hemispheric asymmetries observed in neurological patients may not be representative of normals (Searleman, 1977). In addition, Levy (1974;1980) has cautioned that the population undergoing the Wada test is predominantly composed of patients suffering from epilepsy, a population with a high incidence of left-handedness, further reducing the generalizability of data obtained to neurologically intact normals.

Finally, and perhaps most importantly, the Wada test is a measure of speech production. In contrast, the dichotic listening technique and the visual half field technique, used to assess language lateralization in normals, are measures of speech perception or comprehension. Considering speech production has been predominantly measured in clinical populations, whereas it is speech comprehension that has been measured in normals, the widely differing estimates of language lateralization between clinical and normal populations is not suprising (Searleman, 1977).

The techniques reviewed, and specifically the visual half field and dichotic listening techniques, have generated a substantial data base for a large portion of current theorizing with respect to the function and specialization of the cerebral hemispheres in normal subjects. Unfortunately, too often the limitations of these techniques are not recognized and accounted for. Further, researchers upon finding a biological correlate of a psychological function are tempted to assume that they have somehow explained the existence of the psychological phenomenon (Gruber & Segalowitz, 1977). It is apparant that the brain's response is not only as a function of its static anatomical structure, but such functioning is also greatly dependent on psychological variables. As such, functional cerebral asymmetry may be viewed as a dynamic process (Levy, 1983).

Evidence for Functional Hemispheric Lateralization

Clinical Populations

In 1874 Wernicke presented evidence along with Broca (1865), which clearly implicated the left hemisphere in language processes. Consequently, the lower part of the

third convolution of the left frontal lobe (Broca's area) has been linked to motor aphasia, and the area between Hescl's gyrus and the angular gyrus of the left temporal lobe (Wernicke's area) to sensory aphasia. Broca (1865) also postulated at this time that, in left handers (including ambidexterous individuals), language is represented in the right hemisphere (Penfield & Roberts, 1959). This hypothesis was soon challenged by several cases of crossed aphasia that began to appear in the clinical literature. The incidence of crossed aphasia was low in right-handers, which would be expected if Broca's hypothesis about the relationship between handedness and . language lateralization was accurate. However, evidence began to accumulate suggesting that, for left handers (plus ambidextrals), crossed aphasia was the end result in the majority of clinical cases rather than the exception (Hecaen & Sauguet, 1971). The localization and degree of language lateralization in left handers (including ambidextrals) was not simply the reverse of that found in right-handers as proposed by Broca (1865). Today, it is believed, based largely on the clinical aphasic population, that an estimated 90-99% of all right-handers have language represented in the left hemisphere (Levy, 1974a; Pratt & Warrington, 1972), and an estimated 50-70% of ambidextrous and left handers have language functions also primarily

localized within the left hemisphere (Hecaen & Sauquet, 1971; Warrington & Pratt, 1973). Further, it has been suggested by a number of researchers that ambidextrous or left handed individuals may have linguistic abilities bilaterally represented, both hemispheres being capable of complex linguistic functioning (Beaumont, 1974; Hecaen & Sauquet, 1971; Kimura, 1967; Levy, 1974; Zangwill, 1967; Zurif & Bryden, 1969).

Evidence of hemispheric asymmetry in linguistic processing has been obtained from commissurotomy patients where the corpus callosum has been surgically sectioned as treatment of intractable epileptic seizures. Initial investigations of these patients revealed a lack of functional integration between the hemispheres (Sperry, 1974; Trevarthen, 1974). The right hemisphere appeared incapable of utilizing or processing any verbal material (Gazzaniga, 1970). Later it became apparant that to assess the linguistic capabilities of the right hemisphere a technique requiring a nonverbal response was required. This new data, requiring nonverbal responses, indicated that the right hemisphere appeared to be incapable of verbal expression, its processing being limited to comprehension (Levy, 1970; Gordon, 1973; Zaidel, 1973), and further, that not all linguistic features of speech are processed solely by the left hemisphere (Searleman, 1977).

Linguistic features of speech, such as intonation contours, and pitch processing appear to be not only bilaterally processed, but are often better handled by the right hemisphere (Curry, 1968; Van Lancker, 1975; Zurif, 1974).

Commisurotomy patients all have a history of neurological disturbance, in most cases acquired in infancy, making it difficult to evaluate the extent of the reorganization of the nervous system which is likely to have occurred (Bub & Witaker, 1980). As such, commisurotomy data, or for that matter, any clinical data should be viewed with caution. Caution should also be exercised in making inferences about neurologically normal hemispheric organization employing such data. Gazzaniga (1970) has also argued that cross-cueing strategies employed by commisurotomy patients may lead to an overestimation of the actual linguistic abilities of the right hemisphere. Cross-cuing occurs when one hemisphere is aware of the correct response and manages to relay this information to the other hemisphere.

Nonclinical Populations

Within the last two to three decades, a plethora of literature employing neurologically intact individuals has substantiated and verified the data on hemispheric function

obtained from clinical populations. Employing mainly dichotic listening and the visual half field techniques, investigators have demonstrated the linguistic processing superiority of the left hemisphere, and the specialization of the right hemisphere for nonverbal, visuospatial functions. These studies can be differentiated by the type of stimulus employed. For example, digits, CV syllables, and words have been employed as verbal material, and tones, emotional intonation, spatial configurations, and environmental sounds as nonverbal material. A further differentiating factor is the type of response required of the subject (recall vs recognition). Consequently an REA or left hemisphere processing advantage has been demonstrated for digits (Kimura, 1963, 1964; Briggs & Nebes, 1976; Bryden, 1965,1970; Carr, 1969; McKeever & Van Deventer, 1975; Hiscock & Bergstrom, 1982; Gordon, 1980; Hiscock & Kinsbourne, 1977; Satz, Bakker, Teunissen, Gobel, Van Der Vlught, 1975; Kraft, 1981,1982; Leksa & Jackson, 1983; Goodglass & Caldero, 1977; Knox & Kimura, 1970), CV syllables (Wexler & Halwes; 1983; Wexler, Halwes & Heninger, 1981; Dwyer, Blumstein & Ryalls; 1982; Larsen & Hakonsen, 1983; Dean & Hua, 1982; Eling, Marshall & van Galen, 1981; Shankweiler & Studdert-Kennedy, 1967; Dorman & Porter, 1975; Geffner & Dorman, 1976; Birkett & Terry, 1982; Haggard & Parkinson, 1971; Davidoff & Done, 1981;

Tweedy, Rin & Springer, 1980; Springer & Searleman, 1978; Morais & Landeray, 1976; Spellacy & Blumstein, 1970; Mirabile, Porter, Hughes & Berlin, 1978; Sidtis, 1982; Kraft, 1981; Curry, 1968; Allard & Bryden, 1978; Berrini, Salla, Sprinler, Sterzi & Vallar, 1982; Piazza, 1980), and words (Geffen & Caudrey, 1981; Unger, Novak & Nichols, 1983; Williams, 1982; Leek & Brandt, 1983; Eling, 1983; Gordon, 1980; Best, Hoffman & Glanville, 1982; Saxby & Bryden, 1984; Curry, 1967, 1968). Correspondingly, using the visual half field technique, a RVF advantage or left hemisphere processing advantage has been demonstrated for verbal stimuli (McKeever & Hoff, 1982; McKeever & Jackson, 1979; McKeever & Van Deventer, 1977; Birkett, 1980; Kershner, Thomae & Callaway, 1977; Salis, 1980; Obler, Woodward & Albert, 1984; Allard & Bryden, 1978; Berrini, Salla, Sprinler Sterzi & Vallar, 1982; Mayes, 1982; Levy & Reid, 1978; Piazza, 1980). There is a substantial body of literature pertaining to left hemisphere processing, but there is a decided lack of literature dealing with right hemisphere processing.

Within the last decade, data on the capabilities of the right hemisphere has been accumulating, with an emphasis on discerning its extent of involvement in linguistic processing. In an extensive review of the literature regarding right hemisphere linguistic skills, Searleman

(1977) cites the work of Sussman and his colleagues (Sussman, 1971; Sussman & MacNeilage, 1975a,b; Sussman, MacNeilage & Lumbly, 1974) who employed a variant of the dichotic listening technique, called pursuit auditory tracking, and demonstrated the first accurate account of the left hemisphere's specialization for speech production in normals. This technique emphasized the need to separate speech production from speech comprehension, and further, implied that the left hemisphere's superiority in pursuit auditory tracking is indicative of a functional and not a structural advantage. Searleman (1977) also cites evidence that different linguistic features of speech, such as intonation contours and pitch processing are not only processed bilaterally, but are often better handled by the right hemisphere (Curry, 1968; Schulloff & Goodglass, 1969; Zurif, 1974; Zurif & Mendelsohn, 1972). In addition, studies have demonstrated that the right hemisphere is specialized for processing of nonverbal stimuli. Spellacy (1970) found a significant LEA for dichotic melodies but no significant difference between ears for timbre, temporal or frequency patterns. Similarly, Sidtis (1980) demonstrated that the right hemisphere auditory function is specialized for the analysis of steady state harmonic information. Employing four distinct dichotic pitch recognition tests, Sidtis (1980) found a significant LEA for both accuracy and

latency of response which emerged as stimuli increased in complexity from pure tones to square waves. An LEA has also been found for emotional tone (Carmon & Nachson, 1973; Ley & Bryden, 1982; Saxby & Bryden, 1984; Haggard & Parkinson, 1971), environmental sounds (King & Kimura, 1972; Kraft, 1981,1982; Curry, 1967,1968; Allard & Bryden, 1978; Knox & Kimura, 1970), and for musical and tonal patterns (Kimura, 1964; King & Kimura, 1972; Sidtis, 1982; Goodglass & Caldero, 1977). Similarly, a LVF advantage has been demonstrated for faces (Obler, Woodward & Albert, 1984; Piazza, 1980), and spatial configurations (Salis, 1980; Allard & Bryden, 1978; Berrini, Salla, Sprinler, Sterzi & Vallar, 1982; Mayes, 1982). Further, it appears that the right hemisphere is important for prosody (coloring, melody and cadence of speech) and emotional These two linguistic features are important for gesturing. language to acquire its affective tone (Ross & Mesulam, 1979).

Both the clinical and the nonclinical research supports the view that the left and right cerebral hemispheres in the human are differentially efficient at processing verbal and nonverbal stimuli. It is currently accepted that the left hemisphere is specialized for the processing of verbal material and the control of linguistic skills (Geffen & Quinn, 1984). The right hemisphere is more efficient in

the processing of visuospatial or nonverbal material (Searleman, 1977; Harris, 1978). It is becoming increasingly clear, however, that investigators must be more specific as to what is being processed asymmetrically, a verbal-nonverbal dichotomy appears to be an oversimplification.

The Ontogeny of Hemispheric Lateralization

In contrast to the adult literature there are fewer summaries and theoretical reports concerning the ontogeny of hemispheric specialization (Witelson, 1977). The literature in this area reflects three different theoretical orientations.

First Lenenberg (1967) theorized that within the first two years of life there is bilateral representation of language; that left-hemisphere specialization develops during childhood and is not complete until puberty; and that during puberty hemispheric plasticity is lost and primary language learning is no longer possible.

Second, Krashen (1972, 1975), suggested that the critical period for left-hemisphere language specialization is complete by about five years of age and this includes related cognitive development and hemispheric equipotentiality for speech and language functions. Several investigators applying the verbal dichotic listening technique to children have argued for an increase in left-hemisphere specialization with age (Bryden & Allard, 1978; Satz, Bakker, Teunissen, Goebel & Van der Vlught, 1975) or for no change in the degree of specialization for at least some linguistic functions (Porter & Berlin, 1975). But, it appears that the former findings of increasing left-hemisphere specialization may be artifacts of the differential effects of task difficulty for younger and older children. A task difficult enough to evaluate the abilities of the older children will probably generate floor effects among the younger age group (Porter & Berlin, 1975).

Third, Kinsbourne (1975) has hypothesized that left-hemisphere specialization exists at birth and does not undergo any subsequent change. The acquisition of each higher mental function originates and terminates on the same side of the brain, either right or left. In fact, when task difficulty is held constant, no progressive hemispheric lateralization effects are found (Hiscock & Kinsbourne, 1977; Carter & Kinsbourne, 1979). Further, studies have demonstrated that not only do perceptual asymmetries exist by the age of three (Nagafuchi, 1970; Ingram, 1975; Piazza, 1977), but that they appear to be of the same magnitude as in the later years. Adapting the

dichotic listening technique and using non-nutrative sucking as the dependent measure, Entus (1977) demonstrated a significant REA for speech and a LEA for music in infants four to six weeks of age. Similar specialization was demonstrated in six-month old infants using EEG measures of interhemispheric differences by Gardiner and Walter (1977), and in new born infants (Molfese, Freehan & Palermo, 1975). More recently, Segalowitz and Chapman (1980) obtained similar results in premature infants (mean gestation age 36 weeks). In view of these data, it appears that from birth there seems to be a propensity for the left hemisphere to be specialized for some of the functions involved in the processing of linguistic stimuli.

In comparison to what we know of the ontogeny of the left hemisphere's specialization, relatively little is known about the development of right hemisphere specialization (Witelson, 1976). A number of studies have presented findings which suggest that right hemisphere specialization may follow a developmental pattern similar to that of left hemispheric specialization. Using the visual half field technique Marcel and Ryan (1975), have demonstrated a LVF advantage for faces from seven year old children, this effect was also demonstrated in five year olds (Young & Ellis, 1976). Five studies with infants, one perceptual (Entus, 1977), and three electrophysiological (Barnet, Freeman & Palermo, 1975; Gardiner & Walter, 1976; Molfese, Nunez, Seibert & Ramanaiah, 1976) all report evidence of right hemisphere specialization for nonverbal auditory processing. Similar results have been obtained from investigations of form and space perception in the visual and haptic modalities (Crowell, Jones, Kapunaiai & Nakagawa, 1973).

In view of the data that has accumulated with respect to the ontogeny of hemispheric specialization, two conclusions are warranted. First, there is substantial evidence to support Kinsbourne's (1975) hypothesis that hemispheric specialization may exist at birth and not undergo any subsequent change. However, more data are required, at present this hypothesis is only tentative as there are a substantial number of studies supporting increasing hemispheric lateralization with age (Bryden & Allard, 1978). Second, it appears that both right and left hemispheric specialization may follow a similar developmental pattern. There is an obvious need for more data with respect to the ontogeny of hemispheric lateralization, and in particular, for the specialization of the right hemisphere.

<u>Sex-Related Differences in Hemispheric Lateralization:</u> Adults

A number of sources have suggested that performance differences on spatial and verbal tasks are related to the sex of the individual. Males excell at spatial tasks, and females are superior relative to males on verbal tasks (Harris, 1978; Maccoby & Jacklin, 1974; McGlone, 1980).

