FUNCTIONAL LATERALIZATION OF NEWBORN HEADTURNING TO BINAURAL SPEECH AND HEARTBEAT SOUNDS

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Abstract

FUNCTIONAL LATERALIZATION OF NEWBORN HEADTURNING TO BINAURAL SPEECH AND HEARTBEAT SOUNDS

by

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These studies explore the relationship between the acoustic and temporal characteristics of voices and newborn patterns of responsiveness to voices, suggesting possible prenatal sources for differential responsiveness. In a series of five studies, functional asymmetries in newborns are examined by recording headturning from midline to binaurally presented sounds. Presentation is equivalent to both ears, making differences in lateralized patterns of response indicative of differences in underlying patterns of sensorimotor processing. Headturns to unfiltered female speech sounds are examined in contrast to headturns to 1) intrauterine heartbeat sounds; 2) female speech low-pass filtered at 500 Hz; 3) female speech high-pass filtered at 3500 Hz; 4) female speech band-pass filtered between 1500 and 3000 Hz; 5) a phrase of low-pass filtered speech repeated at the rate of the intrauterine heartbeat, termed "Heartspeech"; and, in each study, a *no-stimulus control*.

Fifty-nine full-term newborns ranging in age from 22 to 55 hours (mean age 36 hours) were presented with eighteen 20 sec stimulus trials via 10 cm speakers bilaterally placed approximately 15 cm from each ear of the supine infant. Each baby's head was centered at midline preceding the onset of each stimulus trial. Results show a robust, asymmetric pattern of headturning occurs in most newborns' responses to binaurally presented unfiltered female speech sounds, with increased initial rightward orientation demonstrated in five replications. Low-pass filters and band-pass filters of

female speech sounds do not significantly alter this rightward orientation bias, although high frequency speech sounds (>3500 Hz) result in an equal propensity to turn right or left, and seem limited in their effectiveness in producing a headturn in male babies. Heartbeat sounds, and "heartspeech" sounds failed to generate the rightward orientation bias.

Female speech sounds are a particularly salient class of stimuli for the organization of lateral biases in orienting in newborns, related to the naturally occurring prosodic characteristics of speech sounds. Examination of the responses of individual babies to unfiltered female speech reveals a distribution of orientation biases, with the majority of babies showing a rightward headturning bias, but a cluster of babies demonstrating a leftward headturning bias.

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CHAPTER 1

Introduction

Newborn headturning to auditory stimulation is a well-documented sensorimotor behavior which is especially important for integrating the infant's visual and auditory worlds. Orientation to sources of moderate stimulation is a consistent behavior among all living things, regardless of the biological complexity of the organism, and despite the fact that the underlying organization of processes constituting the behavior varies across organisms (Schneirla, 1959; 1965). The propensity toward orienting is rarely symmetric; a diverse range of organisms exhibit directional biases in orienting (Denenberg, 1981). These biases seem to fall along certain perceptual-motor axes. In order to begin to understand the nature of the processes underlying such biases, it is necessary to carefully examine both the nature of the behavior in question and the nature of the source of stimulation as well. For example, what physical characteristics need stimuli possess to elicit lateral biases in orientation? Similarly, what are the behavioral characteristics associated with lateralized orientation? Or more specific to this investigation, is bilateral asymmetry a characteristic of a human newborn's orienting response? For that matter, is bilateral asymmetry a characteristic of a human newborn's history of stimulation? The answers to these questions could provide clues to understanding the processes which organize orienting in general, as well as the development of newborn auditory-motor lateralization and its role in the development of later occurring asymmetries.

As with many areas of scientific investigation, the history of study in the area of laterality has provided many highly differentiated bits of data, which over the years have been transformed into broad and unifying theoretical constructs. Unfortunately, the further the umbrella concepts get from the data, the harder it becomes to find the relationship between the two. For example, the cerebral hemispheres are frequently viewed as having general processing characteristics which distinguish them from one another, e.g., "analytic" (left hemisphere) vs. "gestalt" (right hemisphere). The majority of data that these terms were developed to describe stem from a speech processing advantage for the left hemisphere and a visual-spatial processing advantage for the right hemisphere (Springer & Deutsch, 1989). Two very different perceptual modalities are involved, a fact that the umbrella terms tend to obscure. Further, when specific research is examined, the speech processing advantage most frequently attributed to the left hemisphere is actually most clearly a speech production advantage (Previc, 1991). By losing track of the task involved, we have lost significant insights into the underlying sensorimotor organizations involved, as well as a more differentiated picture of how lateralization occurs.

Therefore, in examining the "functional lateralization" of newborn headturning, I am attempting to position myself in relation to an area of inquiry which has a long history, usually referred to as "cerebral localization" or "hemispheric specialization". One of the theoretical shifts which separates these proposed studies from many of the previous studies of infant lateralization is the move away from assumed "hard-wired" cerebral mechanisms as an explanatory construct, and a move toward an examination of the naturally occurring asymmetries in the practical activity of the organism to understand apparent sensorimotor organizations. In other words, this examination moves away from theoretical constructs in which brain organization determines behavior, or experience determines behavior, and shifts to a focus on behavior as the dynamic integration of the changing effects of experience on brain organization and of brain organization on experience. As a result, practical asymmetries of sensorimotor behavior at any point in development become the potential organizers of future sensorimotor processes, serving as functionally asymmetric scaffolding upon which subsequent sensorimotor processes are built. An understanding of functional lateralization thereby necessitates a consideration of changing growth rates, changing kinds and amounts of stimulation and changing relationships between processes in pre and post natal life (Turkewitz, Ecklund-Flores & Devenny, 1990). If different patterns of newborn headturning to sound are related to different characteristics of auditory stimulation occurring in the environment, this would in turn affect the sensorimotor integrations which organize early life and lay the foundation for aspects of later cognition.

Early in the 19th century, before the modern version of the cerebral localization view was formulated, researchers concentrated their efforts on the examination of the measurement of the relative size and weight of contralateral limbs, levels of blood flow to various body parts, positioning during delivery, asymmetric carrying practices, and the like, to try to determine sources for asymmetric development (Harris, 1983). Broca apparently initially believed that the development of the cerebral localization of the speech center was based on accelerated left hemisphere growth and the relationship between such accelerated growth and the development of advanced mental capacities (in Harris, 1983, p. 184). The earliest phrenologists, such as Franz Joseph Gall, felt that localized brain development was the result of exercise and other behavioral practice. Darwin, in his discussions of the role of handedness in evolution, concentrates on the affordances of practical behavior and experience . The contemporary researcher Gerald Edelman (1992) has also shown experimentally, both through studies of primate behavior with concurrent cortical probes and through robotic simulation, that brain organization changes with activity, supporting earlier findings of changes in brain organization as a result of activity in rat pups (Rosenzweig & Bennet, 1972). It is only with the emergence of neo-Darwinism and current beliefs about genetic mechanisms that early emphases on behavior and development have been neglected by some, describing brain/behavior relationships with one-way "causal arrows", using phylogenetically determinist views which conceptualize hemispheric specialization as arising in evolution with particular adaptive advantages and thereby maintained in a "genetic blueprint". The circularity and non-falsifiable nature of such arguments limit their utility in the formulation of a cogent understanding of the development of lateralized behavior, treating the singular structures or functions of people as the isolatable property of a population, rather than as an inseparable, integrated property of a whole, active individual organism (Oyama, 1985). Most importantly, what is missing from these analyses is a consideration of ontogenetic and microgenetic processes which hold a treasure trove of possibilities for the understanding of the organization and origins of contemporaneous functions, alleviating the necessity to call on fictive constructions of evolutionary history for explanation (Gottlieb, 1987). (For further challenges to the neo-Darwinist view, see Gould, 1982; Ho, 1987; Johnston & Gottlieb, 1990.)

The method by which newborn lateral biases in orientation to sounds will be examined is through the use of Klüver's (1931; 1936) "Method of Equivalent and Non-Equivalent Stimuli". As Klüver (1936) states:

> Heterogeneous stimuli may be equivalent in the sense that they call forth the "same" reaction. Yet if the stimulus situation is varied sufficiently or within certain directions this response may be variously disturbed (degrees of equivalence) or it may disappear (non-equivalence).(p.91)

In the present examination the concept of equivalence is used in two ways. First, auditory stimuli are binaurally presented, meaning that the objective stimulation at each ear is equivalent, both qualitatively and quantitatively. Therefore individual directional differences in headturning patterns indicate lateral differences in *effective stimulation* (Schneirla, 1965). Second, in looking for changes in patterns of newborn headturns resulting from changes in the objective characteristics of the stimuli, it is possible to inventory which stimulus features are *equivalent* and which features are *non-equivalent* in influencing directionality of turns. This inventory, and the clues to underlying sensorimotor organizations that it reveals, begins to shed light on the means by which equivalence is manifested, or the *functional equivalence*. Specifically, this group of studies delineates equivalence and non-equivalence in terms of the effects of acoustic and temporal dimensions of auditory stimuli on newborn head orientation.

The theoretical approach utilized in these studies stresses the importance of an organism's history of experience in constructing processes which appear stable at birth. The sounds that are used are based upon a model of prenatal experience, using female voice, intrauterine heartbeat sounds and female voice which has been manipulated acoustically and temporally to resemble aspects of the intrauterine environment.

To set the stage for this research program concerning newborn lateral biases in orientation to binaurally equivalent sounds, a review of fetal and neonatal general responsivity, and specific responsivity to sounds, will follow. Special emphasis will be given to evidence of structural and functional asymmetries across levels of biological and environmental organization. Finally, a focused integration of this information will be provided and applied specifically to the present examination.

Prenatal Period: General Fetal Activity

With an avalanche of technical advances for the study of fetal development has come a growing interest in fetal behavior for the understanding of prenatal development and newborn functioning as well (Smotherman & Robinson, 1988). High resolution ultrasound recording has revealed that cyclically organized motor activity, probably a result of spontaneous nervous system activity, is one characteristic of early fetal behavior (Robertson, 1988). Later, fetuses can be observed moving fingers, mouth, arms and legs in a more complex, possibly reflexogenic way (Birnholz, 1988). Thumb-sucking and amniotic fluid swallowing are also behaviors familiar to observers of fetal behavior. There are also gross changes in fetal position within the uterus over gestation (Previc, 1991). In the final trimester, fetal states of arousal have been investigated, with the finding, based on a combination of EEG and heartrate variability monitoring, that fetuses are usually in one of a number of sleep states (Fifer & Myers, 1990). Cardiac acceleration and deceleration have become useful behaviors in the examination of fetal response to specific stimulation (Emory & Toomey, 1988).

The Intrauterine Environment

While the stimulative aspects of the intrauterine environment may seem minimal compared with extrauterine life, all sources of sensory stimulation, while buffered, are still available to the fetus to varying extents. Acoustic analyses of the intrauterine world reveal that maternal digestive noises, pulse and voice are all recordable using microphones and hydrophones placed within the uterine cavity (Querleu, Renard, Versyp, Paris-Delrue & Crepin, 1988). Airborne sound passing through the uterine wall and amniotic fluid are attenuated by only about 30 dB, but frequencies over 1000 Hz are largely degraded. An interesting finding by Busnel, Granier-Deferre & Lecanuet (1992) reveals that there may actually be a decrease in this attenuation as frequencies approach 4000 Hz. As Querleu, et.al. report, the noise of the maternal vascular pulsations and digestive noises range from a few Hz to 1000 Hz, with amplitude measurements being high in the low frequencies and low for higher frequencies. Externally generated sounds, like conversations, music, etc., emerge as audible above the intrauterine noises in these recordings, despite their low frequency range. To summarize Querleu's results: voices emerge and are not totally masked by the low-pitched basal noise of the intrauterine environment; phonetic information is attenuated by 70%, i.e., only about 30% audible, while intonation patterns are almost completely unattenuated between 100 and 1000 Hz; maternal voice is most salient, perhaps amplified by as much as 12-16 dB in utero (Lecanuet, Granier-Deferre & Busnel, 1989).

It should be noted that basal noise is much quieter before the onset of labor, and as Querleu et.al. state, "....the data in the human, all gathered after rupture of the membranes, could overestimate the importance of the background noise, and subsequently underestimate the emergence of maternal voice and of external voices or noises...." (p. 206). Much of the other data regarding the acoustic properties of the uterus come from pregnant goats and sheep, and "....Because of obvious anatomical difference, direct generalization of the data from sheep to human might be problematic. However, the results obtained on both species are very similar, and the animal model has allowed recording directly from inside the amniotic sac...." (Busnel, Granier-Deferre & Lecanuet, 1992). Given that the recording from human subjects was restricted primarily to late stages of pregnancy and given the limitations presented from the animal work, it is important to keep in mind that the data on the acoustic features of speech in the intrauterine environment probably changes over gestation, and may differ from the information to date in ways that are potentially important to this investigation.

Turkewitz (1991) has addressed the issue of the salience of the maternal voice in utero in his theory of early auditory asymmetries. Due to its polymodal nature, the maternal voice is proposed to have greatest salience to the fetus; it is carried via air conduction and via bone conduction down the maternal spinal cord, as well as providing tactile stimulation through maternal diaphragm movements. Turkewitz also offers a proposal for the changing characteristics of the intrauterine acoustic environment. The acoustic parameters of the uterus are not static during pregnancy; changes in the size and shape of the uterus as well as the thickness of the uterine wall all have implications for the conduction of sound into the uterus. Even fetal activity, i.e., changes in fetal body position in utero would affect change in the salience of auditory stimulation available in utero.

In keeping with earlier discussions about effective stimulation, it is necessary to consider not only what acoustic input is available to the fetus, but also what aspects of this stimulation actually elicit fetal response, and what specific behaviors such responses include.

Fetal Responsivity to Sound

The importance of early stimulative experiences on the auditory and communicative capacities of animals is well documented. Gottlieb (1981; 1988) has shown that the ability of ducklings to learn individual maternal calls is based on early (prehatching) exposure to maternal call, sibling sounds and self-generated sounds. Gottlieb found that ducklings are able to learn synthetically produced differences in repetition rate and frequency spectrum after only 12 minutes of exposure in the first day after hatching, and can learn but not retain this information when exposed embryologically. Gottlieb discusses the general importance of familiarization as a basic behavioral mechanism underlying not only call learning and parental attachment, but dietary and habitat preferences as well.

Extensive examination of human fetal responsiveness to acoustic and vibroacoustic stimulation has revealed that fetuses are responsive to sound by at least 23 weeks gestational age (Busnel, Granier-Deferre & Lecanuet, 1992; Kisilevsky & Muir, 1991). Lecanuet, Granier-Deferre & Busnel's recent (1988) study of fetal auditory reactiveness looked at two different measures of fetal responsiveness - leg movement and cardiac acceleration/deceleration. Their findings show that stimuli with minimum intensities of 113 dB of externally generated broad band pink noise high-pass filtered at 800 Hz induced 100% cardiac responses and 91% motor responses. Given the previously cited attenuation by 30 dB of airborne sounds in utero, this is the first finding that fetuses are not only responsive to loud, direct vibro-acoustic stimulation, but also to externally generated sounds.

In examining reactiveness to auditory stimulation as a function of state of arousal (defined by high or low heart rate variability, see Nijhius, Prechtl & Martin, 1982). Lecanuet, et.al., found greater cardiac acceleration and more brief leg movement latencies for fetuses in the high variability state. Fetuses in both states show response decrement as a function of repeated exposure to a stimulus, but low variability fetuses show the decrement sooner. Finally, mid-low frequency stimulations of moderately intense, rhythmic nature (e.g. maternal speech, music) most frequently induce a cardiac deceleration, in both states. Lecanuet, et.al., conclude by stating that "...fetuses perceived a change in the acoustic structure of the stimulation, and suggest that they may rely on similar auditory competencies to the ones they will use postnatally to run this discrimination." (p. 14).

Given that intrauterine stimulation of a variety of types is available to the fetus, and given that the fetus is differentially responsive to this stimulation, especially acoustic stimulation, what does this tell us about the development of functional asymmetries in the fetuses' behavior? In order to address this question more fully it is necessary to look at the evidence that asynchrony in growth and viability of the fetal systems, together with changes in the acoustic characteristics of the intrauterine world, may give rise to the neonatal auditory processing asymmetries that have been found.

Asymmetries at the Biochemical and Neuroanatomical Levels

Asymmetries in structure and function are an inherent characteristic of development. From the moment of conception there is a migration of cell materials within the ovum, leading to an asymmetric distribution of materials in each cell of the developing zygote. Dynamic systems theory's "sensitive dependence on initial conditions" (Gleick, 1987) predicts that such initial asymmetries have a high probability of increasing exponentially as a system evolves. At no point in the development of bilaterally organized organisms is there an exact synchrony or symmetry between lateralized structures or processes. It is therefore incumbent upon researchers of hemispheric asymmetries to attempt to examine sources for asymmetries along two axes: asymmetries across levels within a given system, as well as asymmetries between systems. In their new book "Developmental Time and Timing", Turkewitz & Devenny (1993) propose that all qualitative change in ontogeny is a result of asynchrony between developing systems. This asynchrony between levels and between systems is very likely the "motor" of developmental reorganization.

Galaburda (1984) reports evidence that the right hemisphere grows faster earlier in fetal development, with the left hemisphere demonstrating a longer growth spurt later in fetal development and extending into the postnatal period. Thatcher, Walker & Giudice (1989) examined the first year of postnatal life and confirm a 'right hemisphere preceding left' growth chronology. Simonds & Scheibel (1989) confirm this with their finding that the basilar dendritic patterns in the cortical pyramids of layer 5 are more prominent in the right hemisphere than the left in infants 3 months to one year old. Bracco, Tiezzi, Ginanneschi, Campanella & Amaducci (1984) postulate that asymmetries in hemispheric growth could result in asymmetries in the time that the hemispheres become functional and processing information, in that choline acetyltransferase activity of the right temporal gyrus reaches adult levels more quickly than the left in human fetuses. Best ((1988) suggests however that a left-right gradient is too simplistic, and describes a 3-D growth torque and twisting of the entire neocortex, resulting in growth differences within as well as between hemispheres. This may help us better understand the data of Chi, Dooling & Gilles (1977), who report a larger temporal speech area in the left hemisphere of human fetuses late in gestation. Witelson & Pallie (1973) also report larger planum temporale and Sylvian fissure in the left hemisphere at 28 weeks gestation. Biochemical asymmetries are not limited to neurotransmitter substances but extend as well to lateralization of neuroendocrine control, with the right side of hypothalmic structures more heavily implicated in gonadal control (Gerendai, 1984). Finally, Kooistra & Heilman (1988) report subcortical growth asymmetries as well. Their study of the globus pallidus, one of the three large subcortical nuclei of the basal ganglia that is important in arm movement control, found greater volume on the left side in fetuses at 28 weeks gestational age.

