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CHANGES IN COGNITIVE PROCESSING ACROSS THE LIFE SPAN AS
MEASURED BY SHIFTS IN LATERALIZATION WITH VOICE RECOGNITION

City University of New York

Ph.D. 1987

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LIFE SPAN AS MEASURED BY SHIFTS IN
LATERALIZATION WITH VOICE RECOGNITION

by

Darlynne Ada Devenny

A dissertation submitted to the Graduate
Faculty in Psychology in partial fulfillment
of the requirements for the degree of Doctor
of Philosophy, the City University of New
York.

1987

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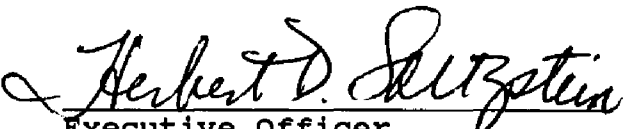
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This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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Abstract

CHANGES IN COGNITIVE PROCESSING ACROSS THE LIFE SPAN AS MEASURED BY SHIFTS IN LATERALIZATION WITH VOICE RECOGNITION

by

Darlynne Ada Devenny

Advisor: Professor Gerald Turkewitz

A series of studies was conducted to investigate cognitive organization across the life span from age 5 through to old adulthood. Cognitive organization was measured by hemispheric differences in processing while subjects were engaged in a dichotically presented voice recognition task. Since voice recognition is a complex stimulus it was anticipated that subjects would employ different strategies depending on their familiarity with the voices and changes in lateralization would be the consequence of using different strategies. The data, therefore, were analyzed in blocks of trials over the course of the task. Proficiency was measured by error rate, lateralization by an index of ear advantage, and the relationship between them by correlations.

It was found that 5 year old subjects performed only at chance level. Subjects at ages 10, 15 and young adults improved over the course of the task. Old adults performed better than chance but did not improve with familiarity to the voices. Across ages, performance on the task improved with increasing age from age 10 through to young adults with old adults performing poorer than age 10 subjects.

Within each age group there was no significant direction of lateralization. However, when subjects at each age were divided into two sub-groups based on the direction of ear advantage at the end of the first third of the task (24 trials) it was found that there were individual differences in lateralization which were masked when all subjects were combined. For age 10 and age 15, beginning the task with an initial left ear advantage and maintaining this lateralization was associated with improvement over the task. This suggests that for these ages maintaining a consistent strategy while performing a complex task is beneficial. For young adults, both sub-groups shifted lateralization to the opposite hemisphere the shifts in lateralization were associated with significant improvement. Both sub-groups of old adults showed only weak lateralization and,

although they shifted lateralization towards the end of the task performance did not improve.

Correlations of lateralization with error scores indicated that greater lateralization was associated with greater proficiency but only for young adults did most correlations reach significance.

Acknowledgements

I wish to thank Gerry Turkewitz, who has been my mentor through these years of my education in psychology, for his guidance and support. He made the task of doing this dissertation exciting and enjoyable. For his contribution to my own development I am profoundly grateful.

I would also like to thank the other members of my committee. Katherine Nelson provided, through the example of her own work and through our discussions, a framework for clarity in thinking and writing. John Sidtis was most generous in sharing his expertise and facilities to expedite the making of the experimental tape. His insightful critique of this work has been invaluable.

The readers of the dissertation must also be acknowledged. Sylvia Scribner has provided an example of scholarship in her own work and teaching which I will always cherish. Elkonon Goldberg has been most helpful in giving his consideration and support to this work.

I wish to thank two colleagues, Susan Engel and Armonit Roter, for their willingness to become involved in my concerns around this dissertation and to help me evaluate my work.

The arduous task of collecting data was facilitated by the cooperation of staff, students and members of several institutions: Dalton School, Hamilton House, Hunter College, Lennox School, New Lincoln School, Yeshiva University Highschool for Girls.

I am dedicating this work to my mother, Ada B. Devenny, who has consistently supported all my ambitions, and to my daughter, Anumaya D.B. Phatate, without whose patience and love this dissertation would never have been completed.

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Introduction

In the history of psychology structure and function have often been described separately with the burden of explanation for psychological processes given almost exclusively to one or the other. It is also recognized, however, that it is the relationship between structure and function which is the topic of inquiry for they are logically inseparable. Similarly, the brain can be examined from a structural position in which segments are characterized by particular types of processing and from a functional position which focuses description on the organization of processing activity. The relationship between cognitive structures and cognitive organization is not static either within a single activity or across the life span. With respect to cognitive structures, extensive research has been conducted with the aim of characterizing processing differences between the two cerebral hemispheres. Findings from this research have established that the left hemisphere in most individuals controls verbal processing and production while the right hemisphere controls activities related to spatial relations, music and mathematics.

The object of the series of studies to be presented is to describe the functional relationship between the activity of the two cerebral hemispheres and to look for cognitive organization as it is revealed in this relationship both within an age level and across the life span from age five to old age. It is believed that cognitive organization changes during the period of learning a task, and, therefore, analyzing performance over time leads to descriptions of change in cognitive organization. Cognitive organization also changes with age, in part because of the underlying maturity of neural structures, and because of prior experience. Since experience is thought to contribute to cognitive organization, individual differences in the organization are anticipated.

In order to begin to examine cognitive organization within a framework of developmental and individual differences, subjects at different ages were given a voice recognition task with voices presented dichotically. Voice recognition was chosen as it is a complex task providing opportunity for flexibility in processing. A preliminary study indicated that the dichotic task was sufficiently complex to elicit changes in lateralization if performance was analyzed over time. Since the topic of cerebral lateralization has been

written about extensively, the review of literature focuses on describing major theoretical positions and research findings with attention given to evidence for dynamic change during processing. The initial sections present findings with young adult subjects. Studies in lateralization across age levels are reviewed. A review of research on voice recognition is presented followed by a description of the theoretical basis of the dichotic procedure and a review of critiques of it as a measurement technique.

Review of Literature

Interest in the relationship between the cerebral hemispheres is not recent. In the 17th century when the soul became identified with the brain, the problem emerged of locating a source for unified consciousness within a divided structure (Harrington, 1985). Descartes suggested the pineal gland while Gigot de la Pyronie suggested the corpus callosum. In the 19th century several physicians, including Wigan, proposed that there were two minds, one corresponding to each hemisphere. An alternative approach by phrenologists, such as Gall, was to attempt to map human consciousness onto the convolutions of the cerebral hemispheres. These two approaches continue to have proponents in contemporary neurological literature in the form of theories of the 'duality of mind' (Puccetti, 1981) and theories of cortical localization of function (Ojemann, 1986) respectively.

Localization of Function

Although Dax, in 1836, was probably the first to associate deficits in language with left hemisphere lesions, his single paper on the subject attracted little attention (Springer & Deutsch, 1985). In 1863 Broca

reported eight new cases with careful clinical and autopsy findings of language disturbances associated with lesions in the third frontal convolution of the left hemisphere. Broca initially was looking for the localization of language in the frontal lobes and his finding of asymmetry was counter to the prevailing notions in French neurology that organs controlling external relations (cerebral hemispheres, sensory organs, arms, legs) were governed by 'laws of symmetry'. In 1865 Brouillard, in defense of lateralization of language, made the analogy, but not a causal relationship between asymmetry of handedness and asymmetry of language (Harrington, 1985). A second area for language reception, in the left temporal lobe, was identified by Wernicke in 1874.

The subsequent findings which support the localization of functions within the hemispheres have come, primarily, from neurology and neuropsychology and the study of the effects of lesions on behavior. This approach to understanding cortical activity has been able to identify specific deficits with lesions of specific areas. For example, a lesion in the left third frontal convolution (Broca's area) results in severe reduction of speech or speech which is agrammatic when it occurs. While cortical areas directly involved in speech may not

be directly affected by a lesion, disrupting the relationship between the speech areas produces an aphasia. Thus, a lesion in the arcuate fasciculus, the bundle of fibers connecting Wernicke's area (left superior temporal gyrus) with Broca's area, produces a conduction aphasia in which the patient has intact reception of language but is unable to repeat what is heard and may produce speech which is fluent jargon.

With the improvement in neurosurgical techniques, Penfield and Roberts (1959) were able to electrically stimulate discrete areas of the cortex and observe the effects on specific behaviors. Surrounding primary projection areas for the senses are secondary, association areas which represent a different level of processing, a level in which stimuli are further encoded and transmitted to cortical areas which receive and integrate projections from several other areas. Much of the work in mapping the cortex has focused on identifying sites connected with language functioning as the procedure is typically performed prior to surgical intervention so that language sites may be identified in an effort to spare them. Ojemann (1986) has extended cortical mapping to the right hemisphere and has found that, in man, spatial functions are not as strongly lateralized as language.

Interest in the functioning of the right hemisphere was slow to develop. It was viewed as a minor hemisphere having a limited role in higher cognitive functioning. Lesions of the right hemisphere, however, do produce a variety of deficits many of which are associated with a specific localization. For example, a lesion in the parieto-occipital region of the right hemisphere is associated with the inability to discriminate between unfamiliar faces (prosopagnosia). Other functions which are described as lateralized to the right hemisphere are spatial perception, music and mathematics.

There have been some exceptions to the finding of localization in lesion studies. Hughlings Jackson (Harrington, 1985) in the late 19th century developed a theory of cognitive functioning which was hierarchical. While preserving the distinction of the speech control in the left hemisphere and visual perception in the right hemisphere, he attempted to understand specialization in relation to automatic and voluntary levels of functioning. In some patients with left hemisphere lesions, then, he observed that while voluntary speech was lost, some aspects of automatic speech were preserved. The highest, voluntary level not only was

found in speech but contained within this mode of functioning was consciousness or self-knowing.

Another exception was Luria (1973) who has described the brain as consisting of interrelated, functional systems. The effects of lesions are to disrupt the organization of cortical functioning, but in predictable ways depending upon the interhemispheric location and the intrahemispheric site of the lesion (Luria & Simernitskaya, 1977). There is now evidence that sub-cortical lesions can produce aphasia which are indistinguishable from those produced by cortical lesions (Alexander, 1986) suggesting complex activity is not dependent on a single location but is generated through the interaction of multiple areas.

Duality of Mind

As Harrington (1985) has discussed, the late 19th Century had an intellectual climate which was highly receptive to the notion that within each cerebral hemisphere there was a separate mind. The observations that the hemispheres had separate functions seemed to fit with descriptions of conscious and unconscious levels, of double personalities (Dr. Jekyll and Mr. Hyde) and of a brain which was in contact with both a real world and the

supernatural. Much of psychiatry used the notion of mental duality to explain hallucinations and personality conflicts.

As mentioned previously, Wigan (1844) is given credit for first having proposed that mental duality is a principle of organization of the brain. Fechner suggested in 1860 that the unity of the mind was dependent upon the anatomical integrity of the nervous system and he hypothesized that if a person could be split in half, with each half maintained, then a doubling of a human could be seen (Harrington, 1985).

Since 1940 the sectioning of the corpus callosum (the transverse neural fibers which connect the two hemispheres) has become a reality and has been used for the control of epileptic seizure activity. The patients for whom this was done have aroused much interest, first for their general level of functioning, which appears to be relatively intact and, second, for the opportunity they have provided to researchers to study the independent functioning of each of the cerebral hemispheres.

As with other types of research, the type of experiment and the findings generated relate to the

models of cerebral functioning. For those investigators of hemispheric specialization whose theoretical framework can best be described as distinguishing between the hemispheres on the basis of a verbal/non-verbal dichotomy (Gazzaniga & LeDoux, 1978) there is an extensive body of work to support their position. The research question never seems to be whether the left hemisphere is better than the right hemisphere in processing language related stimuli, but whether the right hemisphere has any ability at all in this domain. Zaidel (1978) tested auditory vocabulary by presenting stimuli auditorily and to both hemispheres and controlling the lateralization of the response. He found in those subjects tested that the right hemisphere had a vocabulary equivalent to a 10 year old level. One contention with this finding, however, is that patients with disconnected cerebral hemispheres have a variety of compensatory mechanisms including eye movements, visual guidance of motor acts and auditory cross-cuing which serve to integrate percepts and when cross-cuing is experimentally controlled the apparent proficiency of the right hemisphere for processing language is severely reduced (Sidtis & Gazzaniga, 1983).

Studies which have been theoretically based on processing distinctions between the hemispheres rather than the verbal/non-verbal dichotomy have also used

commissurotomed subjects. Levy and Trevarthen (1976) gave ambiguous instructions to one patient and found that she tended to match two different stimuli on the basis of functional equivalence in the left hemisphere and on the basis of appearance in the right hemisphere. This study and other studies by these investigators have supported the description of the left hemisphere as an analytic processor and the right hemisphere as an holistic processor.

As has been noted by most investigators involved with commissurotomed subjects, the total number of cases is relatively small (approximately 40 subjects, to date) and not all have received exactly the same surgical procedures. All these subjects have an abnormal neurological history with undetermined consequences on cortical organization. Significant individual differences between subjects have been noted, particularly with respect to their abilities to process language in the right hemisphere. At present, the extent of individual variation within the normal population has not been established and, therefore, the data base against which these subjects are compared is limited.

Even with these reservations, there are philosophical implications for understanding

consciousness in normal subjects by contemplating the 'splitting of mind'. Puccetti (1981) believes that duality exists at a cortical processing level with each hemisphere unaware of the existence of the other. He argues that if conscious awareness did exist, then each hemisphere would know of the stimulation to both hemispheres and, subjectively, sensory duplication would be experienced. An alternative view is that consciousness, and specifically self-consciousness, is linked to language and that, therefore, only the left hemisphere can be said to be fully conscious (Eccles, 1965; LeDoux & Gazzaniga, 1981). Sperry (1968), however, has argued that the corpus callosum acts to unify consciousness and severing the connections between the hemispheres "splits the mind".

Discussions of philosophical issues have led to general descriptions of hemispheric functioning which are more metaphorical than actual. Lists of dichotomies associated with the different hemispheres both current (Springer & Deutsch, 1985) and from the past (Harrington, 1985) have led to characterizations of the left hemisphere functioning as rational, objective, abstract, with right hemisphere functioning correspondingly intuitive, subjective and concrete. Since, in the normal brain, the two hemispheres are

connected and the transfer across the callosum is rapid, descriptions of brain functioning which metaphorically split the brain have little explanatory value. New approaches, such as information processing, to studying the relationship between the cerebral hemispheres use models which attempt to identify features connected to processing while understanding how these features interrelate.

Hemispheric Differences

From early studies of brain damaged individuals and the localization studies of Penfield and Roberts (1959), there was reason to believe that cerebral hemispheric organization was inherent in its structure. A structural theory of hemispheric lateralization states that each hemisphere is specialized for processing particular stimuli. For some investigators (Gazzaniga, 1983; Levy, 1983) left/right hemispheric differences in lateralization are best described with a verbal/non-verbal dichotomy, respectively. In this dichotomy it is understood that the nature of the stimulus determines laterality effects.

Bradshaw and Nettleton (1981) reviewed the verbal /non-verbal dichotomy and found that the distinction

neither for processing nor lateralization was entirely clear. They support a dichotomy of describing hemispheric differences as analytic/holistic and suggest that because it is a more general distinction it accounts for more of the research results. In this dichotomy the left hemisphere has an advantage for processing which is sequential, segmental and encoded. That is, the left hemisphere has a specialization for analytic processing. The right hemisphere has an advantage for processing configurations and holistic units which is best described as synthetic processing.