Buffery and Gray (1972) proposed that both speech and spatial functions are more symmetrically organized in the male relative to the female brain. The symmetrical nature of the male brain is assumed to develop due to their later lateralization of verbal skills relative to females, in whom verbal skills progressively lateralize in one hemisphere (usually the left) earlier and more quickly. Due to later left hemisphere specialization for verbal skills in males, their spatial skills are more bilaterally represented, which is further reflected on perceptual tasks where performance is superior relative to that of females (eg., spatial ability). This model (Buffery & Gray, 1972) has met with little support from the adult literature and further, appears to be equivocal with respect to the developmental literature. The current view is that the adult male brain is more asymmetrically organized than the female brain for verbal (Harshman, et al., 1974; McGlone,
1977), spatial (Harris, 1978; McGee, 1979; Witelson, 1976,1977), or both verbal and spatial functions (Bryden, 1979; Harshman & Remington, 1974; Hier, 1979; Hutt, 1979; McGlone, 1977,1978,1980). Fairweather (1976) has argued that there exists no convincing sex-related differences either in cerebral organization or in cognitive ability. As such, the evidence will be reviewed and evaluated.

Given that the evidence supports the presence of sex-related differences for verbal and spatial functions, does the brain of one gender differ from that of the other?

Nonclinical Studies

The majority of dichotic listening studies either failed to specify the sex of the subjects or failed to report whether sex-related differences were observed or analyzed (Fairweather, 1976; McGlone, 1980), therefore, only a select number of studies are relevant. McGlone (1980), in an extensive and critical review of sex-related differences in brain asymmetry, reported that studies using multiple sequences of stimuli and small sample sizes have found no significant sex-related differences in ear superiority for verbal material (Briggs & Nebes, 1976; Bryden, 1965,1975,1979; Carr, 1969; Demarest & Demarest, 1979; McGlone & Davidson, 1973; McKeever & Van Deventer, 1977; Scott et al., 1979). One study (Dorman and Porter, 1975) reported a significantly larger REA for CV syllables in right-handed women relative to right-handed men.

In contrast to the above findings, studies which have utilized single dichotic pairs and large sample sizes (over fifty subjects) report significantly greater asymmetries in males relative to females. Lake and Bryden (1976) demonstrated that 94% of right-handed men and only 69% of right-handed women showed a REA on single dichotic CV syllables. Also, in reanalyzing earlier work (Bryden, 1965), Bryden (1979) provided evidence for an REA for In this case, 58% of 60 women showed right-ear digits. effects in contrast to 75% of 112 males demonstrating a significant REA for digits. Thistle (1975) reported similar trends, but the males greater REA was not significantly larger than the REA found for females. Harshman, et al. (1974), combined data from three independent studies of right-handers and found a significantly stronger REA for CV's more often in males relative to females. Similar results were obtained by Gordon (1980) employing the dichotic presentation of words and digits. These findings are supported by a study employing a large sample of twins (Springer & Searleman, 1978). Fifty-three monozygotic and 35 dizygotic, right-handed, same sex twin pairs were tested on a 240

trial dichotic CV listening task. The female twins demonstrated significantly lower percent correct scores relative to male twins which the authors conclude is evidence of less hemispheric lateralization in females relative to males.

At present there is a relative absence of studies examining sex-related differences in lateralization for nonverbal dichotic material (Bryden, 1979; McGlone, 1980). The few studies that exist report a LEA for melodies (Kimura, 1964), environmental sounds (Curry, 1967), intonation patterns (Blumstein & Cooper, 1974), and complex tones (Sidtis, 1981,1982). King (1970) reported the existence of a significant LEA for the perception of hummed melodic patterns and vocal nonspeech sounds, but the LEA did not vary according to sex.

A number of recent visual half field studies have demonstrated the existence of significant sex-related differences in laterality effects for both verbal and nonverbal material. For verbal material there is a preponderance of studies that report a significantly larger RVF effect for right-handed males relative to right-handed females (Bradshaw & Gates, 1978; Bradshaw, et al., 1977; Bryden, 1965,1979; Ehrlichman, 1971; Hannay & Mallone, 1976; Kail & Siegel, 1978; Levy & Reid, 1976; Marshall & Holmes, 1974; Mayes, 1982). Studies that specifically

examined Sex X Laterality interactions on verbal tasks generally failed to find such Sex X Laterality interactions (Hannay & Boyer, 1978; Leehey, et al., 1978; McKeever, et al., 1976; McKeever & Van Deventer, 1977).

Studies employing nonverbal material often report significantly larger LVF advantages in men relative to women eg., faces (Perez, et al., 1975; Rizzolatti & Buchtel, 1977; Obler, et al., 1984), spatial dot patterns (Davidoff, 1977; Kimura, 1969; McGlone & Davidson, 1973; Salis, 1980), and line orientation (Sasanuma & Kobayashi, 1978; Walter, et al., 1976; but not Durnford, 1970; Mayes, 1982). It appears that LVF advantages in the perception of schematic faces, depth perception, and hue discrimination show no reliable sex-related differences (McGlone, 1980).

Studies examining sex-related differences in laterality employing normal right-handed adults are reasonably consistent. Methodological limitations, sex differences in peripheral auditory thresholds (Kannan & Lipscomb, 1974), and possible strategy differences (Bryden, 1979) however, all serve to complicate the study of sex-related differences in hemispheric lateralization. Nevertheless, two conclusions are warranted. First, adult males are more likely to manifest a REA or RVF advantage for verbal stimuli relative to adult females. Secondly, if an REA or RVF advantage is reported for both sexes, adult males

demonstrate the larger REA or RVF advantage relative to adult females. A similar conclusion may be drawn regarding the LVF advantage for nonverbal stimuli, but there simply is not enough data to draw any conclusions concerning a LEA for dichotic stimulation. When sex-related differences are reported, the majority of the data are compatible with the hypothesis of greater male hemispheric asymmetry.

Clinical Studies

The clinical data, based mainly on unilaterally damaged patients, provides additional support for greater male hemispheric asymmetry relative to the female. The clinical studies are based on the premise that, if individuals with damage restricted to one hemisphere do worse relative to individuals with damage restricted to the other hemisphere, the task requirements must be predominantly organized in the first hemisphere. This method has been used to examine sex variation in hemispheric asymmetry by contrasting residual verbal skills and residual nonverbal skills after left and right brain damage.

The performance differences (verbal/nonverbal) ratio scores, based on Wechsler Intelligence scales from patients with temporal lobectomies (Lansdell & Urbach, 1965), strokes and tumors (McGlone, 1978), and commissurotomy

(Bogen, et al., 1972), support the hypothesis of greater hemispheric specialization in males relative to females. However, these data do not indicate which function (verbal, nonverbal, or both) may be more asymmetrically represented in the adult male brain.

The effects of unilateral lesions upon verbal functioning, distinct from their effects on nonverbal functioning has clarified this issue. The incidence of aphasia and severe speech disorders has been found to occur significantly more often, and to be more severe, in adult males relative to adult females (Harris, 1978). Further, acquired aphasia during childhood is more commmon in males relative to females (Hier & Kaplan, 1980). Other verbal deficits, utilizing different language measures (proverb interpretation, word - association, Wechsler's Verbal IQ scores), also suggest greater left hemisphere control of verbal functioning in men than in women (McGlone, 1980).

Inconsistent findings have been obtained for nonverbal, spatial functioning. Nonverbal tasks requiring constructional praxis and perceptual discrimination, appear to be more impaired in males relative to females (McGlone, 1978) after right hemisphere lesions. Dimond (1980) and colleagues obtained similar results utilizing chimeric stimuli tachistoscopically presented. However, sexrelated differences in hemispheric asymmetry involving form

or pattern recognition have not been consistent (Bradshaw, 1980). Line-orientation tasks (Benton, et al., 1975) showed no obvious sex-related differences after unilateral brain lesions. These data suggest that the etiology of the lesion may be an important control factor, particularily when sex-related differences in spatial asymmetries are being examined (McGlone, 1978).

McGlone (1980) noted three methodological problems inherent to clinical studies. First, a number of authors have failed to publish their data, preventing other researchers from replicating their findings, or any further evaluation of their claims. Second, the exact location of the cerebral lesion is unclear in most studies. Third, cross-study comparisons are made difficult because the patient samples differ in central nervous system pathologies. The etiology (pathogenesis) of the lesion may interact with the sex of the subject and the side of the lesion in determining overall intellectual scores. Finally, variables such as the extent and locus of lesion, the age at onset of pathology, and the age at time of testing and surgical intervention, the recovery period, and medications may alter performance on psychological tests. With few exceptions, sex and laterality groups have not been matched for extent and locus of lesions, age, education, hand preference, or familial sinistrality. As

such, McGlone (1980) cautions that one must carefully examine whether reports on sex-related differences in lesion effects can be attributed to systematic differences between the sexes on these uncontrolled variables. In fact, the few studies with adequately matched sex and lesion groups on the above control variables, and which restricted sampling with unilateral lesion patients, do provide evidence for sex-related differences in hemispheric asymmetry (McGlone, 1977; Kimura, 1980).

McGlone (1980) reported that the incidence of aphasia after left hemisphere lesions was found to be at least three times as great in men as in women. Furthermore, when aphasics were removed from the sample, only males showed the expected pattern of depressed verbal IQ and verbal memory loss after left hemisphere damage as compared to males with right hemisphere damage. No significant differences in the verbal scores appeared between females with left and right sided brain damage, however, both female lesion groups were significantly impaired on age corrected verbal IQ scores relative to non-brain damaged controls. Kimura (1980) agrees with McGlone's (1980) conclusions, but also suggests that the organization of speech functions within the left hemisphere is different in males and females. Kimura (1980) classified patients in terms of anterior or posterior lesion location, and in

'terms of aphasic and nonaphasic disorders. Of the twelve aphasic patients with left posterior damage, all were male. In contrast, only three females out of six aphasic patients had left anterior damage. Kimura (1980) concluded that this distribution was significantly different from chance.

The clinical data provide substantial support for the existence of sex-related differences in hemispheric lateralization. The left hemisphere evidently plays a predominant role in speech and language production. Cerebral insult to the left hemisphere almost invariably results in some verbal deficit in male samples, but less consistently so in female samples. There appears to be no. evidence of more frequent right hemisphere dominance for basic speech functions in males than females. McGlone's (1980) findings of impaired verbal IQ scores after right hemisphere lesions in females does however suggest that some degree of bilateral speech representation is present in women. In addition, the findings of Kimura (1980) suggest the existence of differential language organization within the left hemisphere may be related to gender. The small number of clinical studies investigating sex-related differences in visuospatial processing are not consistent. At present, the data seem to imply greater right hemispheric dependence in males relative to females for certain visuospatial tasks. Overall, however, the adult

clinical literature with respect to sex-related differences in verbal and nonverbal functioning supports the hypothesis of greater functional hemispheric asymmetry in the male relative to the female.

<u>Sex-Related Differences in Hemispheric Lateralization:</u> Children

In comparison to the adult studies, even fewer investigators have examined the influence of gender on verbal and nonverbal asymmetries in children. At the present, the developmental data are equivocal.

Verbal Functions

The developmental clinical data, like the adult clinical data, suffer from a lack of methodological controls. Studies which have investigated the effects of strictly unilateral brain lesions in children (Woods & Teuber, 1978; Lansdell, 1976) find no sex-related differences. However, the locus and extent of lesion, hand preference, and side of language representation were not controlled across boys and girls (McGlone, 1980).

In neurologically intact children, lateralization has been demonstrated in the auditory system for both speech

and nonspeech stimuli in infants (Glanville, Best & Levenson, 1977; Molfese, Freeman & Palermo, 1975). One study reported that infant females appear to show a different pattern of lateralization relative to infant males (Molfese & Jones-Molfese, 1977). Due to the small number of infancy studies, no conclusions may be drawn regarding sex-related differences in hemispheric lateralization in infancy.

Dichotic listening studies have demonstrated the existence of a significant REA in both sexes as early as age three (Ingram, 1975; Kinsbourne & Hiscock, 1977; Nagatuchi, 1970), and also in infants (Entus, 1977). It is not clear however, whether this REA occurs more consistently in boys relative to girls. A number of studies have reported a REA slightly more often in boys (Nagafuchi, 1970, Ingram, 1975; Kimura, 1963, 1967; Geffner & Dorman, 1976; Piazza, 1977; Pizzamiglio & Checchine, 1971; Kraft, 1983) than in girls, but the majority report no significant interactions of Sex X Ear superiority (Berlin et al., 1973; Borowy & Goebel, 1976; Geffner & Hochberg, 1971; Hynd & Obrzut, 1977; Kinsbourne & Hiscock, 1977; Knox & Kimura, 1970; Satz et al., 1975; Schulman-Galambos, 1977; Davidoff & Done, 1981; Hiscock & Bergstrom, 1982). It has also been demonstrated that when more difficult dichotic listening tasks are used, the adult

pattern of lateralization does not appear until 9 or 11 years of age (Satz et al., 1975).

Tachistoscopic studies employing verbal material, and taking into account reading proficiency in matching boys and girls for chronological age, have failed to show significant Sex X Visual Field interactions (Marcel & Ryan, 1975; Yeni-Komshian et al., 1975).

Nonverbal and Motor Functions

There appears to be indirect support for sex-related differences in right hemisphere functioning, implying earlier and faster right hemisphere specialization in males. This support is based on the premise that left ear and limb advantages reflect superior right hemisphere functioning.

Witelson (1976), utilizing a dichhaptic identification task with nonsense shapes demonstrated that males had a significantly greater left-hand score relative to the right-hand score across all ages (6-13). No differences were obtained for the female subjects regardless of age. However, Cioffi and Kandel (1979) were unable to replicate these findings. In addition, the dichhaptic task does allow for an attentional bias to one or the other hands (Bryden, 1979). Rudel et al. (1974, 1977) in examining

the acquisition of braille reading in sighted children between the ages of 7 and 14, found a left-hand superiority that appeared gradually, but more quickly and reliably for boys relative to girls. At age 7 to 8, the boys performed equally well with both hands, but the girls right-hand scores were superior. By age 13 to 14 in both boys and girls, left hand scores were superior. Rudel and his colleagues (1974,1977) interpretated these data as evidence for an earlier and perhaps superior pattern of right hemisphere development in boys. Witelson (1976, 1977) has further suggested that the right hemisphere of the male is more specialized for the processing of spatial information relative to the left hemisphere by age 6, whereas spatial abilities may be more bilaterally represented in the female at least until puberty.

Limitations of the Developmental Data

Studies examining sex-related differences in laterality employing normal right-handed adults are reasonably consistent, however, the developmental data are equivocal. One reason for the equivocal nature of the developmental literature may be the use of chronological age (CA) as a criterion for matching male and female samples. The CA matching procedure does not take into account the finding

that girls are maturationally more advanced than boys (Tanner, 1962). This leads to difficulties in the interpretation of the data on sex-related differences (Harshman et al., 1974). For example, Waber (1977) has linked the degree of the ear advantage on dichotic verbal tasks to maturation. When boys and girls were matched for rate of maturation (early,late), rather than chronological age, no sex-related differences in ear asymmetry were observed.

In addition, there are other extraneous variables particular to the developmental data. Reliable data are difficult to obtain due to limits placed on performance by variables such as comprehension, motivation and behavioral variability from task to task, and from session to session. Further, the effects of physical, mental, and cerebral maturational level on sex-related differences in overall performance complicates the interpretation of the relationships between laterality and sex. In addition, due to the extensive transformation of the human cerebral cortex during development (Wolff, 1980), comparisons between developmental and adult data should not be expected to yield parallel findings. The relative absence of developmental studies indicating significant sex-related differences in functional brain asymmetry may suggest that

such differences do not become significant until some stage after puberty (McGlone, 1980).