If certain brain areas are more precocious than others in readiness for processing information, then the probability increases that developing areas will have advantages in processing information that is available in an asynchronous manner. Early processing asymmetries will thereby either be maintained and further strengthened, serve as scaffolding for later functional demands, or be minimized or maximized with greater interhemispheric communication with the myelination of the corpus callosum. Previc (1991) has proposed a theory of the basis of aural lateralization that results from embryonic asymmetries in craniofacial development, accounting for right ear (left hemisphere) advantage in language processing and left otolithic (right hemisphere) superiority in postural control and visuospatial functions. Turkewitz (1990) highlights the importance not only of asymmetric growth to subsequent lateralization but the combination of this factor with the changing characteristics of intrauterine stimulation.

This preceding review of the prenatal period, in terms of general fetal responsivity, acoustic features of the intrauterine environment, fetal responsivity to those specific features, developmental asymmetries at the biochemical and neuroanatomical levels, asymmetric growth gradients, and the implications of those asymmetries for the organization of fetal (and later, newborn) behavior, will inform this research of lateralized headturning to auditory stimuli in the following ways: 1) in the selection of salient stimuli which may be important to the organization of hemispheric specialization (e.g., intrauterine heartbeat sounds and speech sounds); 2) in the selection of stimulus dimensions to be manipulated on the basis of changing acoustic intrauterine characteristics; 3) in predicting connections between sensory and motor processes on the basis of early sensorimotor relationships.

Neonatal Period: General Responsivity

As the evidence provided to this point shows, there exist some continuities between prenatal and neonatal functioning, for example in auditory responsiveness and discrimination. Many discontinuities exist as well, including the physiological demands on the neonate to regulate metabolic, thermal and respiratory systems, the advent of high intensity visual stimulation, as well as the addition of auditory stimulation which was attenuated in utero. Indeed, the move from intra- to extra-uterine life is in many ways quite dramatic; but there are continuities as well, and these continuities have important implications for the organization of new relationships between developing systems.

One of the most well developed sensorimotor responses evident from the very moment of birth is what has been called the "auditory localization response" (Field, 1987; Muir, Clifton & Clarkson, 1989; Muir & Field, 1979). Newborns will orient toward a source of auditory stimulation, effectively bringing their visual field in line with the auditory stimulus, in a fairly well-organized headturn. The auditory stimulation must have certain characteristics to be a reliable elicitor of a headturn; it must be of sufficient duration, intensity and repetition rate (Clarkson & Clifton, 1991; Clarkson, Clifton, Swain & Perris, 1989). This orienting response is probably not simply based on the intensity of the stimulus, as Tarquinio, Zelazo & Weiss (1990) have found that neonates habituated to an auditory stimulus will demonstrate a recovery of headturning to decreased sound pressure level as well.

Neonatal Auditory Preferences

A variety of behavioral measures have been invented in the attempt to understand newborn behavior. One such measure that has proven to be a valuable tool is the measurement of sucking behavior. DeCasper & Fifer (1980) invented a way for researchers to examine newborns' differential control of their non-nutritive sucking when certain contingencies of stimulation are dependent upon certain patterns of sucking, in an adaptation of Butterfield & Siperstein's (1972) study of interburst sucking patterns in newborns. In particular, they used the interburst interval (latency between sucking bursts) as a contingency to hearing pairs of sounds. Associations between sound type and interburst latency type were counterbalanced across subjects to examine the newborn's ability to control sucking patterns to hear specific sounds. In confirming this ability, DeCasper, Fifer and their co-workers (see DeCasper & Carstens, 1981) have been able to test not only newborn discrimination, but newborn preferences.

In an ongoing series of studies these researchers have accumulated an impressive list of newborn preferences, each of which tells us something about prenatal experiences and their importance for the organization of later behavior. For example, newborns prefer to listen to their mother's voice rather than that of another female (DeCasper & Fifer, 1980). They also prefer a female voice to a male voice, and their mother's voice to their father's voice (DeCasper & Prescott, 1984). One of the most astounding of these studies was DeCasper & Spence's (1986) look at newborns' preferences for passages of prose that were read aloud by their mothers during the last month of pregnancy - the findings show that newborns preferred the section of "The Cat in the Hat" which was "read" to them prenatally to a story with which they had had no previous exposure.

These studies of newborn preferences have led researchers to begin thinking about the intrauterine environment and early experience in new ways. For example, newborns have been found to prefer to listen to "motherese", or infant-directed speech, rather than to adult-directed speech (Cooper & Aslin, 1992). Motherese is that distinctive way that people have of talking to very young infants - with exaggerated intonation and intensity, slower and simpler articulation and accompanied by exaggerated facial expression (Fernald, 1989; Fernald & Kuhl, 1987; Fernald, Taeschner, Dunn, Papousek, Boysson-Badies & Fukui, in press). Moon & Fifer (1990) have shown that newborns prefer a prenatal version of the mother's voice, with attenuation of the phonetic information, but preservation of the prosodic information.

These findings leave open the possibility that newborn preferences for motherese are based on prenatal experience with those aspects of speech that motherese tends to emphasize.

DeCasper & Sigafoos, (1983) have examined another stimulus which is proposed to have particular salience in the intrauterine acoustic environment - the intrauterine heartbeat sound. These workers found that the intrauterine heartbeat can be used as a potent reinforcer for newborns, and in later studies Davis & DeCasper (1989) and Prescott & DeCasper (in press) found that intrauterine heartbeat sounds gain reinforcing value when presented to the left ear, and female speech when presented to the right ear, presumably because of active processes of the contralateral hemispheres. Before elaborating the neonatal picture of auditory processing asymmetries, let's consider the data on general newborn speech perception.

Speech Perception in Early Infancy

Recent cross-linguisitic studies of newborn speech discrimination and preference have shown that newborns prefer to listen to the maternal native language over non-native languages, presumably based on prenatal exposure (Mehler, Jusczyk, Lambertz, Halstead, Bertoncini & Amiel-Tison, 1988). Additionally, these studies have found that newborns show no significant preference between two non-native languages. Non-native languages have been used to examine speech discrimination cross-culturally in infants and adults.

Infants as young as one month of age show categorical-like perception for speech stimuli (Eimas, Siqueland, Jusczyk & Vigorito, 1971). These results are not unique to human perception, however, for a variety of animals have been found to be capable of making the same discriminations (Kuhl, 1985). Cross-language studies have found that the distribution of VOT (voice onset time) values cluster around three points in the world's languages, but that different languages demonstrate variability in which voicing categories are used phonemically. As a result some linguistic contrasts are shared between languages and some are not. This phenomenon has been used to examine changes in speech discrimination at different periods of development.

While most work in sound discrimination has been generated by linguistic studies, there has been some work with infant discrimination of non-linguistic sounds. Clarkson, Clifton & Perris (1988) have shown that seven month old infants can discriminate timbre differences in non-linguistic sounds, i.e., can discriminate aspects of the spectral envelope. There is certainly evidence that infants respond behaviorally to music (Trehub, 1990). In investigations of infants six months of age and older, Trehub and her co-workers have found that infants were able to discriminate changes in rhythm, melodic contour and harmonic organizations in music stimuli (Trehub & Thorpe, in press; Trehub, Thorpe & Morrongiello, 1987).

Given this evidence that infants discriminate and respond to linguistic and non-linguistic sounds of these sorts, is there evidence that the acoustic features of sounds are processed differentially by the cerebral hemispheres?

Neonatal Perceptual Asymmetries

While the two ears have neural pathways to both the ipsilateral and contralateral hemispheres, there is evidence that the contralateral representations are stronger than the ipsilateral ones (Rosenzweig, 1951). Doreen Kimura (1961; 1967) used this finding to reason that during dichotic listening (different stimulus to each ear) the ipsilateral connections are essentially overridden by the contralateral ones. Kimura's dichotic presentation procedure has become the focal method for testing asymmetric auditory processing in adults (Hugdahl, 1988) aside from clinical data from medical procedures and disease (e.g., Ojemann & Mateer, 1979). The overwhelming results from adult dichotic tasks, using accuracy and speed of verbal report, reaction time in lever-pressing tasks, and the like, is a right ear advantage in processing speech sounds *in the majority of right-handers.* Slightly less robust and more difficult to attain, but reasonably consistent nonetheless, is a left ear advantage in processing non-linguistic sounds. Kimura extended her original work to children as young as four years old, and found the same pattern of ear advantages.

Dichotic listening procedures have been adapted to examine early lateralization in newborns and young infants with one modification; young infants cannot respond verbally to dichotically presented material, so researchers have predominantly looked to other systems for increased responsiveness as indicators of asymmetric processing advantages. For example, Entus (1977) used a high-amplitude sucking procedure (Siqueland & Delucia, 1969) and found that three and four month old infants have a greater recovery of non-nutritive sucking to speech stimuli presented at the right ear and music stimuli presented at the left ear. Glanville, Best & Levenson (1977) corroborated these findings using cardiac habituation/response recovery to dichotically presented speech and music stimuli, finding greater cardiac response recovery to speech presented to the right ear and music presented to the left ear, also in three month olds. Bertoncini, Morais, Bijeljac-Babic, McAdams, Peretz & Mehler (1989) extended these procedures to neonates, and found that newborns also have a greater sucking response to speech presented at the right ear dichotically.

Dichotic listening procedures assume preferred neural pathways and brain organization, but are indirect behavioral measures of brain activity. Recent advances in positron emission tomography (PET) procedures have afforded researchers direct measures of cerebral blood flow during activation. In a recent study by Zatorre, Evans, Meyer and Gjedde (1992), PET scans of ten adults performing auditory discrimination tasks revealed increased bilateral activity of the primary auditory cortex in response to noise bursts, and bilateral activation of secondary auditory cortices in response to matched speech syllables. When the task required judgments about different aspects of the same speech signal, lateralized activity emerged.

Discrimination of phonetic structure led to increased activity in Broca's area of the left hemisphere, while pitch discrimination increased right prefrontal cortex activity.

No direct studies of brain activity using PET scans have been made with newborns or young infants. There have been examinations of brain electrical activity using auditory evoked potentials, however. Molfese & Molfese (1979) found that sleeping newborns show increased left hemisphere activity on auditory evoked potentials from an EEG in response to particular acoustic features of speech stimuli. In particular, AEP changes seemed to be related to the formant transitions of the consonant-vowel syllables of the speech stimuli used. In another examination of auditory evoked potentials to speech sounds and noise bursts, Kurtzberg, Hilpert, Kreuzer & Vaughan (1984) found an asymmetric intraregional maturational progression of the auditory cortex. In their study of normal full-term and very low birth weight preterm infants, a developmental progression of primary preceding secondary auditory cortex maturation was found, as evidenced in a transition from a predominantly negative to a predominantly positive response polarity, with midline recordings becoming positive earlier than lateral recordings.

The issue of the acoustic determination of cerebral auditory lateralization has been a contested topic in the adult literature (Mattingly & Studdert-Kennedy, 1991; Studdert-Kennedy & Shankweiler, 1970) and will become a crucial issue in the organization of the presently proposed experimental examination of lateralized responsiveness to sound.

Adult Functional Asymmetries

Kimura, in some of her original studies of dichotic listening, found interesting motor relationships to certain stimuli. By engaging adult subjects in tasks requiring reading aloud, reading silently,and humming, Kimura found an increase in free right hand movements during speaking aloud in righthanders (Kimura, 1973a; 1973b).

Subsequent dichotic listening tasks demonstrated the characteristic right ear advantage in discriminating speech stimuli in right handers, and a distribution of ear advantages in left handers.

Marcel Kinsbourne has also done considerable work on the effect of auditory stimuli on lateralized motor behavior (Kinsbourne, 1971). Kinsbourne & Hicks (1974) found a facilitation/inhibition model best described the relationship between auditory processing and motor behavior. In a series of finger-tapping and rod-balancing tasks, adult subjects were found to have some decrement in performance (slower, or increased errors), if the verbal activity which accompanied the motor task was difficult or demanding in any way. Kinsbourne proposes that during concurrent activities such as these, cerebral processes which are in close topographic relationship with each other will have facilitating effect on one another if the demands of the task are moderate, but an inhibiting effect if the task demands are considerable. In a general examination of this model, Kinsbourne (1972) found an increase in eye and head turning to the right when adult subjects were given verbal tasks to complete.

Neonatal Functional Asymmetries

In an examination of infants around 3 months old, Caplan & Kinsbourne (1976) found that infants duration of grasp in holding a rattle was asymmetric, with right hand grasp being significantly longer than left hand grasps. Hammer (1977) also found increased rightward eye movements in newborns in response to speech stimuli, and an increase in leftward eye movements in response to white noise, in a competition based procedure. Turkewitz's finding of a rightward oriented postural bias in the majority of supine infants is an important functional asymmetry, as has been previously discussed. Increased responsivity of newborns to somesthetic stimulation on the right rather than the left (Hahn, 1987; Hammer & Turkewitz, 1974; Kimura, 1973) has also been found.

The Proposed Model

Brain development is asynchronous, making some brain areas and structures functional conductors of nerve impulses earlier than others. As neural pathways become active, they produce self-generated neural activity, as with cyclic motility, and will begin to process whatever afferent stimulation is available. Acoustic stimulation inside the uterus changes throughout pregnancy, making different aspects of stimulation salient at different times. The mapping of asynchronous brain development, asynchronous stimulation and asymmetric behavioral activity is crucial to the understanding of the development of brain lateralization.

The corpus callosum, the primary structure responsible for communicating information between the cerebral hemispheres, is largely unmyelinated at birth, and therefore an inefficient conductor of neural impulses at best. Because of this, there is probably greater independence of the cerebral hemispheres at this point than at any subsequent point in development. In addition, the unmyelinated regions within the cerebral hemispheres makes it likely that non-synaptic conduction (or ephaptic conduction) will occur more at this stage than at any subsequent time. Combining this data of inefficient interhemispheric processing with the likelihood of facilitated intrahemispheric activation, what emerges is a view of the newborn infant as a potentially highly lateralized organism.

Functional lateralization of motor behavior may be related to contralateral organization of sensory processes, as shown experimentally. Hand and arm movements and eye movement have all been found to be lateralized in response to speaking or listening to auditory stimulation of various kinds. An underconsidered component of this lateralization picture is the role of asymmetric subcortical processes, or bilateral differences in the adaptation of the sensory cells of the two ears.

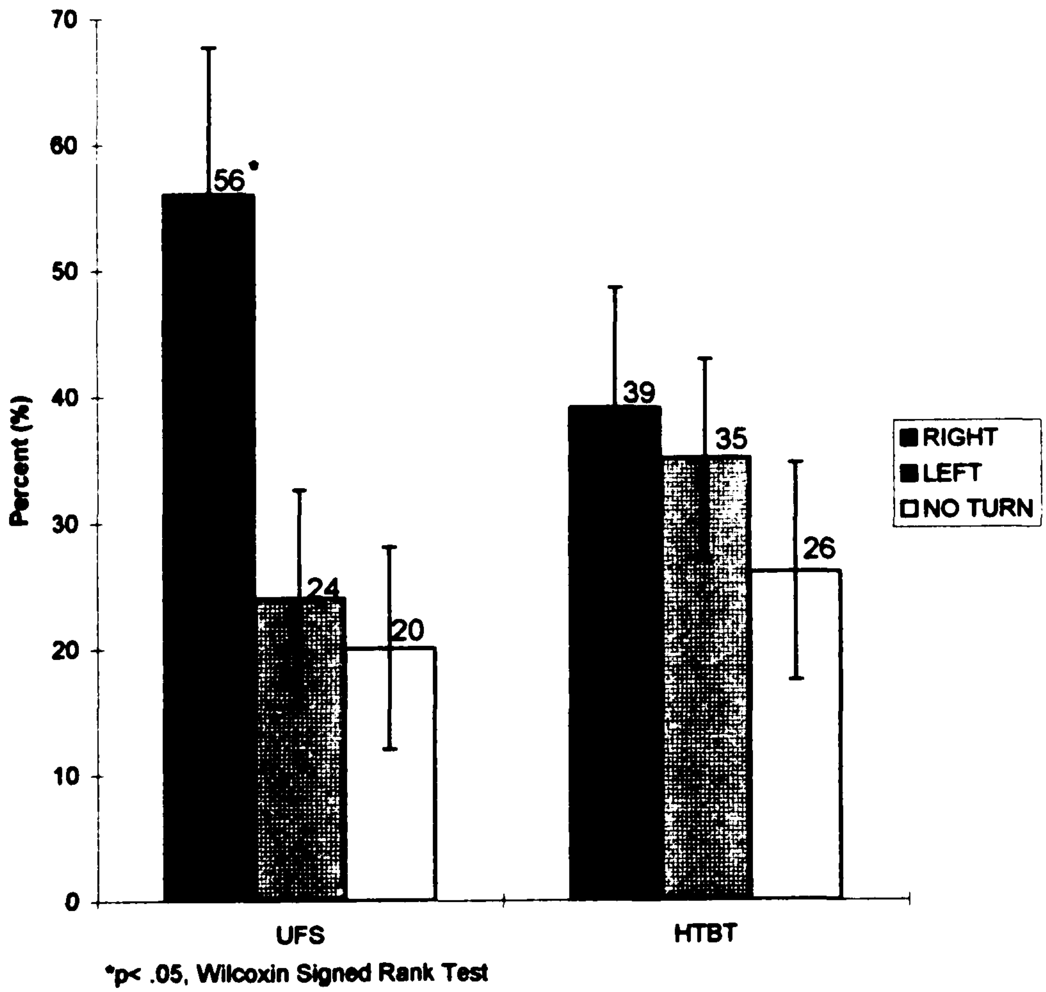
Given this evidence of lateral asymmetry in adult and infant motor activity and the ties which have been made to auditory-motor relationships, an examination of lateral biases in newborn headturning was undertaken.