Assuming that hemispheric differences are real, there are theories of lateral differences which address issues of receptivity for processing. One such theory states that auditory pathways from the sensory end organ to the opposite cerebral hemisphere have priority over sensory input from the same side (Kimura, 1961). Processing of verbal material, therefore, is more rapid and accurate from the right ear. Refinements in the testing of this theory showed that the right ear advantage is strongest for consonants (Studdert-Kennedy & Shankweiler, 1970) and that there is no hemispheric advantage for vowels.

In a different theory, the allocation of attention has a role in processing. Kinsbourne, (1973) has proposed that if one hemisphere is more active, or primed, attention is biased toward the sensory field opposite the more active hemisphere. Since verbal material is thought to prime the left hemisphere and non-verbal material the right, then expectations or strategies of approach will differentially engage the hemispheres.

Klein, Moscovitch and Vigna (1976) experimentally controlled attention in an attempt to distinguish between a theory of direct access and a theory of hemispheric priming. In one experiment they presented, tachistoscopically, pairs of faces and pairs of words together (one word, one face to each visual field) and controlled for the type of material reported first. They argued that the type of material reported first should create an attentional bias which should improve both faces and words for that visual field. They found that for subjects reporting words first there was a right visual field advantage for both words and faces, thereby supporting attentional allocation theory. However, when faces were reported first there was a left visual field advantage for faces but a right visual field advantage for words, thus supporting a direct access theory. These

investigators suggest that functional asymmetries can be influenced by relationships between the two hemispheres.

Information Processing

Information processing is an approach to the study of complex processing in which the contribution of component systems such as perception, encoding, memory, language, to the performance of a task are described. Information processing and neuropsychology share the assumption that cognitive organization can be understood through a description of dissociated functions (Moscovitch, 1979). Unlike neurology, however, information processing approaches are less concerned with underlying structural locations of processing than with describing functional interrelationships between processing systems. Within the information processing approach it is not necessary to situate a cognitive system in a particular cerebral location. When processing sequences are described the logical progression from peripheral sense organs through neural pathways to central processors is usually maintained, although inhibitory pathways, feedback loops and control of lower centers by higher centers suggests that the sequence is not simply linear.

In applying information processing approaches to hemispheric lateralization, Moscovitch (1979) has proposed that processing involves a series of stages, only some of which involve lateralization. According to his model, early low-level processing of stimuli is common to both hemispheres and hemispheric asymmetries emerge only at the level of higher-order relational encoding processes where a central processor integrates information from the periphery and represents it as a configuration, relation or category. Once differential encoding based on lateral differences in hemispheric processing occurs, then this lateralization is transmitted to higher cortical levels.

Allen (1983) has proposed a model of cognitive functioning which is similar to that of Moscovitch in that there is the possibility for processing to occur in stages with hemispheric lateralization coupled to the stage rather than the entire processing sequence. In this model the unit of analysis consists of sub-processors which receive input, perform a specialized operation on the input and then pass it along to other sub-processors. Allen suggests that sub-processors can be located and function entirely within a hemisphere, can function bilaterally and symmetrically, or function bilaterally with a hemispheric bias. In contrast to a

view of hemispheric specialization which locates face recognition or language within a hemisphere, in this model, tasks are viewed as complex and requiring several sub-processors to perform with each sub-processor having a lateral distribution.

"hemispheric specialization would now be some complicated, interactive, perhaps dynamic (time-dependent) function of the relations between the subprocessors." p.95

In that lateralization and processing can be understood as dynamic and responsive to situational and individual differences, the information processing approach clearly has a conceptual advantage over more static descriptions. When considering multiple options for processing, however, there is a problem in being able to specify the nature of a central control mechanism which coordinates sub-processors (Allen, 1983; Marshall, 1981).

Time-Dependent and Practice Changes in Lateralization

Within the framework of problem solving an individual, while keeping an end goal in mind, can divide the task into manageable segments with many interim sub-

goals. This division is dynamic, individual and very likely related to strategies of processing. The few studies which have examined lateralization across time have found that it changes neurophysiologically and also with practice in performing a task.

Neurophysiological Time-dependent Changes

Although several studies have reported lateral differences in evoked potentials with linguistic stimuli, Gevins (1983) has criticized many of these studies for not providing stringent experimental controls and using too low a level for reporting statistical significance. For his own study he developed a task in which subjects had to exert a finger force proportional to either the distance between an arrow and target or proportional to the number from 1 to 100. He found linear statistical methods (correlations, ANOVA) which did not analyze the data in relation to possible dynamic changes during processing showed essentially no difference between the two tasks. When Gevins applied pattern recognition statistics to sequential latency intervals of the evoked potentials he found that differences between the tasks occurred during the middle intervals (N1 (N170) through to P3b (P450)) showing a complex, rapidly shifting picture of lateralization. For example, in the arrow

task for the N1-P2 interval, neural activity was higher over the right parietal area; at P3a there was left sided lateralization; at P3b there was a midline pattern; and at P4 posterior right activity.

Gevins' findings show that for a relatively simple task lateralization can change and that this occurs within a time frame of milliseconds.

Behavioral Practice Changes

Experimentally, shifts in lateralization have been found for both simple and complex stimuli. Sidtis and Bryden (1978) found that with the dichotic presentation of piano tones subjects initially did better with the right ear, but with familiarization, relative proficiency shifted to the left ear. An opposite, but weaker, effect was produced with two-syllable words, where initially the ear of advantage was the left but with familiarization shifted to the right. These effects were independent of the order of testing the two different types of stimuli, suggesting that subjects were developing perceptual strategies specific to the type of stimuli and not a general strategy of approach to the task.

In the Klein, Moscovitch and Vigna (1976) study described previously, practice had an effect on lateralization. In another experiment, subjects were shown either pairs of faces (priming set) followed by pairs of words (test set), or pairs of words followed by pairs of faces. During the priming set the non-primed, subordinate hemisphere improves with practice more than the hemisphere dominant for the type of material. During the test set the effect of practice is to shift the subjects' attention back towards the hemisphere dominant for the test set material. For example, for those subjects who had the words presented first, when tested with the faces there was a weak right visual field advantage during the first half of the test set while there was a left visual field advantage during the second half. For subjects who saw faces first, the right visual field advantage, although present in the first half of the word test set, increased during the second half.

Ross-Kossak and Turkewitz (1984; 1982) found that hemispheric lateralization shifted during the course of repeated tachistoscopic presentations of faces. Those individuals who began this task with a right hemisphere advantage shifted advantage to the left and then back to the right hemisphere, while those who began with a left hemisphere advantage shifted to the right hemisphere and

remained with this advantage. Changes in the particular set of faces (Turkewitz & Ross, 1983) did not disrupt this pattern of organization, suggesting that the strategies being used for facial recognition were general and not tied to the specific stimuli.

Ross-Kossak and Turkewitz (1986) suggest that shifts in lateralization during the complex task reflect a cognitive organization in which strategies using analytic or synthetic modes are employed sequentially. As faces are thought to have special, gestalt properties, the generalizability of this phenomenon of cognitive processing was tested using voice recognition as a complex auditory task. Using a dichotic presentation technique, shifts in lateralization for voice recognition were found during the course of the test (Devenny & Turkewitz, in prep.). Taken together, the studies of face and voice recognition suggest that there are stages during the processing of complex stimuli which are sequential and systematic.

Conceptual Models of Shifts of Hemispheric Lateralization

It has been suggested by many (Bever, 1980; Bradshaw & Nettleton, 1981; Goldberg & Costa, 1981) that the hemisphere which will process most efficiently is not

determined by the nature of the stimulus alone but by a composite of factors, one of which is prior experience with the type of stimulus. Goldberg and Costa (1981) suggest that one of the consequences of experience is that a descriptive system or a code becomes part of the means of processing. Normal cognition requires multiple descriptive systems and the individual construction of these descriptive systems is influenced by culture. Their proposition is that a well-established, well-routinized descriptive system and tasks utilizing such a system will be left lateralized. The usefulness of an encoded system is that it increases processing proficiency. The right hemisphere has a role in approaching tasks which do not have a previously established descriptive code and has a role in establishing such a code. The prediction from Goldberg and Costa, therefore, is that the two hemispheres have differential roles in the establishment and utilization of descriptive codes and are active at different stages of processing. Specifically, they suggest that in learning a new task the right hemisphere is initially more active and that control shifts to the left hemisphere as a descriptive code is established.

Bradshaw and Nettleton (1981) briefly suggest a related but slightly different basis for shifts in

lateralization. Interestingly, they acknowledge Costa as the source of the following hypothesis (p.84): the initial approach to a novel task activates the right hemisphere differentially as it is more susceptible to arousal. Presumably, although not stated by Bradshaw and Nettleton explicitly, processing shifts to the left hemisphere. When the task is over-learned and automatic the right hemisphere is once again the more active.

Ross-Kossak and Turkewitz (1986) have argued that the assimilation of perceptual information takes place across time and that the processing of the information can be characterized by qualitatively different, sequential stages corresponding to shifts in hemispheric advantages. Referring to their experiments in tachistoscopic presentation of initially unfamiliar faces, they propose that early stages of processing involve attention to contour of the face with points of contrast within the face. That is, an undifferentiated perception is associated with holistic processing of the right hemisphere. With familiarization, features of the face become distinguished and processing shifts to an analytic mode and the left hemisphere. The final stage of processing incorporates both previous stages into an integrated percept and returns to the right hemisphere. This third stage in the processing sequence is at a new

level of organization as compared to the first stage, although both are characterized by right hemisphere advantage.

Individual Differences

Generally, the experimental search for lateralization has led to looking for consistency of hemispheric advantage within an experimental group. Variability has been reduced most often by using only dextrals. Lesion and sodium amobarbital studies have established that close to 95% of dextrals have language functions in the left hemisphere (Springer & Deutsch, 1985). From this finding there has been the unwarranted conclusion that, therefore, all dextrals have the same cognitive organization and any deviation within this group is due to uncontrolled experimental factors. Seldom has there been an active search for individual differences.

Levy (1983) has proposed that individual differences in hemispheric specialization are associated with differences in hemispheric arousal levels. Levy, Heller, Banich and Burton (1983) found that subjects who showed a strong right visual field advantage for nonsense syllables had overall better performance. This finding

is discussed in relation to individual differences in patterns of hemispheric usage. While Levy et al. (1983) divided their subjects based initially on the degree of asymmetry, Devenny and Turkewitz (in prep.) found a similar association between proficiency and degree of lateralization when subjects were divided initially by performance. That is, better performing subjects tended to show a greater degree of lateralization. Although this latter finding should not be identified strictly with a hypothesis of differential hemispheric arousal, it is not incompatible with the notion that patterns of hemispheric involvement in cognitive tasks can vary among dextrals.

Ross and Turkewitz (1981) found on a face recognition task that a substantial number of subjects had a right visual field advantage. Although this finding is at variance with most of the literature which report a left visual field advantage for facial recognition, it is likely that right visual field processing for faces occurs early in the processing sequence for some individuals. They found that when the number of trials was extended (Ross-Kossak & Turkewitz, 1984) all subjects eventually established a left visual field advantage. Ross and Turkewitz (1981) found that when subjects were divided according to a

visual field advantage on a face recognition task that the two groups differed in performance for inverted or partially masked faces. They argued that inverting faces changes configurational relationships between facial features and they found subjects with a left visual field advantage were more affected by the inversion than those subjects with a right visual field advantage. Conversely, they found that subjects who had a right visual field advantage were more affected by the obliteration of specific facial features. Their findings support the claim that there are individual differences in lateralization occurring early in learning a task which reflect qualitative hemispheric processing differences.

Using recognition of nonsense shapes presented tachistoscopically, Birkett (1978) found that those subjects who were more lateralized performed better regardless of the direction of laterality. If laterality reflects the employment of a strategy, which this investigator suggests, then consistent use of the strategy is more effective than the particular direction of laterality. Ross-Kossak and Turkewitz (1986) discuss similar findings in their studies of facial recognition although when the relationship between proficiency and lateralization was examined over time it appeared that

the adoption of lateralization had proficiency advantage only during some phases of familiarization.

Development of Lateralization

Structure and Function

Structural and functional differences in laterality have been documented for all ages but from the work done thus far there is no clear understanding of the ontogenetic relationship between the anatomy of the central nervous system and behavior. Levy (1981) has suggested that the development of asymmetry is guided by genetic information but that environmental factors impact on development in such a way as to co-determine final outcome.

Neuroanatomical Basis for Lateralization

Lateral differences in the cerebral cortical and sub-cortical structures have been found prenatally. For example, the left planum temporale, an auditory association area, is larger in 65% of adults (Galaburda, 1984) and has been found to be larger in infants as early as the twenty-ninth gestational week (Wada, Clarke & Hamm, 1975). Lateral differences in rates of development

have also been noted, with the right hemispheric convolutions in the frontal and temporal regions appearing as much as two weeks earlier than those on the left (Galaburda, 1984). The homologous areas in the left hemisphere, although slower to develop, eventually reach a larger size.

Behavioral Measures of Lateralization in Early Development

In most adults the use of the right hand is dominant. In newborn infants a right turning bias has been documented (Turkewitz, 1977). A right hand preference is established by 18 mos. of age but prior to that age it is unclear if infants use their hands differentially. It does seem, however, that development of a motor dominance is not simple and not unrelated to co-occurring developments in sensory processing (Young, Segalowitz, Corter & Trehub, 1983; Turkewitz, 1977).

On measures of eye turning (Hammer, 1977), sucking habituation (Entus, 1977), and heart-rate habituation (Glanville, Best & Levenson, 1977) infants from neonates to 3 mos. had asymmetrical responses, with speech producing a differential response in the right ear. In a series of studies described by Molfese and Molfese (1983)

these investigators found greater left hemisphere response to speech and greater right hemisphere response to non-speech stimuli on measures of auditory evoked response ,for infants, children 4-11 years and young adults. In refinements of their initial study using the same electrophysiological measure, they found that speech perception involved processing using a number of mechanisms. Specifically, they investigated the mechanism of voicing onset time and place of articulation and found both hemispheric and developmental differences. Place of articulation appears to be lateralized to the left hemisphere and does not change from the neonatal period through to adulthood. Voicing onset time appears to have two mechanisms, one lateralized to the right hemisphere, the other bilaterally represented in childhood but becoming right lateralized with increasing age.

Lateralization in Childhood

Lateralization is established early in development and those functions which have been described in infancy, specifically a right motoric side preference and a right predominance for speech reception are in the same direction as in adults. When lateralization is measured in children by tasks which involve additional processing,

such as linguistic or memory, there are conflicting positions as to whether lateralization increases, decreases or is established early and remains unchanged. Attempts to unify data which show no change in lateralization with development with data which show some change have led to three different explanations.

With respect to speech, measurement of lateralization has utilized the technique of dichotic listening, the simultaneous presentation of two different stimuli, one to each ear. A review of dichotic listening tests (Witelson, 1977) has shown a consensus of right ear advantage (REA) for speech generally and no magnitude change with development. In a study which reported an increase in magnitude of REA with increasing age, digit names and up to four pairs of digits on any one trial were presented (Satz, Bakker, Goebel & Van der Vlugt, 1975). Porter and Berlin (1975) have suggested that discrepant findings with regard to the development of lateralization could be resolved by taking into account levels of processing. In their theory, when laterality is measured by dichotic presentation of nonsense syllables, a REA is the result of competition between the two signals, where the signal entering the right ear has a more direct, less 'noisy' access to the left hemisphere in which the processing is to occur.