<u>Biological Evidence for Sex-Related Differences</u> <u>in Hemispheric Lateralization</u>

Anatomical Asymmetry: Animal Studies

Recently evidence has been accumulating to indicate that differences between the left and right cerebral hemispheres exist in animals anatomically, biochemically and functionally. In addition there are data to suggest that hemispheric lateralization is sexually dimorphic and present at birth (Ross, Glick, & Meibach, 1982).

Nottebohm (1970) was one of the first to demonstrate evidence for lateralization of function in animals. Nottebohm (1970; 1971; 1972) demonstrated that severing the left hypoglossus, which abolished neural control over the left half of the syrinx, caused most of the components of the Chaffinch's song to disappear. Severing the right hypoglossus had only a minor effect on song production. This same phenomenon has been demonstrated in the canary, white-crowned sparrow (Nottebohm & Nottebohm, 1976), as well'as in the white-throated sparrow (Lemon, 1973) and is termed left hypoglossal dominance (Nottebohm, 1979). However, anatomical differences between the right and left cerebral vocal areas are not found in either sex (Nottebohm & Arnold, 1976), but there does appear to be a functional dominance of the left hemisphere for complex song patterns in males (Nottebohm, 1977).

Recently Andrew and Brennan (1983) have demonstrated a complex pattern of specialization of functions in the chick. The development of right/left differences in fear responses in the domestic chick suggested marked progressive specialization for fear behavior of systems fed by the left eye, with a considerable degree of independence of development of right and left side systems (Andrew & Brennan, 1983).

Motoric behaviors that correlate with asymmetric neural and chemical mechanisms have been recently demonstrated in rodents (Denenberg, 1981; Giick, Jerussi, & Zimmerberg, 1977). Adult female mice have been observed to be more strongly lateralized than males for both left and right paw preference on a food-reaching task (Collins, 1975). Sex-related differences in spontaneous circling behavior and in the lateralization of dopamine concentration have been demonstrated in rats (Zimmerberg, Glick, & Jerussi, 1974). More recently it has been shown that there exist asymmetries in 2-deoxy-D-glucose incorporation in several brain regions of the adult (Glick, Meibach, Cox, & Maayani,

1979; Ross, Glick, & Meibach, 1982), and neonatal (Ross, Glick, & Meibach, 1981) rat brain. In the rat at least, left-right asymmetries appear to change with age, there being both left-to-right and right-to-left maturational gradients in different brain structures. In addition, in most brain regions, the more active a structure is relative to the rest of the brain, the more likely that structure is right-biased and visa-versa. Some of these relationships manifest sexual dimorphism, specifically in striatium and cortex. Males demonstrate smaller changes in relative activity associated with larger changes in left-right asymmetries. Using energy utilization as an index of brain development Ross, Glick and Meibach (1983) have demonstrated the existence of structure-specific and sexually dimorphic maturational gradients. For example, in female rats the midbrain maturational gradient proceeds from left to right, whereas in males it proceeds in the opposite direction. Hemispheric asymmetries have also been demonstrated for the effects of hormones in the sexually differentiating brains of rats (Nordeen & Yahr, 1983). Newborn female rats between 24 and 48 hours after birth received either left or right intrahypothalamic implants of estrogen. The effects of estrogen on gonadotropin secretion and reproductive behavior depended on both the region and side of implantation. Exposure of the left

hypothalamus to estrogen resulted in defeminizing development. The converse was found after exposure of the right hypothalamus to estrogen, the effect being one of masculinized development. Collectively these data indicate that certain motor and bichemical asymmetries in rodents may be sexually dimorphic and present at birth. The female rodent being more lateralized relative to the male.

A number of investigators have presented evidence of left-right anatomical brain asymmetries in rodents. Diamond and colleagues (1975; 1980) measured cortical-thickness in male Long-Evans and Sl maze-bright rats at ninety days of age in various brain regions. The right hemisphere was found to be thicker than the left in the frontal and parietal regions, but these differences were not significant. The posterior cortex on the right side was significantly thicker than the left. The Long-Evans females had a thicker left relative to right hemisphere, but none of these differences was significant. However, a group of Long-Evans females that had been ovariectomized at one day of life and whose brains were examined at ninety days demonstrated an identical brain thickness pattern relative to that of the males. These data suggest that the male brain pattern in these females is related to the lack of female hormones, since these gonadectomized females had not received androgen.

Studies employing primates as subjects have often yielded inconsistent findings and there is little support for the proposition that monkeys show cerebral asymmetries similar to those in man (Hamilton, 1976; Nottebhm, 1979; Walker, 1980; Warren, 1980). The inconsistent findings may be partly due to the type or the stimuli or the experimental manipulation expected to reveal lateralization of function. A number of investigators have demonstrated that some functions involving auditory or sequential processing may be lateralized (Beecher, Petersen, Zoloth, Moody & Stebbins, 1979; Dewson, 1977; Hamilton & Vermeire, 1982). In addition Petersen, Beecher, Zoloth, Moody and Stebbins (1978; 1979) have presented strong evidence that the left hemisphere in Japanese macaques and Old World monkeys is preferentially involved in processing conspecific vocalizations that carry communicative information. These results are similar to the findings of Dewson (1978; 1979) who demonstrated the involvement of the left temporal lobe for auditory functions in Irus macaques. Recently Hamilton and Vermeire (1983) investigated the ability of each hemisphere to discriminate photographs of the faces of other monkeys. These tasks were chosen because facial recognition is generally found to be significantly lateralized to the right hemisphere of man (Bradshaw & Nettleton, 1983) and because macaques are a

highly social species that communicate extensively by facial expression (Redican, 1975). The eighteen split-brain rhesus monkeys quickly learned the four facial discriminations with each hemisphere and subsequently demonstrated good generalization to new sets of photographs of the stimulus faces. Despite the indication that the monkeys recognized facial characteristics, there were no overall significant differences in the learning or generalizing abilities of the monkeys' left and right hemispheres. Similarly, Overman and Doty (1982) demonstrated that human subjects favored their right hemisphere when recognizing facial photographs of people but not facial photographs of monkeys while pigtail monkeys showed no evidence of lateralized processing for either category of stimuli. As such, their findings suggest no hemispheric lateralization for facial discrimination in monkeys, in contrast to results obtained from studies with humans (Bradshaw & Nettleton, 1983).

However, Hamilton and Vermeire (1983) did find some interesting subsidiary results. First, there was an almost significant correlation between the magnitude of the dominance index and the weight of the monkey at the time of surgery, with greater dominance associated with greater weight. These data suggest the possiblity that hemispheric lateralization is not fully established until monkeys are

several years old, and that the underlying lateralization may be more meaningful if surgery were performed at ages nearer to the monkey's sexual maturity. An additional finding was that the dominance index of the female monkeys was significantly different from zero relative to male monkeys. In addition, the indices for the two sexes were significantly different from each other. Because the females as a group were almost significantly heavier than the males, these results of greater dominance in females may reflect greater age at surgery, rather than a sex difference "per se" (Hamilton & Vermeire, 1983). There is an obvious need for further investigation to confirm the findings of a significant degree of hemispheric specialization in the female rhesus monkey.

In summary, it is evident that sex-related differences in hemispheric lateralization have hardly been studied in the animal population. In addition, the inability to obtain consistent hemispheric differences in monkeys with tasks that appear appropriate and that demonstrate lateralization in humans is disappointing. There are, however, a number of investigators who believe that lateralized processing evolved earlier than, and independently of language in human beings (Hamilton, 1977a; 1977b; Overman & Doty, 1982; Warren, 1980; Hamilton & Vermeire, 1983). The subsidiary findings of Hamilton and

Vermeire (1983) are particularily interesting in view of the hormonal and maturational models that have been proposed to explain the existence of sex-related differences in hemispheric lateralization in humans (Petersen, 1977; 1979; Waber, 1976; 1977). There is an obvious need for investigations of hemispheric lateralization in nonhuman species. The phylogenetic basis of human hemispheric differences should eventually become clear from comparative studies of lateralization in different species. Questions about the ontogenetic development and usefulness of lateralized mechanisms are more difficult to answer (Hamilton & Vermeire, 1983). These questions could be most directly studied in humans however, the necessary techniques of controlled rearing and invasive manipulations of the brain are simply not feasible. As such, if related hemispheric asymmetries were discovered in nonhuman species, critical investigations into the developmental and functional significance of hemispheric specialization in man would be aided enormously (Denenberg, 1981; McGlone, 1980; Hamilton & Vermeire, 1983).

Anatomical Asymmetry: Man

There are data suggestive of sex-related differences in the anatomical structure of the cerebral hemispheres in man (Wada, Clark & Hamm, 1975; Witelson & Pallie, 1973).

In infant brains the appearance of an enlarged planum temporale was found to be significantly more prevalent in female infants than in male infants (Witelson & Pallie, 1973). However, this report was based only on five brains of each sex. Studies which have employed a large sample of infants report both frontal and temporal lobe anatomical asymmetries, but these asymmetries did not vary between males and females (Chi et al., 1977; Wada et al., 1975).

The structural asymmetry of the planum temporale has been extensively cited as indicating greater male asymmetry in language function. The planum temporale, posterior to Hescl's gyrus, located on the superior surface of the temporal lobe, is believed to subserve auditory functions. In the majority of cases the planum temporale is reported to be larger on the left side than on the right side for both sexes (McGlone, 1980). However, Wada et al (1975) have further demonstrated that this anatomical asymmetry is attenuated in adult females. Significantly more female than male brains showed the reverse pattern, a larger right than left planum temporale. It appears that brain growth in man has two components (Epstein, 1974). The first is an increase in brain weight corresponding to an increase in body weight. The second component appears in 5% to 10% increases in brain weight during the age periods from two to four, six to eight, ten to twelve, and fourteen to sixteen years, the latter two spurts being slightly earlier for girls and slightly later for boys. The increase in brain weight and head circumference both show a marked difference between the sexes after the age of ten. Girls head growth between age ten and twelve years is about twice that of boys, while the situation is reversed for the growth spurt centered around age fifteen years (Epstein, 1977).

In summary, anatomical data regarding sex-related differences in brain lateralization is inconclusive. The interpretation of suggestive sex-related anatomical differences is difficult, as there is little support for the assumption underlying the significance of these findings. A structural asymmetry is assumed to underlie cerebral specialization. According to this assumption, sex-related differences in the planum temporale structural asymmetry reflect right hemisphere involvement for some speech functions in females (Harris, 1978). At present nothing can be concluded from these asymmetries. As McGlone (1980) points out, no mechanism relating size to

function has been elaborated. Asymmetric morphology may form the basis for subsequent functional specialization or it may merely reflect balanced accommodation for an irregularly developing cortical mantle.

To understand the existence of sex-related differences in hemispheric asymmetry, one must examine the underlying biological mechanisms that serve to differentiate the two sexes. The sex of an individual is determined before the first division of the fertilized egg, and depends upon the presence of either an X or a Y chromosome in the fertilized spermatozoon. The introduction of this chromosome is the principal determinant of the direction of sexual development, which includes the differentiation of the genital ducts, the appearance of external genitalia, the synthesis of hormones and sexual behavior.

The Influence of Hormones

It has been proposed that one of the possible biological mechanisms influencing sex-related differences are the sex hormones (Englander-Golden, Willis & Dienstbier, 1976; Petersen, 1976). Two major sources of evidence suggest the possible function of sex hormones in development. The present discussion will focus on the influence of sex hormones during normal and atypical

development.

Hormones are highly specialized and powerful chemical substances. The hormones' specificity relates to the density and presence of particular receptors, cells differentiated specifically to receive and bind with the hormone. When the hormone and receptor link up on the cell membrane, a message is released intracellularly that triggers a particular piece of cell machinery (Tanner, 1978). In comparison to the nervous system, hormonal action is specific but slower, the speed of movement being limited to that of the blood. The endocrine system and the nervous system of the body function in a closely coordinated way, each dependent upon the other for its proper operation.

The functional interdependence between the brain and the endocrine system is quite apparent over the course of development. At the time when the maturing brain is capable of influencing the function of the endocrine system, this system in turn is able to influence the nervous system. Of major importance in morphological and functional differentiation is the thyroid gland. Other endocrine glands, such as the pituitary, pineal gland, adrenal cortex and sex glands, also influence development, although their effects are more subtle (Reinis & Goldman, 1980).

The initial progression of sexual differentiation is generally quite subtle, and male-female differences are indistinguishable. In the early period of embryonic development, both the Wolffian and Mullerian urogenital ducts appear simultaneously in males and females. It is only later that they begin to shift in different morphological directions. In females, the Wolffian duct further develops into the uterine (fallopian) tube, while in males, it becomes the vas deferens. The Mullerian duct gives rise to the female uterus and to parts of the male epididymis.

The early development of the sex organs is primarily under hormonal control and the presence or absence of testosterone is the decisive factor in this process. The absence of testosterone directs somatic development in the female direction. The sex hormones, a class of biochemical organic compounds termed steroids, are produced primarily by the gonads (ovaries and testes) and the adrenal gland. Females produce two major groups of hormones, estrogens and progestins. Males produce androgens. Females also produce androgens but in smaller quantities, and males also produce estrogens but in smaller quantities. Further, many forms of the sex hormones can be biochemically transformed into one another.

In addition to being involved in normal sexual

development and functioning, sex hormones influence many other important functions. The development and maintenance of primary and secondary sex characteristics, gametogenesis, regulation of salt and water balance, metabolism, and growth, are all dependent upon an adequate amount of circulating sex hormones and the receptivity of the target tissues.

Progesterone appears to have a major function in preparation for pregnancy. Outside of the reproductive system it plays a minor role in the biosynthesis of adrenal, testicular, and gonadal steroids from cholesterol (Tepperman, 1968). However, estrogens and androgens have a strong influence on body functions. In females, estrogen is necessary for complete development of the uterus and vagina, and the growth of tissues related to reproductive processes. At puberty it is responsible for epiphyseal closure of the bones, maintains proper calcium balance, and lowers serum cholesterol. The presence and/or absence of androgen is thought to be of greater importance in development than either estrogen or progesterone. However, recent evidence suggests that estrogen may be the active agent actually operating on the central nervous system (Goto & Fishman, 1977; Reinisch, 1976).

Androgens are responsible for the masculinization of the hypothalamo-pituitary axis and appear to be the

critical hormones responsible for male sexual differentiation (Jost, 1958) and brain masculinization (Martini, 1978). However, it is not testosterone per se, but the female hormone estradiol converted from testosterone which is responsible for the secondary sexual differentiation in the male (Martini, 1978; Ohno, 1979). Androgens are responsible for beard, axillary, and pubic hair growth. Androgens are also related to the lowering of voice pitch occuring at puberty, increased muscle mass and decreased subcutaneous fat and, like estrogens, accelerating epiphyseal closure of the bones at puberty. Androgens and estrogens appear to be antagonistic (Marcus & Korenman, 1976) and, further, the flow of these sex hormones is controlled by a negative feedback system. The pituitary gland controls endocrine levels, and is itself controlled by the hypothalamous. The pituitary, through the hypothalamus, maintains the optimum level of . circulating sex hormones.

Both testosterone and estradiol are found in differing concentrations at birth. Testosterone levels decrease in female neonates (from birth to two weeks), and remain higher in males during the same time period (Forest et al., 1973). Estradiol also appears to be higher in male than female neonates (Doering, 1975). Once the perinatal endocrine values stabilize, no sex-related difference is

found among prepubescent males and females in sex hormone levels (Forest et al., 1973).