The Pilot Study

In an initial investigation of newborn directional headturning to binaurally presented auditory stimuli (Ecklund-Flores, Turkewitz & Edmondson, 1992), 12 newborns were presented with three different auditory conditions: female speech, intrauterine heartbeat sounds and a no-stimulus control. Presentation was binaural, not dichotic, in an attempt to see how auditory stimulation which is more like that occurring in the newborn's natural environment might affect lateralized motor activity. The results showed an increased tendency of newborns to turn right in response to speech stimuli when compared with response to intrauterine heartbeat sounds (see Figure 1). Intrauterine heartbeat sounds resulted in decreased right headturns, but not the predicted increase in left headturns. This study is supported by an earlier study by Young & Gagnon (1990) in which it was found that speech sounds presented at midline from the back resulted in greater newborn tendency to turn right, and presentation of music sounds in this way resulted in a greater frequency of left turns. There have also been anecdotal reports of similar headturning patterns (Muir, 1992, personal communication). Most recently, Moon (1994) replicated the findings of this pilot study, finding a newborn tendency to turn right to binaural speech sounds when infants were in a quiet, awake state.

Two important questions arising from these studies and the literature reviewed seem to be; 1)Are the differences in the acoustic characteristics between linguistic and non-linguistic sounds related to lateralized motor behavior? 2) Are there other salient differences between linguistic and non-linguistic sounds which may also relate to lateralized behavior?

Figure 1. Pilot study results showing increased mean right headturns to binaurally presented female speech sounds (N=12).



UFS - Unfiltered Speech
HTBT - Heartbeat

The basis of these studies is to manipulate the acoustic and temporal parameters of female speech sounds to see if a different pattern of lateralized headturns results. Acoustic and temporal manipulations are based on a model of prenatal experience in which acoustic features of the intrauterine environment have different developmental histories and thereby change as effective stimuli, and are possible bases for later hemispheric processing asymmetries.

CHAPTER 2

Methods

Subjects

75 full-term newborn babies ranging in age from 24 to 72 hours in age were selected from the well-baby nursery of Long Island College Hospital in Brooklyn, New York. All infants met the following criteria: 1) birth weight between 2500 and 4000 grams; 2) gestational age from 38 to 42 weeks; 3) spontaneous vaginal delivery; 4) a 1 minute Apgar of no less than 8; 5) no evidence of maternal drug use; 6) evidence of prenatal care. Attempts were always made to maintain babies in a quiet alert state, but testing proceeded regardless of subject state. Data from 12 babies was eliminated for lack of responsiveness (criterion - fewer than four turns out of eighteen trials), and testing had to be discontinued for 4 other babies due to fussiness. The total number of babies entered into the analyses is therefore 59. Each baby participated in only one of the five studies (see Table 1 for a listing of sample size and sex distribution for each study). Demographic information for these 59 subjects is presented in Table 2. Demographic information for the 16 excluded babies are given in Table 3, showing that both groups were members of comparable populations.

General Procedure

The same general procedure was used for each study. Infants were tested in a quiet room on the neonatal unit approximately 30 minutes after feeding. The experimenter attempted to manipulate the infants into a quiet alert state before testing began. Subjects were placed in a supine position on an infant mattress, tightly swaddled to regulate arousal and to prevent self-stimulation of the face and head. Stimuli were presented via 10 cm speakers bilaterally placed approximately 15 cm

Table 1. Sample size and sex distribution on a study by study basis.

	Males	Females	Total
Study 1	7	5	12
Study 2	5	7	12
Study 3	5	5	10
Study 4	7	7	14
Study 5	5	6	11
Total	29	30	59

Table 2. Demographic Data of Included Infants

Subject Number (N=59)	BW[a] (gm)	EGA[b] (wks)	PNA[c] (hrs)	APGAR SCORES (1 min)	APGAR SCORES (5 min)
	Demographic Data				
1	3495	40	23.5	9	9
2	3765	40	26.75	8	9
3	3615	38	25.5	9	9
4	3605	40	43	9	9
5	3650	37	28	9	10
6*	3255		31.5	7	9
7*	3065		32	8	9
8	3215	39	44.75	9	10
9	3445	40	26.5	9	10
10	3600	40	39	9	9
11	3660	41	30.75	9	10
12	2980	38	31.5	9	9
13	3825	40	20	9	10
14	3270	41	30	9	10
15	3765	41	53.25	8	9
16	2550	39	44	9	9
17	3210	39	49.5	8	9
18	4065	41	35.5	9	10
19	3735	40	25.5	9	9
20	3685	39	29.75	9	9
21	2795	41	29	9	9
22	2950	41	52.75	9	10
23	3090	39	22.5	9	9
24	3360	38	41.5	9	10
25	2680	40	31	9	9
26	2585	40	27	9	9
27	3985	39	26.75	8	9
28	3485	39	31.75	9	10
29	2965	39	44.5	9	9
30	3185	42	55.5	9	10
31	3010	39	53	9	9
32	3730	41	27.5	9	9
33	2765	39	25.25	8	9

Table 2 (cont'd.)

34	3265	41	38	9	10
35	3665	39	44	9	10
36	2740	39	30.5	9	10
37	3550	40	53.75	9	9
38	3965	41	36.25	9	9
39	3790	42	29.75	9	9
40	3300	39	49	9	10
41	3605	39	36.75	9	10
42	3990	40	26.5	9	10
43	4220	41	45.75	9	9
44	3315	39	43	9	10
45	3760	41	40	8	9
46	3025	40	50	8	8
47*	2965	39	36.5	8	9
48*	2565	39	36.75	9	9
49	2890	40	36	9	9
50	3850	40	37.25	9	9
51	3670		32.25	9	10
52	3390	41	40.5	9	9
53	3100	37	31.5	9	9
54	3275	40	42	9	10
55	3370		30.5	7	9
56	3495	40	48.5	7	9
57	3310	42	39.75	9	10
58	3925	40	34	9	10
59	3500		32.5	9	9
MEAN	3381.9	39.8	36.3	8.7	9.3
SD	409.99	1.14	9.06	0.54	0.52

[a] BW stands for Birth Weight measured in grams
[b] EGA stands for Estimated Gestational Age measured in weeks
[c] PNA stands for Postnatal Age measured in hours

* These subjects are pairs of twins

Table 3. Demographic Data of Excluded Infants

Subject Number (N=16)	BW[a] (gm)	EGA[b] (wks)	PNA[c] (hrs)	APGAR SCORES (1 min)	APGAR SCORES (5 min)
	Demographic Data				
1	2810	37	32	9	10
2	2875	40	31	9	9
3	2425	36	24	9	9
4	3250	40	56	8	9
5	2970	37	48	8	9
6	2795	40	38	9	9
7	3290	40	52	9	10
8	3940	38	46	9	10
9	3410	39	45	9	10
10	3865	40	50	9	10
11	3840	39	32	9	10
12	4140	40	27	9	9
13	3085	39	32	9	10
14	3110	39	54	9	9
15	2980	40	25	9	10
16	3870	41	38	9	10
MEAN	3290.9	39.1	39.4	8.9	9.6
SD	503.28	1.39	10.79	0.34	0.51

[a] BW stands for Birth Weight measured in grams
[b] EGA stands for Estimated Gestational Age measured in weeks
[c] PNA stands for Postnatal Age measured in hours

* These subjects are pairs of twins

away from each ear. Auditory stimuli were initiated by depressing a footpedal attached to a CFS-W350 SONY Cassette Player.

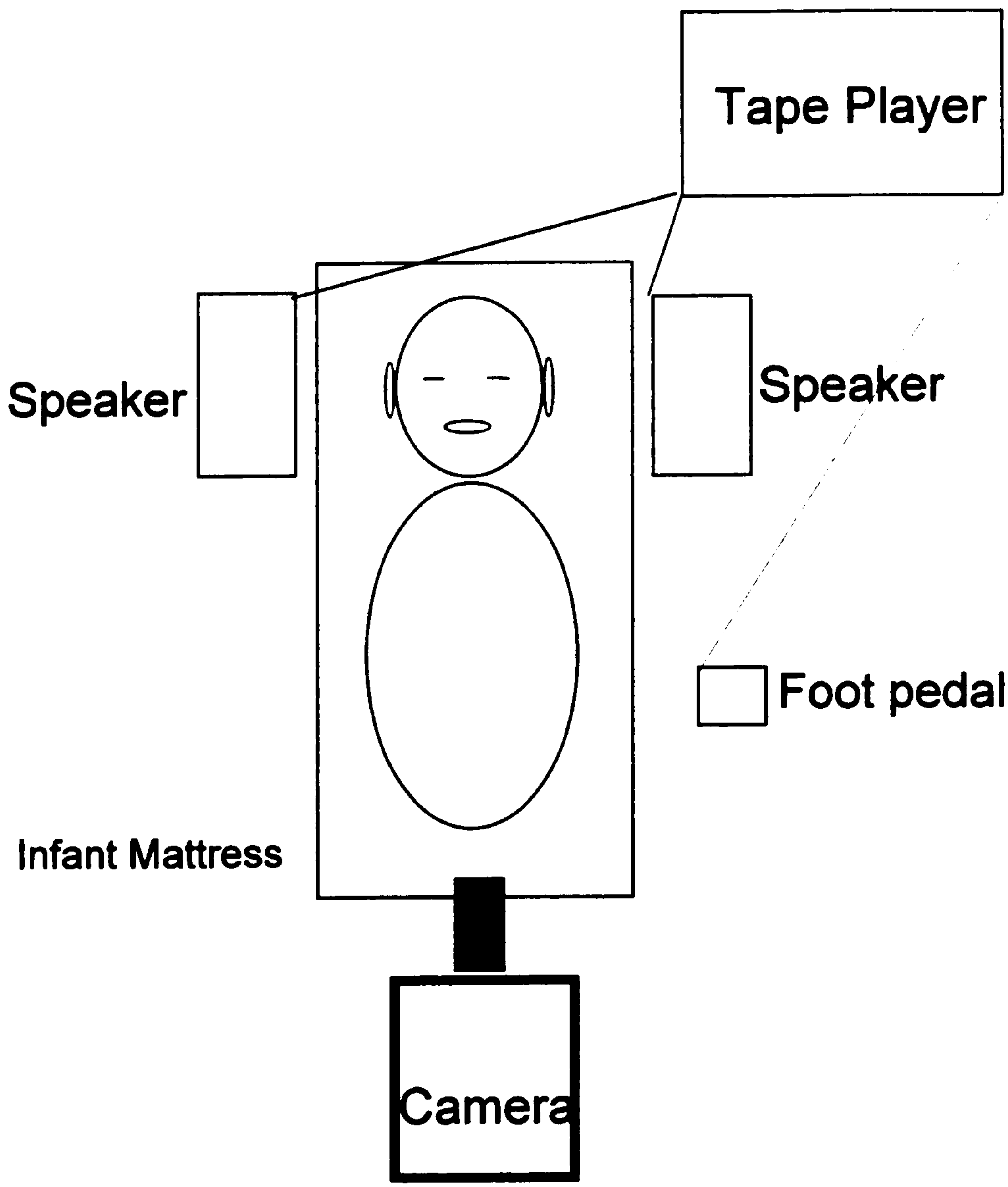
Each subject was presented with eighteen 20 sec trials of three possible binaural auditory stimuli: unfiltered female speech, intrauterine heartbeat sounds or modified female speech, and a no-stimulus control. Auditory stimuli were presented in semi-randomized blocks of six trials, with a short break to arouse or calm subjects between blocks if necessary. In order to counteract effects of positional biases and to start babies from a neutral position, the subject's head was held at midline preceding the onset of each trial until there was no pressure to turn against the experimenter's hands. The mean inter-trial interval (ITI) was 18.7 s; there was slight decrease in ITI over the eighteen trials, probably due to decreased neck muscle tonus in babies as the headturning task progressed (see Appendix A for ITI data). There was also a slight decrease in ITI over the five studies, probably due to improvement in the experimenter's head-centering technique between trials. The experimenter was blind to stimulus order. All test sessions were videotaped using a Panasonic AG160 videotape recorder. See Figure 2 for a schematic drawing of apparatus set up.

In addition to infant testing, a maternal interview was conducted to collect information to help characterize each individual baby's general prenatal experience, mother's experience of fetal responsiveness, the nature of the external acoustic environment, and whether explicit fetal stimulation routines were used. See Appendix B for an example of the maternal interview form.

Coding

Subsequent to test sessions videotapes were scored blindly (with audio off) for initial direction and final position of headturn. Turns were scored directionally from the infant's perspective. Initial turns were defined as the first detectable directional

Figure 2. Schematic drawing of the experimental situation.



head movement, scored right, left or no turn. Final head position was defined as subject head posture at the conclusion of each 20 sec trial, scored right, left or center.

Reliability

In order to assess the reliability of the coding procedure, reliability raters randomly selected three babies from each study and coded all eighteen test trials according to the instructions given in the coding section above. Matches were converted into percent agreement scores and then averaged over the fifteen subjects selected. Interrater reliability scores of 90% were achieved in coding initial turns and 95% in coding final head position.

Stimuli

In each of the five studies, headturning response to binaurally presented unfiltered female speech (UFS) was compared to headturning to binaural intrauterine heartbeat sounds or female speech which had been modified either acoustically or temporally, and a no-stimulus control.

UFS: Unfiltered female speech. The female speech tape plays a repeated spoken sequence "Hello. How are you today? What are you doing? Let's go for a walk."[1] While no spectral analyses were performed on this stimulus, women's voices are usually described as having a higher fundamental frequency, higher formant frequencies and larger formant bandwidths then men's voices (Kent & Read, 1992).
HTBT: Intrauterine heartbeat. The intrauterine heartbeat tape is a continuous recording of vascular pulsations recorded from within the uterus (Marooka, 1974).

[1]Thanks to Robin Panneton-Cooper for providing the female speech stimulus.

LPS: Low-pass filtered speech. The UFS sample referred to above was subjected to a low-pass filter at 500 Hz using a Krohn-Hite Model 3550 Variable Filter.[2]

HPS: High-pass filtered speech. The UFS sample was subjected to a high-pass filter at 3500 Hz in the manner described above.

BPS: The UFS sample was subjected to a band-pass filter with the lower cutoff at 1500 Hz and the upper cutoff at 3000 Hz.

HTSP: "Heartspeech". In order to tease apart the differential effects of spectral and temporal differences between speech and heartbeat sounds, a stimulus was created in which a small phrase of speech from the LPS condition was repeated at the rate of the intrauterine heartbeat stimulus. A phrase of LPS was used because heartbeat sounds are characteristically low in frequency range in utero. Two versions of the "heartspeech" stimulus were created; one using the phrase "Good morning" and one using the phrase "What are you doing?" Each phrase was repeated at a rate of 84-96 bpm. To create this stimulus, each LPS phrase was recorded onto the sequencer software program "Studio Vision" on a MacIntosh CI Computer, and then "looped" to match the repetition rate of the HTBT stimulus.

All stimuli were recorded onto a Tascam DA30 Digital Audio Tape Recorder in a semi-randomized order, with peak sound pressure levels matched using the VU meter, and then re-recorded onto SONY UX-Pro High Bias cassette tapes using a Tascam 122 Mark II Tape Recorder. All stimuli had a peak sound pressure level of approximately 80 dB (linear scale re .002 dynes/cm^2) measured using a Brüel & Kjaer Type 2203 Precision Sound Level Meter.

[2] It should be mentioned that the Kron-Hite Model 3550 Variable Filter that was used to create all filtered speech stimuli does not completely attenuate target frequency ranges. Rather, target frequencies are filtered to 24 dB, allowing a minimal amount of low intensity information from filtered frequency ranges to remain.

CHAPTER THREE

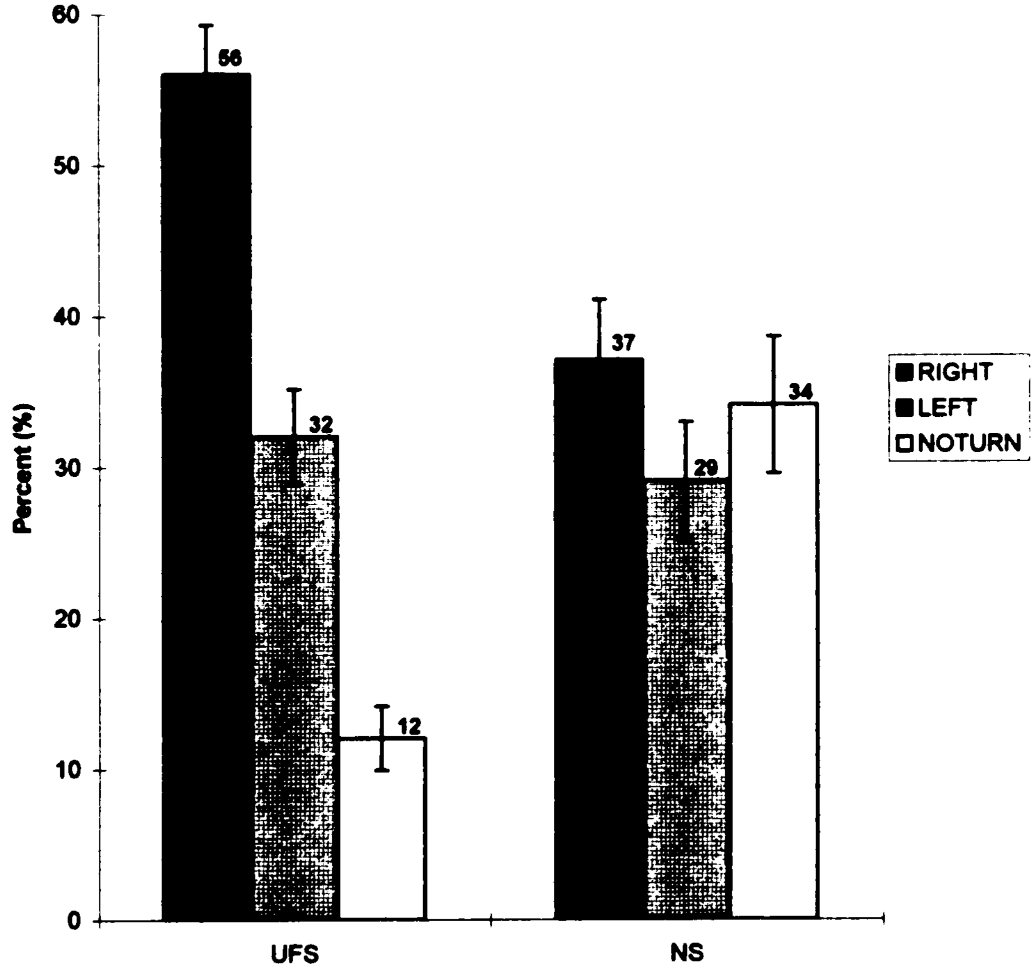
Results

This series of studies replicates and extends the findings of the pilot study, attempting to tease out the salient stimulus characteristics responsible for eliciting the lateral asymmetries observed in the initial investigation of headturning to binaurally presented sounds. The first study replicates the pilot study, addressing issues of stimulus intensity. The second, third and fourth studies explore response differences to specific spectral features of female voice. In the final study, changes in headturning patterns as a function of prosodic or temporal changes in female speech are the focus. These alterations are theoretically similar to the stimulus modifications developed by Gottlieb (1988). In each study, unfiltered female speech is compared to one other auditory condition, as well as a no-stimulus control.