This explanation for a REA at an acoustic level of processing is similar to Kimura's original theory (Kimura, 1961) of why dichotic presentation produces an ear advantage. Porter and Berlin suggest that auditory or phonetic processing develops early and remains lateralized and that those studies which tap this level of processing do not show changes in lateralization with age. According to these authors, in order to process the four digit pairs of the stimulus, demands are placed on short term memory which produces the change with age.

Kinsbourne and Hiscock (1983) have proposed an alternative explanation to account for instances where there appears to be an increase in lateralization with age. For Kinsbourne and Hiscock, lateralization for discrete functions (such as the REA for consonant-vowel transitions) does not change with development but with the increase in complexity of processing of the multiple components of the speech signal, each cognitive function has its lateral preference and the degree to which various functions are employed is in some sense determined by attention or perceptual strategy. Hiscock and Kinsbourne (1980) varied the length of paired digits in order to assess the effect of memory load on ear asymmetry for children of ages 3 to 12 years. They found that overall proficiency increased with age but the

magnitude of the REA remained relatively stable. They argue that the absence of an increase in REA between the ages 3 to 12 years with an increase in length of the digit string is evidence against the levels of processing hypotheses of Porter and Berlin.

In addition to explanations involving levels of processing and attention there is the possibility that the relationship between the hemispheres changes with development. Larsen (1984) has interpreted findings of a verbal, dichotic listening task in terms of just such a hemispheric relation model. He found that although the magnitude of asymmetry decreased over the ages 8 to 16 years the proportion of children showing a right ear advantage increased. The greater asymmetry of the early years may be due to an interhemispheric transmission loss superimposed upon a hemispheric specialization for processing speech.

"Thus it should be proposed that in the developmental perspective of cerebral lateralization, the principle of specialization is preceding the principle of unity. It could even be argued that a delayed establishment of efficient transmission between the hemispheres is a necessary pre-

condition of hemispheric specialization
because a relative separation might facilitate
independent and different functions in early
childhood." p.14

In the normal adult brain, neural transmission time within and between cerebral hemispheres is rapid, and, therefore, both hemispheres, at least in theory, could be involved in processing. The cortical connection between the hemispheres is the corpus callosum, a structure in which myelination, although largely complete by 6 years, continues slowly through 8 - 10 years (Yakovlev & Lecours, 1967). Although the corpus callosum is functional well before this age it is assumed that the rate of conductivity and, therefore, the exchange of information between the hemispheres increases during early development. Gazzaniga (1970) suggested that at birth the two hemispheres may be functionally disconnected. Studies show an increase in interhemispheric transfer in childhood. On one set of tasks (O'Leary, 1980) children were asked to reproduce motor-movement or spatial-pattern ipsilaterally and contralaterally. Five year olds were better for both tasks in the ipsilateral condition; 7 year olds were better at motor-movement reproduction ipsilaterally but reproduced equally well spatial patterns under

ipsilateral or contralateral conditions; 9 year olds had no difference between the hand conditions. Joseph, Gallagher, Holloway and Kahn (1984) found 4 year olds to have difficulty on interhemispheric transfer of a tactile form recognition task and to confabulate more about details of a picture presented tachistoscopically when the picture was flashed to the right hemisphere; 7 year olds confabulated more than 10 year olds. There is, then, some independent evidence to support Larsen's position that the development of lateralization is characterized by initially a separation of hemispheric functions with a developmental change towards hemispheric integration.

Lateralization in Aging

Aging has the effect of decreasing certain intellectual capacities, such as facility in learning new material, memory and reaction times to stimulus presentations, while preserving ability to conceptualize and utilize previously acquired knowledge. The distinction between these two types of functions is often described, respectively, as fluid and crystallized intelligence, suggesting that structure may be differentially affected by aging (Horn, 1982).

Neural cell loss and diffuse cortical changes within the cells and tissues have been identified in aging, particularly in association with senile dementia of Alzheimer Type (Petit, 1982). Diamond (1984) reported that while for young, male rats (up to 400 days) the right hemispheres of the cortex and hippocampus are significantly thicker, with aging (900 day old rats) the asymmetry is lost. In humans there is a loss of neural cells during aging with proportionally more decrease in white (myelinated) cells after 50 years of age. Anatomical studies of old age suggest a thinning of the corpus callosum.

There have been discrepancies in results of lateralization studies with aging subjects. Clinical evidence that left hemisphere lesions produce aphasia in the elderly indicates that at least some aspects of lateralization persist throughout life. There is some evidence from the normal aging population (reviewed by Borod & Goodglass, 1980) that functions mediated by the right hemisphere decline with age. Since the right hemisphere is thought to be involved in arousal and attention to novel situations (Bradshaw & Nettleton, 1981) a relative decrease in right hemisphere functioning could affect the learning of new material and what is described as fluid intelligence. In dichotic

listening tasks, findings suggest that the right hemisphere decreases in function disproportionately to the left hemisphere with aging (Clark & Knowles, 1973; Johnson, Cole, Bowers, Foiles, Nikaido, Patrick, & Woliver, 1979). A possible confound in these studies, which the authors acknowledge, is differential effects of short term memory on hemispheric processing as in both these studies digit pairs were presented 3 and 4 at a time. Other studies have found evidence for a symmetrical, hemispheric decline in processing ability with aging. Borod and Goodglass (1980) also used digit triads presented dichotically and found that the right ear advantage was preserved through old age. Their evidence for this conclusion was the absence of age by ear interaction on an ANOVA. They, apparently, treated the ears as independent in responding and did not use a relational measure (such as a lateralization index) to correct for differences in error. A constant, absolute difference between ears results in a diminished degree of lateralization as error score increases, if an index is used. Since Borod and Goodglass were basing their conclusion of preserved right-left asymmetry with aging on absolute ear differences with increasing errors it is possible that had they used an index of lateralization they would have found a decrease in lateralization.

Support for the position that relative lateralization does not change with advanced age comes from a study by Nebes, Madden and Berg (1983) in which nonsense syllables were presented dichotically. Using a relational measure (the phi coefficient) they found no significant difference between young and old subjects. In their discussion they suggest that as the complexity of the task increases differential hemispheric deficits may be produced. The involving of short term memory for the earlier studies may have had a bigger effect on processing in the right hemisphere than in the left hemisphere.

From neuroanatomical evidence cortical structural changes occur with aging. Psychological measures suggest decrements in short term memory, rate of processing, learning of new material and perceptual deficits when encoding is required. Under task conditions when areas of known deficit are controlled there appear to be few qualitative changes in lateralization with aging. The relationship between the hemispheres in a complex task with the elderly has not been explored.

Recent studies which address processing in relation to lateralization often use complex stimuli such as facial recognition or require complex judgments such as

matching by association. These studies have been conducted primarily on normal adults or clinical patients. Developmental studies generally have used tasks or responses which are highly constrained. This has served two purposes: to maximize the lateralization effect and to define what might produce the effect. Although this has informed us repeatedly that lateralization is a real phenomenon it has been difficult to apply evidence of lateralization gained from specific materials to an individual's functioning in the real world. The task chosen for these studies is learning to recognize the voices of initially unknown persons. In terms of acoustic and psychological parameters it is a complex task. Furthermore, the subject is relatively unconstrained in terms of making a response. This complex task was chosen because it was felt that under these conditions listeners would be free to employ their own strategies of learning.

Voice Recognition

Voice recognition is generally thought to involve pattern recognition as there are multiple acoustic cues which can vary with partial independence. In everyday life the process of identifying a known individual based on hearing the voice involves listening to the voice and

matching it to an internal representation. For long speech samples, identification of up to 65 different voices have been reported when recorded samples were taken from the work-place (Pollack, Pickett & Sumbly, 1954). Individual differences in the ability to recognize voices and in the identifiability of voices have been reported (Stevens, Williams, Carbonell & Woods, 1968). Voiers (1964) had listeners rate speakers on a semantic-differential scale in an attempt to specify the phenomenological aspects of voice recognition. He reported that ratings along dimensions of clarity, roughness, magnitude and animation were most helpful in identifying the speakers for the listeners. He also suggested that the ratings used to describe a speaker were not independent of the listener. Another individual difference was reported by Pollak, Pickett and Sumbly (1954) as an anecdote to their study in which they presented voices of 3, 4 or 5 speakers in different paired combinations:

"it appears that listeners who are able to identify the combinations of voices as unique patterns, identify these combinations nearly as well as they identify single voices. Other listeners, who attempt to abstract each of the two voices,

individually, identify the combinations more poorly than the individual voices." (p.405)

As a complex auditory stimulus, the human voice has been shown to lend itself to both acoustic pattern processing (Abberton & Fourcin, 1978) and to feature analysis (Brown, 1981; LaRiviere, 1972). Previous studies of voice recognition which have examined the nature of the stimulus have shown that recognition can be based on acoustic information which is separate from the intelligibility of the speech (Abberton & Fourcin, 1978; LaRiviere, 1972). The acoustic features of the stimulus can be divided into source features, generally described as the fundamental frequency, and vocal tract components, described as properties of the formants. Both source and vocal tract components can be used to identify a speaker (Abberton & Fourcin, 1978; Miller, 1964; Shearme & Holmes, 1959). LaRiviere (1972) found these two factors to be equal and additive while in a more elaborate manipulation of several factors, Brown (1981) found them to be interactive. This suggests that alternate ways of processing the same stimulus are available simultaneously.

Attempts to characterize voice recognition as a unitary function located in one of the cerebral hemispheres have produced unclear results. Two clinical studies (Assal, Zander, Kremin & Buttet, 1976; Grenier, 1969, reported in Doehring & Ross, 1972) report that lesions of the right hemisphere produce disturbances in voice recognition. From these studies there is converging evidence that the organization for recognition of a voice may be situated in the temporal lobe of the right hemisphere. In the Assal et.al study, patients with right temporal lobe lesions were more impaired for voice recognition than were patients with lesions in other right hemisphere lobes. It was reported (Doehring & Ross, 1972) that Grenier found that patients with right hemisphere lesions were more impaired than those with left hemisphere lesions and that the two groups did not differ on facial recognition. Clinical observations of patients with prosopagnosia (disturbance of familiar facial recognition) indicate that voice recognition is used as a compensation for the disability (Hecaen & Angelergues, 1962). Although facial recognition is primarily a right hemisphere function, prosopagnosia is associated with bilateral lesions with right occipital lobe involvement (Benton, 1980). Disturbances of voice recognition without facial recognition disturbance and, conversely, the ability to use voice as a compensatory

mechanism when there is disturbance of recognition of familiar faces, suggests that these two functions have separate loci of organization in the right hemisphere. In interpreting lesion studies, however, it is important to recognize that the disruption of a function with a localized lesion is evidence that the particular area is necessary for the function, but it does not also mean that it is the only area which is involved in that function.

Few studies with normal adult listeners have demonstrated hemispheric advantage for voice recognition. Doehring and Bartholomeus (1971) presented sub-sets of speech stimuli (vowels, consonants, nonsense syllables, words) in a dichotic matching-to-sample task. A right ear advantage was found under two conditions: listeners reporting in which ear the matching voice was heard, or listeners circling the speech stimulus spoken by the matching voice on a response sheet. The right ear superiority was found for all types of stimuli with words reported with greater accuracy. In this study by Doehring and Bartholomeus listeners were required to recognize voices on the basis of very short samples and had available articulatory acoustic cues and pitch cues but did not have available rate of speaking, rhythm or intonation. An interesting finding from this study is

that increased familiarity with the speakers through an experimental manipulation did not improve voice recognition. As the ability to recognize voices in the real world increases with contact with the speaker, this failure to find improvement with increased familiarity is likely due to the experimental constraint of providing brief samples for recognition. Landis, Buttet, Assal and Graves (1982) presented subjects with 1 male and 1 female voice in dialogue for familiarization then tested voice recognition by reaction time to the two familiar voices saying monosyllabic words, when the choice was among four voices. They found that learning was greater for the right ear. There was also a gender difference in voice identifiability, with the male voice giving a right ear advantage and the female voice a left ear advantage.

The ability to recognize voices has a long developmental history. DeCasper and Fifer (1980) have demonstrated that neonates prefer their own mother's voice to that of another female. Spence (1984) has argued that the basis of this preference is the infant's prior experience with the maternal voice. In utero the maternal voice is audible with some reduction in high frequency energy. The fetus, presumably, hears the low frequency energy of the voice through tissue conduction. To test the hypothesis she presented neonates with

maternal voice unfiltered and filtered through a low pass filter and used these conditions to modify a sucking pattern. Spence found that for neonates maternal voice filtered and unfiltered were equivalent and suggests that the infant is attending to acoustic cues which are speaker specific and contained in low frequencies. A similar comparison of stranger female voices filtered and unfiltered produced a prenatal preference for unfiltered voice, possibly because there has been no prior experience with these voices in a filtered (ie.in utero) condition.

At one month of age infants are able to discriminate between their own mother and another female but only if the speech is intonated (Mehler, Bertoncini, Barrier & Jassik-Gerschenfeld, 1978). The basis for this differentiation may be very different from the neonatal preference for maternal voice as in the intervening month the infant has had considerable experience with sound and the mother's voice. The exaggerated intonation pattern of 'motherese' may not only attract the infant's attention but facilitate the development of a 'category' of mother's voice vs. other voices by making salient invariants in voice quality over pitch changes.

Categorization within perceptual function involves the ability to treat as similar, classes of stimuli which have a parameter in common while at the same time, ignoring differences in other parameters between the stimuli. By 7 months of age, infants can respond to the category of male vs. female voice. In a habituation paradigm, Miller, Younger and Morse (1982) presented infants with 6 exemplars of one category (eg. male) and trained turning to any of the 6 exemplars of the other category (eg. female). In two separate experiments they showed that the basis for responding was neither overall pitch differences between the groups nor memorization of the specific voices.

Tulkin (1973) compared 10 month old female infants from middle class families with working class families on their attention to mother's voices. He found that middle class children looked more at the mother, quieted more while hearing the mother's voice and vocalized more after presentation than did working class children. These findings suggest that early experiences influence attentiveness and differential responding towards particular voices.

Young children's ability to recognize voices has not been a topic of inquiry for either developmental or

perceptual psychology. It is assumed to be a function they can perform, but the parameters used and the basis for the performance have not been investigated.

Measurement of Laterality by Dichotic Technique

Recent interest in laterality has largely focused on trying to situate various processing proficiencies for a variety of stimuli in either hemisphere. As the studies have accumulated and shown often contradictory results, it has become apparent that participation of the two hemispheres shows only a relative advantage. Documenting this advantage in normal individuals using non-invasive techniques has met with limited success. One technique which has been used consistently over the past 20 years is the dichotic listening technique.