Three hypotheses have been proposed to account for the relationship between functional hemispheric lateralization and the sex hormones. First, the responsivity hypothesis (Beach, 1945) suggests that early hormonal priming alters the responsivity of the CNS to circulating hormones in later life. Studies supporting the responsivity hypothesis have demonstrated that prenatal and/or perinatal exposure to estadiol and testosterone can modify later response to sex hormones (Balazs, Potel & Hajos, 1975).

Second, the organizational hypothesis suggests that alterations in gene expression induced by sex hormones are in turn expected to influence protein production, neural growth and cerebral organization (Arai & Matsumoto, 1978; Cavallotti & Bisanti, 1972). It is still unclear at this point whether male and female brains differ in organization at birth or even earlier. Those who postulate in utero effects on brain development consider sex hormones to act in the cell nucleus by triggering changes in gene expression. The organizational effect of estradiol in the brain appears to be dose dependent; either too much or too little is damaging, while intermediate levels of estradiol seem to optimize neural development. In support of this hypothesis is the finding that short-term cyclic

estrogen/gestagen treatment may restore spatial ability in Turner's syndrome women to a normal level, while long-term cyclic estrogen/gestagen therapy is associated with low spatial ability (Nyborg & Nielsen, 1981).

Third, the activation hypothesis considers the regulatory actions of sex hormones on genes to be responsible for the activational effects of the hormones in a specific or general manner (Hoyenga & Hoyenga, 1979). The specific effect consists in hormones temporarily changing the cellular activity in a specific area of the brain, thereby increasing the probability of a particular response to a specific environmental stimulus. The general activational effect of hormones consists in affecting temporarily the general level of activity in rather large parts of the brain (Kobayashi, Kobayashi, Kato & Minaguchi, 1966; Broverman et al., 1968; Gorski, 1976).

The influence of sex steroids on the developing organism and subsequent behavior is best demonstrated by clinical syndromes in which the in utero levels of androgens have been either excessive or too low during the critical period of hypothalamic differentiation. For the human, this critical period occurs between the fourth and seventh fetal month (Dorner, 1978).

a) Adrenogenital Syndrome: The adrenogenital syndrome is a metabolic dysfunction caused by an autosomal recessive The adrenal gland secretes excessive amounts of gene. adrenal androgens. Due to an enzymatic insufficiency the adrenal gland fails to respond to pituitary adrenocorticotrophic hormone (ACTH) and secrete cortisol. The absence of cortisol causes the pituitary to secrete large quantities of ACTH which, in turn, increases the output of the masculinizing hormone by the adrenal glands (Ehrhardt, Evers & Money, 1968). The male with this syndrome typically appears normal but of short adult stature due to premature cessation of bone growth. Further, the excess androgen will increase the rate of muscle growth and initiate precocious puberty. The female exposed to elevated levels of androgens during the fetal period is characterised by varying degrees of masculinization of the external genitalia, in some cases an enlarged clitoris and in others causing fusion of the labia. If untreated after birth, facial hair, deepening of the voice, and failure of breast development and menstruation occur.

From a behavioral perspective, females exposed to excess androgen during gestation seem to be more athletic and assertive, preferring more vigorous outdoor play, and display tomboyish behavior in general (Ehrhardt & Baker,

1974; Ehrhardt & Meyers- Bahlburg, 1979; Money & Schwartz, 1977). It has also been proposed by a number of investigators that the adrenogenital individuals as a group have higher IQ scores (Money & Lewis, 1966; Baker & Ehrhardt, 1974). However, AGS children and their families have similar IQ's, ruling out the possibility that the hormonal component is responsible for the elevated IQ observed in this syndrome (Baker & Ehrhardt, 1974). In addition, comparable IQ's in parents, unaffected siblings, and AGS children raises the possibility that some factor linked to the gene may be responsible for a familial IQ elevation, since both parents and theoretically two out of every four offspring are heterozygotic for the trait (Reinisch, Gandelman & Spiegl, 1979).

b) Androgen Insensitivity Syndrome: In the androgen insensitivity syndrome genetic males cannot utilize either endogenous or exogenous androgen and as a consequence develop as morphological females (Money, Erhhardt & Masica, 1968). Furthermore, the full scale IQ has been found to be normally distributed, however, a significant superiority for verbal in comparison to performance IQ was found (Masica, Money, Ehrhardt & Lewis, 1969). This is similar to scores obtained in normal female samples. In addition, Perlman (1971) demonstrated that the androgen insensitive

male displays a deficit in spatial-manual perceptual skills. These data should be viewed with caution, for the possibility exists that abnormally low levels or the absence of androgen may relate to less spontaneous activity in childhood, as elevated levels of prenatal androgen are related to higher childhood activity level in AGS females (Money, Ehrhardt & Masica, 1968). Differential experience may influence the development of certain skills measured on tests of cognitive ability.

Certain cytogenetic syndromes are also accompanied by atypical levels of sex hormones.

a) Klinefelter's Syndrome: Klinefelter's syndrome, one of the two major clinical sex chromosome aberrations, is diagnosed when a male has an extra X chromosome (XXY). The disorder is usually not detected until puberty at which time both the phenotypic and endocrine influences can be detected. The clinical findings at puberty consist of hypogonadism, lack of libido and potency, aspermatogenesis because of the abnormal structure of the seminiferous tubules in the testes, increased excretion of follicle stimulating hormone in the urine, sparse facial and body hair, a female distribution of pubic hair, and in some cases, breast development and increased stature. The abnormal genotype in Klinefelter's syndrome apparently predisposes the patient to a wide variety of conditions including mental disease, epilepsy, male breast cancer, and disturbances of behavior (Moore, 1966). Among institutionalized mentally retarded males the proportion of Klinefelter's males is considerably high (Scott & Thomas, 1973; Robinson & Robinson, 1976).

b) Turner's Syndrome: Turner's syndrome is a cytogenetic defect in which only one X chromosome is present or a significant portion of the second X chromosome is missing in the female which, in turn, correlates with a dysgenesis of the gonads and the total absence of gonadal hormones. At puberty these phenotypical females must be given estrogen in order for secondary sex characteristics to appear. Turner's syndrome females may also be characterized by varying degrees of malformations, including webbed neck, shieldlike chest, and extremely short stature. The majority of Turner's females exhibit normal intelligence. The full scale IQ does not differ significantly from that of the normal population. However, a large percentage of these females demonstrate difficulties in the area of spatial abilities (Money & Alexander, 1966; Hier, Atkins & Perlo, 1980), and exhibit relatively poor performance IQ scores relative to their

verbal IQ scores. Utilizing the dichotic listening procedure, investigators have demonstrated atypical hemisphere specialization in Turner's females. For example, Netley and Rovet (1982) using a verbal dichotic listening task found that Turner's individuals either have a reversal or an absence of left hemisphere specialization for verbal processing. The presence of androgens and progesterone is known to be associated with the development of male morphology and behavior, and the absence of these fetal hormones is known to be associated with the development of female morphology and behavior (Money & Ehrhardt, 1972). It is conceivable that the degree to which hemisphere lateralization is observed by measures such as the dichotic listening task is also related to the levels of fetal sex hormones (Levy & Reid, 1978).

Puberty

The term adolescence chronologically encompasses a much broader period of time than puberty, lasting almost a decade and lacking a sharply defined begining or end. Adolescence has several identifiable morphological, physiological and biochemical criteria, including dental and skeletal indices. Puberty, on the other hand, is a more specific term describing only the onset of sexual
maturation, and usually appears shortly before the midpoint of adolescence (Reinis & Goldman, 1980).

The biological changes that occur during puberty affect the entire body, including the brain. Sex hormone levels begin to slowly increase before puberty (Heald & Hung, The immediate change that triggers the onset of 1970). puberty appears to reside in the hypothalamus. Just prior to this time the gonads and pituitary are prepared to respond to their particular trophic hormones. The change in the hypothalamus has been described as a lowering of the threshold of the negative feedback sensitivity to the sex hormones. As puberty approaches, there is a decrease in the sensitivity of the hypothalamic negative feedback receptors to the sex steroids (Kulin, Grumbach & Kaplan, 1969).

Extrahypothalamic centres also influence the onset of puberty. For example the complete deafferentation of the basal or anterior hypothalamus causes precocious ovarian development and early vaginal opening in the rat (Ramaley & Gorski, 1967). Studies of the extrahypothalamic effects have focused mainly upon the amygdala. Docke (1976) discovered that the anterior part of the amygdaloid mediocortical nucleus has a gonadotrophin inhibitory effect, while gonadotropin stimulating activity develops in the posterior mediocortical amygdala. Both of these

effects are related to estrogen feedback. The anterior part of the cortical amygdala contains a negative feedback system which, in the adult individual, may stimulate the secretion of FSH (follicle stimulating hormone) in the presence of low levels of estrogen. The activities of both hypothalamic and amygdaloid nuclei are probably also affected by higher cortical centers, although there is very little experimental evidence concerning these influences presently available.

Another brain area which may be involved in the onset of puberty is the pineal gland, a structure that is part of the epithalamus. In mammals, it has an inhibitory effect on the gonads. It delays vaginal opening and reduces ovarian weight in very young rats (Reinis & Goldman, 1980).

The sequence of increases in various sex hormones are identical for males and females, although females mature 1.5-2 years earlier than males (Ducharme et al., 1976). Adrenal hormones begin increasing before gonadal hormones, leading some investigators to suggest that adrenal steroids have at least a permissive role in the onset of puberty (Korth-Schultz, Levine & New, 1976). However, the two systems may be independent as no relationship exists between gonadotropin levels and those of the adrenal androgens (Lee, Jaffe & Midgley, 1974). The increase in gonadotropin levels (particularily FSH) is followed by an

increase in gonadal hormones and the development of secondary sex characteristics (Blizzard et al., 1970; Rifkind et al., 1970). While puberty is marked by elevated noctural levels of the gonadotropin LH (luteinizing hormone), waking levels of LH increase after the appearance of secondary sex characteristics (Winter & Faiman, 1973).

It has been proposed that all adrenal androgens show significant sex-related differences (Heald & Hung, 1970). Hopper and Yen (1975) report that significantly higher plasma levels of dihydroepiandrosterone (DHEA) are evident among girls. Boys, on the other hand demonstrate higher levels of dihydroepiandrosterone sulfate (DHEAS). Similar findings for DHEA levels have been found by other investigators (Sizonenko & Paunier, 1975; Ducharme et al., 1976). Korth-Schultz et al. (1976) found no sex-related differnces in either DHEA and DHEAS.

Gonadal hormones also show dramatic increases through puberty in both males and females, the sex difference becoming apparent by Pubertal Stage 3 as measured by Tanner's (1962) stages of pubertal development (Angsusingha et al., 1974; Ducharme et al., 1976; Gupta et al., 1975; Korth-Schultz et al., 1976; Sizonenko & Paunier, 1976).

In summary, sexual differentiation is faciliated through steroid hormones, hypothalamic regulatory and pituitary gonadotropins. The type, concentration, and

timing of hormone activity appear to be more critical for male sexual differentiation than for that of the female (Mosley & Stan, 1984). It is clear that genetic and hormonal factors influence the ontogenesis of males and females in distinct ways, and further, may be implicated in sex-related behavioral differences.

The Influence of Hormones on Cognitive Behavior

The assessment of hormonal levels has advanced in recent years, but these are still confounded by a number of methodological problems. Petersen (1979) suggests that the endocrine system and specifically the sex hormones are influenced by a variety of external factors (eg., food, ingestion, drug intake, sleep, physical exercise, and stress). Any of these factors can have a direct influence on hormonal levels and, in addition, the influence of each can vary due to individual psychological differences.

Regardless of the inherent problems associated with hormonal assessment, a number of investigators have employed methodologies which, they feel, have allowed them to examine the relationship between hormones and sex-related differences in cognitive ability. Notably, Broverman and colleagues (Broverman, Broverman, Vogel & Palmer, 1964) have extensively investigated the

relationship between sex hormones and various types of behavior. Observing somatic differences between male subjects who were good versus poor automizers, it was hypothesized that the hormones were involved (Broverman et al., 1964; Broverman, 1972). Automizing is defined as the ability to perform simple repetitive tasks. Strong automizers being proficient at developing skills on repetitive tasks (Broverman et al., 1966) and weak automizers perform relatively more efficiently on tests requiring the inhibition of responses to obvious stimulus characteristics in favor of responses to less obvious characteristics (Broverman, 1964; Broverman & Klaiber, 1969). Females are considered strong automizers, surpassing males on simple repetitive tasks (eg., color naming, digit symbol, fine manual dexterity), and males are weak automizers, outperforming females on tasks such as mazes, embedded figures, Rod-and-Frame test (Broverman, Klaiber, Kobayashi & Vogel, 1968). It was hypothesized that the sex-related differences in cognitive style reflect differences in the relationships between adrenergic activating and cholinergic inhibitory neural processes which, in turn, were suggested to be sensitive to androgens and estrogens.

Their conclusions have been critisized by a number of investigators. Singer and Montgomery (1969) feel that

Broverman et al. (1968) have not provided adequate supportive evidence to justify their conclusions. Specifically, Broverman et al. (1968) based much of their argument on the claim that the terms adrenergic and cholinergic are frequently used interchangebly for sympathetic and parasympathetic in discussions of the autonomic nervous system. Further, they make the error of extending results about the autonomic nervous system to the CNS (Singer & Montgomery, 1969). Parlee (1972) further argued that Broverman et al. (1968) reviewed the literature on cognitive sex-related differences selectively and established the conclusion that a functional relationship exists between activation-inhibition (or adrenergic-cholinergic neural processes or sympathetic-parasympathetic activity) and the cognitive tasks described as perceptual-motor and perceptual-restructuring. In summary, the Broverman et al. (1968) hypothesis of hormonal influence on sex-related differences in cognitive performance does not find support.

Waber (1976,1977) proposed that sex-related differences in cognitive ability are a reflection of sex-related differences in maturation rate, a factor under endocrine control (Grumbach, Grave & Mayer, 1974). Waber advanced the view that adolescent girls may develop stronger verbal ability than adolescent boys because they are generally

physically more mature (by about two years) than boys of the same chronological age. Waber controlled for maturity by comparing young (10 year-old girls; 13 year-old boys) early and late maturing girls and boys and older (13 year-old girls; 16 year-old boys) early and late maturing girls and boys. In the study, late maturing males (16 yrs) and females (13 yrs) tended to be better at spatial ability than verbal ability, and to be more lateralized. In the dichotic listening task, late maturers demonstrated a significantly greater REA than early maturers in the chronologically older grouping, but there was no such difference in the chronologically younger grouping, nor was there a sex-related difference within a chronological age grouping (young versus older). These results suggested that the rate of maturation rather than the sex of the individual is the important factor in determining hemispheric lateralization. Waber (1977) proposed a model in which maturational rate influences central nervous system development which, in turn, leads to variations in field dependence and personality characteristics. According to Waber (1977), endocrinological development influences the organization of higher cortical functions and the variation in such organization is reflected in both cognitive functioning and personality. Waber's (1976) results are similar to the findings of Bock, Wainer,

Petersen, Thissen, Murray and Rache (1973) and Broverman et al. (1964).