Overall Analyses

The same general procedure was used in each study, making it possible to pool data across the five studies from the Unfiltered Speech (UFS) and No Stimulus (NS) conditions for analysis. The results of these analyses can be found in Figure 3. Overall, there were significantly more initial right turns than left turns or no turns within the UFS condition [$F(2,174)=62.28$, $p<.001$] with no significant difference in the directionality of initial turns within the NS condition overall. Further, there were significantly more initial right turns in the UFS conditions than in the NS condition [paired comparisons $t(58)=4.65, p<.001$, one-tailed]. It is interesting to note that the same pattern of directionality seen in the initial response to UFS overall was replicated almost identically in each of the subsequent studies.

Figure 3. Mean percentage of initial direction of turns (N=59).



UFS - Unfiltered Speech
NS - No Stimulus

An examination of possible changes in responses to UFS sounds over the course of the eighteen trial test situation compared initial turn frequencies to the first presentation of UFS to responses to the last presentation of UFS. No significant differences in directional responses as a function of the timing of stimulus presentation were revealed. These results are presented in Appendix C.

There were no significant differences in initial headturning directionality within the NS condition overall. Results of analyses of variance of each NS condition on a study by study basis are presented in Figure 4. The only significant main effect in these analyses was in Study 3, however a subsequent comparison of initial right vs. initial left turns using a paired comparisons t test found no signficant difference between them. Rather, there was a significant reduction in occasions of no response, an apparently anomolous finding.

As in the pilot study, initial turns seem to be more highly related to stimulus presentation than does final head position. All final head position data, with the exception of one condition in Study 5, show a tendency for right-oriented posture. Final position data is presented in Figure 5. These data suggest that initial direction of turn is a more sensitive measure of auditory responsiveness, with final head position more strongly influenced by babies' position preferences.

Finally, when individual response patterns were examined more closely, a possible bimodal distribution of directionality was revealed in the unfiltered speech condition. 63% of all babies showed the expected rightward orienting bias to unfiltered speech sounds, 25% showed a leftward bias in orientation to unfiltered speech sounds, and 12% showed an equal propensity to turn either left or right. A graphic demonstration of this distribution is presented in Figure 6, comparing individual subjects' laterality scores in both the unfiltered speech and no-stimulus conditions. As shown in this figure, the laterality scores in the NS condition approach a normal distribution around zero, while in the UFS condition the distribution clusters around +4 with a remaining

Figure 4. Mean percentage of initial direction of turns within each no-stimulus condition across studies.

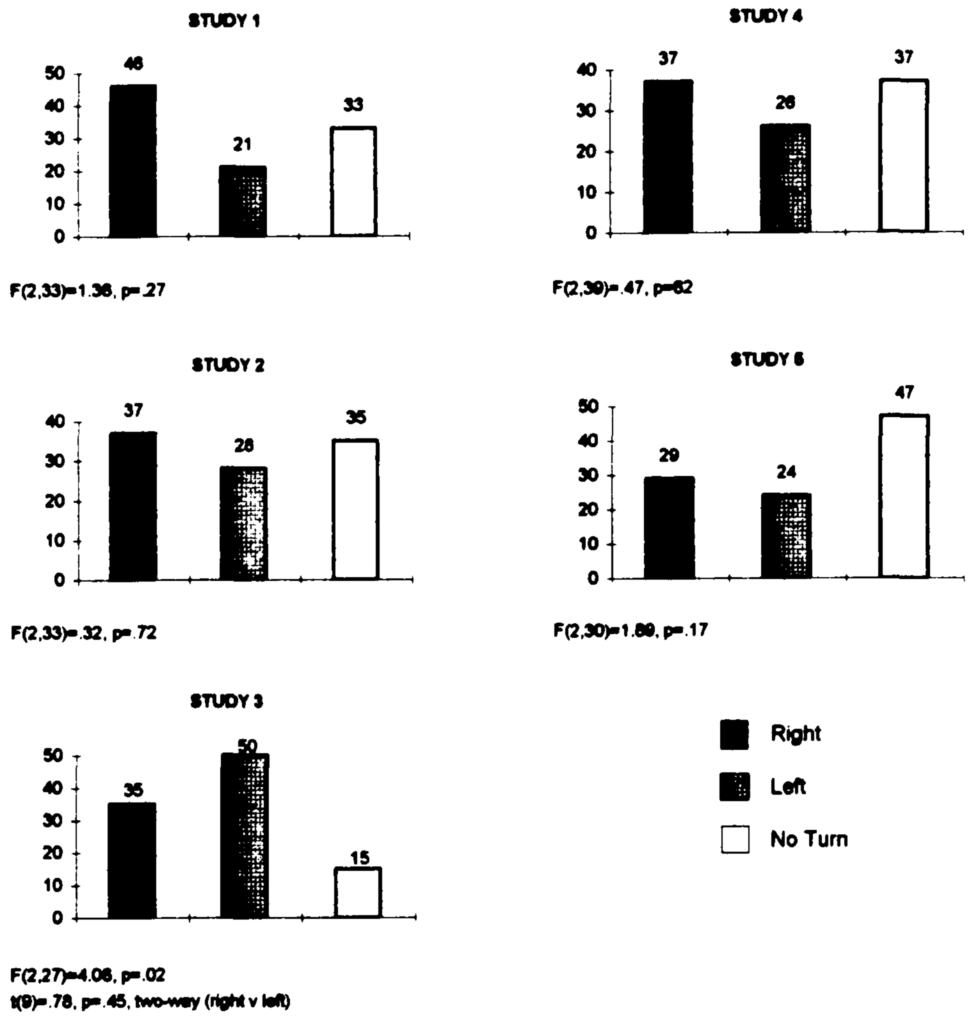


Figure 5. Mean percentage of final head position across studies.

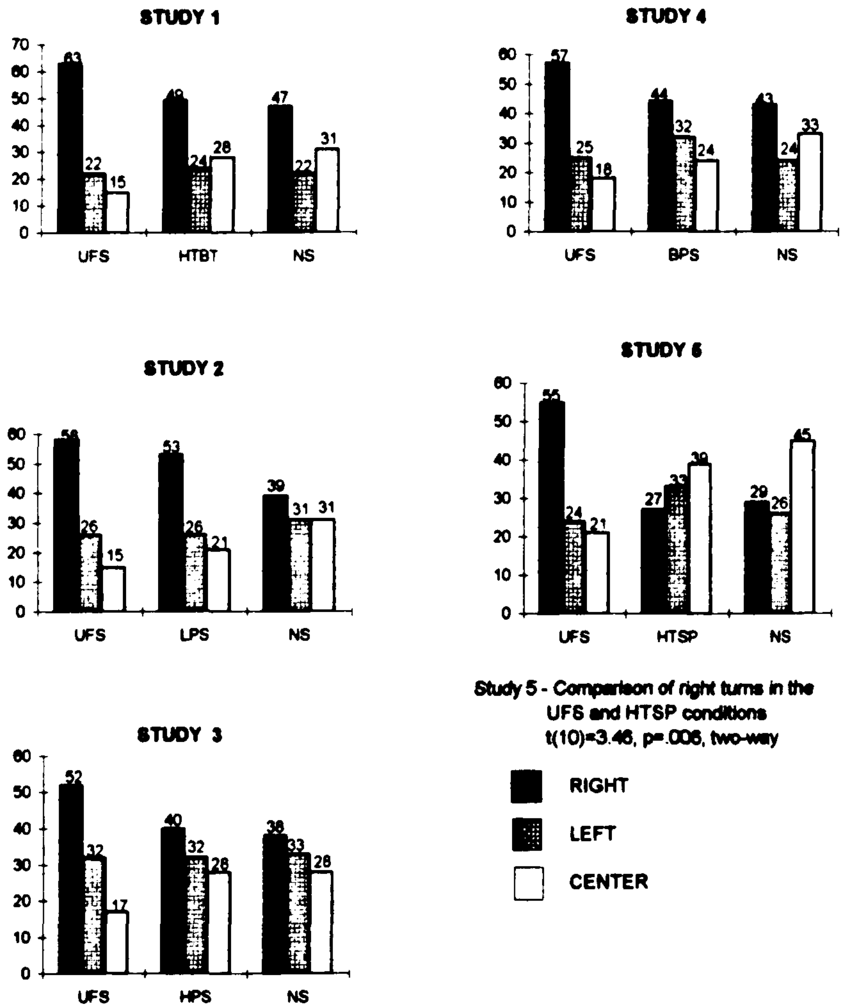
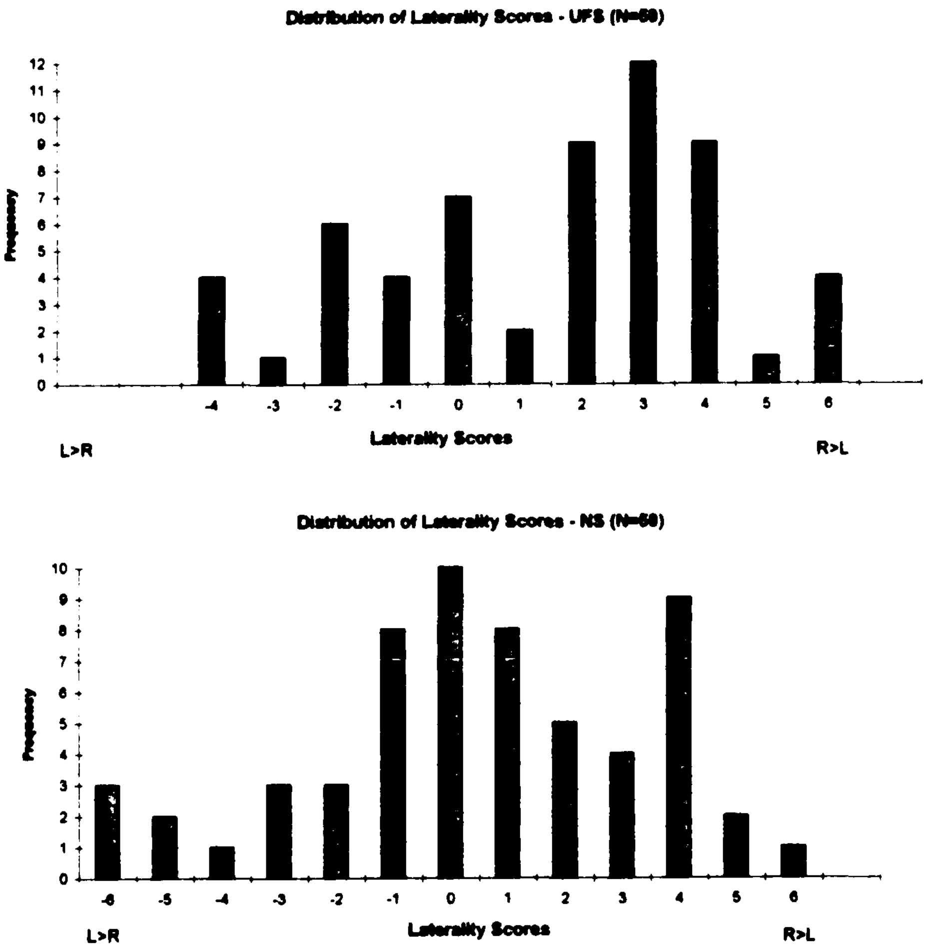


Figure 6. Comparison of laterality scores in the UFS and NS conditions.



Laterality Scores = Right - Left, where positive score indicates rightward bias and negative score indicates leftward bias cluster of negative scores which do not seem clearly related to the rest of the distribution. These percentages approach proportional distributions of laterality for other structures and functions (Harris, 1983; Previc, 1991) and will be discussed more fully in a later section.

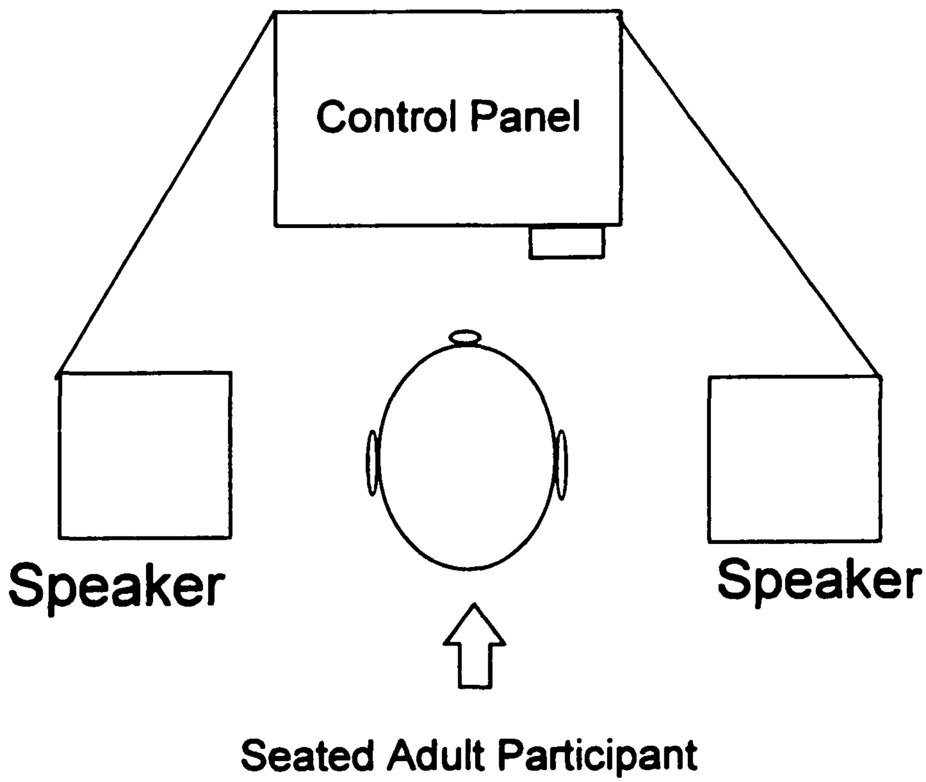
Unfiltered Speech and Intrauterine Heartbeat: A Replication

The first of this series of studies compared newborn directional headturning patterns to Unfiltered Speech (UFS) sounds with headturning patterns to intrauterine Heartbeat (HTBT) sounds. This is a replication of the pilot study discussed earlier. In the pilot study, both stimuli were administered at an intensity range of 74-82 dB. However, given that speech sounds are more dynamically changing in intensity and frequency range than intrauterine heartbeat sounds, the possibility exists that newborns' increased right headturns to the UFS stimuli were due in some way to a phenomenological difference in relative intensity. To test this possibility, a replication was planned in which the HTBT sounds would be presented at a higher peak dB level than that of the UFS stimuli. In order to select a meaningful ratio of amplitude between UFS and HTBT, a group of adults were asked to match, phenomenologically, the amplitude of the HTBT to the UFS stimulus in a series of 10 trials. The details of this adult matching test are presented below.

The Adult Matching Task

Seven adults ranging in age from 16 to 46 years (mean age = 27 years) served as raters in this matching task. Subjects were asked to sit in a chair facing a volume control panel with 10 cm speakers placed bilaterally at ear level 15 cm away (the same stimulus placement as used with newborn subjects). See Figure 7 for a schematic drawing of the test situation and apparatus placement. In each of ten trials, raters were asked to match the amplitude of the HTBT sounds coming from one speaker

Figure 7. Schematic drawing of adult matching task experimental situation.



with the UFS sounds coming from the other, by turning a wheel which controlled amplitude. The UFS stimulus was the target stimulus and had a fixed amplitude. The stimuli used were identical to those used with newborn subjects. Stimulus presentation was rotated after five trials so that equal numbers of each stimulus were presented to each ear. Similarly, half of the trials required an increase in amplitude to match to the target stimulus and half required a decrease in amplitude. Sound pressure level was measured following each trial with a Brüel & Kjaer Type 2203 Precision Sound Level Meter. The results of this matching task are presented in Figure 8. The amplitude range of the UFS stimuli was between 72 and 82 dB. After the first few trials, each adult rater consistently adjusted the amplitude of the HTBT sounds to be louder than UFS. The mean increase in amplitude over the last six trials was 5.6 dB louder than the peak dB level of the UFS stimulus. On the basis of the results of this adult matching test, it was decided that HTBT sounds would be presented with a peak amplitude 6 dB louder than UFS in the newborn replication study.

Replication Results

The comparison of newborn headturning response to UFS and HTBT (n=12) are presented in Figure 9. A within-condition analysis of variance of initial turn frequencies revealed significantly more right headturns than left turns or no turns to UFS [$F(2,33)=14.91, p<.001$], but no significant differences in directionality in the HTBT condition. Between condition comparisons of mean frequencies of initial right turns to UFS and HTBT revealed significantly more initial right turns to UFS [paired comparisons $t(11)=2.53$, $p=.014$, one-tailed].

Comparisons of the results of this study with the results of the pilot study reveal strikingly similar response patterns, indicating that stimulus intensity differences of the magnitude utilized in the replication are not sufficient to influence the effect. On this

Figure 8. Results of adult matching task (N=7).