In the dichotic presentation of stimuli there is a simultaneous presentation of two different stimuli, one to each ear. In 1961, Kimura, using the Broadbent (1954) technique of simultaneously presenting different digits to each ear, published results indicating that normal, right-handed subjects showed a right ear advantage and that in patients who had speech lateralization determined by sodium amobarbital testing, there was an ear advantage contralateral to the hemisphere in which speech was

situated. Kimura (1967) views the dichotic listening technique as a measure of structural neurological organization. Nerve conduction pathways leading from an ear to the auditory cortex are both crossed and uncrossed. There is some neuroanatomical evidence that the crossed pathways have more fibers and more rapid conduction than the uncrossed pathways. That is, there is a prepotency for conduction along the crossed pathway. There is also the possibility that when two competing messages are presented there is some suppression of the ipsilateral signal. Both contralateral prepotency and ipsilateral inhibition may then contribute to the ear advantage found. Numerous subsequent studies have replicated Kimura's (1961, 1964) initial findings of a right ear advantage for speech and a left ear advantage for music. However, the discrepancy between the incidence of left hemisphere language in right-handed individuals (97-99%) and the incidence of right ear advantage on dichotic listening tasks (75-87%) (reviewed in Blumstein, Goodglass & Tartter, 1975) has made it somewhat difficult to interpret what is being measured. Although the dichotic listening technique is not a reliable predictor of the location of the language hemisphere for an individual listener, the consistency of findings with the technique have continued to make it

useful as a measure of asymmetric functions of the cerebral hemispheres.

Test-retest reliability has varied both for the type of material and the number of trials. For consonants, Blumstein, Goodglass and Tartter (1975) found Pearson product moment correlations of $r=.74$ for 80 dichotic trials while Wexler, Halwes and Heninger (1981) report an $r=.91$ for 120 dichotic trials. For vowels the correlation was not significant, while for music it was low but significant ($r=.46$; Blumstein, Goodglass & Tartter, 1975). The Blumstein et al. study found that although on retest most subjects maintained their ear advantage, 29% of the subjects switched ear advantages on consonants and 19% on music. Subjects who had greater laterality on these two types of stimuli tended to be those subjects who maintained their ear advantage.

Studies have shown that the ear advantage is vulnerable to changes in attention, memory and experience. Many investigators (Bryden, 1982; Hiscock & Bergstrom, 1982; Studdert-Kennedy, 1975) have advocated control of the factors known to influence the outcome of a dichotic listening task. This approach is useful in isolating those components of a signal which are strongly

lateralized and gives support to the type of structural model that Kimura (1961) proposed.

An alternative approach is to view the factors such as attention, experience, memory as interactive and inseparable from the properties of the stimulus. That is, certain features of the stimulus may be easier to attend to at particular times in the course of performing a task and memory for these salient features may enable a listener to subsequently attend to less salient features. Attention to a particular feature may have an orienting effect of the listener directing his processing asymmetrically to one side or the other (Kinsbourne, 1973) or it may be that an 'executive decision' is made to attend to a complex stimulus in a particular way (for example, to decide to process linguistically) and that decision determines which hemisphere will be the more active. For either interpretation a testing paradigm must be provided in which there is enough complexity in the stimulus that processing can occur in more than one way and with few constraints, to allow for flexibility of processing strategies. In relation to a dichotic listening task, the assumption necessary is that the ear in which processing is relatively more accurate is contralateral to the more active hemisphere.

Introduction to the Studies of Voice Recognition

There are parallel, but apparently contradictory positions with regard to research on hemispheric lateralization. The first maintains that there are hemispheric differences in processing and a wealth of research supports the verbal/non-verbal distinction between the hemispheres. The second position maintains that no dichotomy can capture cortical organization and as numerous studies have shown (reviewed by Bradshaw & Nettleton, 1981) lateralization of processing as anticipated by the traditional verbal/non-verbal distinction is influenced by familiarity to the stimulus, personal history and individual differences. The alternative to simply accepting either position is to examine hemispheric differences within a context of dynamic change.

"In place of a sharp distinction between the verbal and non-verbal, each assigned to its respective hemisphere, we have to think rather in terms of a variety of factors involved in the organization of psychological processes and of a hierarchy of functional levels in their cerebral representation." (p.175, Luria & Simernitskaya, 1977).

Moscovitch (1979) and Allen (1983) have provided a framework within information processing which can accommodate both hemispheric specialization and flexible interaction of hemispheric processing and some researchers have begun to analyze their findings in lateralization as time dependent changes.

The research program which has had the most influence on the studies to be presented is that of Ross-Kossak and Turkewitz. It is not only their findings of shifts in lateralization in the early learning phase of their experimental task, individual differences in initial lateralization and changes in the pattern of shifts in lateralization with development which has been influential, but that their findings can be accounted for within a microgenetic and a macrogenetic theoretical framework (Ross-Kossak & Turkewitz, 1986). The studies in this dissertation examine the generalizability to the auditory modality of the Ross-Kossak and Turkewitz findings by presenting a voice recognition task. This is a stimulus which is equally complex to facial recognition and serves a similar biological function in identifying familiar persons. Although Ross-Kossak and Turkewitz examined facial recognition in adolescents they have not extended their developmental studies to the very young or

old adults. These studies in voice recognition extend the developmental base of investigation across most of the life span.

Procedure

The series of studies involve presenting a voice recognition task to approximately 30 subjects at each of the following ages: age 5, age 10, age 15, young adults, and old adults. Across this span of ages many changes in development and cognitive organization occur. Since these studies were concerned with the investigation of the interrelationship of hemispheric functioning the ages for the subjects was, in part, determined by the maturation of the corpus callosum. Earliest estimates place completion of myelination of the corpus callosum at 6 years of age. Age 5 was chosen to represent biological immaturity of hemispheric connections. Age 10 is the upper boundary of estimates of corpus callosum myelination. At this age children are also often described as being relatively inflexible in using cognitive strategies (Nelson & Nelson, 1978). At age 15 perceptual strategies are probably mature while cognitive development is likely to be immature. For young adults, perception and cognition can be expected to be complex and integrated. Biological changes with aging may affect the relationship between perception and cognition. Specifically, new information may not be learned easily because it is not integrated with existing knowledge or because there is an inflexibility in the employment of

cognitive strategies resulting in inefficiency in processing new perceptual information.

Task

The voice recognition task consisted of two parts, a familiarization period to the voices and a test for recognition. During the familiarization period each speaker was presented binaurally and individually saying "my name is _____" and including their own name. The speakers were all female adults and were always presented in the same order. On each trial there was a familiarization period and a test of recognition which consisted of a dichotic presentation of two of the voices each saying "my name is" without including their names. Participants were asked at the end of each trial to name the two speakers "who were talking at the same time". Two samples of voice were used for each speaker, one for familiarization, the other for recognition.

All subjects were presented with four voices for recognition except the five year old subjects who had three voices.

All testing was conducted individually with the subject alone in a room with the tester. The level of ambient noise varied, but was always below the level of presentation of the test tape.

To control for small differences in the earphones producing artifacts in the experimental results, earphone placement was reversed for half the subjects in each age group.

Tape

This series of studies was conducted in stages. The initial tape and testing procedure was used for the young adult group. Modifications in procedure and a new, technically refined tape were presented to the other groups. To verify that modifications in testing did not alter the outcome of the experiments, separate groups of young adults were tested with each modification and their performance was compared with that using the initial tape.

Young Adults

The test tape was made in the speech sciences laboratory of the Graduate School of the City University

of New York. The tape was constructed using a TEAC model 35-2 tape-recorder with Switchcraft 308TR mixer amplifier and Altec 681A and Norelco D24E microphones. Two female speakers, acoustically isolated from one another, but in visual contact, coordinated simultaneous onset of a single phrase. Each speaker was recorded on a separate channel. A single best example from each pair of speakers was dubbed onto the test tape. The test tape was transferred to a cassette and subjects then heard this tape played on a Pioneer CT-5151 stereo tape-recorder over Koss Pro 4AA earphones at approximately 70 dB SPL.

The test tape was constructed by pairing the four speakers in all combinations for the dichotic presentation. Each pair was presented three times in both right-left combinations. The resulting dichotic pairs were randomized over the full set of 36 and the tape was presented twice in succession to each subject. Each dichotic presentation was followed by the four binaural presentations in which the speakers said their names. Subjects were asked to give, by name, the speakers heard during the dichotic presentation.

Twenty-three adults were tested with this tape and testing procedure. Procedural modifications used for the

other young adult subjects and age groups are detailed below.

Old Adults

The same tape was used for testing the old and young adults. However, because preliminary testing indicated that old adults found it easier to follow the task instructions when the dichotic presentation followed the four comparison voices, they were tested with that modification in the procedure. As a control for changing the procedure a group of young adults were tested in the same manner as were the old adults.

Age Groups 9-10 years and 14-15 years

In order to produce a more refined test tape and to insure that the onset of the two voices for the dichotic presentation was essentially simultaneous, a new test tape was made at the Division of Cognitive Neurosciences at Cornell University Medical Center using a Waved program (Mertus, 1984). Four different female speakers were recorded, individually, in an IAC sound booth on a Marantz PMD 360 tape-recorder. Single samples of the two test phrases were used to construct the new tape.

In this tape the four voices were presented, binaurally first, followed by the dichotic presentation. The tape was organized into six 12 trial blocks (6 paired combinations X 2 right-left combinations). Each block was randomized individually. The total length of the tape was 72 trials, the same as the initial tape.

The tape was recorded onto a Onkyo TA 2056 stereo tape-recorder with settings of high bias, 70 sec. and the Dolby noise reduction system. Subjects were tested using a Marantz PMD 360 stereo tape-recorder with Sennheiser MS 100 earphones at approximately 70 dB SPL.

There were two versions of the test tape and the earphones were rotated for half the subjects in a split design.

As a control for the comparability of the old and new tape, a group of young adults were tested using the second tape.

Age Group 4-5 years

A test tape was made using only 3 of the 4 voices. The method of construction was the same as the second

tape. The tape was organized into blocks of 6 trials (3 paired combinations X 2 right-left combinations) with a total of 60 trials. As with the previous tape, there was no demarcation between blocks so that listeners were (presumably) not aware of the divisions between blocks.

As was the case with the other groups of young subjects, there were two versions of the tape and two earphone positions with half the subjects tested with each alternative.

Subjects

All subjects were right-handed females. The three youngest age groups were children attending private schools in New York City. The young adults were primarily undergraduate volunteers from a university. The old adults attended a community senior citizens center and lived independently. This group was paid \$5.00 each for their participation in the study.

Handedness was determined by asking for the hand which was used in performing the following tasks: writing, brushing teeth, throwing a ball, using scissors, opening a door (Bryden, 1977). The 5 year olds were asked to mime these activities. Only persons who used

the right hand for all these activities were used as subjects in the study.

Hearing Screening

Age groups 5, 10, 15 years

Prior to presenting the test tape all subjects had their hearing screened to insure that they did not have a hearing loss which exceeded 20 dB HL for frequencies 500, 1k, 2k, 4k Hz.

Young Adults

Subjects were asked prior to testing if their hearing was normal but hearing was not tested.

Old Adults

For a subject to participate, hearing in the poorer ear had to be no poorer than 40 dB HL (pure tone average - best 2 out of 3 speech frequencies) and the difference between ears not more than 10 dB. The 40 dB hearing level criterion was such that even subjects with this maximally allowable hearing level could be expected to hear the test tape with no difficulty. The 10 dB

difference between the ears was allowed because such a difference is small enough that any differences in ear advantage could not readily be accounted for on the basis of peripheral hearing acuity.

Group Description

Subjects were eliminated from the study if they could not complete the task (2 at age 5; 2 old adults), were known to have learning disabilities (2 at age 10) or performed below chance (1 young adult; 2 old adults) or had a hearing loss which exceeded the criterion for such loss (4 old adults). Analyses were performed on a total of 149 subjects :

<u>Age Group</u>	<u>no.Ss</u>	<u>Mean Age (yrs.mos.)</u>	<u>Age Range</u>
4-5 yrs.	30	5.3	4.5 - 6.0
9-10 yrs.	30	9.6	8.6 - 11.3
14-15 yrs.	30	14.5	13.8 - 15.1
Young adults	32	25	17 - 40
Old adults	27	73	64 - 85

Results

As described in the procedure, the three youngest groups had a split design involving two trial order versions of the test tape and two earphone positions. A preliminary ANOVA showed no significant differences for the two tape versions or the earphone position and no interaction between these factors. For the two adult groups there was no difference in earphone position. Therefore for all subsequent analyses, data from subjects tested under these different conditions were merged.

The data were analyzed by age group, beginning with the youngest subjects. This approach comes from the assumption that, at any point in development cognitive processing is organized but the nature of the organization changes with age and experience. To begin to describe the cognitive processing associated with the task, performance on the test task is examined within an age group; changes in this organization are examined by comparisons across age groups. The contribution of experience to cognitive organization is examined by looking at changes in performance with familiarization to the voices through sequential analyses of the data across the test task.

In order to determine if subjects were performing above chance, the group distribution of scores for the number of correct identifications for the first named speaker on the first block was compared to the binomial distribution in a chi square analysis for each age. The rationale for using this procedure to test for chance performance, rather than testing the number correct for each ear separately, involves the inability to determine the correspondence between named speaker and ear of presentation in the subjects' response. The probability ($p=.66$ for age 5; $p=.5$ for all other groups) of assigning the first named speaker to either one of the speakers presented dichotically can be determined. Subjects were said to perform above chance if the distribution of the scores for the age group was higher than the binomial distribution. To avoid the inflated chi square values associated with low expected frequencies on the test trials, the probabilities associated with higher numbers (12-10 for age 5 and 12-8 for all other age groups) and the lower numbers (6-0 for age 5 and 4-0 for all other age groups) were combined to yield an expected value which approximated 5.

The data were analyzed quantitatively and qualitatively. Section I is a quantitative analyses of the performance of all subjects beginning with an overall

analyses of the subjects but focusing on each age group and the relationship between age groups. Proficiency in performance is based on errors made and on the trials in which both voices were correctly identified. In the qualitative analysis (Section III) errors are entered into confusion matrices and the degree of association between voices is calculated separately for each age group.

The first in this series of studies of voice recognition was with young adult subjects. Examination of the data suggested that there were individual differences within the group of subjects with respect to the initial ear advantage and changes in ear advantage across the test task. To examine the consequences on later processing of initial lateralization, this group was divided into sub-groups based on ear advantage at the end of the first third of the test tape (after 24 trials). This criterion was adopted as it seemed a reasonable amount of time for the establishment of an initial strategy. Although the division of the groups based on the first third of testing is arbitrary, other possible divisions are equally arbitrary. It should be noted that when a different classification criterion for initial ear advantage was used, (that is, the first ear in which 5 consecutive correct responses occurred), the

outcome was very similar to the classification system adopted.

In Section II data for each of the two sub-groups formed on the basis of initial ear advantage was analyzed using the two proficiency measures, error score and trials in which both voices were correctly identified. As this division into sub-groups derived from observations on the data of the young adult group, this age group is presented first.

Comparisons between and within groups are based on the statistical GANOVA program of Brecht, Woodward and Bonett (1987). This program is a general multivariate analysis based on a linear model.

Section I: Whole Group

Age 4-5 Years:

Since the youngest subjects had fewer trials (60) and three, instead of four, voices to choose from their error rates are not comparable to those of the other age groups. Results from this group, therefore, are

analyzed separately. For the sequential analysis the 60 trials were divided into 5 blocks of 12 trials each.