However, the relationship between early and late maturation and cognitive performance was not supported by Petersen (1976). Using peak height velocity as a measure of puberty, no relationship was found in relation to cognitive ability between early and late maturers (Petersen, 1976). Utilizing analysis methods identical to those of Waber, Petersen (1976) found that early and late maturing males were more proficient at spatial tasks relative to fluent production tasks where as the converse was found for early and late maturing females.

It was hypothesized by Petersen (1976) that physical androgeny was related to the observed sex-related differences in spatial abilities. Inferring the degree of sex hormone influence from the degree of secondary sex characteristic development observed in males and females, Petersen (1976) demonstrated that highly physically androgenized males are more proficient in fluent production tasks than in spatial tasks. The reverse pattern was observed for less physically androgenized males. However, the more physically androgenized females were more proficient on spatial tasks and the less physically androgenized females were more proficient on the fluent production tasks. The curvilinear nature of the

relationship between body and rogenicity and spatial and verbal ability found by Petersen (1976) suggests that at least a minimum androgen level is required for spatial ability. Furthermore, regardless of gender, the less sexually differentiated individual will perform better on spatial tasks relative to a more sexually differentiated individual. It appears that an optimum estrogen-androgen balance is required, overandrogenization of males moves them toward proficiency in fluent production tasks, but androgenization in females leads to proficiency in spatial There are a number of sources which support this tasks. contention. Males with androgen insensitivity syndrome demonstrate superior verbal IQ relative to performance IQ, and poor perceptual organization relative to verbal comprehension (Masica et al., 1971). Females with Turner's syndrome (phenotypic females, who have one X or a large portion of an X chromosome missing and no gonadal hormones) demonstrate poorer spatial abilities (Silbert, Wolff & Lilienthal, 1977), poorer directional sense (Alexander et al., 1964), and greater field dependence (Serra et al., 1978) than both males who also have only a single X chromosome and genetically normal females.

At present, only tentative conclusions may be drawn from the available data relating to hemispheric asymmetry of function in both cytogenetic and endocrine syndromes.

However, it is very evident that there is both a genetic and hormonal contribution to human sexual dimorphism soon after the zygote is formed. The importance of the normal integration of these two components is nowhere more evident than in the development and function of the reproductive system in the human. Descriptions of cognitive differences between the sexes cannot constitute explanations independent of the mechanisms that underlie such differences. Each of the reliably demonstrated sex-related differences (eg., early female superiority in verbal ability, male superiority in visuospatial ability) suggests the operation of a genetic and/or a hormonal mechanism (Mosley & Stan, 1984).

Approaches which have inferred hormonal status from somatic characteristics suggest that earlier maturation leads to greater symmetry in hemispheric functioning. The methods of assessing physical development (Broverman et al., 1968; Petersen, 1976; Waber, 1976) and by inference hormonal status have included the analysis of physical characteristics (eg., muscle development, genital or breast size, pubic hair distribution) which are crude and imprecise indices of sexual differentiation relative to the more direct methods of hormonal assay. Due to the inherent methodological problems associated with hormonal level assessment (Petersen, 1979), the paucity of research investigating this relationship is understandable. Until such direct empirical investigation is forthcoming, caution must be exercised. Earlier maturation may lead to greater symmetry in hemispheric functioning, but as noted by Waber (1976), the brain as a whole acts as an integrated system. Sex-related cognitive differences may reflect variation in the mechanisms that integrate the activity of the cerebral hemispheres rather than reflecting variation in the cerebral hemispheres themselves.

Conclusion

There is a growing body of evidence, derived from a variety of sources, that sex-related differences in hemispheric asymmetry exist, particularily in adulthood.

With respect to neurologically intact adults, evidence indicates that males demonstrate greater functional asymmetry relative to females. This contention is supported by clinical, dichotic listening, and tachistoscopic studies and is in contrast to the model proposed by Buffery and Grey (1972) who suggested that males demonstrate greater hemispheric symmetry relative to females. The much larger body of literature investigating linguistic representation relative to spatial representation suggests that verbal functions are

represented in the left hemisphere, and are more lateralized in males relative to females. The few studies that have investigated spatial or nonverbal functioning suggest compatible results, the male has greater right hemisphere lateralization for nonverbal functions relative to females.

Even fewer studies have investigated sex-related differences in hemispheric asymmetry in children. At present, the data is equivocal. Hemispheric lateralization appears to be evident very early in development, but independent of sex. Furthermore, there appears to be no consistent or linear increase in the degree of hemispheric lateralization with age (Krashen, 1972,1975; Kinsbourne, 1975), in contrast to the model proposed by Lenenberg (1967) of progressive lateralization. The adult pattern of hemispheric asymmetry does not appear consistently until puberty, at which time males demonstrate greater hemispheric asymmetry for both verbal and nonverbal functions relative to females.

A number of possible explanations have been proposed to explain the existence of these small but consistent sex-related differences in hemispheric lateralization. First, there may be a biological difference in hemispheric organization between males and females, such that cognitive and perceptual functions are more likely to be more

bilaterally represented in females relative to males. The biological medians underlying hemispheric differences are assumed to be of a genetic and/or hormonal nature. Recently, hemispheric asymmetry has been related to physical androgeny (Petersen, 1976), and to the rate of physical maturation (Waber, 1976,1977).

The preceding discussion has focused on possible biological predispositions to explain the existence and pattern of sex-related differences in hemispheric lateralization. Although such differences are also influenced by environmental factors and neither biological mechanisms nor the environment should be considered in isolation, the major contributor appears to be the complex of genetic-hormonal interactions which underlie the basic biological differentiation between male and female (Mosley & Stan, 1984).

The Present Study

The present research will examine the degree of hemispheric lateralization in a pre- and post-pubescent sample of males and females. Broverman and colleagues (Broverman, Broverman, Vogel, & Palmer, 1964) were one of the first investigators examining the relationship between hormones and sex-related differences in cognitive ability.

However, their hypothesis that sex-related differences in cognitive style reflect differences in the relationship between adrenergic activating and cholinergic inhibitory neural responses (which in turn are suggested to be sensitive to androgens and estrogens) has met with a number of criticisms (Petersen, 1979; Singer & Montgomery, 1969; Parlee, 1972).

An alternative approach has been taken by Petersen (1976). In examining physical androgeny, Petersen (1976) has linked the level of physical androgeny to the observed sex-related differences in spatial ability. Petersens' (1976) data demonstrated that regardless of gender, the less sexually differentiated individual will perform better on spatial tasks relative to the more sexually differentiated individual. The findings of Petersen (1976) are interesting in their own right and suggest that an optimum estrogen-androgen balance is required for proficiency in spatial and/or verbal tasks. However, Petersen (1976) did not examine for hemispheric lateralization, and it is inherent in Petersen's androgeny rating scheme that it confounds androgeny and physical maturity (Hirst, 1982).

Waber (1976,1977) advanced the view that maturation rate, or its physiological correlates influence the development of higher cortical functions and may therefore

be an important determinant of sex-related differences in verbal and spatial abilities. As such, adolescent girls may develop stronger verbal ability than adolescent boys because they are generally more mature than boys of the same chronological age (CA). In testing her hypotheses, Waber controlled for maturity by comparing young (10 and 13 year-old) early and late maturing girls and boys and older (13 and 16 year-old) early and late maturing girls and boys. There was a total of 80 subjects, ten subjects in each group. The CA differences between the sexes was intended to reflect the sex difference in the onset of peak height velocity. A scale of physical development devised by Tanner (1962) was employed to classify individuals as early or late maturers.

Waber (1976) tested for sex-related differences in verbal and spatial ability employing a verbal dichotic listening task, the Digit Symbol subtest of the Wechsler Intelligence Scale for Children (WISC); the Word Fluency subtest of the Primary Mental Abilities Test (PMA); the Color-Naming subtest; the Stroop Color-Word Test; the Block Design subtest of the WISC; the Spatial Abilities subtest of the PMA; and a modified version of the Embedded Figures Test. The verbal dichotic listening test of consonant vowel (CV) pairs was chosen as a laterality measure.

Analyses of the verbal and spatial ability data

revealed that the main effect for sex and all the interactions involving the sex variable were not significant, although the sex differences were in the predicted direction. The main effect for maturation was not significant for the verbal scores, but the late maturers performed significantly better than the early maturers on the spatial ability tasks. Further, analysis of the difference scores (subtracting the spatial from the verbal score) indicated a significant main effect of maturation. Within individuals, early maturers scored significantly better on verbal relative to spatial tasks and late maturers scored significantly better on spatial relative to verbal tasks. Again, sex-differences, while not significant, were in the predicted direction.

Analysis of the dichotic listening data revealed that the late maturers showed significantly greater hemispheric lateralization for speech perception relative to early maturers of the same sex and age, but this difference was only significant among the older age group within each sex.

There are a number of explanations possible for the pattern of differences in ear advantage found by Waber (1976,1977). First, lateralization patterns develop at puberty. Second, lateralization patterns develop during chidhood but are disrupted by the onset of puberty, therefore, differences between early and late maturers

among the older group reflect the resumption of the lateralization pattern after the pubertal disruption. A third possibility is that lateralization increases during the course of puberty and drops off somewhat by its end. Because Waber chose her sample through puberty, her data do not permit one to choose among the three alternative explanations. As such, the present study was designed to examine the above alternatives by assessing hemispheric lateralization in pre- and post-pubescent males and females matched for physiological maturation rather than CA.

If Waber's conclusion, that the differences in cognitive ability and hemispheric lateralization are not due to gender "per se" but rather to the differential rates of physical maturation between the sexes the present study should reveal the following:

> Independent of sex, the ear advantage as assessed by dichotic stimulation would not be significantly different in a pre-pubescent sample of females and males, but would be significantly different in a early post-pubescent sample of females and males.

However, it has been suggested that puberty itself may not be the critical factor (Levy & Reid, 1978; Harris, 1978), but is a correlate of the levels of fetal sex hormones. The sex-related differences may already be

present but of a smaller magnitude and don't reach statistical significance until puberty, where the endocrinological changes at puberty act as a trigger to complete a pattern that has already been formed prenatally. If this were the case, then the present study should reveal the following:

> 2) The ear advantages demonstrated by the pre-pubescent females and males will be significant, however, the magnitude of the ear advantages will be statistically greater in the early post-pubescent sample of females and males, relative to the pre-pubescent sample of females and males as assessed by the dichotic stimulation technique.

A pre-pubescent (Tanner Stage 1), an early post-pubescent (Tanner Stage 5), and an adult group of males and females were given three dichotic listening tasks consisting of CV's, simple tone and complex tone stimuli. The question being addressed is whether the adult pattern of hemispheric lateralization is already present (to a degree) in a pre-pubescent sample of males and females, or whether the endocrinological changes associated with puberty (physical maturation) are a prerequisite for the adult pattern of hemispheric lateralization.

METHOD

Subjects

The present study employed equal numbers of males and females who were exclusively right handed. Handedness was determined by requiring the subject to demonstrate the hand used for writing, throwing a ball, and brushing ones' teeth. In addition, only those right-handed subjects having a dominant right foot (kicking a ball) and dominant right eye (paper- hole test) were selected as subjects. Each subject was given a Speech Reception Threshold (SRT) Test using a Maico Hearing Instrument (Model MA 22) Advanced Diagnostic Audiometer.

The 96 subjects comprised six groups distinguished by gender and degree of maturation: pre-pubescent, early post-pubescent, adult. Criteria proposed by Marshall and Tanner (1969, 1970) were employed to asses the level of maturation of the pre- and post-pubescent sample. The pre-pubescent group consisted of 16 grade five females (CA = 10.49, SD = 0.44; MA = 12.40, SD = 4.51) and 16 grade five and six males (CA = 11.20, SD = 0.55; MA = 10.90, SD = 1.30) rated to be in Stage 1 (pre-pubescent). The early post-pubescent group consisted of 16 grade ten females (CA = 15.58, SD = 0.55; MA = 15.20, SD = 2.34) and 16 grade eleven males (CA = 17.53, SD = 0.98; MA = 20.16, SD = 6.68)

rated to be in Stage 5 (Post - pubescent). The early post-pubescent males were significantly older, heavier and taller relative to females in both the pre-pubescent and early post-pubescent group. The early post-pubescent females were also older, heavier and taller relative to females in the pre-pubescent group. However, the early post-pubescent female PPVT scores were not significantly different from the PPVT scores obtained by the pre-pubescent females. In contrast, the early post-pubescent males had obtained PPVT scores that were significantly higher than the PPVT scores obtained by the pre-pubescent males (see ANOVA Summary Tables, Appendix C). The means and standard deviations for the Subject Characteristics are presented in Table 1 (Appendix D).

For the adult group, the only Subject Characteristic obtained for the purposes of this study was chronological age (CA). The mean CA of the adult group is 18.98 years (females = 18.75 years, SD = .54; males = 19.20 years, SD = .78). The chronological age difference between the adult males and females was not significant.

The pre- and early post-pubescent subjects were selected from the separate school system in the city of Calgary. These subjects were of average verbal ability or above as determined by the Peabody Picture Vocabulary Test (PPVT). Subjects were selected from middle and upper

middle class schools. The adult sample consisted of undergraduate students at the University of Calgary and was assumed to be of average intelligence or above.

Potential pre- and post-pubescent subjects had a letter sent to their families or guardians. The consent letter informed the families and the subjects of the aims and procedures of the study, and requested the informed consent of the parents and the subjects themselves. In addition, subjects were informed of their right to withdraw from the study at any time. Informed consent was also obtained from the adult subjects. Both the voluntary aspect of the study and the confidentiality of the data were emphasized and maintained.

Apparatus

Tanner's Scale of physical development: In order to accurately classify an individual as pre- or post-pubescent, a physical examination employing the criteria proposed by Marshall and Tanner (1969;1970; Tanner 1962) was administered by a medical practitioner Dr. H. Black (family medicine specialist) who had consented to undertake the physical maturation assessments for this study. The staging criteria and physical examination protocol are described in Appendix A.

Speech Reception Test: Each subject was given a Speech Reception Threshold (SRT) Test using a Maico Hearing Instrument (Model MA 22) Advanced Diagnostic Audiometer. Both left and right ears were tested at the following frequencies: 500, 1000, 2000, 3000, 4000 Hz. At the frequencies tested a criterion of 5 dB was the acceptable ear threshold difference at an intensity level no greater than 25 dB.

Assessment of Laterality: A ballpoint pen, a baseball and a toothbrush were used to demonstrate handedness. A soccerball was used to assess the dominant foot and the paper-hole test was used to indicate the dominant eye.

Dichotic Listening Task: A Sony (Model FC-FX44) dual channel casette stereophonic tape recorder and Superior SP-40 earphones were used to present the dichotic stimuli. All stimuli were recorded on Sony UCX-S low noise magnetic tape cassettes and presented at a mean intensity of approximately 65 dB as measured by a Bruel and Kjoer sound level meter (Model 2218) and filter (Model 1613). The dichotic stimuli consisted of spoken pairs of CV's, pairs of simple tones and pairs of complex tones. Onset alignment and regular spacing of the dichotic pairs and the probes on channels 1 and 2 was achieved using a digitizing programmme (speech editor) with a VAX 11/730 computer. A PDP 11/23 plus computer was used to generate the simple and

complex tone stimuli and to control the frequency and duration (200 ms.) of each of the dichotic and probe tones. The simple and square wave tones each had three ms. rise/fall times, shaped according to a raised cosine function.