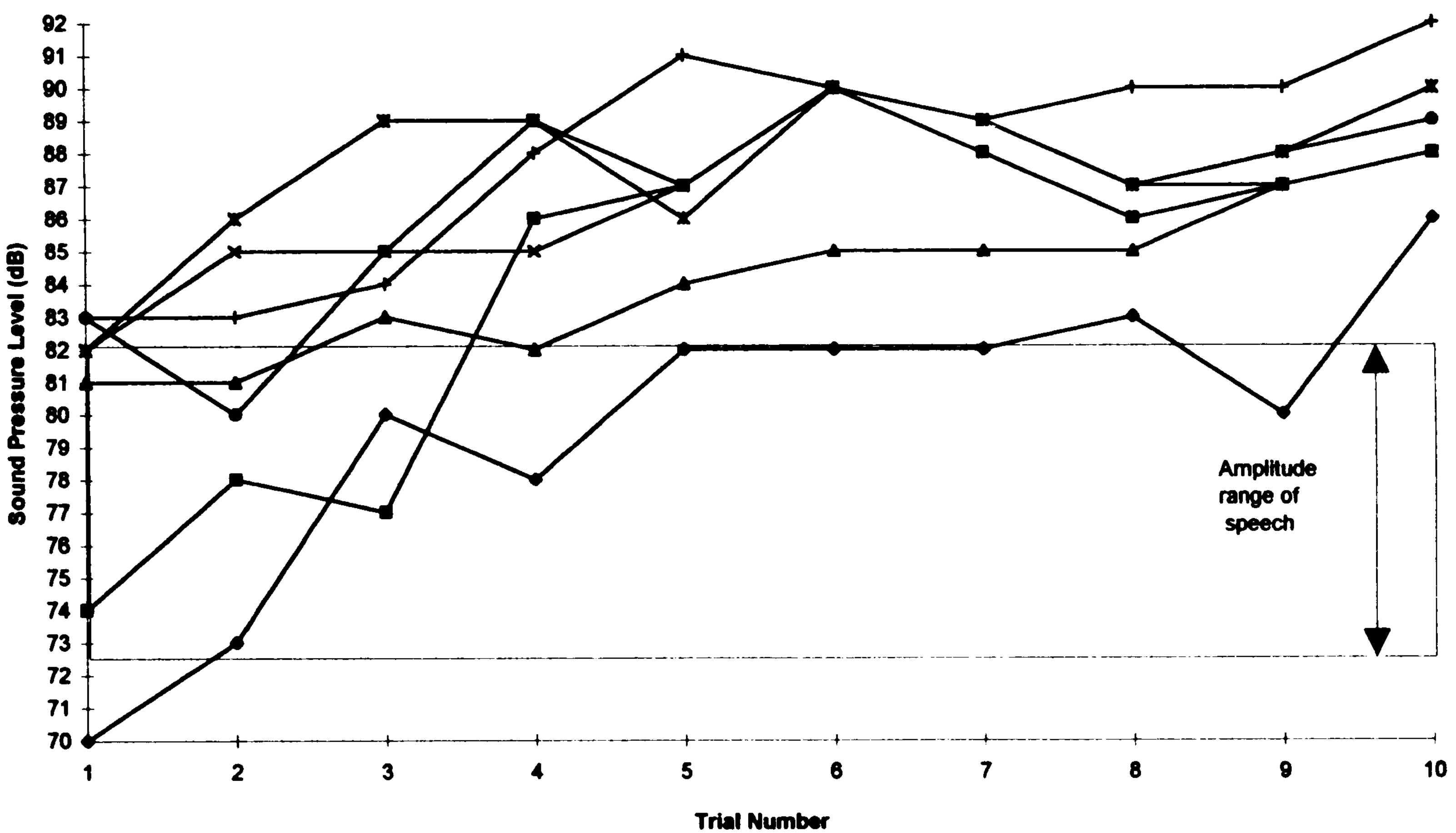
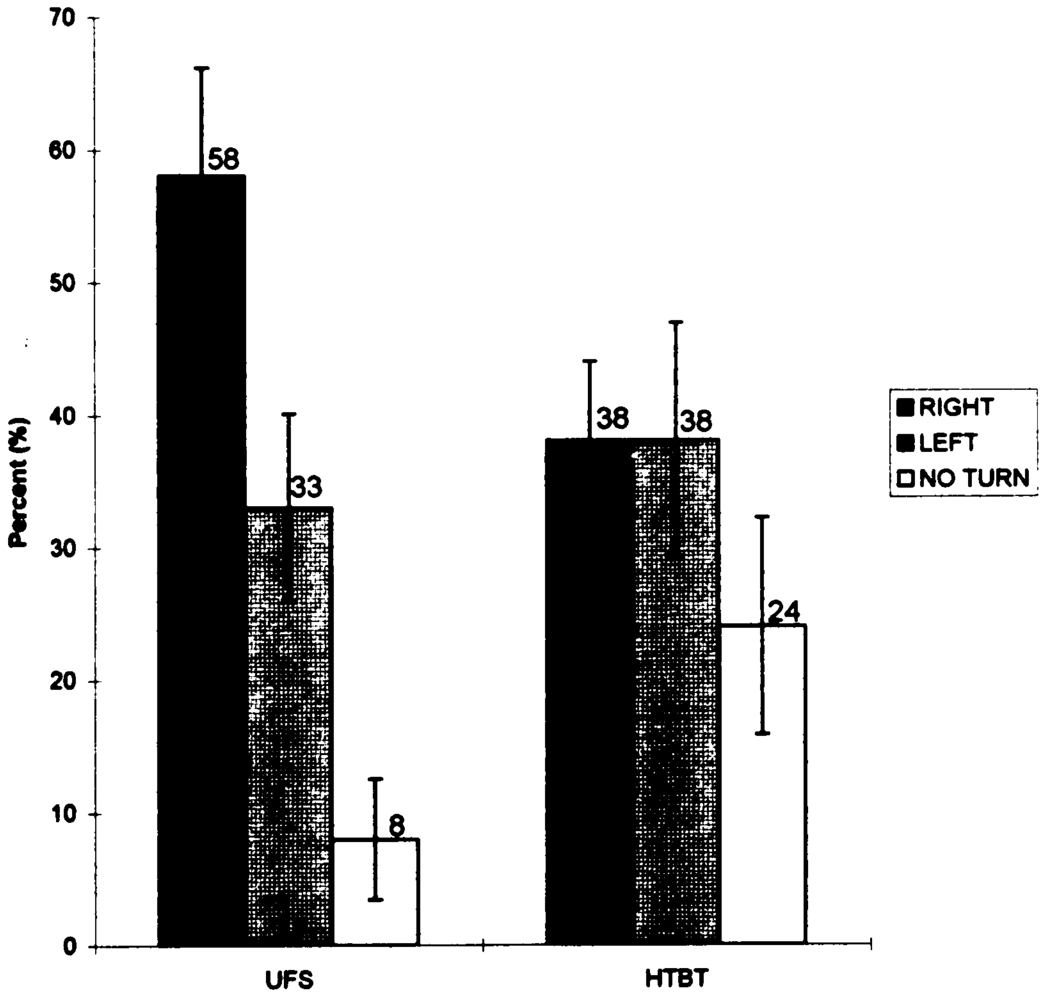


Figure 9. Mean percentage of initial direction of turns (N=12).



UFS - Unfiltered Speech
HTBT - Heartbeat

basis the decision was made to match stimuli according to peak sound pressure level in all subsequent studies.

Acoustic Manipulations of the Speech Stimulus

The next three studies all involve the examination of changes in patterns of directional headturning as a function of changes in the spectral characteristics of the speech stimulus. In each study headturns to UFS are compared with turns to a sample of the same speech stimulus which has been filtered, based upon what we believe to be the acoustic properties of speech sounds in utero.

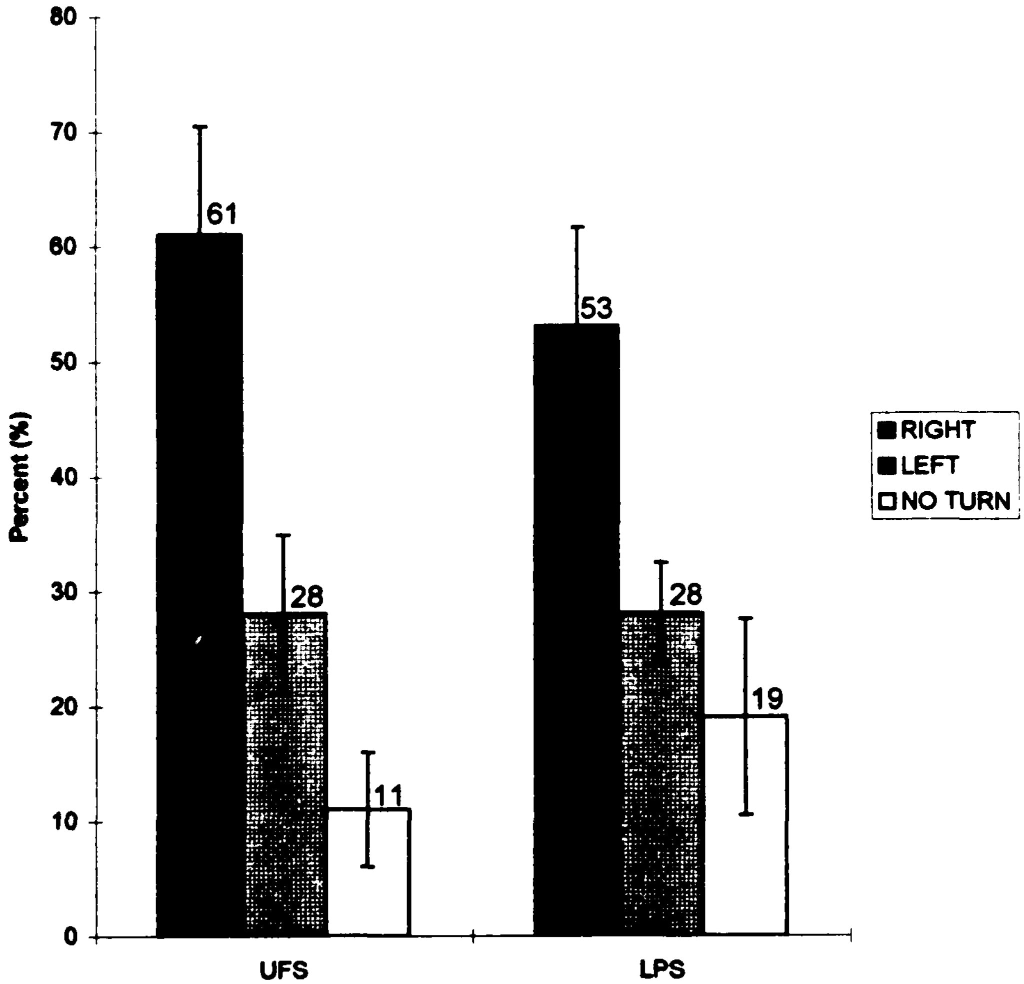
Unfiltered Speech and Low-Pass Filtered Speech

This study (n=12) compared headturning response to UFS with turns to speech which had been Low-Pass filtered (LPS) at 500 Hz. Within-condition analysis of variance of initial turn frequencies showed significantly more right turns than left turns or no turns to both UFS [$F(2,33)=13.20, p<.001$] and LPS [$F(2,33)=5.98, p<.01$], with no significant difference in mean frequencies of right turns between UFS and LPS (see Figure 10).

Unfiltered Speech and High-Pass Filtered Speech

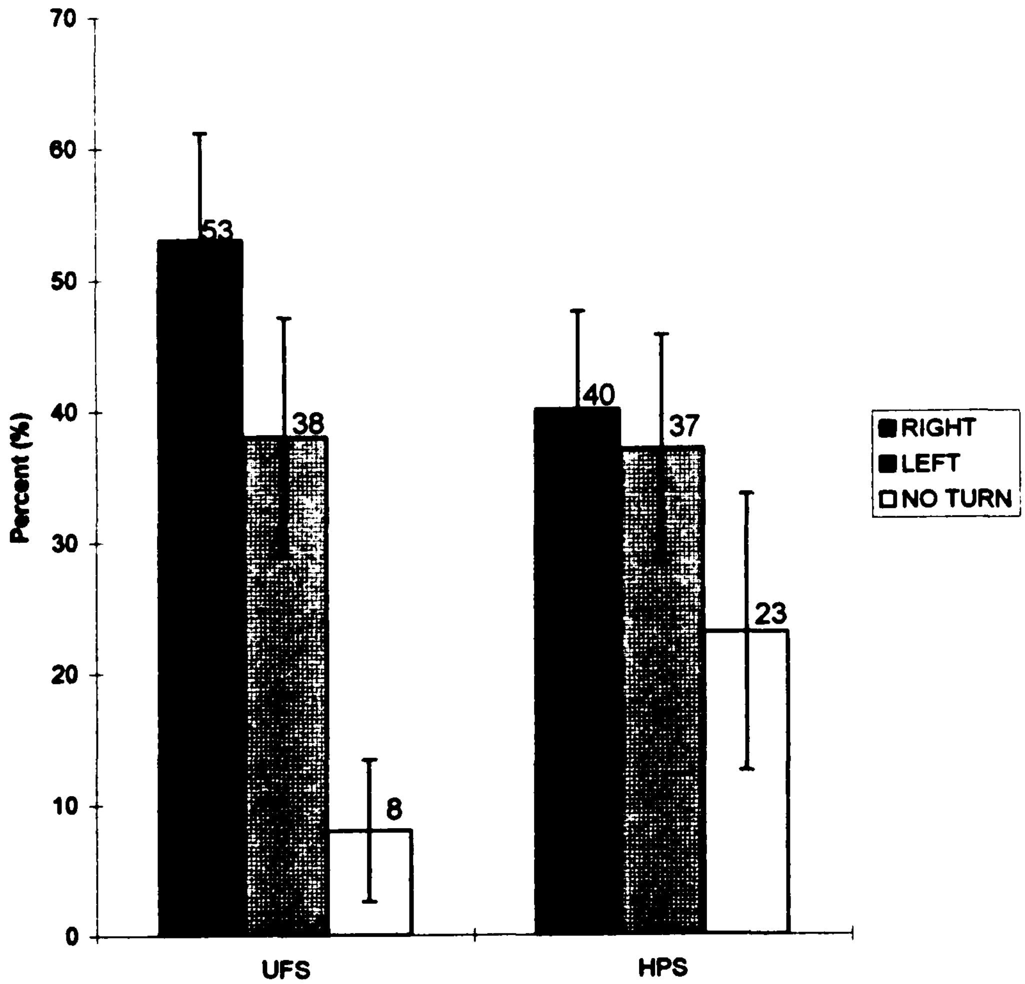
The next study (n=10) compared headturning response to UFS with turns to speech which had been High-Pass filtered (HPS) at 3500 Hz. Within-condition analysis of variance of turn frequencies showed significantly more right turns than left turns or no turns to UFS [$F(2,27)=9.82, p<.001$], and no significant difference in directionality within the HPS condition. However, no significant differences were found in comparisons of mean frequencies of initial right turns between UFS and HPS (see Figure 11).

Figure 10. Mean percentage of initial direction of turns (N=12).



UFS - Unfiltered Speech
LPS - Low-Pass Filtered Speech

Figure 11. Mean percentage of initial direction of turns (N=10).



UFS - Unfiltered Speech
HPS - High-Pass Filtered Speech

Unfiltered Speech and Band-Pass Filtered Speech

The last of this series of studies (n=14) examining headturning patterns to acoustically manipulated speech sounds involved a comparison of response to UFS and speech which had been Band-Pass filtered (BPS) between 1500 and 3000 Hz. Within-condition analysis of directional turn frequencies showed significantly more initial right turns than left turns or no turns to UFS [$F(2,39)=18.72, p<.001$] and BPS [$F(2,39)=6.88, p<.01$], and no significant difference in mean frequencies of right turns between UFS and BPS (see Figure 12).

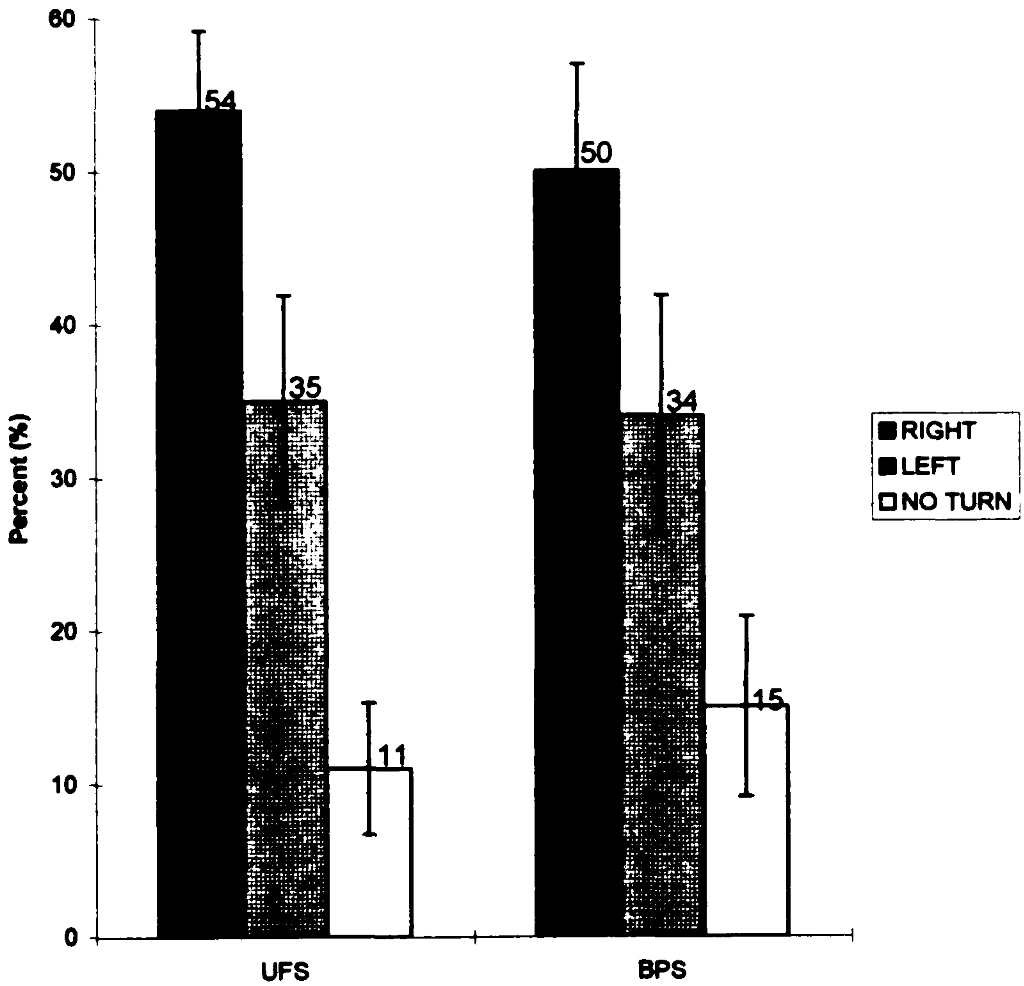
A Temporal Manipulation of the Speech Stimulus

Given the results of the first four studies, which indicate significant differences in newborn headturning to UFS and HTBT sounds, but quite similar response to both unfiltered and filtered speech sounds, an examination of the differences between speech and heartbeat sounds which is not solely acoustic was undertaken, i.e., a manipulation of the rhythmic or prosodic characteristics was planned. Heartbeat is a continuous and repetitive sound, not discrete and episodic like speech sounds. The possibility that this robust, right-lateralized headturn to UFS was based not only on the frequency characteristics of speech, but also on the temporal properties of speech, was explored in this final study.