For those trials in which the first speaker named was correct, the distribution of scores was not significantly different from the binomial distribution on a chi square test for either the first (block 1) or the last (block 5) blocks. That is, these subjects did not perform above chance. In order to verify this finding using other, related measures further analyses was done. Using overall error scores subjects did not improve over the task (Table 1). On an ANOVA (ear X block) there were no main effects and there was no interaction.

Laterality was measured using an ear advantage (EA) index ($R - L / R + L$) which examines the effect of ear of presentation on accuracy while taking into account the subject's overall level of proficiency. For the 5 year old subjects an ANOVA for differences in mean indices across blocks was non-significant (Figure 1).

One approach to understanding the functional significance of lateralization is to measure the degree of association between the direction of ear advantage and proficiency. To do this the degree of laterality as

measured by the EA index was correlated with the error score using a Pearson product moment correlation for each block separately for subjects showing right ear advantage (REA) or a left ear advantage (LEA). Most correlations were not significant (Table 2) and when tested against a binomial distribution, the number of blocks on which there was a negative correlation was not significant.

Since this voice recognition task, in some sense, involves attending to input from both ears simultaneously, it was thought that proficiency might be meaningfully measured in the number of trials in which both voices were correctly identified (Table 3). When the distribution of these scores was tested using a chi square against the binomial distribution, it was found that subjects performed at chance level on both the first and last blocks. This measure supports the findings using error rate that repeated contact with the voices did not improve proficiency.

These results were somewhat unexpected and contrary to behavioral observations. These four and five year olds generally approached this task with some eagerness and throughout the testing exhibited confidence in their own performance. Answers were given with certainty and

very little general praise was needed to keep the children apparently focused on the task.

Table 1

Total Errors by BlockAge 5

Ear	Block				
	1	2	3	4	5
Right	4.10	4.07	4.50	3.43	3.90
Left	3.83	3.67	3.60	3.77	3.87
Com- bined	7.93	7.73	8.10	7.53	7.77
SD	1.56	1.44	1.68	1.41	1.58

Table 2

"r" Values for Pearson Product Moment Correlations
Between Error Score and Index of Ear Advantage.
Subjects are Divided According to Direction of
Ear Advantage on Each Block

Age 5

	Block				
	1	2	3	4	5
REA	.027	-.752**	-.482	.061	.031
LEA	-.477	-.273	-.490*	-.261	-.281

* $p < .05$ ** $p < .01$

Table 3

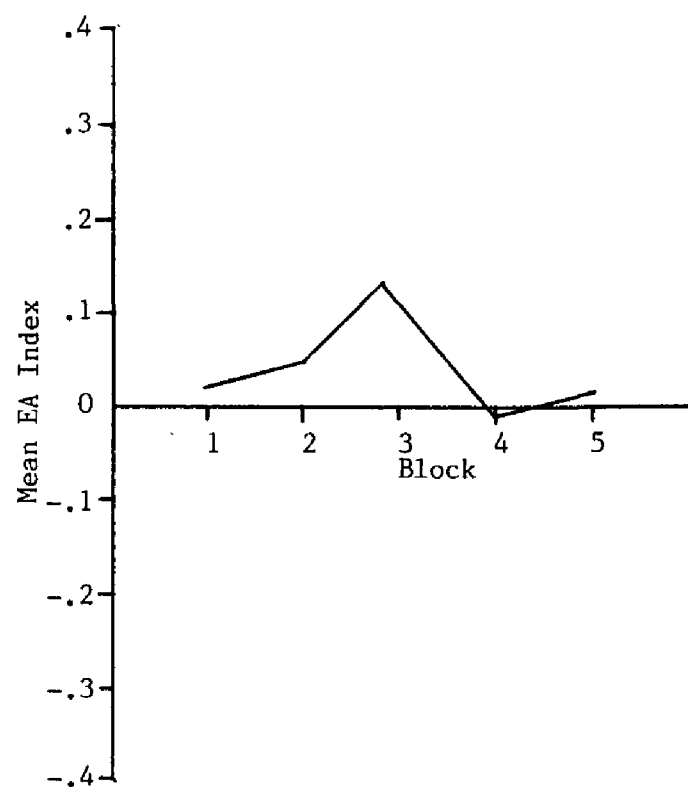
Mean Number of Trials in which Both Voices Presented
were Named Correctly

Age 5

Block					
	1	2	3	4	5
	4.19	4.22	3.85	4.38	4.20
SD	2.02	1.56	1.68	1.36	1.62

Figure 1: Mean Ear Advantage Index across blocks for age 5 subjects.

Figure 1



General Results From All Subjects From Age 9-10 Through
Old Adults

For each age group the distribution of scores for the first speaker named was better than chance on block 1 as tested against the binomial distribution with a chi square.

A comprehensive ANOVA (age X block X ear) based on error scores had significant main effects of age ($F=39.686$; d.f.=3,115; $p<.001$), block ($F=8.480$; d.f.=5,575; $p<.001$) and ear ($F=5.589$; d.f.=1,115; $p<.020$) and an interaction of age with block ($F=3.244$; d.f.=15,575; $p<.001$). There was improvement in the ability to perform the test task with increasing age up to the young adult level and then a decline in ability with old adults. Within each age group, except for old adults, there is improvement in performing the task with increased familiarity to the voices.

Similarly, on a second measure of proficiency, the trials on which both voices presented were named correctly, there was improvement with age to the level of young adults, with a decline for old adults. There was also improvement over the course of doing the task for

all age groups except the old adults. On an ANOVA there were significant main effects of age ($F=33.162$, $d.f.=3,115$; $p<.001$) block ($F=5.946$; $d.f.=5,575$; $p<.001$) and an interaction of age and block ($F=3.239$; $d.f.=15,575$; $p<.001$).

Plan of Analyses for Separate Age Groups

The initial analysis for each age group involved examining overall proficiency and differences on error score for ear of presentation across blocks. For this analysis there was a separate ANOVA (ear X block) on errors for each age group. A second one-way ANOVA across blocks using the lateralization index as a measure was also carried out separately for each age group.

The results in Section I are presented in the following order:

1. overall proficiency based on total errors across blocks
2. comparison of errors made on each ear
3. relative ear advantage as measured by the lateralization index
4. correlation of proficiency with direction and

- degree of ear advantage on each block
5. proficiency as measured by trials in which both voices were correctly identified

Findings within each age group will be presented, followed by qualitative and quantitative comparisons between age groups.

When 9 young adults were tested with the second test tape the means at each block (except block 3) were within one standard deviation of the means of the young adults on the initial test tape. The two test tapes were, therefore, considered comparable. The 9 subjects in the young adult control group were not included in any other analysis.

Age 9-10 Year Group

For children aged 9-10 years there was significant improvement in their ability to recognize voices with increasing familiarity to those voices (Table 4). On the ear X block ANOVA the main effect of block was significant ($F = 3.143$; d.f. = 5,145; $p < .01$) with a significant linear component on trend analysis ($F = 5.598$; d.f. = 1,145; $p < .025$). The main effect of ear

approached significance ($F = 3.389$; d.f. = 1,29; $p < .07$) with fewer errors made in identifying voices presented to the left ear. There was no interaction of block with ear.

The analysis of lateralization, as measured by the EA index, showed no significant differences in indices on an ANOVA across the 6 blocks (Figure 2).

The relationship between degree and direction of laterality and proficiency as measured by the Pearson product moment correlation of EA index with error score was primarily negative, with 2 of the 12 correlations significantly negative, suggesting that, in general, those subjects who have greater lateralization perform better (Table 5). When tested against the binomial distribution, however, the number of blocks on which a negative correlation occurred was not significant.

When the measure of proficiency is the number of trials in which both voices are correctly identified (Table 6), the distribution of subjects' scores was at chance level on block 1 but by block 6 their scores were significantly better than would be expected by chance alone. The observed improvement was not sufficient to

reach significance on a planned contrast of block 1 with block 6, however.

Table 4

Total Errors by BlockAge 10

Ear	Block					
	1	2	3	4	5	6
Right	5.27	5.40	5.33	4.80	4.60	4.67
Left	5.23	4.70	3.97	4.30	4.07	4.43
Com- bined	10.50	10.10	9.30	9.10	8.67	9.10
SD	2.26	2.18	2.38	2.44	2.18	2.59

Table 5

"r" Values for Pearson Product Moment Correlations
Between Error Score and Index of Ear Advantage.
Subjects are Divided According to Direction of
Ear Advantage on Each Block
Age 10

	Block					
	1	2	3	4	5	6
REA	.243	-.429	.304	-.537*	-.350	-.080
LEA	.101	-.631*	-.048	-.372	-.229	-.213

*p<.05 **p<.01

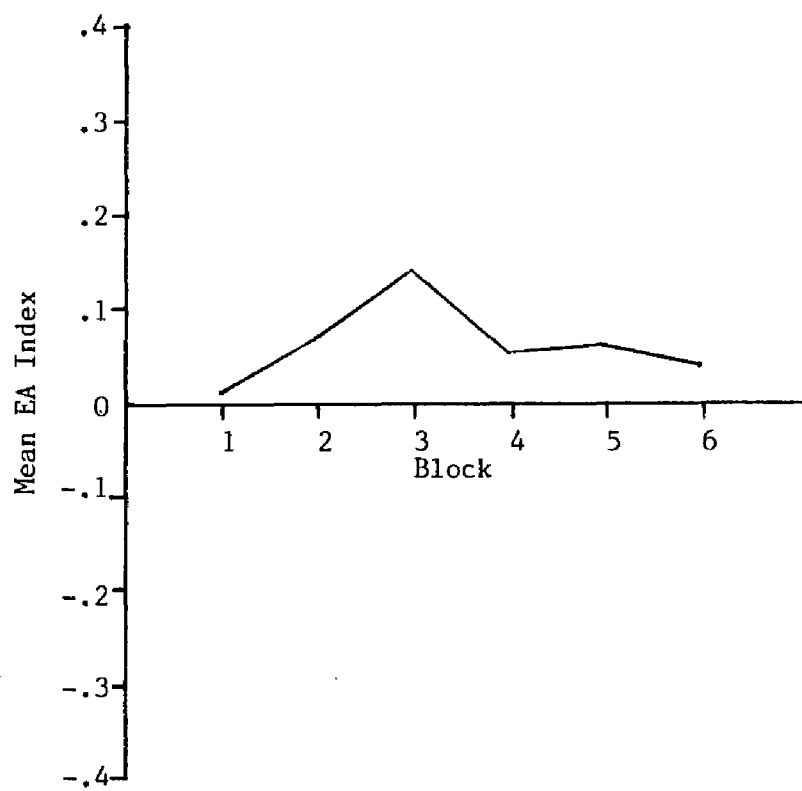
Table 6

Mean Number of Trials in which Both Voices Presentedwere Named CorrectlyAge 10

Block						
	1	2	3	4	5	6
	2.80	3.37	3.57	3.47	4.07	3.80
SD	1.56	1.14	1.78	2.08	1.81	1.97

Figure 2: Mean Ear Advantage Index across blocks for age 10 subjects.

Figure 2



Age 14-15 Year Group

Subjects in the 14-15 year old group generally improved during the course of testing (Table 7). The ANOVA on errors (ear X block) showed a significant block effect ($F = 7.059$; d.f. = 5,145; $p < .001$). The trend analysis was significant for the linear component ($F = 7.242$; d.f. = 1,145; $p < .01$) supporting the interpretation that subjects improved. On the same ANOVA the ear effect approached significance ($F = 3.676$; d.f. = 1,29; $p < .06$) with fewer errors made in identifying the voice presented to the left ear.

Changes in lateralization, as measured by an ANOVA using the EA index, were not significant across the blocks (Figure 3).

As with the younger age groups, the general direction of correlations of laterality and proficiency (as measured by the EA index and error scores, Table 8) was negative. Although only one of the 12 correlations was significant, 10 of the correlations computed were negative and only two were positive, a difference which was significant ($p < .04$, two-tailed test).

Analysis of the number of trials in which both voices presented were correctly identified showed that distribution of scores was initially at chance level (block 1) but there was improvement during the test task (Table 9) such that the distribution of subjects' scores at block 6 were significantly different from the binomial distribution. On a planned contrast from the comprehensive ANOVA for this age group block 6 was significantly different from block 1 ($F = 13.327$; $d.f.=1,115$; $p<.001$).

Table 7

Total Errors by BlockAge 15

Ear	Block					
	1	2	3	4	5	6
Right	5.20	4.47	4.37	4.00	4.83	4.43
Left	4.70	3.97	3.67	4.13	4.10	3.60
Com- bined	9.90	8.43	8.03	8.13	8.93	8.03
SD	3.45	2.87	2.18	2.00	2.98	2.81

Table 8

"r" Values for Pearson Product Moment Correlations

Between Error Score and Index of Ear Advantage.

Subjects are Divided According to Direction of

Ear Advantage on Each Block

Age 15

	Block					
	1	2	3	4	5	6
REA	-.540	-.493	-.062	.089	-.668*	-.201
LEA	-.387	.091	-.201	-.260	-.239	-.415

*p<.05 **p<.01

Table 9

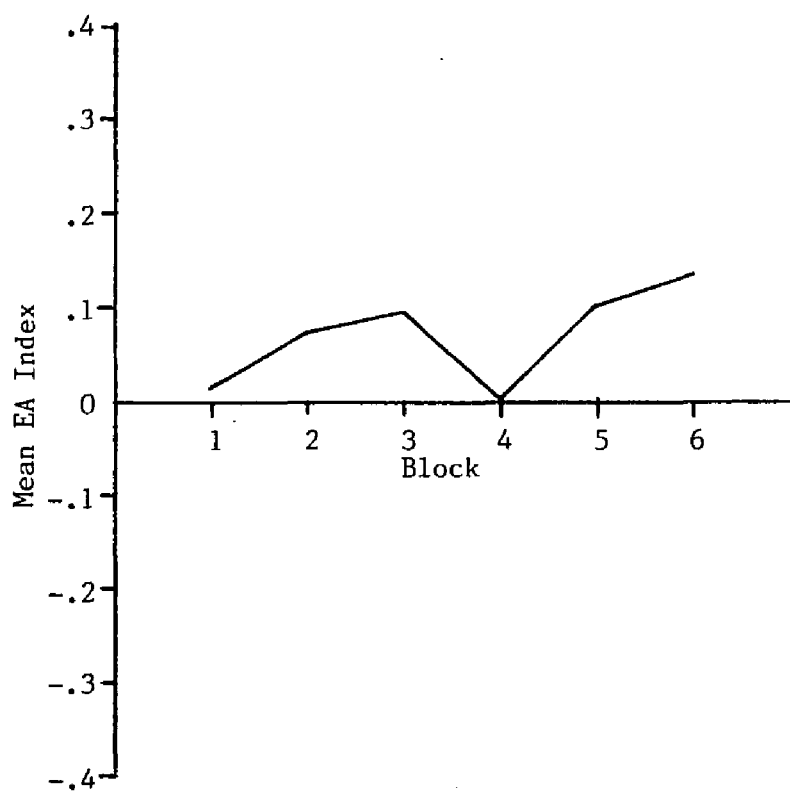
Mean Number of Trials in which Both Voices Presented
were Named Correctly

Age 15

	Block					
	1	2	3	4	5	6
	2.97	3.90	4.73	4.30	3.83	4.60
SD	1.52	1.68	1.75	1.77	2.16	2.09

Figure 3: Mean Ear Advantage Index across blocks for age 15 subjects.