The spoken CV pairs were chosen from among the following syllables: ba da ga pa ta ka. All syllables were produced by a female speaker and had a duration of 200 All possible paired combinations of the six CV stimuli ms. were produced yielding 30 dichotic stimulus pairs. The 30 dichotic stimulus pairs were then repeated three times and randomized to yield a total of 120 stimulus pairs. Each CV pair was followed at 500 ms. by a CV probe. For one half of the trials the probe was the same as one of the original dichotic CV's (distributed randomly and equally to each of the original pairs) and for the remaining trials the probe was different. The intertrial interval was four seconds. A second Sony UCX-S low noise magnetic tape on which the CV stimuli were recorded in a different random order was constructed to rule out an order of presentation effect. The two random orders were alternated across subjects.

Another Sony UCX-S low noise magnetic tape cassette was used to present the simple square wave tones. The simple square wave tones had frequencies corresponding to the six notes in the octave between C4 and C5 on the major scale (D

[297 Hz]; E [330 Hz]; F [352 Hz]; G [396 Hz]; A [440 Hz]; B [495 Hz]. The six possible combinations of the simple tones were generated, repeated three times and randomized to yield 120 dichotic stimulus pairs. Each of these dichotic stimulus pairs was followed at 500 ms. by a tone probe. On half the trials the probe was the same as one of the dichotic simple tones (distributed randomly and equally to each channel) and half were different. The intertrial intervals were four seconds. In order to rule out an order of presentation effect a second Sony UCX-S low noise magnetic tape was constructed employing a different order relative to the first tape. The two orders were alternated across subjects.

An additional Sony UCX-S low noise magnetic tape cassette was used to present the complex square wave tones. The complex square wave tones were constructed by adding to the simple square wave tone a second square wave whose frequency randomly varied between +50 Hz and -50 Hz of the simple square wave tone. The algorithm for generating the complex square wave tones is outlined in Appendix B. The six possible combinations of the complex tones were generated, repeated three times and randomized to yield 120 dichotic stimulus pairs. Each of these dichotic stimulius pairs was followed at 500 ms. by a tone probe. On half the trials the probe was the same as one of the original

dichotic complex tones (distributed randomly and equally to each channel) and for the remaining trials the probe was different. The intertrial intervals were four seconds. In order to rule out an order of presentation effect a second Sony UCX-S low noise magnetic tape was constructed employing a different order relative to the first tape. The two orders were alternated across subjects.

Procedure

The children who had informed consent were seen in school for a brief physical examination by the medical practitioner. The physical examination protocol is described in Appendix A. Within one week subjects who met the criteria specified for pre- or post-pubescent were seen in school individually for three sessions each separated by one week.

The first session lasted approximately 30 minutes. The Speech Reception Threshold Test, the PPVT, and the assessment of laterality (hand,foot,eye) were undertaken.

For the following two sessions (15-30 min. each) the dichotic listening tasks were administered in a quiet but not soundproof room. One half received the CV dichotic pairs in session one followed by the two types of tonal stimuli in session two. The remainder of each group

received the reverse order. During the dichotic tone session one half the subjects received the simple square wave tones first followed by the complex square wave tones, the other half received the reverse order. Headphones were reversed after each subject to compensate for a potential mechanical laterality influence. The same procedure was followed for the adult sample. However, no physical examinations were undertaken and all testing was done in a quiet but not soundproof room at the University of Calgary.

In the CV stimulus condition subjects were presented with the dichotic CV pairs, a different CV to each ear simultaneously. These were followed by a CV probe, presented to both ears simultaneously. The subject was required to verbally indicate whether the dichotic CV stimulus and the probe were the same or different. The subjects were instructed to respond on every trial. The trials consisted of half the probes being the same (distributed randomly and equally to each ear) and half being different.

Prior to the presentation of the 120 dichotic pair-probe trials were 30 practice trials. These practice trials were binaural presentations of the six types of CV's repeated and randomized to yield 30 binaural stimuli. Each binaural stimulus was followed by a binaural CV probe. The practice trials consisted of 75% of the probes being the

same and 25% being different. Subjects were required to obtain 100% accuracy on the practice trials before the presentation of the dichotic stimuli. If necessary the practice trials were repeated. The two random orders of the CV stimuli were alternated across subjects. The total session lasted approximately 15 minutes.

In the tonal stimulus condition subjects were presented with two tones, one to each ear simultaneously, followed by a single probe tone simultaneously to both ears. The subject was required to motorically indicate with the left hand whether the dichotic tones and the probe tone were the same or different. A black response panel on which were centered two identical response keys (5 cm apart) was inclined at 30 degrees and located at elbow height to the left of the subject. Above each response key was either a red or green light (P bulb with a 1.25 cm lens cover) which came on when the appropriate response key was depressed. The lights designated a same or different response. The response value of each light and associated response key was counterbalanced across subjects. The dichotic trials consisted of half the probes being the same (distributed randomly and equally across right and left ears). On the remaining half of the trials the probe differed from both dichotic tones.

Again, prior to the presentation of the 120 dichotic

pair-probe trials of each type of tone were the 30 binaural practice trials for each type of tone respectively. The practice trials consisted of 75% of the probes being the same and 25% being different. The subjects were required to achieve 100% accuracy on these trials before proceeding with the dichotic pair-probe trials. If necessary the practice trials were repeated. During the dichotic stimulus tone session, one half of the subjects received the simple square wave tones first followed by the complex square wave tones. The other half received the reverse In addition, the two random orders of each type of order. tone stimuli were alternated across subjects. This session lasted approximately 30 minutes.

RESULTS

All the statistical analyses were executed employing the Biomedical Computer Programs-P series (BMDP) software which handle general univariate and multivariate repeated measures analyses of variance. For all within subject effects with more than one degree of freedom, the Greenhouse-Geisser adjustment to degrees of freedom were The Greenhouse-Geisser adjustment to degrees of reported. freedom yields a conservative test by reducing the numerator and denominator degrees of freedom to adjust for the fact that the classical univariate approach to repeated measures tends to be too liberal (see Frane, 1980, for a general discussion on this test). As a further precaution, due to the large number of contrasts, the conservative alpha level of .01 was adopted and maintained for all tests of significance.

Assessment of physical matuurity: Marshall & Tanner (1969,1970)

In total 74 individuals were examined by the medical practitioner, Dr. H. Black (Health Services, University of Calgary). Of the 42 volunteers in the pre-pubescent group, 2 individuals did not meet the criterion for laterality (hand, foot, eye). Of the remaining 40 individuals, 8 were excluded from the study as a result of being either in

Stage 2 (5 individuals) or Stage 3 of physical development. In the early post-pubescent group, 3 out of the 35 volunteers did not meet the laterality criterion for the present study. The remaining 32 individuals were all assessed, by the physical exams, to be in Stage 5 of physical development.

Laterality

The 96 individuals who participated in this study, irrespective of group, were all right lateralized on five performance measures. All individuals wrote, threw a ball, and brushed their teeth with the right hand, kicked a ball with their right foot and relied on their right eye in the paper hole test. Since only right-handed individuals were approached, only right-handed individuals volunteered to participate in this study. However, approxiametly 5 individuals out of a total of 109 right-handed volunteers were not right lateralized for all the laterality performance measures. These individuals either had no preference or preferred to use their left hand for throwing a ball, left foot for kicking a ball, and/or their left eye in the paper hole test. As such, these individuals were not included in the study.

Assessment of the Influence of Guessing

A Group (3) X Gender (2) X Stimulus Order (4) X Stimulus Type (3) mixed analysis of variance was conducted on the total correct "different" scores with Stimulus Order and Stimulus Type being the within subject repeated measures. Four Stimulus Orders were employed in the present study: Order One (CV-ST-CT); Order Two (CV-CT-ST); Order Three (CT-ST-CV); Order Four (ST-CT-CV). The two types of tonal stimuli were always presented in the same session. Overall accuracy in reporting the correct "different" scores was 73.7% (females = 74.15%, males = 73.27%). Considering these percentages are substantially greater than the chance level of 50%, the influence of guessing on the dichotic listening data was not considered to be significant.

Headphone Counterbalancing and Light Response Assignment

A Group (3) X Gender (2) X Stimulus Type (3) X Headphone Position (2) X Light Response (2) X Ear (2) mixed analysis of variance was conducted on the total correct "same" response scores with Ear being the within subject repeated measure. The analysis failed to reveal any significant findings, consequently, all subsequent analyses

collapsed across headphone position and light response assignment.

Assessment of Hemispheric Lateralization

The number of correctly reported "same" responses were subjected to a Group (3) X Gender (2) X Stimulus Order (4) X Stimulus Type (3) X Ear (2) mixed analysis of variance with Stimulus Order, Stimulus Type and Ear being the repeated measures. The analysis indicated a significant main effect for Group (F = 6.78, df = 2,72, p < .002). Inspection of the percent correctly reported "same" responses indicated that the adults were the most accurate (72.8 %), followed by the early post-pubescent group (68.7 %), and lastly, by the pre-pubescent group (64.0%).

The main effect of Stimulus Type failed to reach significance, however, the interaction of Stimulus Order X Stimulus Type (Figure 1) was significant (F = 3.63, df = 4,88, 117.14, p < .005). Simple main effects analysis on the Stimulus Order X Stimulus Type interaction indicated a significant difference in accuracy under Stimulus Order Three (F = 8.50, df = 1.65,151.38, p < .001), accuracy for complex tone stimuli being significantly affected by Stimulus Order (F = 4.65, df = 3,92, p < .005). The cell means for the Stimulus Order X Stimulus Type interaction are presented in Table 2 (Appendix D). Accuracy for the CT Figure l Correct "same" Stimulus Order X Stimulus Type Interaction



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and ST stimuli was significantly less than for CV stimuli under Stimulus Order Three however, accuracy was significantly improved for CT stimuli under Stimulus Order Two. Performance for CV stimuli does not change significantly as a function of Stimulus Order. However, accuracy for CT stimuli significantly improved if CV stimuli were presented first, as indicated by the low accuracy for CT stimuli if they were the first Stimulus Type presented (ie., Stimulus Order Three).

The Stimulus Type X Ear interaction effect (Figure 2) was significant (F = 13.72, df = 1.66,119.40, p > .001). The cell means for the Stimulus Type X Ear interaction are presented in Table 3 (Appendix D). Right ear performance was significantly better for CV stimuli. In contrast, left ear performance was significantly better for ST and CT stimuli. In addition, the Group X Stimulus Type X Ear interaction effect (Figure 3) was significant (F = 4.30, df = 3.32,119.40, p < .005). Simple interaction effects analysis indicated a significant Stimulus Type X Ear interaction only in the early post-pubescent group (F = 18.18, df = 1,72, p < .001). The cell means for the Group X Stimulus Type X Ear interaction are presented in Table 4 (Appendix D). In the early post-pubescent group right ear performance was significantly more accurate for CV stimuli,

Figure 2

Correct "same" Stimulus Type X

Ear Interaction


STIMULUS TYPE

Figure 3

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Correct "same" Group X Stimulus Type X

Ear Interaction

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and the left ear performance was significantly more accurate for ST and CT stimuli.

Absolute Ear Advantages

In order to further examine the perceptual asymmetries to the CV and tonal stimuli the directions of the asymmetries observed for each group on each test were tabulated based on the percent right and left ear correct "same" accuracy scores (Table 1; Appendix E), and categorized into the three traditional categories of ear advantage ie., right ear advantage (REA); no ear advantage (OEA); and left ear advantage (LEA) (Table 2; Appendix E).

Inspection of the mean percent ear advantage data indicates that a suprisingly low percentage of the 96 subjects (21.8%) demonstrated the expected asymmetries on all three tests (CV - REA; ST and CT - LEA). In contrast to the pre-pubescent group (12.5%) and adult group (15.6%), twice as many early post-pubescent subjects (31.2%) demonstrated the expected asymmetries on all three tests. The majority of the subjects (79.2%), regardless of group demonstrated either an absence and/or the opposite asymmetry on one or two of the three tests. The large number of subjects demonstrating the opposite asymmetry on one or two of the tests is unexpected when contrasted with the results obtained by Sidtis (1982), who reported that

52% of his subjects demonstrated the opposite asymmetry on one of two tests (consonant-vowels, complex tones), and no subject demonstrated a reversal on both tests. The remaining 46% of the subjects in the Sidtis (1982) study demonstrated the expected asymmetries.

Relative Ear Advantages

It is apparent that there are substantial differences in the ear advantages shown for each category of sounds by individual listeners in each group. These substantial individual differences lead to no clear conclusions as to patterns of hemispheric lateralization with respect to the three traditional categories of ear advantage (REA, LEA, OEA). As such, not only the direction but the magnitude of the ear advantages were examined.

Although individual differences are substantial, it is of interest to determine the existence of patterns within and across individual listeners in relation to the type of stimulus. Lauter (1982, 1983) has demonstrated that there are significant individual differences in terms of absolute ear advantages for a given sound, however, comparison of such differences across stimuli reveal agreements among listeners as to relative ear advantages, when both direction and magnitude of ear differences are considered. In fact, because of the substantial individual differences in terms of absolute ear advantage, averaging across listeners as has traditionally been the approach, dramatically decreases the observed magnitude of ear advantage.

The correct "same" scores were expressed as simple difference scores: mean percent correct in the more accurate ear minus mean percent correct in the less accurate ear (Lauter, 1982,1983). The differences, for each listener, in each group for each sound are presented in Table 3 (Appendix E). There are substantial differences in the ear advantage shown for each type of sound by individual listeners within and across groups.

In Figures 4-6 are plotted the profiles for the relative ear advantages for each listener on each type of sound in each group, indicating both direction and magnitude of each ear difference score. Each profile is centered over zero ear advantage (OEA) with increasing magnitude of ear advantage toward the left (REA) and toward the right (LEA). The scale of magnitude ranges from 60% REA at the far left to 50% LEA at the far right. Values from Table 3 (Appendix E) were entered with the stimulus code for each type of sound marking the ear advantage obtained by each listener for that sound.

Figures 4-6 makes it possible to see an agreement

Figure 4

Pre-pubescent Relative Ear Advantage Profiles

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EAR ADVANTAGES

Figure 5

Early Post-pubescent Relative Ear Advantage Profiles



EAR ADVANTAGES



Adult Relative Ear Advantage Profiles



EAR ADVANTAGES

among listeners that was not apparent in our prior treatment of the absolute ear advantage scores. In Table 3 (Appendix E) there were obvious differences between listeners in the absolute ear advantages demonstrated for each type of sound. However, as Figures 4-6 illustrate, these differences in absolute ear advantages are accompanied by an agreement among listeners in terms of relative ear advantages. For example, although the listeners show different categories of ear advantage for the CV stimuli, these sounds evoke the right-most ear advantage of each of the sounds tested for each group regardless of gender. For the pre- and early postpubescent listeners, the CT stimuli evoked the left-most ear advantage of all sounds tested. The adult listeners demonstrated the left-most ear advantage for ST stimuli, again regardless of gender. It is interesting to note that ST stimuli evoked equal relative ear advantages in the " pre-pubescent group (for 9 listeners evoking the right-most ear advantage, and a left-most ear advantage in 9 listeners), a stronger relative LEA in the early post-pubescent group (ST stimuli evoked the right-most EA for 4 listeners and a left-most EA for 11 listeners), and finally the ST stimuli evoked the left-most EA in the adult group (for 6 listeners evoking the right-most EA and a left-most EA for 13 listeners). The terminology

"left-most" and "right-most" appears to best describe subject agreements in absolute ear advantages since, for a given listener, all sounds showing significant ear superiority may favor the right ear or favor the left ear. The patterns of ear advantage observed for each stimulus type for this data set are in agreement with the patterns observed by Lauter (1982,1983).