Unfiltered Speech and "Heartspeech"

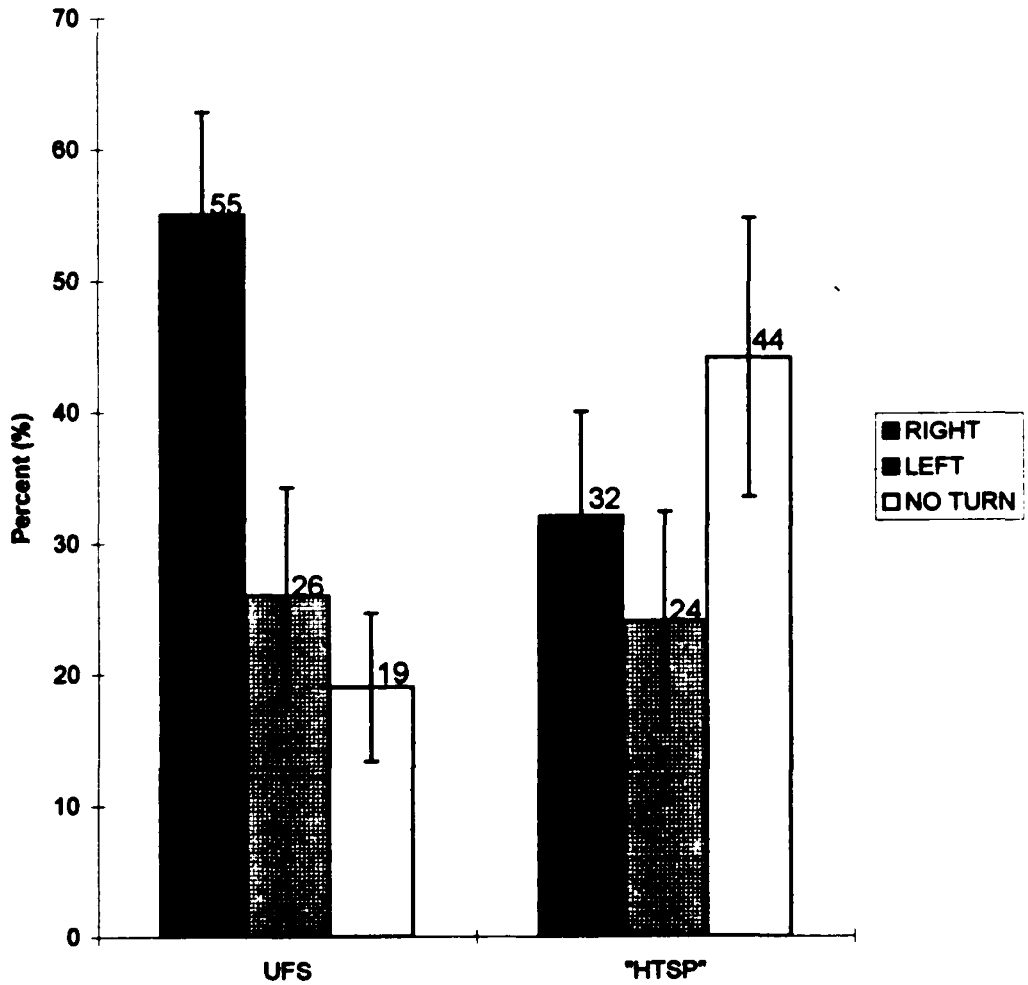
In this study (n=11) headturning patterns to UFS were compared with responses to a phrase of LPS which was repeated at the rate of the intrauterine heartbeat. Two stimulus versions were created, one using the phrase "Good Morning" and one using the phrase "What are you doing?", each repeated at a rate of 84-96 bpm. This stimulus is termed "Heartspeech" (HTSP). The results of this study are shown in Figure 13. Within-condition analysis of variance revealed significantly more initial

Figure 12. Mean percentage of initial direction of turns (N=14).



UFS - Unfiltered Speech
BPS - Band-Pass Filtered Speech

Figure 13. Mean percentage of initial direction of turns (N=11).



UFS - Unfiltered Speech
"HTSP" - "Heartspeech"

right turns than left turns or no turns to UFS [$F(2,30)=7.15, p<.01$], but no significant differences in directionality within the HTSP condition. Additionally, comparisons of frequencies of right turns between the UFS and HTSP conditions showed significantly more right turns in the UFS condition [paired comparisons $t(10)=2.10, p<.05$, one-tailed].

Maternal Interview

Mothers were asked a series of questions about their experiences with fetal activity and reactivity while they were pregnant. Questions were open-ended and mothers were encouraged to offer anecdotes about their experiences. 81% of mothers reported responsive movement by the fetus; of those mothers, 45% reported fetal movement in response to sound (speaking or singing), 19% reported response to tactile stimulation (rubbing abdomen) and 36% reported fetal movement to maternal eating or sleeping. 50% of mothers interviewed said they purposefully stimulated their fetuses; 85% of those reporting stimulation routines said they talked, sang or played music for their fetuses daily. Results of the maternal interviews are presented in Appendix D.

Summary of Findings

A robust, asymmetric pattern of lateral headturning occurs in most newborns' responses to binaurally presented unfiltered female speech sounds, with increased initial right orientation revealed in five replications. This consistent pattern of lateralized headturning occurs in the majority of newborns despite changes in relative stimulus intensity, and does not occur in the absence of an auditory stimulus. Examination of individual response patterns reveals a bimodal distribution of laterality in response to unfiltered female speech sounds, with proportional distributions of rightward and leftward laterality resembling bimodal distributions found in other areas of lateralization cited in the literature.

Intrauterine heartbeat sounds, on the other hand, do not elicit the same pattern of headturning lateralization. Group analyses show a nearly equal propensity to turn right, left, or not at all, significantly undermining the right-oriented headturn bias found in response to unfiltered female speech.

This right-oriented bias is not disturbed when the female speech stimulus undergoes a low-pass filter at 500 Hz. Newborns treat these stimuli as equivalent, i.e., the proportional distribution of directional turns was nearly identical when comparing response to unfiltered female speech and low-pass filtered speech. This is not surprising given the impressive amount of information from the literature which suggests that frequencies below 500 Hz are the least attenuated in utero and therefore the most available to the fetus.

Newborn response to high-pass filters of the speech stimulus at 3500 Hz is not equivalent to response patterns to unfiltered female speech, although the picture is not clear-cut. While there were no significant directional differences within the high-pass condition, there is also not a significant difference in right-oriented headturns between unfiltered speech and high-pass filtered speech. This issue will be more fully explored in a later section dealing with post hoc analyses.

Comparisons of newborn headturning response to unfiltered female speech and band-pass filtered speech are puzzling. Group analyses show no significant differences in newborn responses to these stimuli, and proportional distributions of directionality are almost identical between the two conditions. This is puzzling because this band-pass filter leaves undisturbed those frequencies which are hypothesized to be most completely attenuated in utero, from 1000 to 3000 Hz. Several factors may be operating here. First, the filter used in these studies is not complete; target frequencies are attenuated only to 24 dB. Perhaps there is still sufficient stimulation from the lower frequencies to elicit a right-lateralized response. Second, all newborns may not be responding equivalently to this stimulus, an issue which again will be addressed in the section on post hoc analyses listed below. Third, the processes which underlie this orientation bias to speech sounds may be not solely acoustically based, a possibility which becomes compelling in the final study of this series. Either way, the results of the study comparing response to unfiltered female speech and band-pass filtered speech are at once both puzzling and intriguing.

The final stimulus manipulation was chosen on the basis of the mixed picture emerging from the response data to acoustical manipulations of the female speech stimulus. While lateralized response in headturning to unfiltered female speech and low-pass filtered speech are comparable, group responses to high-pass filters and band-pass filters are harder to interpret. Manipulations of the prosodic characteristics of speech seem the next most likely place to look for difference in response. As predicted, it appears that changes in the rhythmic characteristics of the stimulus, as is the case with continuous repetitive stimuli like heartbeat sounds or speech phrases having analogous repetition rates to heartbeat, undermine or degrade this right-oriented response bias, resulting in an equal propensity to turn right, left or not to turn at all. Stimuli of this repetitive nature do not seem to be equivalent to stimuli with linguistic rhythmic characteristics in terms of the right-oriented headturning bias to binaural stimuli.

Post Hoc Analyses

There are several places in the group data where questions remain open. In an attempt to tease apart factors which may be at play, some post hoc analyses were performed. In particular, there have been reports that different rates and trajectories of the development of lateralization may exist for males and females (Lewkowicz & Turkewitz, 1982). Although the subject size is small when comparing male and female babies for these analyses, the findings suggest potentially important issues for understanding the development of sensorimotor asymmetries.

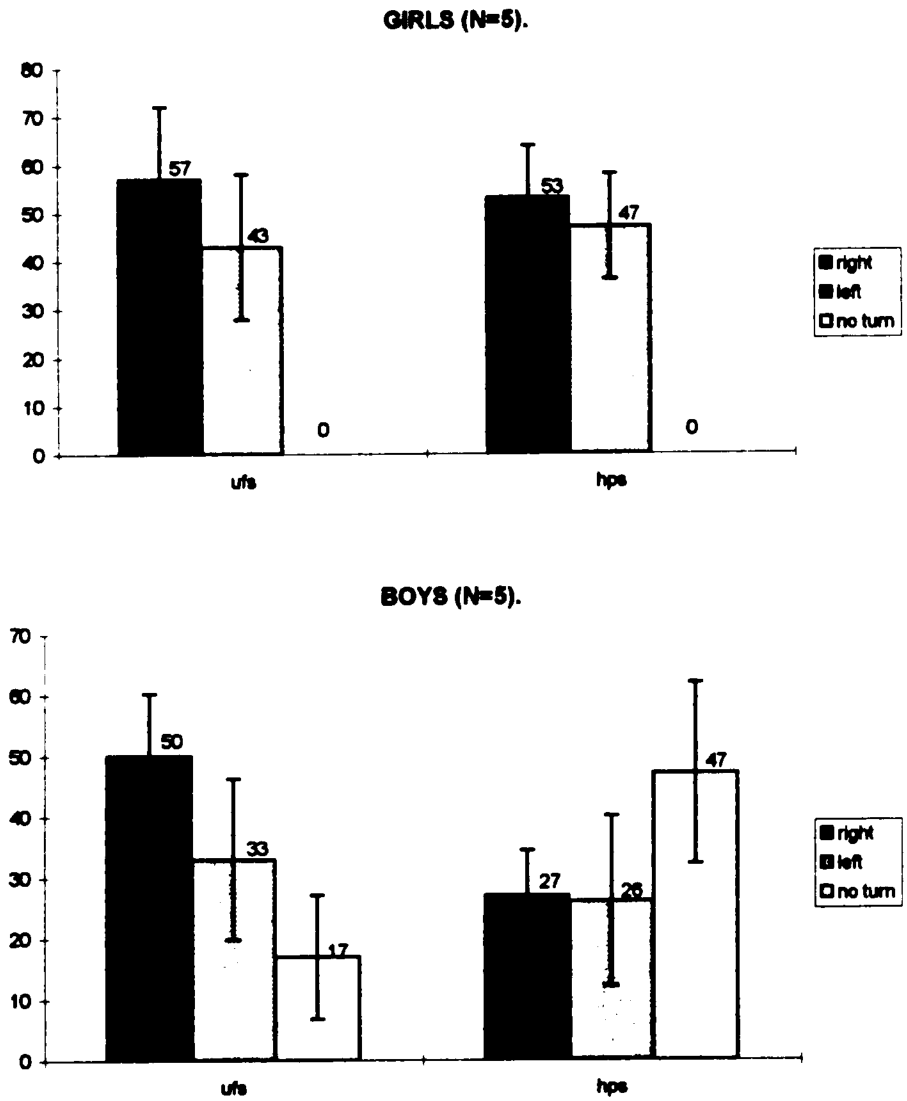
In the study comparing initial headturns to unfiltered speech and high-pass filtered speech, although as a group babies showed no difference in directionality within the high-pass condition, closer examination of scores by sex reveals that males had a tendency to be less responsive to the high-pass condition than females, with males showing a 53% response rate while females responded with a turn 100% of the time [$t(3)=-2.67, p<.07$, two-tailed]. See Figure 14.

In the study examining newborn headturning to band-pass filtered speech, as a group babies showed significantly more right headturns to band-pass filtered speech, but analyses by sex reveal that female babies tended to show more right headturns than male babies in this condition [$t(7)=1.98, p=.08$, two-tailed]. See Figure 15.

Male and female babies exhibited no detectible difference in response to unfiltered female speech, low-pass filtered speech and "heartspeech". No significant sex differences were found in these conditions.

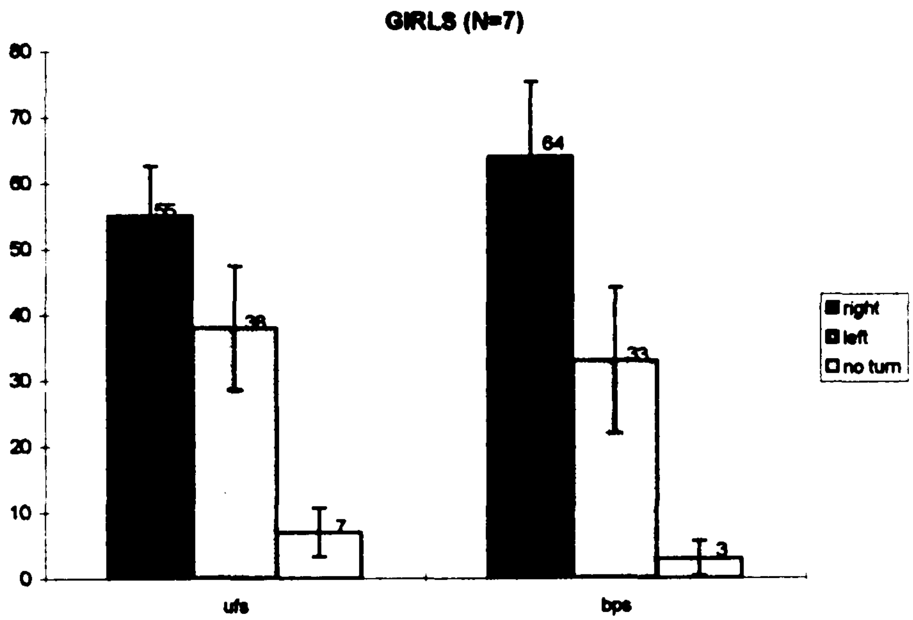
While only suggestive, these findings reveal interesting possible differences, and similarities, between male and female newborns in terms of their patterns of auditory-motor lateralization. The combined data derived from the group results and post hoc analyses may give us important clues to the underlying processes involved in this lateralized orienting behavior, an idea which will be explored in the next section.

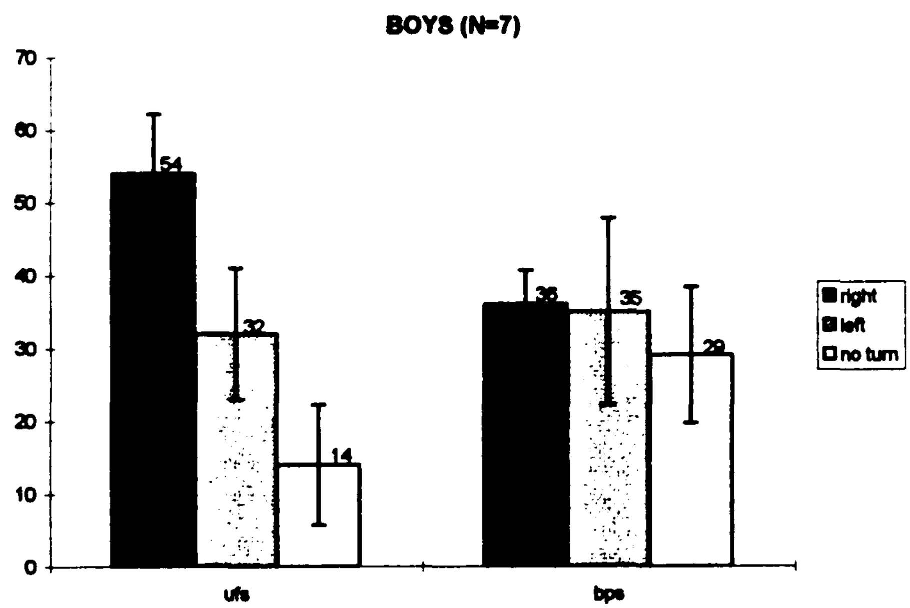
Figure 14. Comparison of mean percentages of initial directional turns by sex - UFS , HPS.



UFS - Unfiltered Speech
HPS - High-Pass Filtered Speech

Figure 15. Comparison of mean percentages of initial direction of turns by sex - UFS , BPS.





UFS - Unfiltered Speech
BPS - Band-Pass Filtered Speech

CHAPTER 4

Discussion

Before considering the possible underlying sensorimotor processes which may be organizing the behaviors found in these studies, a brief review of the findings seems in order.