Figure 3



Young Adults

As described in the procedure section, 23 of the young adult subjects heard the dichotic presentation before hearing the comparison voices and 9 of the subjects heard the comparison voices first followed by the dichotic presentation. Examination of errors made in the right and in the left ears for the first and second halves of the tape showed no differences as a result of order of dichotic presentation. These subjects were combined for analysis as a single group.

Young adults improved over the course of the task in their ability to recognize the voices (Table 10). The ANOVA based on error score indicated a significant block effect ($F = 7.409$; d.f. = 5,155; $p < .001$). The ear effect on the ANOVA was not significant and there was no interaction between ear and block effect. A trend analysis was significant for the linear component ($F = 25.109$; d.f. = 1,31; $p < .001$) confirming the impression that subjects improved over the task.

Changes over the test task in lateralization, as measured by the EA index, were not significant on a one-way ANOVA across blocks.

All of the 12 correlations of ear advantage with error score (Table 11) were negative, a finding significant at the $p < .001$ level when tested against a binomial distribution. In addition, eight of the individual correlations were significant. For subjects with a REA correlations were significant for blocks 2, 4, 5 and 6. The correlation on block 3 was not significant even though half of the subjects had a REA on this block. For subjects with a LEA correlations were significant from block 3 through block 6.

On the other measure of proficiency, the number of trials in which both voices were correctly identified, young adults performed better than chance at the onset of testing (Table 12) and continued to improve in their ability to attend to simultaneous input to the two ears throughout the task (ANOVA: $F = 3.348$; d.f. = 5,535; $p < .01$).

Table 10

Total Errors by BlockYoung Adults

Ear	Block					
	1	2	3	4	5	6
Right	4.25	4.16	3.72	2.94	3.41	3.06
Left	3.94	3.50	3.69	3.00	2.91	3.00
Com- bined	8.19	7.66	7.41	5.94	6.31	6.06
SD	2.71	1.90	2.82	2.81	2.98	2.81

Table 11

"r" Values for Pearson Product Moment Correlations
Between Error Score and Index of Ear Advantage.
Subjects are Divided According to Direction of
Ear Advantage on Each Block
Young Adults

	Block					
	1	2	3	4	5	6
REA	-.383	-.783**	-.294	-.770**	-.611*	-.759**
LEA	-.416	-.448	-.743**	-.735**	-.625*	-.904**

* $p < .05$ ** $p < .01$

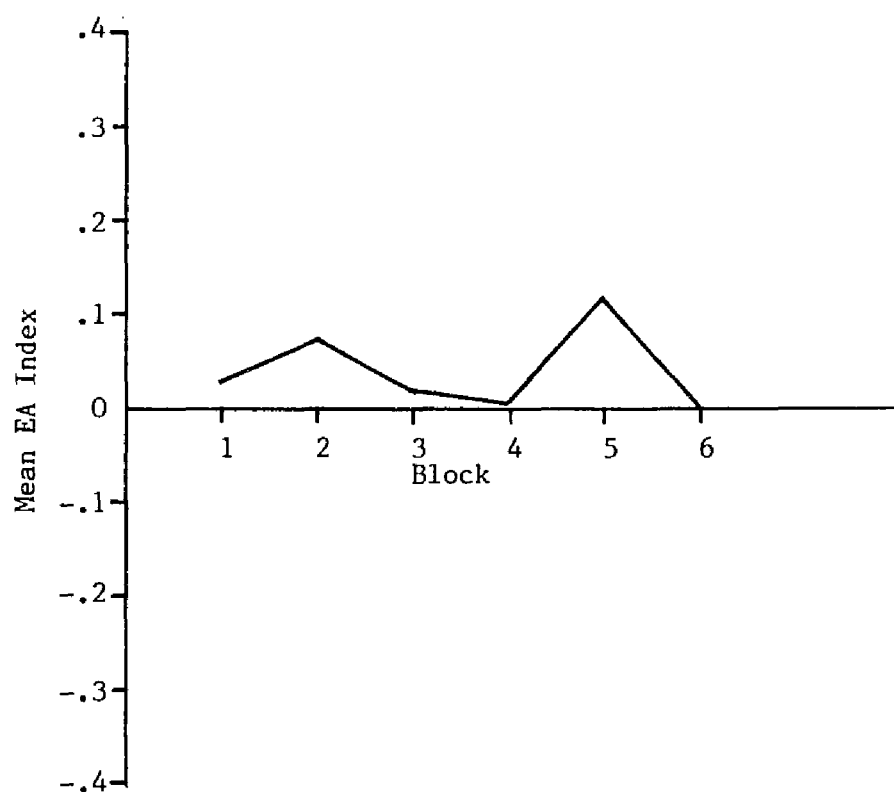
Table 12

Mean Number of Trials in which Both Voices Presented
were Named Correctly
Young Adults

	Block					
	1	2	3	4	5	6
	4.77	4.93	5.33	6.47	6.13	6.30
SD	2.38	2.02	2.30	2.46	2.46	2.47

Figure 4: Mean Ear Advantage Index across blocks for young adult subjects.

Figure 4



Old Adults

Old adults made more errors than any of the younger age groups and they did not improve with increased familiarity to the voices (Table 13). Tests for change in score over the test task were not significant for old adults. On an ANOVA based on error score neither ear nor block main effects nor their interaction were significant.

Lateralization, as measured by the EA index, was not significant (Figure 5).

Three of the correlations of error score with indices were significantly negative and 10 of the 12 correlations were negative which is a significant divergence from chance ($p < .04$, two-tailed test) when tested against a binomial distribution (Table 14).

The old adult group were at chance level on block 1 when trials of both ears correct were compared to the binomial distribution (Table 15). There was no improvement over the course of the test task for this measure either.

Table 13

Total Errors by BlockOld Adults

Ear	Block					
	1	2	3	4	5	6
Right	5.56	5.70	5.56	5.37	5.74	6.15
Left	5.63	5.48	5.67	5.63	5.74	5.70
Com- bined	11.19	11.19	11.22	11.00	12.44	11.85
SD	2.04	2.19	2.44	1.98	1.97	1.65

Table 14

"r" Values for Pearson Product Moment CorrelationsBetween Error Score and Index of Ear Advantage.Subjects are Divided According to Direction ofEar Advantage on Each BlockOld Adults

	Block					
	1	2	3	4	5	6
REA	-.752**	-.420	-.236	-.215	-.340	.096
LEA	.118	-.582	-.757**	-.656*	-.554	-.405

*p<.05 **p<.01

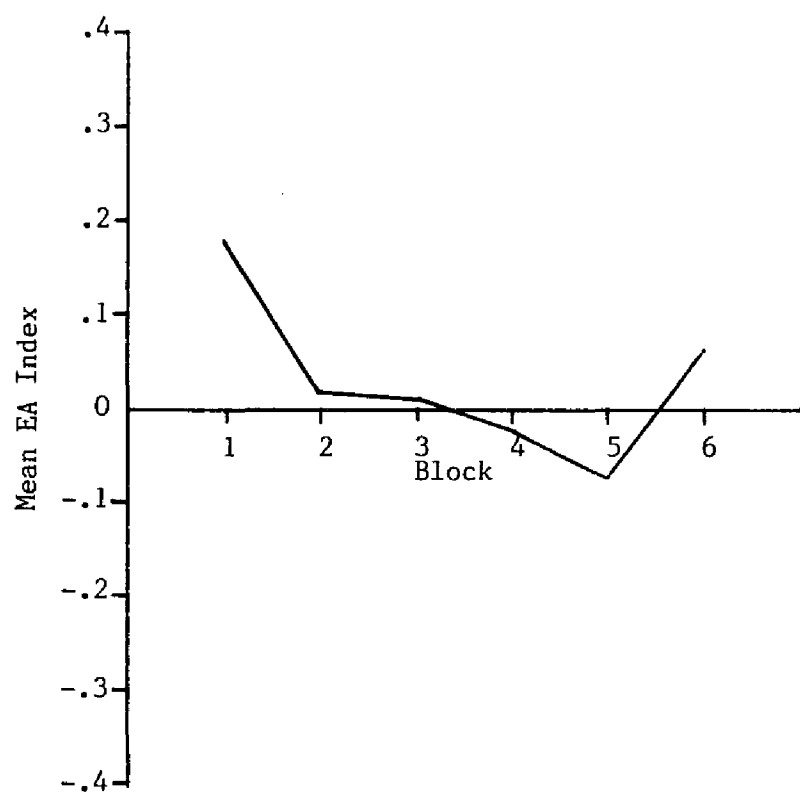
Table 15

Mean Number of Trials in which Both Voices Presentedwere Named CorrectlyOld Adults

Block						
	1	2	3	4	5	6
	2.78	2.44	2.22	2.41	1.96	2.04
SD	1.37	1.52	1.20	1.57	1.32	1.45

Figure 5: Mean Ear Advantage Index across blocks for
old adult subjects.

Figure 5



General Summary

Proficiency based on errors.

While the 5 year olds did not improve in their ability to recognize the voices, the 10 year olds improved significantly on the measure of error rate.

The 15 year old subjects also showed improvement in proficiency for recognizing voices with familiarity to the voices. The overall difference in proficiency, as measured by error scores, bntly over the course of the task. When

contrasted with the age 15 group using the comprehensive ANOVA, the overall performance of the young adult group was better ($F=18.492$; d.f.=1,115; $p<.001$). Although both groups had significant block effects on an ANOVA based on errors, when block 1 was eliminated the young adult group continued to show improvement on the remaining blocks 2 through 6 ($F=5.696$; d.f.=4,460; $p<.001$) while the age 15 group did not (Table 16).

Old adults have more difficulty with thintly over the course of the task. When

contrasted with the age 15 group using the comprehensive ANOVA, the overall performance of the young adult group was better ($F=18.492$; $d.f.=1,115$; $p<.001$). Although both groups had significant block effects on an ANOVA based on errors, when block 1 was eliminated the young adult group continued to show improvement on the remaining blocks 2 through 6 ($F=5.696$; $d.f.=4,460$; $p<.001$) while the age 15 group did not (Table 16).

Old adults have more difficulty with this voice recognition task than do young adults. On a contrast from the comprehensive ANOVA based on total error score, the difference between the old and young adult groups was significant ($F=115.618$; $d.f. = 1,115$; $p<.001$). The difference between these two groups was maintained when errors were examined across blocks also (young vs. old adults X block from the comprehensive ANOVA: $F=6.357$; $d.f.=5,575$; $p<.001$).

Lateralization across blocks.

For none of the 5 age groups was lateralization, as measured by the EA index, significant.

Relation between proficiency and lateralization.

Although correlations of ear advantage on each block with error score were generally negative in the age 10 and 15 groups, there were few significant correlations. In contrast, the young adult group had four blocks on which there were significant correlations both for blocks on which there was a REA and blocks on which there was a LEA. For both directions of ear advantage greater lateralization was associated with better performance on the last half of the test task.

As with all the younger groups, for old adults there was an association between proficiency and laterality. There were, however, fewer significant correlations on individual blocks than there were for young adults.

Proficiency based on both voices named correctly.

When proficiency is measured by number of trials in which both voices presented were named correctly, the age 10 15 and young adult groups made significant improvement. The old adults, although performing above chance on this measure, did not improve (Table 17).

Table 16

Group Mean Error Score by Block:
Right and Left Ears Combined

(Maximum error score is 24)

Group	BLOCK					
	1	2	3	4	5	6
Age 10	10.50	10.10	9.30	9.10	8.67	9.10
SD	2.26	2.18	2.38	2.44	2.18	2.59
Age 15	9.90	8.43	8.03	8.13	8.93	8.03
SD	3.45	2.87	2.18	2.00	2.58	2.54
Young Adults	8.19	7.66	7.41	5.94	6.31	6.06
SD	2.71	1.90	2.82	2.81	2.98	2.81
Old Adults	11.19	11.19	11.22	11.00	12.44	11.85
SD	2.04	2.19	2.44	1.98	1.97	1.65

Table 17

Mean Number of Trials in which Both Voices Presented were
Named Correctly

Group	BLOCK					
	1	2	3	4	5	6
Age 10	2.80	3.37	3.57	3.47	4.07	3.80
SD	1.56	1.14	1.78	2.08	1.81	1.97
Age 15	2.97	3.90	4.73	4.30	3.83	4.60
SD	1.52	1.68	1.75	1.77	2.16	2.09
Young Adults	4.77	4.93	5.33	6.47	6.13	6.30
SD	2.38	2.02	2.30	2.46	2.46	2.47
Old Adults	2.78	2.44	2.22	2.41	1.96	2.04
SD	1.37	1.52	1.20	1.57	1.32	1.45

Section II: Initial Ear Advantage Sub-groups

As described in the introduction to the results section, observations of the performance of individual young adult subjects indicated that ear advantage changed over the course of the voice recognition task. This age group was then divided into two sub-groups based on initial ear advantage (ear advantage at the end of the first 24 trials) and performance of each sub-group over all trials was examined separately. Using the same criterion, each age group was then divided into sub-groups and quantitative and qualitative comparisons were made with respect to the sub-group division, within and across age groups.

The division of age groups into initial ear advantage sub-groups appears to be a qualitative distinction initially. An overall ANOVA (age X initial ear advantage sub-group X block X ear) based on error score was significant for age effect ($F=21.855$; $d.f.=3,107$; $p<.001$) and block effect ($F=8.903$; $d.f.=5,535$; $p<.001$). The significant interactions were age with block and two interactions which were with the sub-group division, the sub-group with ear and the sub-group with ear across block effects. The sub-group

effect and the ear effect were not significant. Within an age group differences between initial ear advantage groups are examined by selecting for contrasts from the ANOVA. For each age group there is also a separate ANOVA (initial ear advantage group X block) using the EA index as the dependent variable.

Analysis within an age group will be reported in the form:

1. ANOVA and trend analysis of EA indices
2. proficiency differences as measured by error score between the sub-groups including comparisons between sub-groups and within sub-group changes over the course of the task
3. Pearson product moment correlations between proficiency and degree of lateralization.

Young Adult Group

Using the criterion of ear advantage at the end of the first 24 trials, three sub-groups were formed: 12 subjects had an initial right ear advantage (IREA); 18 subjects had an initial left ear advantage (ILEA); and 2 subjects had no advantage (NA). As the number of subjects in the no advantage sub-group was very small

these subjects were eliminated from the subsequent analysis.

Comparing Figures 4 and 6 it can be seen from the mean EA indices that when the group was analyzed as a whole changes occurring within the IREA and ILEA sub-groups were masked. Once this group was divided on the basis of initial ear advantage it became clear that ear advantage changed over the course of the task. The ANOVA based on EA indices showed no main effects for either sub-group or block but there was a significant interaction of these factors ($F = 3.294$; d.f. = 10,145; $p < .001$). When the sub-groups were tested separately there was a significant block effect for both the IREA group ($F = 2.984$; d.f. = 5,145; $p < .01$) and the ILEA group ($F = 2.790$; d.f. = 5,145; $p < .02$).

In the IREA group, subjects shifted ear advantage later in processing (Figure 6). That these shifts in ear advantage represented systematic changes in lateralization was shown by the trend analysis which was significant for a linear trend ($F = 9.302$; d.f. = 1,29; $p < .005$). A cubic trend approached significance ($F = 3.389$; d.f. = 1,29; $p < .07$). Subjects who had an ILEA also appeared to shift advantage to the opposite ear but only on the last block. For this sub-group there was

also a significant linear trend ($F = 8.198$; d.f. = 1,145; $p < .01$).