It may be concluded from these comparisons that scoring ear advantages along a "continuum" rather than in terms of three discrete categories might be of help in studying both the perception of complex sounds and functional hemispheric lateralization. Even though the pre-pubescent group did not demonstrate significant patterns of lateralization with respect to the three traditional categories of ear advantage, in terms of relative ear advantage, the CV stimuli evoked the right-most EA of all sounds tested, and the CT stimuli evoked the left-most EA of all sounds tested. The adults who had previously demonstrated no significant ear advantages (as indicated by traditional analysis) also demonstrated the predicted pattern of results for relative ear advantages. The CV stimuli evoked the right-most EA while the ST evoked the left-most EA. In addition, the left-most EA demonstrated by the adults for ST stimuli appears to follow a developmental pattern. The ST stimuli

evoked no EA in the pre-pubescent group, increased in magnitude (left ear) in the early post-pubescent group, and finally "emerged" as the stimulus evoking the left-most EA in the adult group. The agreements among listeners on these distributions of relative ear advantages for the sounds tested indicate patterns of hemispheric lateralization across and within listeners that were not revealed by an analysis depending only upon the three traditional categories of ear advantage.

DISCUSSION

Physical Maturity and Hemispheric Lateralization

The present study has demonstrated that the endocrinological changes associated with puberty may be an important factor in determining patterns of hemispheric lateralization. When females and males were equated for stage of physical maturation rather than for chronological age (independent of gender) the pre-pubescent group demonstrated no significant hemispheric lateralization patterns. However, the early post-pubescent group demonstrated the predicted asymmetries on the three dichotic listening tests.

The present findings are in agreement with those of Waber (1976) who proposed that differences in hemispheric lateralization are not due to gender "per se", but rather to the differential rates of maturation between the sexes. Waber (1976) reported differences in ear advantage only in her older (13 year-old females; 16 year-old males) early and late maturing females and males. The older late maturers demonstrated a significantly greater REA for CV stimuli relative to early maturers in the chronologically older grouping. There was no such significant difference in the chronologically younger grouping (10 year-old females; 13 year-old males) between early and late

maturers.

The present data support this finding and further suggest that the reliably reported lateralization patterns may develop at puberty. If lateralization patterns developed during childhood, we would expect to find significant differences in ear advantages in the pre-pubescent group. Such was not the case, even though the patterns of ear advantage demonstrated by the pre-pubescent group were in the predicted direction. It has been suggested that sex-related differences in hemispheric lateralization may already be present prior to the onset of puberty but are of a lesser magnitude and do not reach statistical significance until puberty (Levy & Reid, 1978; Harris, 1978). As such, the endocrinological changes at puberty may act as a trigger to complete a pattern that has had its formation prenatally.

The possibility of a relationship between functional hemispheric lateralization and sex hormones is supported by evidence of sex-related differences in the plasma levels of estradiol and testosterone during development (Nyborg, 1983). Plasma estradiol (E2) values are very similar in the two sexes up to 10 years of age. Eleven year old boys (Tanner Stage 1: Tanner, 1962) have plasma E2 levels of 4.8 pg/ml +/- 1.4 pg/ml, while girls at the same age have E2 levels of 9.8 pg/ml +/- 2.4 pg/ml (Aususingna et al.,

1974). This sex-related difference in plasma E2 levels increases rapidly during puberty eventually reaching adult E2 levels (ie., 20 and 35 pg/ml for adult men and a mean level of 40 pg/ml +/- 3 pg/ml for adult women). In contrast, testosterone (T) levels increase rapidly from 40 ng/100ml in Stage 1 boys to 550-650 ng/100ml in the typical adult male. The plasma T levels do not increase as dramatically in females. The pre-pubescent female plasma T levels of 25 ng/100ml increase only slightly during puberty to a T level of 65 ng/100ml in typical adult females (Doering et al., 1975).

The responsivity, organizational and activational effects of estrodiol and testosterone are probably not independent (Nyborg, 1983). Early steroid activity determining target organ responsivity may be understood, in part, in terms of an organizational effect (McEwan, 1976). Similarly, the early disappearance of receptor cells due to such organizational effects probably lowers later overall target tissue responsivity. Thus, the influence of estradiol on neural processes suggests that many aspects of behavior may be impacted by steroid priming, early organizational and later activational mechanisms (Nyborg, 1983).

The developmental patterns of hemispheric lateralization observed by Waber (1977) and those of the

present study appear to be most congruent with the activation hypothesis of steroid action. It is possible that early influences by hormones organize the brain in a way that shows up prepubertally as an inductive effect which, upon facilitation, will show pubertal activational effects. According to the activation hypothesis, the early effects of sex hormones can be favorable or detrimental for the development of nervous tissue. In addition, E2 is assumed to determine each individual's level of functional hemispheric lateralization by exerting activational effects on certain brain tissues. At puberty and afterwards, the level of functional hemispheric lateralization can be either depressed permanently by the activational effects of either a continously too high or too low level of steroids, or can be enhanced permanently at puberty by the central activational effect of a continous adult range of optimal sex hormone levels. Thus, the early influences of hormones may exert organizational and responsivity effects on certain brain tissues. At puberty, the surge in E2 production has an activational effect, leading either to enhanced or detrimental functional hemispheric lateralization.

Higher than normal plasma E2 levels prior to puberty are assumed to accelerate not only body maturation but also the organization of those brain tissues important for

processing certain types of information (eg., spatial ability). Continously high plasma E2 levels that exceeed the optimal range of central values following puberty may result in an activation-induced inhibition of certain brain functions. For example, the observed postpubertal decline in spatial ability in early maturing girls (Nyborg, 1983). Conversely, in late maturing girls, the lower than normal plasma E2 levels delay sexual maturation and lead to weak organizational effects on relevant brain tissues. Then, a slow and moderate increase in plasma E2 levels eventually results in delayed puberty preceeded by a long maturational period during which extensive organizational processes take place. The relatively low adult plasma E2 levels after puberty ensure that the central E2 level is kept within the optimal activation range leading, for example, to an expression of high spatial ability.

The relationship between sex hormone levels and functional hemispheric lateralization is more complicated and less well understood in the male. In the male, a rise in E2 and T during puberty is assumed to balance out because of the antagonistic effects of T on E2. In the early maturing male the central level of E2 is assumed to be higher than the optimal range, perhaps due to excessive central conversion of T to E2. It may also be that preand perinatal surges of T prime male pubertal

responsitivity to E2, or that when converted at certain brain sites T acts as a prohormone and influences patterns of functional hemispheric lateralization through an organizational effect on the relevant brain tissue. This organizational effect of T may become functional by pubertal activation. Alternatively, antagonistic peripheral effects and central reinforcing activational effects may balance out and have no activational effect on functional hemispheric lateralization at puberty. However, for both females and males high plasma E2 levels are considered to lead to postpubescent impairments of certain brain functions (eg., decreased spatial ability in postpubescent early maturing females and males). The adult stabilization of plasma E2 levels is assumed to be responsible for the adult expression of functional hemispheric lateralization (Nyborg, 1983). The hypothesized relationship between sex hormone levels and functional hemispheric lateralization is outlined in Figure 7.

The Instability of Ear Advantages

It had been anticipated that the adult group would demonstrate the expected asymmetries on the three dichotic listening tests as did the early post-pubescent group. In addition, it was anticipated that the adult males would

Figure 7

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Hemispheric Lateralization and Sex Hormone Levels

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- T Turner¹s Syndrome females
- A Pre-pubescent late maturing females and males Strongly masculine males
- B Adult males_stabilized Pre_pubescent early maturing females and males
- C- Androgenous males
- D-Androgenous females
- E Post-pubescent late maturing females
- STT Short term treated Turner¹s Syndrome female
 - F-Adult females-stabalized Post-pubescent early maturing females and males
- LTT-Long term treated Turner's Syndrome females

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. . demonstrate a stronger REA and LEA relative to the adult females. Suprisingly, the adult group demonstrated no significant ear advantages for the stimulus types tested (CV, ST, CT) regardless of gender. These findings are in contrast to the consistent reports of a reliable REA demonstrated by adults for CV stimuli in general (Wexler & Halwes, 1983), and a sex-related difference in REA favoring males in particular (Lake & Bryden, 1976; McGlone, 1980).

An examination of mean percent ear advantages for each group of subjects revealed that, for each stimulus type individually, the majority of the subjects demonstrated the predicted asymmetries (eg., CV = 58.4 %; ST = 62.5 %; CT = 59.4 %: see Table 2; Appendix E). However, a very small percentage of subjects, regardless of group or gender, demonstrated the predicted absolute ear advantages on all three dichotic listening tests (21.8%). This situation being the most pronounced for the adult group of subjects.

It has been determined by the Wada Test that between zero and five per cent of right-handed individuals appear to have language lateralized to the right hemisphere. Yet, approximately twenty per cent of right-handed individuals demonstrate a LEA for verbal stimuli. In addition, the instability of ear advantages was highlighted in test-retest situations. For example, in testing and retesting subjects one week later on three different

dichotic tapes consisting of consonants, vowels, and music, Blumstein et al (1975) found that a substantial percentage of subjects had switched ear advantages in the unexpected direction during the second session. Sidtis (1982) proposed that both cortical and subcortical functional asymmetries contribute to perceptual asymmetries. Sidtis (1983) found that 54% of his 28 subjects tested on a dichotic listening task with CV's and complex tones demonstrated a single reversal of asymmetry on one of the two tests, but not both. For Sidtis (1982) a reversal was defined as an asymmetry in the unpredicted direction. Sidtis presented the argument that the individuals demonstrating a reversal of asymmetry do not simply represent a different pattern of cortical organization, but rather that reversals are due to sources independent of hemispheric specialization, the major source probably being due to the asymmetry of the ascending auditory system.

The results of the present study would also suggest substantial individual differences in the asymmetry of the ascending auditory system. Only 21.8 % of the 96 subjects demonstrated the predicted absolute ear advantages on all three dichotic listening tests. The majority of subjects demonstrated either an absence and/or the opposite asymmetry on one or two of the three dichotic tests. Three of the 96 subjects demonstrated the opposite of the

expected ear advantages on all three tests.

It appears then that the functional relationship between ipsilateral and contralateral auditory pathways proposed by Kimura (1967) as the mechanism underlying stimulus lateralization is only appropriate in roughly 50% of right-handed individuals (as calculated by Sidtis, 1983), or possibly even less as the results of the present study suggest. In the remaining right-handed individuals, for whom Kimura's (1967) model is inappropriate, there appears to be either a significant asymmetry in the ascending contralateral auditory pathways or some combination of cortical and subcortical asymmetry. Electrophysiological evidence supports the presence of sufficient intersubject variability in the ascending auditory system to ensure that across subjects, the same acoustic features in a dichotic pair will exhibit different degrees of cortical availability via ipsilateral and contralateral pathways (Sidtis, 1983). Individual subjects have exhibited asymmetrical advantages as well as no contralateral advantage in such studies. Analysis of the latencies of one of the early cortical auditory-evoked potentials has shown that only 77% of the right-handed subjects had superior contralateral relative to ipsilateral pathways. The magnitude of the contralateral auditory pathway varied from 4.5% to 18.0% and was not symmetrical

(Majkowski, Bochenek, Bochenek, Knapik-Fijalkowska, & Kopec, 1971). These findings further suggest that the influence of ipsilateral input may also contribute to the instability of dichotic listening data. The possibility that the occlusion of ipsilateral input is not complete has been pointed out by Gruber and Segalowitz (1977). In addition, Geffen and Quinn (1984) have suggested that the indirect transcollosal route and weak ipsilateral sensory route may be responsible for the poor report of left-ear verbal stimuli, and not because the ipsilateral pathway is suppressed as the Kimura (1967) model suggests.

The Influence of Stimulus Characteristics

As a result of her 1979 findings, Lauter (1983) reanalyzed the individual subject scores from 12 earlier experiments to determine whether patterns of "relative ear advantages" were present. These 12 experiments had alltested several listeners with several different sounds. The reanalysis revealed patterns of relative ear advantages which had been obscured by the analyses which had focused upon the average listener. The examination of these patterns and the stimuli employed suggested that certain features of sounds seem to affect ear advantages in a consistent way from listener to listener and under a variety of experimental procedures. There was also a

number of stimulus characteristics that did not seem to influence ear advantages, ie., overall stimulus duration, frequency (formant) transitions and whether or not a stimulus is heard as speech. These characteristics had been previously offered as the determinants underlying the ear advantage (Cutting, 1974; Godfrey, 1974; Schwart & Tallal, 1980). At least three characteristics did seem to influence the ear advantage (Lauter, 1983): (1) bandwidth of test sounds; (2) sound complexity, measured in terms of number of auditory dimensions changing over time; and (3) duration of events, or "rate of change" within a sound. The acoustic characteristic whose influence seemed most pervasive in the experiments surveyed (Lauter, 1983) was The shorter effective durations of events event duration. within a test sound favored the right ear. The influence of event duration or "rate of change" within a sound encompasses a wide variety of stimulus characteristics such as the amplitude contours of vowels in noise, the rate of tone occurrence in pitch patterns, and differences in voice-onset time (see Lauter, 1983).

The present findings are certainly compatible with a hypothesis that shorter effective duration of events within a test sound favors the right ear. The CV syllables, with the shortest event durations within the 200 ms test interval, showed the right-most ear advantage relative to

the left-most ear advantages for tone patterns made with 200 ms tones (ST,CT), where the effective event duration was 200 ms.

Relative vs. Absolute Ear Advantages

The present findings further suggest that categorizing responses into the three traditional categories of absolute ear advantage (REA, OEA, LEA) is inappropriate. The significant differences in the absolute ear advantages shown for the set of sounds by individual listeners in each group lead to no clear conclusions as to patterns of hemispheric lateralization. However, Lauter (1982,1983) has demonstrated that comparing individual differences in terms of absolute ear advantages across stimuli reveals agreements among listeners as to relative ear advantages, when both <u>direction and magnitude</u> of ear differences are considered.

An analysis of the present findings taking into account both the direction and magnitude of ear differences for each listener for each type of sound, revealed agreements among listeners. Regardless of group or gender the CV stimuli evoked the right-most ear advantage of all the sounds tested. Correspondingly, the ST and CT stimuli evoked the left-most ear advantage regardless of group or gender. The analysis of individual scores for these different sounds suggests that the magnitude of an ear advantage is as important as the direction of an ear advantage in determining patterns of hemispheric lateralization. Ear advantages should be scored on a "continuum" (Marshal et al., 1975; Wexler et al., 1981; Lauter, 1982,1983).

This new look at old data (Lauter, 1983) has revealed the importance of acoustical dimensions in determining relative ear advantages. The observed interactions between stimulus characteristics and individual differences in ear advantages found by Lauter (1983) might be useful in studying the details of the influence of different aspects of test sounds on dichotic listening. With attention to the systematic manipulation of characteristics of the test sounds, patterns of relative ear advantages may prove helpful in telling us more about the perception of complex sounds (Lauter, 1983).