- **A robust, asymmetric pattern of headturning occurs in most newborns' responses to binaurally presented unfiltered female speech sounds, with increased initial rightward orientation demonstrated in five replications.** Although external stimulation was equivalent to each ear, all studies revealed a significant tendency for babies to orient in a rightward direction when presented with unfiltered female speech sounds.
- **This orientation bias occurs despite changes in aspects of relative stimulus intensity.** Moon (1994) has argued in her replication of this phenomenon that lateralization processes may not be at work here. She contends that speech sounds may simply be more arousing than heartbeat sounds, and that this increased arousal increases a behavior that is already part of the newborn's repertoire - a right-oriented head posture. The findings from the first replication study presented here, in which heartbeat sounds were presented to newborns at a greater amplitude than speech sounds, seems to refute this idea. Despite this change in relative amplitude, and thereby the greater arousal-producing potential of heartbeat sounds presented in this way, no rightward bias was elicited.
- **Overall, changes in the spectral characteristics of female speech sounds do not significantly alter this rightward orientation bias, although male and female babies may respond differently to such changes.** The results of the responses to filtered stimuli are mixed and harder to interpret. Changes in spectral characteristics change the intensity of the stimulus as well, although in an attempt to address this issue all filtered speech stimuli were presented with peak sound

pressure level matched to unfiltered speech stimuli. The sex differences suggested in response to these filters will be examined in terms of the clues they provide to the relationship between asynchronous growth patterns and changes in effective stimulation as a basis for the development of lateralization. The discussion of this issue will question the role of frequency characteristics as necessary and sufficient factors for lateralization, a notion which most theories of speech lateralization use as their central explanatory construct.

- **Binaural presentation of intrauterine heartbeat sounds, resulted in an *equivalent propensity to turn right, left, or not to turn at all.*** Intrauterine heartbeat sounds and female speech sounds are both known to be important prenatal sources of auditory stimulation, although newborn headturning response to them is quite different. This difference in response and key differences in these stimuli will provide important clues to their sensorimotor organization in this discussion.
- **Presentation of speech sounds which were manipulated temporally, i.e., made more heartbeat-like, failed to generate the rightward orientation bias as well.** Low-pass filtered speech sounds were used in this "heartspeech" condition, providing the hardest test case given the significant right-lateralized response these sounds elicited when prosodic characteristics were undisturbed. Despite the fact that low-pass filtered speech sounds were used, the manipulation of the rhythmic characteristics of the speech stimulus significantly altered the newborn headturning response to it. The role of temporality as a significant factor for lateralization becomes an interesting notion which is almost completely unconsidered in the lateralization literature.
- **Examination of the response characteristics of individual babies to unfiltered female speech reveals a distribution of orientation biases, with the majority *of babies showing a rightward headturning bias, but a cluster of babies***

demonstrating a leftward headturning bias and a small group of babies showing an equal propensity to turn right or left. As with other lateralized motor behavior, e.g., adult handedness, there is a proportional distribution of laterality. A review of other authors' explanations of the meaning of this distribution for understanding the processes leading to these behaviors will inform the treatment of this issue here.

The Rightward Orientation Bias to Speech Sounds

The results clearly indicate that female speech sounds are a particularly salient class of stimuli for eliciting asymmetric response biases in newborn headturning when presented binaurally. The presentation of unfiltered female speech sounds, as well as low-pass filtered speech sounds, resulted in a response profile of laterality which is highly stable across all subject groups.

Previously cited evidence has emphasized the salience of maternal speech sounds in the intrauterine world of the developing fetus; maternal speech sounds which possess spectral characteristics highlighting its lowest frequencies. Taken together, the current results and this evidence seem to implicate prenatal experience with female speech sounds as the likely antecedent to the response bias in headturning that these studies revealed. How such experience might result in response asymmetries is the question before us.

The results of the maternal interviews suggest that fetuses are responsive to maternal speech in a way that is perceptible by mothers. Maternal voice is not a static, unconnected stimulus, but rather a responsive and dynamic one, which is often accompanied by related movement and tactile stimulation. Fetal activity elicits stimulation as well, and the integration of different stimulus modalities in activity and responsive movement surrounding speech sounds must add to the general salience of this stimulus for the fetus.

Denenberg (1981) provides data suggesting a role for general stimulation in the development of laterality in his examination of the multiple effects of early handling upon behavioral, physiological, biochemical and morphological parameters of development. In a study of rat pups, Denenberg compared groups that received daily handling and exposure to an enriched environment, and the subsequent effect on open-field activity, right-left directionality, and taste aversion in pups who received hemispherectomy of the right or left neocortex. Denenberg found that the effects of general stimulation in early development was asymmetrically distributed between the two hemispheres. For example, in an examination of subsequent right/left orienting during open-field exploration, handled animals demonstrated a significantly greater tendency to exhibit leftward oriented exploration than those in the nonhandled experimental condition, an effect which greatly increased in animals who had left brain removed, but right hemisphere intact. These studies support both the idea of the development of functional lateralization as the result of general stimulative experience, and that right/left orienting behavior may be under contralateral hemispheric control.

The message from Denenberg's work is that seemingly unchanging stimulative experience varies in the effectiveness of its impact on, and role in the development of, the changing organism. In the real world, however, even general stimulative experience is not static. Turkewitz (1990) offers an interesting proposal implicating the importance of the characteristics of the developing fetus and its experiences in a changing environment in shaping the asymmetric cortical capacities apparent at birth. Turkewitz cites evidence of variable growth gradients of different brain regions, in particular differential hemispheric growth. The effective stimulation available varies through gestation as a result of uterus distension, which would allow more unattenuated speech stimulation in more advanced stages of pregnancy, a period during which there is also an increase in left hemisphere growth. Kellaway (1989) has confirmed the relationship between periods of heightened neural growth and simultaneous effective stimulation as critical in defining the processes at work during "sensitive periods". Turkewitz highlights airborne maternal speech, somesthetic stimulation via pressure changes resulting from maternal diaphragmatic movements, and speech stimulation via bone conduction, as stimulative sources critical to the development of left hemisphere advantages due to heightened growth rates during this period. These same asymmetries may give rise to subsequent lateralization via processes such as those described by Turkewitz & Kenny (1982) in terms of sensory limitations and limitations on neural space. To illustrate, Turkewitz proposes that neonatal hemispheric specialization for processing different types of acoustic information may have a more general role in establishing characteristic modes of information processing. For example, the co-occurence of auditory stimulation from speech with visual exposure to faces, combined with the constraints imposed by the neonate's visual system (poor contrast sensitivity to low/moderate density spatial frequencies) is seen as providing the foundation for the development of right hemisphere specialization for processing configurational visual information. In this example the relative unavailability of the left hemisphere due to speech processing specialization is seen as a developmentally crucial impetus for the emergence of a right hemisphere visual processing specialization. A recent study of neonatal headturning to visual stimuli (faces) which moved laterally from midline out of the neonate's field of vision found a newborn tendency to visually fixate for longer durations on faces which moved laterally left than faces moving laterally to the right (Easterbrook, 1994). The evidence from Easterbrook's study showing a left headturning bias to face stimuli, combined with the results from these studies showing a right headturning bias to speech stimuli seems to support Turkewitz's theory for the development of hemispheric specialization.

Heartbeat Sounds - The Great Equalizer?

Previously cited evidence from the literature has also focused on the salience of intrauterine heartbeat sounds and maternal and placental vascular pulsations as important aspects of the intrauterine acoustic environment. The results of these studies has shown that intrauterine heartbeat sounds do not elicit lateral response biases. Continuous, repetitive stimuli of this kind undermined the lateral response bias in newborn headturning, reducing it to chance levels.

Given that female speech sounds and intrauterine heartbeat sounds are both present and audible prenatally, what differences exist between these two stimuli, and how might these differences provide clues to the nature of the newborn perceptual-motor asymmetries revealed in these studies? First, speech sounds are episodic and event-like, not continuous and ever-present like heartbeat or vascular pulsations might be. And while variations in pulsation rate may be related to maternal or fetal activity, the range of such variations would be minimal compared to the wide variations in rate, amplitude, frequency range and incidence of occurrence of maternal speech sounds. Another important difference between these two stimuli to consider is changes in audibility with changes in fetal position. It has been shown that vascular pulsations are louder closest to the placenta. It stands to reason that fetal movement toward or away from the placental region would affect the salience of this stimuli to the fetus. The polymodal nature of maternal speech would change this picture somewhat. Speech is carried in several ways in utero; down the maternal spinal column, via diaphragm movements and through air conduction. Fetal position changes might change the primary modality of transmission but not necessarily significantly alter its overall salience. Another important factor to consider is that pulsation sounds would always serve as the background acoustic field, whether maternal speech, maternal digestive sounds, or any other auditory stimulus were present or not. Finally, it is likely that these two stimuli would differ in their changes in character over gestation. Turkewitz has theorized that early in gestation internally generated sounds would be more audible, given the thick and insulating quality of the uterus at this point, while later in gestation as the uterus becomes thin and distended, externally generated sounds would increase in amplitude in utero.

Acoustic Parameters - Necessary? Sufficient?

Typically hemispheric specialization for processing speech sounds has been thought to be acoustically based in some manner. Studies of speech processing lateralization have pitted responses to speech sounds (usually synthesized consonant-vowel syllables) against other non-speech sounds, such as live or synthesized instrumental music, environmental sounds, white noise, etc., based on their presumed spectral differences from speech sounds. Theories have been developed (Liberman, 1985; Molfese & Molfese, 1979; Previc, 1991) which focus on one of the unique spectral characteristics of speech sounds, i.e., formant transitions, as the critical factor separating speech from the rest of the acoustic world in terms of hemispheric specialization. Formant transitions have unusually high and complexly changing frequency characteristics and occur in the segmental parts of speech, i.e., during the transitions between consonants and vowels in the speech stream. The spectral characteristics of formant transitions uniquely define speech as different from other sources of auditory stimulation, and thereby have been the most frequently considered factor when theorizing about mechanisms underlying a left hemisphere specialization for speech processing.

The group of studies presented here explore the role of spectral characteristics in determining lateralization. In particular, this exploration pursues the idea that frequency-based lateralized processes occurring later in development may be based on limitations on early (prenatal) exposure to certain spectral characteristics of speech, based on the acoustic characteristics of the uterus.

Low-pass filters of the speech stimulus did not change the lateralization profile. The majority of infants, regardless of sex, responded in an equivalent manner to both low-pass filtered speech and unfiltered speech; with a robust and stable rightward oriented bias. These frequencies are the most prominent, i.e., least attenuated, in utero.

High-pass filters seemed to "level out" this lateralized response, with no significant difference in directionality within the high-pass condition. However, between conditions comparison of initial right headturns to unfiltered and high-pass filtered speech showed no significant difference in rightward orientation. While there is a decrease in attenuation of frequencies approaching 4000 Hz in utero, the intensity of these frequencies may not be sufficient to 1) manifest change in the development of early perceptual asymmetries in utero, or 2) elicit a lateralized orienting response after birth. A look at the results of post hoc analyses by sex is informative here. Male babies tended to be less responsive to this stimulus than female babies, with females responding with a headturn in either direction 100% of the time, and males responding with a headturn only 53% of the time. Neither group showed any tendency toward lateral bias in this condition. From these results it seems that frequencies of 3500 Hz and higher may not be intense enough in utero to significantly impact the development of lateralization, and that postnatally these frequencies are limited in their ability to elicit orienting in general, especially in boys. This finding is supported by a recent study by Spence & Freeman (1994) in which it was found that newborns can recognize mother's voice on the basis of fundamental frequency but not formant frequencies, presumably based on the relative intensity of these frequencies in utero. These findings suggest that speech lateralization may not be based on spectral characteristics alone, at least during the prenatal and early postnatal periods.

Band-pass filters of frequencies between 1500 and 3000 Hz produced the rightward orientation bias; there was no significant differences in lateral response between unfiltered speech and band-pass filtered speech conditions in group results. This is at first puzzling because these frequencies have been found to be almost completely attenuated in utero. However, as has been previously discussed, measurements of the intrauterine acoustic environment have not been taken over time, and this attenuation picture surely changes over gestation. Also, it should be re-emphasized at this point that the filtering techniques that were used here did not completely attenuate the target frequency ranges. Target frequency ranges were attenuated to 24 dB which may have allowed enough low frequency information through to elicit the rightward turning bias. But these facts may not completely explain the results. Further analysis of group results reveals a startling difference in response between male and female babies. Females actually responded with a greater rightward orientation bias, while males exhibited no directional bias in headturning. This further supports the proposal that male and female babies may have very different trajectories of lateralized development. It has been theorized that testosterone may delay development of the left hemisphere (Geschwind & Galaburda, 1985). Is it possible that a variation in the timing of a lag or spurt in developmental rate of this sort could significantly affect the lateralization trajectories between the sexes?

A good example of how timing of stimulative events can affect developmental organization comes from the development of the tonotopic organization of the structures of the ear and the auditory nuclei of the brain stem. In the adult cochlea, the structure of the inner ear which is responsive to the frequencies of sounds, the basal region is responsive to higher frequencies while the apical sections are most responsive to lower frequencies. This topographic relationship is preserved throughout the auditory pathways, and is known as the place principle.

During development, all birds and mammals respond to frequency in a 'low to high' chronology, even though the differentiation of the organ of Corti progresses from the basal region to the apical region, in a seemingly paradoxical way. Rubel & Ryals (1983) found that acoustic overstimulation (500, 1500, or 3000 Hz at 125 dB for 12 hours) of domestic chickens at different points of development (embryologically, as hatchlings and at 30 days postnatal age) resulted in damage of the hair cells at different places along the cochlea. Examination of the brainstem auditory nuclei in a similar experiment by Lippe & Rubel (1983) showed that there was a complimentary developmental change in the frequencies that neurons were maximally responsive to along the cochlea. Manley, Brix & Kaiser (1987) raise the possibility that the middle-ear admittance of stimulation changes in development, and that the effective intensity of a standard stimulus changes with age.

This example elucidates the importance of timing of stimulation in the developmental organization of the perceptual system. It is conceivable that sex differences in the timing of growth spurts of the auditory-perceptual structures could result in differences in the timing of significant stimulative events and thereby differences in the organization of auditory-perceptual systems. This also raises the possibility that exposure to particular frequencies of input at one stage of development may influence response to other frequencies later in development, changing relative equivalence relationships throughout development.

In summary, the results of the acoustic manipulations of the speech stimulus in terms of lateral headturning biases are mixed. Findings in which response characteristics were less variable (more stable) are more easily interpreted. For example, speech sound frequencies below 500 Hz are just as effective in producing laterally biased headturns as speech sounds with full spectral qualities. On the other hand, speech sound frequencies above 3500 Hz were not sufficient to produce lateral biases in headturning, and also seem insufficient as general elicitors of orienting in male babies. Speech frequencies between 1500 and 3000 Hz produced a lateralized response in female babies and no lateral bias in male babies, a finding which may be at least partially understood by potential differences between these two groups in the developmental timing of fetal perceptual systems.

So far it has been demonstrated that changes in the spectral qualities of speech sounds in some cases may be sufficient to produce changes in lateral biases in orienting, although not in the manner expected from the adult literature. Spectral changes alone may be sufficient - but are they necessary?

Temporal Parameters - The "Rhythmicity" Factor

The final study in the series presented here was developed to provide the "acid test" for the role of spectral characteristics in organizing lateralized processes, and to pursue the notion that a previously unconsidered element - rhythmicity - may be an important organizer of lateralization. The differences in the stimulus characteristics of speech and heartbeat sounds has been previously considered. The most obvious differences between these two prominent prenatal stimulative sources are their characteristic sound (spectral characteristics) and their characteristic rhythm (temporal characteristics). A stimulus was developed to tease apart the effects of each of these components - speech sounds with the temporal characteristics of heartbeat. Termed "heartspeech", a small phrase of low-pass filtered speech was repeated at the rate of the intrauterine heartbeat stimulus: Low- pass filtered speech was used to provide the hardest test case, given that this stimulus which accentuated the lowest frequencies of speech was such a strong elicitor of a rightward oriented bias in an earlier study. The results are persuasive; there was no significant bias in directional orienting, and there was a significantly decreased tendency for babies to turn right when compared to their response to unfiltered speech. Spectral character was not a necessary inducer of laterality, and temporal factors were sufficient.

These results force a rethinking of much of the literature on hemispheric lateralization. With almost exclusive focus on spectral differences in auditory stimulation in the lateralization literature, a new look at the characteristics of stimuli used in past studies in terms of temporality seems critical. Certainly the kinds of stimuli traditionally compared on the basis of acoustic differences (speech vs music, environmental sounds, white noise), possess important temporal differences as well. To what extent has temporality unexpectedly and unrecognizedly influenced the results of past studies?

Models developed to explain evidence of newborn lateralization address issues of asymmetry at various neurobehavioral levels. For example, Previc (1991) discusses auditory lateralization in humans in terms of a right ear/left hemisphere perceptual advantage in processing frequencies of stimuli over 1000 Hz (i.e., speech). Previc's theory, and others which base lateralized differences solely on frequency characteristics, are not supported by the results of these studies. Previc's additional notion that perception of prosody is predominantly localized to the right hemisphere becomes interesting, although the picture may not be that simple. Normal prosodic characteristics were necessary in these studies to maintain the right ear/ left hemisphere lateralized response. The problem may be that, as with many studies of prosody, prosodic characteristics have been viewed as the "affective" components of speech (as opposed to the spectrally-based "linguistic" components), emphasizing the intonational and inflectional characteristics. The studies presented here indicate that such a definition of prosody may be too narrow, in that it neglects a solely rhythmic component of prosody. If organizing factors of this lateralized response are indeed cortical, then the hemispheric differences may lie in temporal constraints on neural processing, with changes in rhythmic characteristics of auditory stimuli invoking different sensorimotor integrations.

In support of this idea, Middlebrooks, Clock, Xu & Green (1994) have shown that in the anterior ectosylvian sulcus of the auditory cortex of the cat there is no "place map"; rather neuronal networks respond in chronological firing patterns (like "Morse Code") to perceive sound location. Some interesting data which relates here is the finding of a right ear advantage for processing low-frequency Morse Code sequences in human adults (Papcun, Krashen, Terbeek, Remington & Harshman, 1974), suggesting a possible link between the new research on temporality issues in auditory perception and the potential role of rhythmicity in auditory lateralization found in the studies presented here.

Organizing Factors - Cortical or Subcortical?