On contrasts from the comprehensive ANOVA based on error scores there were no proficiency differences between the IREA and the ILEA sub-groups (Table 18). For the IREA sub-group there was no difference between ears, no block effect but a significant interaction of block with ear effect ($F=2.305$; d.f.=5,535; $p < .04$). For the ILEA sub-group there was a significant ear effect ($F=5.604$; d.f.=1,107; $p < .02$), a significant block effect ($F=5.288$; d.f.=5,535; $p < .001$) and a significant interaction of ear and block effects ($F=3.515$; d.f.=5,535; $p < .004$). Both sub-groups made improvement across blocks as shown by significant linear trends (IREA sub-group: $F=5.015$; d.f.=1,107; $p < .03$; ILEA sub-group: $F=10.634$; d.f.=1,107; $p < .002$).

In order to examine the relationship between proficiency and degree of lateralization, the same Pearson product moment correlation of error score with index which was performed for the total subjects in each age group was done separately for each sub-group. On the previous correlations each block was divided into subjects with a particular ear advantage and, therefore, all indices were of the same sign. When testing the sub-

groups there was not the same consistency of signs. Since the measure is for degree of laterality and not direction, absolute indices were used for calculation. Correlations of errors with indices were all negative except for block 1 ($p < .04$, two-tailed test) and generally indicate that young adult listeners perform better when they are more lateralized on the task (Table 19). For the IREA sub-group the correlation falls below the level necessary to attain significance at block 3, the period when there is a crossover from a REA to a LEA. The data, therefore, indicate that although this group of subjects was selected for an initial REA, later in processing they are able to utilize a LEA effectively. For the ILEA sub-group, although their largest ear advantage occurs at block 2 (Figure 6), there was no significant relationship between lateralization and proficiency at that point. Later in processing, lateralization and changes in lateralization, including a shift to a REA (block 6) are associated with fewer errors.

This division of subjects based on initial ear advantage in the young adult group has the advantage of focusing attention on the sequential nature of processing. The findings with this division suggested that there were individual differences in lateralization when the listeners approached a complex auditory task and

that over the course of processing they changed lateralization. These shifts in lateralization and greater lateralization are associated with greater proficiency on the task. Although the number of trials used to divide the groups into initial ear advantage is arbitrary, division does begin to address issues of individual differences in lateralization and particularly the functional use of lateralization. It was, therefore, decided to employ the same criterion of ear advantage after the first 24 trials to the other age groups and to look for patterns of change across the task.

Figure 6: Mean Ear Advnatage Index acaross blocks of initial right ear advantage (IREA) and initial left ear advantage (ILEA) sub-groups of young adult subjects.

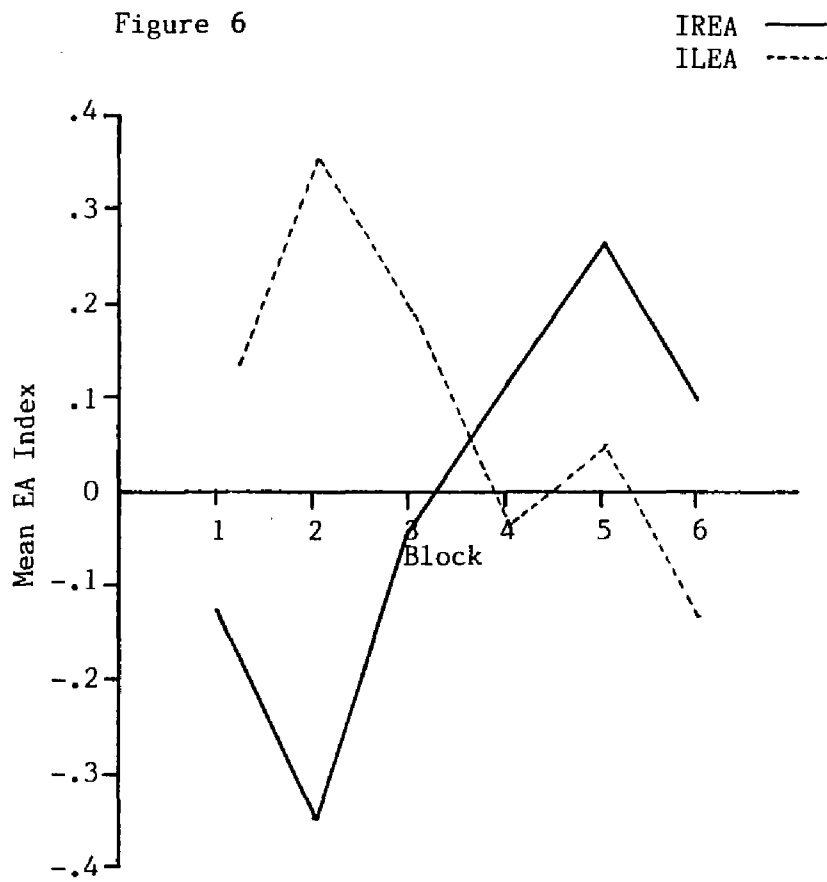


Table 18

Mean Errors of Initial Ear Advantage Sub-groupsYoung Adults

Sub-group	Block					
	1	2	3	4	5	6
IREA n=12	7.50	7.58	7.00	6.42	6.33	5.75
ILEA n=18	8.22	7.56	7.94	5.56	6.22	6.39

Table 19

Pearson Product Moment Correlations of Errors with
Absolute Indices for Initial Ear Advantage Sub-groups
Young Adults

	Block					
	1	2	3	4	5	6
Sub-group						
IREA	.086	-.739**	-.397	-.758**	-.582*	-.704**
ILEA	.039	-.373	-.525*	-.585*	-.471*	-.706**

*p<.05 **p<.01

Age 5 Group

Since the age 5 group did not perform above chance, initially, and did not improve with familiarity to the voices on two measures of proficiency no further analysis of this group is warranted.

Age 10 Group

In the age 10 group 13 subjects had an IREA, 12 subjects had an ILEA and 5 subjects had no initial advantage. When lateralization during processing for the sub-groups was examined using the EA index the profile was one in which the IREA group showed almost no lateralization after block 2 while the ILEA group maintained a LEA throughout (Figure 7).

On an ANOVA, based on EA indices, there was a significant initial ear advantage group effect ($F = 11.823$; d.f. = 2,27; $p < .001$) with no block effect and no interaction of these factors. The trend analysis showed no significant trends for either sub-group.

On contrasts from the comprehensive ANOVA based on error scores, there was no proficiency difference between the IREA and ILEA sub-groups. For the IREA sub-group there was no difference between ears, no block effect but a significant interaction of block with ear effect ($F=2.492$; d.f.=5,535; $p<.03$). For the ILEA sub-group there was a significant ear effect ($F=33.147$; d.f.=1,107; $p<.001$) with the score consistently better for voices presented to the left ear. For this sub-group there was also a block effect ($F=3.230$; d.f.=5,535; $p<.007$) but no interaction of these factors. Subjects in both sub-groups improved over the test task (Table 20) but only for the subjects in the ILEA sub-group was the improvement significant as shown by a significant linear trend ($F=9.581$; d.f.=1,107; $p<.003$) on the block effect.

Correlations of absolute indices with error scores were generally non-significant (Table 21) and the number of negative correlations was not significantly different from the number of positive correlations.

Figure 7: Mean Ear Advantage Index across blocks of initial right ear advantage (IREA) and initial left ear advantage (ILEA) sub-groups of age 10 subjects.

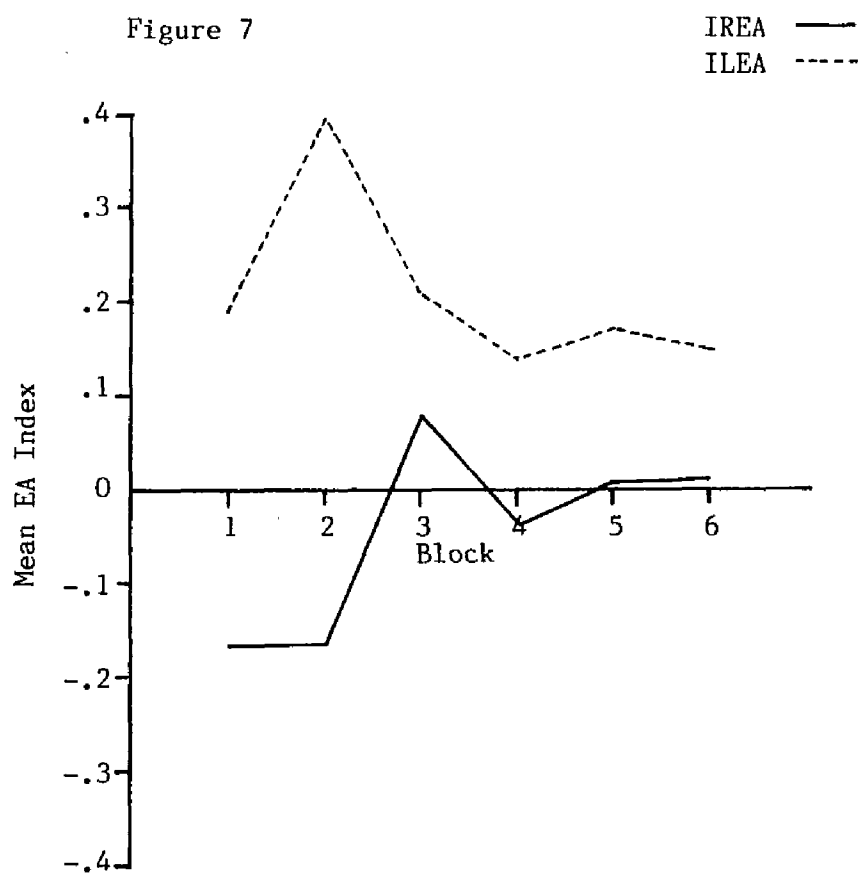


Table 20

Mean Errors of INitial Ear Advantage Sub-groupsAge 10

Block						
Sub-group	1	2	3	4	5	6
IREA n=13	10.31	10.39	9.08	9.31	8.69	9.46
ILEA n=12	10.42	10.01	10.17	8.83	8.17	8.17

Table 21

Pearson Product Moment Correlations of Errors with
Absolute Indices for Initial Ear Advantage Sub-groups
Age 10

Sub-group	Block					
	1	2	3	4	5	6
IREA	.436	-.193	.204	-.819**	-.035	-.175
ILEA	-.106	-.112	.057	-.179	-.202	-.189

*p<.05 **p<.01

Age 15 Group

When the age 15 group was divided into sub-groups 12 subjects had an IREA, 16 subjects had an ILEA, and 2 subjects had no initial advantage. On the EA indices, the IREA sub-group shifted ear advantage to a relatively weak left ear advantage while the ILEA group generally maintained the direction of ear advantage (Figure 8). On an ANOVA based on EA indices, the main effect of initial ear advantage group approached significance ($F = 3.093$ d.f. = 2,27; $p < .06$); there was no significant block effect but the interaction of sub-group with block was significant ($F = 2.699$; d.f. = 10,135; $p < .01$). The trend analysis showed a significant linear trend ($F = 13.177$; d.f. = 1,135; $p < .001$) for the shift in lateralization for the IREA group. In the ILEA group there were no significant trends.

On contrasts from the comprehensive ANOVA based on error scores there were no proficiency differences between the IREA and the ILEA sub-groups (Table 22). For the IREA sub-group there was no difference between ears, but a significant block effect ($F=2.931$; d.f.=5,535; $p < .01$) and a significant interaction of ear and block effects ($F=3.141$; d.f.= 5,535; $p < .01$). For the ILEA sub-group there was significance for the ear effect ($F=15.569$; d.f.=1,107; $p < .001$), the block effect ($F=3.257$; d.f.=5,535; $p < .01$) and

their interaction ($F=2.183$; $d.f.=5,535$; $p<.05$). Trend analysis approached significance for the linear trend for both sub-groups. It was noted previously that the age 15 group appeared to show a reduction in errors from block 1 to block 2 then an asymptote with very little further decrease (Table 7). When this age group was divided into sub-groups based on initial ear advantage it appeared that the two sub-groups had different rates of reduction in errors (Table 22). For the IREA group there was a significant improvement between blocks 1 and 2 on a planned contrast from the ANOVA ($F=7.222$; $d.f.=1,107$; $p<.008$) but this proficiency improvement in recognizing the voices was not maintained and the final error rate (block 6) was not significantly lower than the initial error rate (block 1). On planned contrasts for the ILEA sub-group the improvement in proficiency between block 1 and block 6 was significant ($F=7.889$; $d.f.=1,107$; $p<.006$) but not between block 1 and 2. For this sub-group the decrease in errors is associated with a weakening of left ear advantage.

Pearson product moment correlations of lateralization with error score were generally non-significant (Table 23) as was the difference in the number of blocks on which negative and positive correlations occurred.

Figure 8: Mean Ear Advantage Index across blocks of initial right ear advantage (IREA) and initial left ear advantage (ILEA) sub-groups of age 15 subjects.

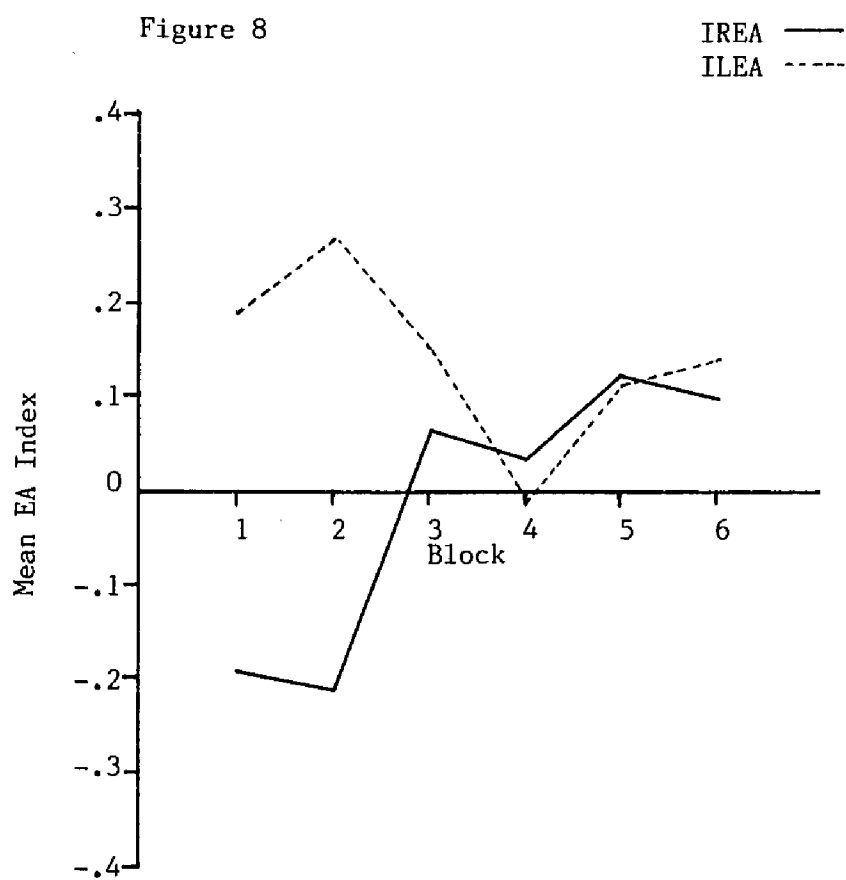


Table 22

Mean Errors of Initial Ear Advantage Sub-groupsAge 15

Sub-group	Block					
	1	2	3	4	5	6
IREA n=12	9.33	7.67	8.17	7.42	8.17	8.42
ILEA n=16	10.06	9.06	7.88	8.50	9.44	7.94

Table 23

Pearson Product Moment Correlations of Errors with
Absolute Indices for Initial Ear Advantage Sub-group
Age 15

Sub-group	Block					
	1	2	3	4	5	6
IREA	-.037	.414	.003	-.184	-.315	-.069
ILEA	-.590*	.141	.586*	.227	-.383	-.572*

* $p < .05$ ** $p < .01$

Old Adult Group

When the old adult group was divided on the basis of initial ear advantage 13 subjects were in the IREA sub-group, 10 subjects were in the ILEA sub-group and 4 subjects had no initial ear advantage. As with the other age groups, the data for the no advantage group were not included in the subsequent analysis.