Conclusion

In summary, the present findings suggest that the endocrinological changes associated with puberty may affect both the pattern and degree of hemispheric lateralization. The endocrinological changes at puberty possibly act as a catalyst to complete a pattern that has been determined prenatally. Although such differences are also influenced

by environmental factors, and neither biological mechanisms nor the environment should be considered in isolation, the major contributor appears to be the complex of genetic-hormonal interactions which underlie the basic biological differentiation between female and male. The genetic sex of an individual normally determines the gender appropriate levels of sex hormones which, in turn, influence the rate of physical maturation and, as the present findings suggest, the patterns of hemispheric lateralization.

The present findings further suggest that the action of sex hormones associated with puberty contribute to, but are not the sole predictor of hemispheric lateralization. The substantial individual differences in absolute ear advantages shown for a given set of sounds suggests that both cortical and subcortical functional asymmetries may significantly contribute to perceptual asymmetries. These differences, in turn, cannot be adequately classified into the three discrete categories of absolute ear advantage (REA, OEA, LEA). As Lauter (1983) and Sidtis (1982)) illustrate, stimulus characteristics and subcortical asymmetries (especially at the individual level) are more important than dichotomizing stimuli as verbal/nonverbal in predicting ear asymmetries.

The present findings suggest caveats for the future

investigations of functional hemispheric lateralization. It is simply not feasible nor utilitarian for neuropsychological investigations of lateralization to proceed by a chain of inferences which associate regions of the cortex with observed perceptual asymmetries (assumed to be due to the verbal-nonverbal dichotomous classification of stimuli). If we are interested in predicting brain organization more attention must be paid to the variables used to index cerebral lateralization. Stimulus characteristics, subcortical structures and intersubject variability need to be accounted for in our models of functional hemispheric lateralization. The data suggest that the relationship between these variables may be complex and do not lead to a direct correlation between perceptual asymmetries and functional hemispheric lateralization. If a behavioral test (dichotic stimulation) is to provide a basis for speculation about the interactions between the auditory nervous system and functional hemispheric lateralization (brain organization) then we need to know more about how the results of such tests change as a function of systematic changes in the stimulus.

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APPENDIX A

Physical Maturation Staging Criterion and Physical Examination Protocol

Physical Maturation Staging Criterion

FEMALE

Breast Stages

Stage 1: Pre-adolescent; elevation of pappila only.

Stage 2: Breast bud stage; elevation of breast and papilla

as a small mound, enlargement of areola diameter. Stage 3: Further enlargement of breast and areola, with no

separation of their contours.

Stage 4: Projection of areola and pappila to form a secondary mound above the level of the breast.

Stage 5: Mature stage; projection of papilla only, due to recession of the areola to the general contour of the breast.

Pubic Hair Stages

- Stage 1: Pre-adolescent; the velus over the pubes is not further developed than over the anterior abdominal wall, ie., no pubic hair.
- Stage 2: Sparse hair growth of long, slightly pigmented, downy hair, straight or only slightly curled, appearing chiefly along the labia.
- Stage 3: Considerably darker, coarser, and more curled. The hair spreads sparsley over the junction of the pubes.

- Stage 4: Hair is now adult in type, but the area covered by it is still considerably smaller than in most adults. There is no spread to the medial surface of the thighs.
- Stage 5: Adult in quantity and type, distributed as an inverse triangle of the classically feminine pattern. Spread to the medial surface of the thighs, but not up the linea alba of elsewhere above the base of the inverse triangle.

MALE

<u>Genitalia</u> Stages

- Stage 1: Pre-adolescent. Testes, scrotum, and penis are of about the same size and proportion as in early childhood.
- Stage 2: The scrotum and the testes have enlarged and there is a change in the texture of the scrotal skin. There is also some reddening of the scrotal skin.
- Stage 3: Growth of the penis has accurred, at first mainly in length but with some increase in breadth. There has been further growth of testes and scrotum.
- Stage 4 Penis further enlarged in length and breadth with development of glans. Testes and scrotum further enlarged. There is also further darkening of the scrotal skin.

Stage 5: Genitalia adult in size and shape. No further enlargement after Stage 5 is reached.

Pubic Hair Stages

- Stage 1: Pre-adolescent. The velus over the pubes is no further developed than that over the abdominal wall, ie., no pubic hair.
- Stage 2: Sparse hair growth of long, slightly pigmented downy hair, straight or only slightly curled, appearing chiefly at the base of the penis.
- Stage 3: Considerably darker, coarser, and more curled. The hair spreads sparsley over the junction of the pubes.
- Stage 4: Hair is now adult in type, but the area covered by it is still considerably smaller than in most adults. There is no spread to the medial surface of the thighs.
- Stage 5: Adult in quantity and type, distributed as an inverse triangle of the classically feminine pattern. Spread to the medial surface of the thighs but not up the linea alba or elsewhere above the base of the inverse triangle.

Note: From Marshall and Tanner, 1969;1970.

Physical Examination Protocol

In order to delineate the pre-pubescent and early post-pubescent groups, a total of 74 females and males were examined at their respective schools.

The pre-pubescent students were seen in their elementary school nurse's office with the school nurse in attendence. The early post- pubescent students were seen in a designated private room at their high school.

To determine each individuals level of sexual development, the five stages of secondary sexual characteristics for females and males as depicted by Tanner (1962; Marshall & Tanner, 1969;1970) were used as the criterion.

In addition to the determination of each individuals level of physical maturation, the measurements of weight and height were also obtained.

For the purposes of the present study, the pre-pubescent group of 16 females and 16 males (n = 16) who participated in this study were in Stage 1, and the 16 early post-pubescent females and 16 males (n = 32) were in Stage 5 of Tanner's classification of secondary sexual characteristics (Tanner, 1962; Marshall & Tanner, 1969;1970).

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APPENDIX B

Algorithm for generating Complex Square Wave Tones

- Step 1: Fs = frequency simple tone (constant frequency)
 square wave.
- Step 2: Fr = random number between 50 and + 50.
- Step 3: F = Fs + Fr.
- Step 4: T 1/2 = 1/2F
- Step 5: Generate 1/2 period.
- Step 6: Repeat Steps 2 5 until a 200 ms random frequency square wave is generated.
- Step 7: Add 200 ms simple square wave to the random frequency square wave.

APPENDIX C

Source Tables for the Subject Characteristics

Analysis of Variance

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Source Table for the Age variable Analysis of Variance

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Source	SS	DF	F	р
Between Subjects				
Group	545.806	l	1139.94	0.001
Sex	22.920	1	47.87	0.001
Group X Sex	3.950	1	8.25	0.006
Error	28.728	60		

Table 2

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Source Table for the Weight variable Analysis of Variance

Source		SS .	DF	F	p
Between Subje	ects				
Group		13340.250	1	218.90	0.001
Sex		625.000	1	10.26	0.002
Group X	Sex	324.000	1	5.32	0.025
Error		3656.500	60		
	• ••• ••• ••• ••• •••				

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Table	3
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Source SS \mathbf{DF} \mathbf{F} р . Between Subjects Group 11236.000 266.95 0.001 1 1105.562 Sex 26.27 0.001 1 Group X Sex 885.062 1 21.03 0.001 Error 2525.375 60

Source Table for the Height variable Analysis of Variance

Ta	b]	Le	4
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Source Table for the PPVT Analysis of Variance

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Source	SS [.]	DF	F	р
Between Subjects				
Group	583.223	1	32.31	0.001
Sex	48.303	l	2.68	0.107
Group X Sex	166.410	l	9.22	0.001
Error	1083.083	60		-
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APPENDIX D Means and Standard Deviations: General Analysis of Variance

Table 1

Pre- and Post-pubescent Subject Characteristics

		AGE(years)		WEIGHT(kg)		HEIGHT (cm)		PPVT (MA)	
		MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
Pre	-pubescei	nt							
	Female	10.49(0.44)	33.90(6.55)	142.1(6.82)	12.40(4.51)
	Male	11.20(0.55)	33.45(6.61)	143.0(7.50)	10.90(L.30)
Pos	t-pubesce	ent							
	Female	15.84(0.65)	58.01(7.55)	161.0(5.40)	15.20(2	2.34)
	Male	17.53(0.98)	68.95 (9.97)	176.8(6.11)	20.16(6.68)

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Table 2

Stimulus Order X Stimulus Type Means

and Standard Deviations

	STIMULUS TYPE						
	c	V	S	Т	С	T.	
Stimulus Order	MEAN	SD	MEAN	SD	MEAN	SD	-
One							
(CV-ST-CT)	20.00	3.04	20.27	4.36	20.31	4.38	
Two							
(CV-CT-ST)	21.04	3.21	21:71	4.01	22.54	2.92	
Three							
(CT-ST-CV)	21.50	3.72	19.46	3.72	18.52	3.68	
Four							
(ST-CT-CV)	21.04	3.13	19.77	3.29	20.40	3.82	

			STIMULU	S TYPI	E		
_	C	:V	S	Т	С	т	
Ear	MEAN	SD	MEAN	SD	MEAN	SD	
Right	21.31	4.67	19.38	4.46	19.61	4.59	
Left	20.48	4.58	21.23	4.68	21.27	4.49	

Stimulus Type X Ear Means and Standard Deviations

Table 3

Table 4

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Group X Stimulus Type X Ear Means

and Standard Deviations

	STIMULUS TYPE						
	c	v	S	Т	С	T	
Group	MEAN	SD	MEAN	SD	MEAN	SD	
Pre-pubescent							
Right	19.66	4.60	19.03	3.49	18.03	3.40	
Left	19.31	5.20	.19.56	3.83	19.56	4.06	
Post-pubescent	-						
Right	23.00	4.71	18.72	5.43	19.31	4.92	
Left	20.06	4.25	20.94	4.50	21.56	3.89	
Adult							
Right	21.28	4.21	20.38	4.20	21.50	4.75	
Left	22.06	3.88	23.19	5.03	22.69	4.99	

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APPENDIX E

Ear Advantages: Absolute and Relative

Table l

Correct "Same" Mean Percent Accuracy

	STIMULUS TYPE	
CV	ST	СТ
1944 596 600 600 600 600 400 400 600 600 600 60		
65.83 63.33 65.20 65.40	63.13 65.20 63.73 65.20	61.47 63.53 58.75 66.87
75.42 67.08	59.58 68.97	64.79 70.83
77.92 66.67	65.20 70.62	63.96 72.92
71.46 71.87 70.42 75.20	72.92 79.17 62.92 75.42	74.17 78.12 69.17 73.12
	CV 65.83 63.33 65.20 65.40 75.42 67.08 77.92 66.67 71.46 71.87 70.42 75.20	STIMULUS TYPE CV ST 65.83 63.13 63.33 65.20 65.20 63.73 65.40 65.20 75.42 59.58 67.08 68.97 77.92 65.20 66.67 70.62 71.46 72.92 71.87 79.17 70.42 62.92 75.20 75.42

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Table 2

Mean Percent Ear Advantages

	i	STIMULUS TYPE	,
Group	CV	ST	CT
400 400 500 500 500 500 500 500 500 500			
Pre-pubescent			
remare	21 25	60 75	
Bight	51.25 68 75	00./5	43.75
0 Night	0 0	0 0	57.50 10 75
Male	0.0	0.0	10.13
Left	43.75	43.75	75 0
Right	50.00	37,50	25.0
0	3.13	9.38	0.0
D 1 1 1		N	
Post-pubescent		,	
remare	25 00		
Diabt	25.00 62 50	02.5U · 10 75	56.25
0 Night	12 50	10.75	31.25
Male	14.00	T0.12	12.50
Left	18.75	56.25	75 00
Right	81.75	31,25	18.75
0 1	0.0	12.50	6.25
\\\.\.\.\.\.\.\.\.\.\.\.\.\.\.\.\.\.\			
Female			
Left	37.50	62,50	56.25
Right	50.00	31,25	37.50
0	12.50	6.25	6.25
Male			···-· ,
Left	62.50	81.25	50.00
Right	37.50	18.75	43.75
0	0.0	0.0	6.25
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Relative Ear Advantages: Direction and Magnitude

STIMULUS TYPE

FEMALES

Pre-pubescent			Pos		Adult			
cv	ST	СТ	CV	ST	CT	CV	ST	CT
R 7 R 7 R10 L 3 R 7 L17 R20 R 7 R23 R 3 L23 R 3 R17 R 7 L30 R63	R 7 L10 R 7 L 7 L 7 L 3 L17 L10 L10 R23 L20 R10 R30 L 3 L17 L 7	L13 L20 R 7 L20 L10 0 L 7 R 3 R 7 R17 L 7 L13 R 7 L13 R 7 0 0 R17	0 L20 L13 R20 R27 R 3 R23 0 R43 L13 R13 R13 R43 R10 L40 R10 R27	L 3 L27 0 L13 0 R 3 L30 R13 L27 L 7 L 7 L 7 L13 L23 R10 L20	R17 L27 L13 0 R17 L13 L10 L23 R 7 0 L27 L 7 R 7 L17 R 7 L17 R 7 L10	L17 R 3 L30 L20 R33 R27 0 R10 0 L27 R10 R 7 L30 R10 L10 L 7	L23 L10 0 L17 R27 L17 L13 L10 R10 L33 L23 R 7 R13 L 3 L23 R17	L30 R 7 L17 L20 R40 L10 L10 R10 R10 R10 L17 L 7 0 L27 L13 R17
Averages:								
R 6	L 2	L 2	R 8	Г 9	L 6	L 3	L 6	L 4

The direction of the ear advantage (which ear showed overall the more accurate scores) is indicated by a letter (R or L), and the magnitude of the ear advantage is given as the simple difference between mean percent correct in the two ears.

Table 3

STIMULUS TYPE

MALES	5							
Pre-pubescent			Pos	-	Adult			
CV	ST	CT	CV	ST	СТ	CV	ST	СТ
L23 R23 L 7 0 L33 R20 R13 L27 R30 R23 R13 L 7 L13 R 3 R40 L47	L 7 0 R 7 L27 L43 0 L10 L20 R13 L 7 R13 R17 R13 L 3 R30 0	L 7 R 3 L13 L 7 L27 R20 L13 L27 R10 L 7 L10 R 7 L20 L20 L20 L 3 L17	L23 R33 R10 L 7 L27 R37 R 7 R33 R17 L 3 R10 R 7 R47 R 3 R 7 R 3 R 7 R 3	L17 L 7 R 7 L 7 L 7 L 3 0 L50 R 7 L 7 R 7 R 20 R 3 L 7 L20 L13	L27 L 3 R 3 L17 L20 0 L27 R13 L17 L 3 R17 L 3 L 3 L 3 L23 L30	L 3 L23 L10 R20 L17 R30 L 3 R 3 R 7 R 3 R 7 L23 L10 L20 L23 L13	L23 L50 L 3 L27 R13 L 7 L17 R 3 L13 L13 L13 L10 L10 L 7 R 3 L 3	L10 L53 R20 R 3 L27 R 3 L10 0 L10 R13 L20 R 7 R 3 L 7 L 3 L13
Averages:								
0	L l	L8	R10	L 5	L 9	L 5	L13	L 6
Group Average:								
R 3	L 2	L 5	R 9	L 7	L 8	L 4	L10	L 5

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