Historically much attention has been given to the cerebral hemispheres as asymmetrically "specialized". The earliest empirical work involving asymmetries of the cerebral hemispheres dates back to 1861 with Broca's discovery of a correlation between impaired use of the dominant (right) hand and impaired speech in certain victims of stroke. His post mortem work revealed a commonly localized lesion in the posterior section of the left frontal lobe in these patients. Subsequent work by Wernicke described a different type of speech impairment, one involving perception, also in stroke victims, and localized to lesions of the left posterior temporal lobe. This group of studies seemed to lend support for a model of cerebral localization, with specific areas of the cerebral cortex designated to perform specialized functions.

There is evidence from the current literature on auditory-motor and auditory-perceptual asymmetries of adults which certainly supports the notion that such lateral specialization is cortically based. Kimura's theory on the function of dichotic listening rests on the evidence that there is greater neural representation of each ear at the contralateral hemisphere than the ipsilateral one. Kimura uses these findings, along with her assumption that dichotic listening tasks exaggerate these strengths, to explain ear advantages in processing speech and non-speech sounds. Kinsbourne bases his facilitation/inhibition model on the results of performances by adults of concurrent tasks which are believed to be cortically controlled, e.g., speech-motor versus other-motor. Results of brain imaging procedures as previously cited support the idea that asymmetric brain activity between the cerebral hemispheres takes place during certain speech-related auditory-perception tasks.

Methods used for adult testing have been used with infants with some analogous results. Right ear advantages for processing speech sounds that are presented dichotically with other non-speech sounds have been found as measured by increased responsivity in sucking, changes in relative heartrate, enhanced reinforcement value, and preference. Auditory evoked potentials have shown increased left hemisphere involvement in certain aspects of speech processing in sleeping newborns.

Additionally, newborn infants possess some unique characteristics which could make a same-hemisphere facilitation model compelling for the present application. Kinsbourne has stated that the corpus collosum usually has an excitation equalizing function. In "split-brain" patients, facilitation effects are exacerbated due to the failure of the corpus collosum to perform this equalizing function. Turkewitz, Ecklund-Flores & Devenny (1990) cite research suggesting that newborns have increased independence of the cerebral hemispheres and decreased communication between them due to the relatively unmyelinated state of the corpus collosum, along with the likelihood of increased same-hemisphere facilitation related to non-synaptic conduction of neural activity in unmyelinated brain regions. Combining evidence of increased intrahemispheric communication, decreased interhemispheric communication, greater neural representation of the ear at the contralateral hemisphere, and analogies typically drawn between infant studies and adult studies of hemispheric specialization tasks, there seems to be considerable support for the notion that the functional asymmetries found in these studies are cortically based.

But what if infants are responding on the basis of different discriminations and processes than the adult, although the outcome looks the same? Heinz Werner (1957) saw just such a paradox between "surface structure" and "deep structure" (Glick, 1992) as the primary indicator that research should be approached developmentally. For example, it is well-known that cortical activity in the neonate is limited in the first two months, with a burst of cortical growth occurring in the second and third postnatal months (Hofer, 1981). Brain imaging studies of neural activity in response to auditory stimulation are few during this period, and so do not provide definitive information. Finally, the nature of the task involved in these studies, i.e., headturning, may involve quite different process integrations than tasks involved in adult studies of lateralization. The issue of the task-bound nature of functional asymmetries is traditionally underconsidered in the lateralization literature, as is the case with the literature on handedness (Guiard, 1987).

Clifton, Morrongiello, Kulig & Dowd (1981) have raised the possibility that the auditory localization response is subcortically mediated. In studies of the precedence effect (binaural presentation when stimulation at one ear precedes the other by 5-7 msec) Clifton found that newborns did not discriminate the effect, while 5 month olds did. Work with cats and monkeys implicate the auditory cortex in this function. Clifton proposes that the auditory localization response is initially a subcortical function which later comes under cortical control as those brain regions gain in functional efficiency between 2 and 5 months. This finding weakens the explanation of lateralized newborn headturning to binaural stimuli solely in terms of hemispheric specialization, but leaves open the possibility that an initially subcortically-based functional asymmetry could lead to later developing hemispheric asymmetries.

Evidence from the animal literature supports the notion that subcortical processes may be at work. A study by Middlebrooks & Knudsen (1984) on sound localization processes in the owl revealed that a "place map" exists in the superior colliculus of the midbrain, in which sound locations are represented by spatially tuned neurons which map on to a particular place on the collicular neuronal map. This brain area is responsible for organizing a reflexive process by which the owl turns its head to face a sound. Recent work on the inferior colliculus of the midbrain has shown that an auditory "duration map" exists exclusively in this brain area (Casseday, Ehrlich & Covey, 1994). In the brown bat, stimulus duration tuning for auditory stimuli is achieved through the relative activity, or "temporal dynamics", between inhibitory and excitatory neural processes related to stimulus onset and offset. Both of these findings seem to implicate subcortical organizers in auditory orientation processes.

Previc (1991) provides an extensive consideration of the possibilities of subcortical relationships for the organization of human auditory, vestibular and motoric laterality. His treatment is very thorough but too lengthy and complex to fully consider at this point. However, he makes a very strong case for the development of subcortical asymmetries on the basis of differential timing of growth and stimulative events, particularly fetal position in utero.

The Role of Arousal

Several possibilities have been considered thus far for the physiological means by which orienting biases could be organized, and how prenatal experience with speech and heartbeat sounds might result in sensorimotor lateralization. At least one other issue needs to be considered. Since newborn motor behavior of a variety of types has been documented (and described previously) as rightward oriented, it seems possible that components of the newborn arousal system which underly general increases and decreases in newborn activity could in turn result in general increases and decreases in rightward laterality. If changes in newborn arousal are in turn related to changes is stimulus type, this could result in lateral biases in orienting like those found here.

The first issue is how arousal is to be defined. Arousal as defined in terms of infant state organization may be different than arousal to specific transient sensory contexts, most obviously in terms of the time it takes to "assemble" the arousal characteristics. There is evidence that headturning to unfiltered female speech sounds most reliably results in a rightward turn when babies are in a quiet alert state (Moon, 1994). It will be important in subsequent research to determine whether infant state varies systematically with the type of stimulus presented.

If arousal issues do turn out to be related to biases in orientation, is lateralization a dead issue? Absolutely not. For even if postural biases are organized entirely separately from orienting biases, but result in orientation biases as a function of arousal, then this perceptual motor activity may progressively result in de facto lateralization, by limiting and asymmetrically distributing sensory information and building asymmetric sensorimotor associations, and will have implications for development, serving as functionally asymmetric, activity-based scaffolding upon which subsequent sensorimotor processes are built.

Bimodality and Individual Difference

It is important to keep in mind that the examination of the respective roles of cortical and subcortical processes, as well as issues of newborn arousal, in isolation of one another is not reflective of real world function, in that all neuroanatomical levels and systems play an integrated role in activity. The specific and unique ways that processes across levels combine in service of behavior vary both between and within individuals. For example, as previously stated in the results section, a bimodal distribution of lateral biases in headturning to unfiltered female speech sounds may describe the data more fully. This means that although the majority of the subject population exhibits a rightward headturning bias, this bias should not be treated as a singularly defined state, for some babies exhibited a leftward headturning bias, and some exhibited no systematic turning bias. In addition, within any given baby's history of performance on this orientation task, a certain proportion of responses were likely to fall in the opposite direction of the bias. The organization of this lateralized behavior is stochastic, or probabilistic, not determined.

The recognition of probabilistic trajectories in development is further evidenced in the 2:1 ratio that describes the distribution of laterality in a variety of other areas, such as fetal position in the last trimester of gestation (LOA : ROP), ear advantages for speech processing in adult dichotic listening tasks (REA : LEA), the percentage of the population showing greater summating potential recordings from the right cochlea than from the left, and the percentage of adults showing increased size of the left planum temporale (the brain area adjacent to the primary auditory cortex) (see Previc, 1991, for a review). Previc has shown theoretically how anatomical and physiological asymmetries of the two major vestibular projection areas correlate with postural and turning lateralizations in the same 2:1 ratio. The similarities between the proportional distributions of laterality in these areas, all of which are highly related in this discussion, leads one to consider the distribution of processes leading to these biases that they must reflect.

Two seemingly paradoxical points should be taken from this section. Newborn orienting via headturning to binaural unfiltered female speech sounds exhibits a robust and stable rightward bias in the majority of newborns. The underlying processes leading to this lateral bias are probabilistic, given that there is a distribution of laterality outcomes, but this distribution correlates with a number of other functions which possess laterally defined characteristics. All of these functions may be related developmentally to something as simple as prenatal fetal position. This seemingly contradictive interplay between stable processes and variable processes in development holds the key to both the similarities we exhibit and our infinite potential for individual difference.

Conclusion: Theoretical Concepts

T.C. Schneirla (1959; 1965) described the relationship between objective and subjective factors in understanding stimulation and behavior as "effective stimulation", a concept which has become a central organizing construct in the present investigation. Schneirla viewed this concept of effectiveness as a function of the *relative* intensity of the stimuli under examination. McGuire & Turkewitz (1979) state this relationship clearly:

> Objective intensity refers to those characteristics of a stimulus which can be measured independently of the organism upon which they impinge. Effective intensity is dependent upon the objective stimulus intensity and the characteristics of the organism....Effective (stimulus) intensity is thus considered to be the result of both external and internal factors.(p.63)

Theoretically, the concept of effective stimulation forces an examination of stimulation and behavior as an integrative system, "....not simply interrelated but...*fused*...in each stage...." (Schneirla, 1965, p.352). Schneirla repeatedly emphasized the bidirectional relationships between organisms and their effective experiences, describing behavioral development as "....progressive, changing relationships between organism and environment in which the contributions of growth are always inseparably interrelated with those of the effects of energy changes in the environs...." (Schneirla, 1965, pp. 351-2). Earlier discussions of the importance of stimulative events in the development of the auditory pathways illustrate this concept of effective stimulation clearly. Further, researchers describe auditory neurons as "spatially tuned" or "durationally tuned" in reference to their intimate relationship with the stimulative environment.

No one would deny that social, societal and cultural practice influence development. But Schneirla (1972) expanded the idea of nurture from simple learning to an intricate leveled formulation. The environment is leveled too, and each level of the environment corresponds to a level of the organism, in an integrated system of effective relationships. For example, there are physical sources of stimulation (temperature, light, chemical conditions), nonspecific effects of gross stimulus input, the effects of forced practice, the effects of spontaneous nervous system activity, interoceptive conditioning, simple conditioning from spontaneous movements, and simple instances of conventional conditioning and learning (Lehrman, 1970). Here it is easy to see how Schneirla's treatment of the levels concept grew out of his thinking about effective stimulation.

Schneirla rejected the nature/nurture dichotomy for blurring the levels integrated in both nature and nurture. Nature is not just genes - genetic processes involve chemical reactions on the molecular/biochemical level and thereby necessitate the use of the terminology of biomechanics, biochemistry and physics. In addition, genetic does not mean fixed, for genetic processes are fluid and dynamic processes which are responsive to the demands of the intracellular environment in terms of molecular concentrations of gene products and responsive to the activity of other genes. In reducing nature to the genetic level, we are pre-empting the importance of intermediary organic systems as a foundation to behavior, neglecting the microgenetic and ontogenetic relationships between systems as important explanatory constructs in understanding developmental change.

The conflict between Lenneberg (1967) and Kinsbourne (Kinsbourne & Hiscock, 1977) in their respective theories of the development of lateralization illustrates this point best. According to Lenneberg's model, children begin initially unlateralized, with both hemispheres equipotent in function, and only with cerebral maturation acquire the characteristic adult pattern of left hemisphere specialization for speech. On the other hand, Kinsbourne postulates that the characteristic pattern of specialization is an invariant property of human function, proposing that the neural substrate subserving lateralized function is focalized from birth. These treatments either narrowly define development in terms of an invariant unfolding or maturational process, or depict cerebral organization as static and unchanging after it has emerged. It seems at least equally possible that while infants possess certain lateralized functions at birth these need be considered neither invariant nor unchanging. Infants may utilize processing asymmetries which are quite differently organized than those found in adults. In other words, it is likely that there is both early lateralized function and change in function with development. Early sensorimotor asymmetries may be the natural outcome of asynchronous growth rates and asymmetric effective stimulation across levels, serving as a foundation for later sensory and cognitive function which may be quite differently organized.

Tobach (1987) delineates levels of organization in a way that is accessible for social scientists: the biochemical level (genetic and hormonal processes), the physiological level (sensory, motor, metabolic systems and the central nervous system), and the psychological level (cognitive, social and societal systems). This formulation is unique in its representation of social and societal processes as levels within the psychological level, in a provocative view of the role of social and societal practice in the organization of the psychological system. Recognition of the integrating role of activity in the organization of psychological processes (Tobach, 1981) is another central, organizing construct to the present investigation. For example, what might be the importance of newborn headturning as an integrating activity in the sensorimotor development of the neonate? The newborn auditory system is well-developed and functionally stable at birth (Aslin, 1987). The newborn visual system, on the other hand, is underdeveloped and unstable at birth, as evidenced by the dramatic reorganizing effects changes in stimulation and activity can have at this time (Hubel & Wiesel, 1962; 1965). Newborn headturning to sound is a sensorimotor behavior which integrates visual and auditory information, bringing the visual field in line with sound sources. This integrated behavior may be conceptualized as organized by newborn auditory and attentional systems, serving to functionally bootstrap the organization of the visual system.

Without a consideration of activity as an integrative process with developmental impact, important sensorimotor connections in understanding later function can be missed. For example, Previc (1991) states "Despite their similar ratios, however, very little relationship apparently exists between ....the auditory and motoric aspects of cerebral lateralization."(p.3) Previc further states "Indeed, the only prenatal influences that are as highly lateralized as speech and handedness in the adult literature appear to have little if any functional significance." (p. 81) Previc misses the important point here that auditory and motor systems are integrated in activity, and functional asymmetries in practical activity early in development may have unexpected functional significance in the development of sensorimotor integrations later in life. Functional significance is relative; "local" effects can increase exponentially in impact through development, with important relationships existing between apparently unrelated factors.

An example of how seemingly unrelated factors can form important, organizing relationships in development comes from George Michel (1981). He found that head posture in neonates is a good predictor of later handedness, and in a series of longitudinal studies found that preferential hand use may result from increased visual exposure to, and subsequently increased visual-motor experience with, the hand which is more often in the line of vision as provided by the postural bias. Here we have an example of a probabilistic but epigenetically related sequence of developmental events- a postural asymmetry, whose source of organization is presently unknown, but the existence of which may be important to the organization of both auditory lateralization and the development of handedness.

In his description of change as a dynamical system, Ilya Prigogine (1988)points up the importance of the irreversible arrow of time as a constructive force in the probabilistic system of developmental change. In a paper entitled "Origins of Complexity", he describes a new cognizance of "instability which leads to stochastic and irreversible processes." (Prigogine, 1988, p.69). As a result of this new cognizance of stochastic processes in development, individual differences cease to be "noise" and become the clues to understanding the forces behind variability and stability. And in uniting the twin concepts of stochasticity and timing in development, the theoretical need for ultimate, deterministic mechanisms disappears. Rather, a more "local" look at developmental events which are related in time serves us better. Once some events occur, they construct processes or structures or effect influences that cannot disassemble and thereby affect the course of subsequent events. One minute just after birth, for example, is manic with change. Synaptogenesis occurs at the rate of approximately 250,000 new connections per second in rat pups (Greenough, Black & Wallace, 1987). Respiratory and thermal regulatory systems are functional for the first time. A whole new visual world provides stimulation to a relatively underdeveloped sense system. Simultaneously, there is an asychrony in the rate of change between systems. One system's instability may serve as an anchor for another's stability - or instability in one system may throw other seemingly stable systems into reorganizing shifts. Developmental time is relative, and just as Einstein proposed, is as valid and theoretically measurable as conventional time. The probabilistic and epigenetically related nature of developmental process may be the singularly most important idea to take from these studies.

Appendix A. Inter-trial Interval (ITI) Data.

	TRIALS 1-6	TRIALS 7-12	TRIALS 13-18	OVERALL
STUDY 1	29.0 s	16.8 s	14.2 s	20.0 s
STUDY 2	24.2 s	15.1 s	17.6 s	18.9 s
STUDY 3	20.1 s	14.1 s	18.5 s	17.6 s
STUDY 4	20.8 s	15.0 s	10.5 s	15.4 s
STUDY 5	18.2 s	12.2 s	11.4 s	13.9 s
OVERALL	22.5 s	14.6 s	14.4 s	

MEAN ITI ACROSS SUBJECTS - 18.7 s

Appendix B. Maternal Interview Form.

Did you notice fetal response to sound or activity during pregnancy? How would you describe it?

How would you describe your general activity during pregnancy?
Walking? Exercise? Singing? Speaking? Specific fetal stimulation routines?

Did you work outside of the home during pregnancy? When? What was the nature of your work?

How would you describe your home environment? What types of sounds are present in your home?

Appendix C. Comparison of subjects' first and last responses to UFS (N=59).

	1st stim.		
	right	left	no turn
Study 1	10	2	0
Study 2	7	2	3
Study 3	6	4	0
Study 4	8	6	0
Study 5	6	5	0
TOTAL	37	19	3

	Last stim.		
	right	left	no turn
Study 1	7	4	1
Study 2	9	3	0
Study 3	3	5	2
Study 4	8	5	1
Study 5	6	3	2
TOTAL	33	20	6

Appendix D. Results of Maternal Interview

Work outside the home?	Yes	38.2%
	No	61.8%
Detected fetal responsive movement?	Yes	81.2%
	No	18.8%
Of those reporting responsive movement by the fetus:		
To sound (speaking or singing)		44.6%
To tactile (rubbing abdomen)		18.8%
To maternal activity (eating/sleeping)		36.2%
Special stimulation routines?	Yes	50.4%
	No	49.6%
Sound stimulation (talking,singing,music)		85.4%
Tactile stimulation		14.6%

Other types of maternal activity reported to elicit fetal movement:

Dancing, swimming, bending, poking abdomen, showering, coughing

Some unsolicited remarks indicating reciprocity:

"When the baby moved I rubbed my stomach and talked."

"When I was quiet she moved, when I moved she was quiet."

CHAPTER 5

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