From Figure 9 it can be seen that both sub-groups shift lateralization although the change occurs late in the processing sequence (between blocks 5 and 6 for the IREA sub-group and between blocks 4 and 5 for the ILEA sub-group).

On the ANOVA based on indices the old adult group had no significant main effects for initial ear advantage group or block but a significant interaction ($F = 2.219$; $d.f. = 10,120$; $p < .02$) between these factors. On contrasts for separate sub-groups the change in indices across blocks approached or was significant (IREA group: $F = 2.173$; $d.f. = 5,120$; $p < .06$; ILEA group: $F = 2.565$; $d.f. = 5,120$; $p < .03$). The trend analysis showed significant linear ($F = 5.067$; $d.f. = 1,120$; $p < .025$) and cubic trends ($F = 5.067$; $d.f. = 1,120$; $p < .05$) for the IREA group and a

significant linear trend ($F = 10.430$; $d.f. = 1,120$; $p < .01$) for the ILEA group.

Old adults, as a group, did not improve in the recognition of the voices during the task. This finding remained consistent when this group was divided into the two sub-groups based on initial ear advantage (Table 24). There was no proficiency difference between the IREA and the ILEA sub-groups. For the IREA sub-group there was no ear effect and no block effect, but a significant interaction between these factors ($F=3.189$; $d.f.=5,535$; $p < .01$). On contrasts from the comprehensive ANOVA for the ILEA sub-group the findings were similar; there was no ear effect, no block effect, but a significant interaction of these factors ($F=3.176$; $d.f.=5,535$; $p < .01$).

Pearson product moment correlations between error scores and the index were generally negative and there were significantly more blocks on which the correlation was negative than blocks on which the correlation was positive ($p < .01$, two-tailed test; Table 25). The correlations on most individual blocks, however, were non-significant.

Figure 9: Mean Ear Advantage Index across blocks of initial right ear advantage (IREA) and initial left ear advantage (ILEA) sub-groups of old adult subjects.

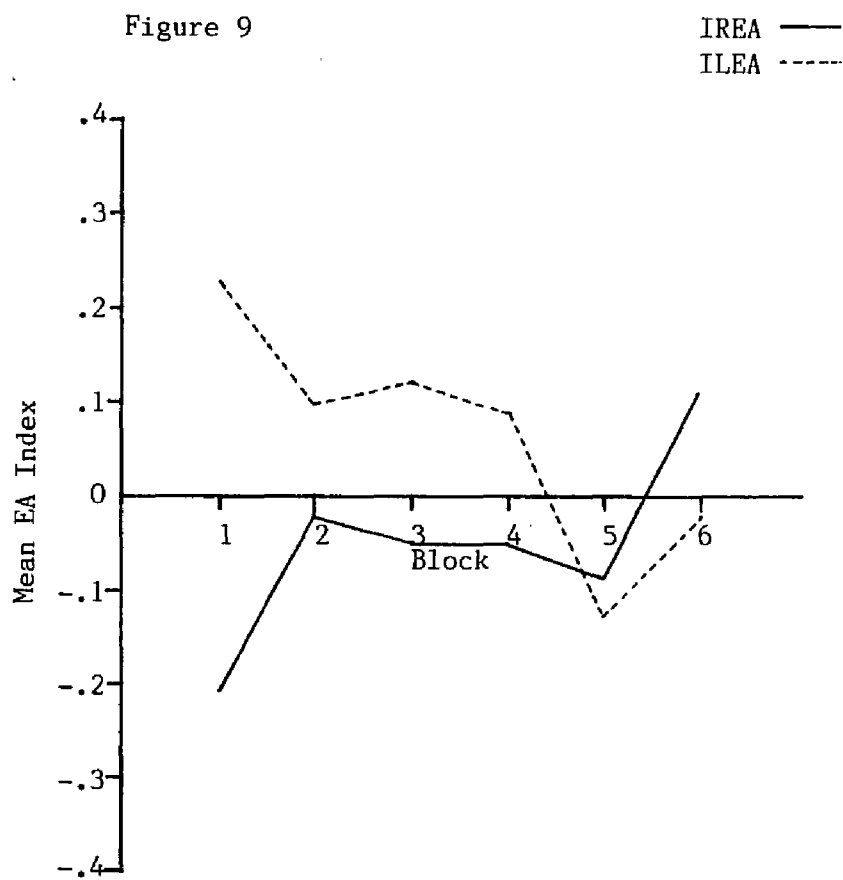


Table 24

Mean Errors of Initial Ear AdvantageOld Adults

Sub-group	Block					
	1	2	3	4	5	6
IREA n=13	11.08	10.92	11.46	10.77	12.96	12.31
ILEA n=9	11.11	11.33	10.67	11.00	12.67	10.89

Table 25

Pearson Product Moment Correlations of Errors with
Absolute Indices for Initial Ear Advnatage Sub-groups
Old Adults

Block						
Sub-group	1	2	3	4	5	6
IREA	-.508	-.290	-.261	-.589*	-.350	-.358
ILEA	.191	-.407	-.828**	-.129	-.012	-.227

* $p < .05$ ** $p < .01$

General Summary

Subjects in each age group were divided on the basis of their initial ear advantage (that is, the ear advantage at the end of the first 24 trials). The number of subjects with either an IREA or an ILEA was approximately the same.

When processing across the test task was examined for each initial ear advantage sub-group separately, it was found that there were differences between the sub-groups. It appeared that the direction of initial ear advantage had implications for subsequent processing during the task. In the young adult group and the old adult group lateralization shifted to an opposite ear advantage. For each sub-group at these ages the shift in lateralization was significant as measured by significant linear trends. Only for the young adult group were shifts in lateralization associated with improvement in proficiency on the task, however. For the age 10 group and the age 15 group the ILEA sub-group did not shift lateralization over the task and this maintaining of ear advantage was associated with significant improvement. The IREA sub-group for the age 10 group changed from initial lateralization to

essentially no ear advantage and did not improve while the IREA sub-group for the age 15 group shifted lateralization but did not improve significantly.

Section III: Qualitative Analysis

Confusion Matrices

Thus far the analyses have been restricted to a consideration of data derived from proficiency measures. That is, data derived from error score or the number of trials in which both voices presented were correctly named. Another approach is to examine qualitative differences between age groups in the performance of the test task. In voice recognition there are multiple acoustic cues, such as fundamental frequency, voicing onset, time duration of vowel sounds, and psychophysical cues such as timbre, articulation intonation, each of which could have a hemispheric advantage for processing. There is also the possibility that voice recognition is accomplished by pattern recognition in which no single auditory cue takes precedence. It is argued that in order to perform this voice recognition task it is likely that listeners form a strategy for identification of the voices. If it is found that confusions between voices are systematic then understanding the acoustic basis of

the confusions may illuminate the strategies being used. Further, if there are hemispheric differences in the strategies used, then examining confusions between voices on blocks in which there is a right or left ear advantage may help to distinguish these different strategies. As a preliminary step to understanding the relationship between acoustic information and voice recognition, confusion matrices were constructed.

Upon inspection it seemed that there were no differences between the matrices for the right and left ears or between the first and second halves of the test tape. Consequently, the results for the ears and the entire test tape were combined.

From inspection of the confusion matrices (Table 26) it appears that there is no difference in the pattern of confusions between those blocks on which there is a REA and those blocks on which there is a LEA for any age group. The age 10, age 15, and young adult groups appear to be systematic in their confusions. That is, for the age 10 and age 15 groups which had the same voices to choose between, confusions involving speaker "J" were fewer than those between the other three speakers. In the young adult group more confusions occurred between speakers "Bri" and "Bre" than for any other speakers. In

contrast, the old adults had approximately equal distribution of confusions over the speakers, suggesting that these confusions may be due to less systematic use of a particular strategy.

Table 26

Confusion Matrices Between Voice Presented and Named Speaker
for Blocks on which there is a REA or LEA. The Confusion
Presented is a Proportion of the Total Confusions

		REA Blocks					LEA Blocks		
		Voice Presented					Voice Presented		
Age 10		CH	J	F		CH	J	F	
	CA	.27	.12	.18		CA	.28	.12	.20
	CH		.12	.18		CH		.10	.23
	J			.08		J			.07
Age 15		CH	J	F		CH	J	F	
	CA	.33	.10	.21		CA	.27	.11	.22
	CH		.11	.19		CH		.12	.21
	J			.06		J			.07
Young		T	BRI	BRE		T	BRI	BRE	
Adults	J	.15	.14	.16	J	.08	.14	.17	
	T		.19	.12	T		.16	.17	
	BRI			.24	BRI			.28	
Old		T	BRI	BRE		T	BRI	BRE	
Adults	J	.16	.21	.14	J	.16	.19	.14	
	T		.17	.16	T		.19	.15	
	BRI			.16	BRI			.17	

First Speaker Named

Another factor contributing to ear advantage is attentional bias to one ear. In a dichotic task, there are possibilities for attention to be shared or for a rapid sequential shift of attention from the signal in one ear to the signal in the other ear. Only in the latter circumstance would differences in ears be expected. In these studies no attempt was made to direct attention to a particular ear. The order in which voices were named by subjects, however, was recorded. The first named voice was considered, in this study, to have priority of attention because of the ear to which attention was directed and/or the saliency of a particular voice. The measure of attention, then, was the number correct of first named voices tabulated for ears separately.

Similar to the proficiency measures, as age increased the number of correctly first named speakers increased up to the young adult group with a decline for the old adult group. When the IREA and ILEA sub-groups were compared on overall proficiency on this measure there were no differences between these sub-groups. In order to examine attentional differences as they relate

to processing over time and lateralization, tabulation for the first and second halves of the test task and the ears separately was made on this measure.

The scores were analyzed to determine if there were differences between the first and second halves of the test tape. T-tests for non-independent means showed that for the IREA group, only, there were there significant differences between blocks 1-3 and blocks 4-6 (Table 27). For the age 10 group there were more first named speakers correct in the second than the first half of the test for voices presented to the left ear ($t = 2.793$; $p < .02$). For the age 15 group and the young adult group there were significant changes in the relationship between ears on the first and second halves of the test tape. For the age 15 group, although for the first half of the test the number correct from first speaker named was approximately equivalent, during the second half of the tape there was an increase in the left ear and a decrease in the right ear. The differences between the first and second halves were significant for each ear (RE: $t = 4.223$; $p < .01$; LE: $t = 4.197$; $p < .01$). For the young adult group more first named speakers were correct for voices presented to the right ear during the first half of the test ($t = 2.474$; $p < .05$) and more correct for voices presented to the left ear during the second half ($t = 3.466$; $p < .01$). The

change in predominant ear for correctly naming first corresponds to the shift in lateralization for the IREA sub-group. The old adult group did not show any differences between the first and second halves of the test on this measure.

When T-tests for non-independent means were used to compare the right and left ears, it was found that significant differences, were, generally, in the ILEA sub-group (Table 28). For age groups 10, 15 and young adults in the ILEA group, when the speaker presented to the left ear was named first, significantly more trials were correct and this directional bias was maintained throughout the test task. For the old adult group there was a significant difference between ears only in the IREA group during the first half of the task and more correct were named in the right ear first. The other occurrence of an ear difference in the IREA sub-group occurred only for the second half of the test task and only for the age 15 group where significantly more voices were correct when the left ear was named first.

Table 27

Mean Correct of First Named Speaker for Initial EarAdvantage Sub-groups.Summary Table

T-tests for non-independent means show differences between first and second halves of the tape.

	IREA Sub-group		ILEA Sub-group	
	RE	LE	RE	LE
Age 10				
Blocks 1-3	12.92	10.38 *	8.25	15.08
Blocks 4-6	12.00	13.38	10.17	15.50
Age 15				
Blocks 1-3	12.92 **	13.08 **	10.50	13.75
Blocks 4-6	9.58	17.08	11.13	15.00
Young Adults				
Blocks 1-3	14.33 *	12.50 *	10.28	16.22
Blocks 4-6	11.67	16.08	11.50	16.67
Old Adults				
Blocks 1-3	11.85	9.31	8.00	12.56
Blocks 4-6	10.49	9.62	8.33	11.89

*p<.05 **p<.01

Table 28

Mean Correct of First Named Speaker for Initial EarAdvantage Sub-groups.Summary Table

T-tests for non-independent means show differences between the right and left ears.

	IREA Sub-group		ILEA Sub-group	
	RE	LE	RE	LE
Age 10				
Blocks 1-3	12.92	10.38	8.25 *	15.08
Blocks 4-6	12.00	13.38	10.17 **	15.50
Age 15				
Blocks 1-3	12.92	13.08	10.50 *	13.75
Blocks 4-6	9.58 **	17.08	11.13 *	15.00
Young Adults				
Blocks 1-3	14.33	12.50	10.28 **	16.22
Blocks 4-6	11.67	16.08	11.50 *	16.67
Old Adults				
Blocks 1-3	11.85 *	9.31	8.00	12.56
Blocks 4-6	10.49	9.62	8.33	11.89

* $p < .05$ ** $p < .01$

Discussion

These five studies on voice recognition present a complicated set of findings. Superficially it can be concluded that subjects from age 10 to old adulthood recognized the unfamiliar voices on the test tape and successively improved in the ability to do so up to young adulthood followed by a decline in old age. Within such a complex task as voice recognition there are many possible acoustic cues to be utilized. Cognitive processes such as attention, perception and memory interact with the various acoustic cues to produce what could be described as a cognitive organization around performing this task. It was anticipated that for this task the cognitive processes which were utilized would change with different developmental levels as different acoustic cues can be utilized at different stages of processing. It was further anticipated that subjects at different developmental levels would approach the task with different cognitive organizations and that developmental differences would be found in processing within the task. In analyzing the data, therefore, attention was paid to looking for evidence of different cognitive organizations at different ages.

Lateralization was chosen as the means to tap this organization as there is independent evidence that there are structural and functional differences between the cortical hemispheres.

The approach of analyzing the performance on this task by age is consistent with a developmental model which proposes that an organism functions in an integrated manner and that developmental change can be characterized as reorganization of existing processes at increasingly more complex levels. The difficulty with the approach, however, is that comparisons between age groups are not made easily and little can be inferred from a change in outcome (or score) about underlying cognitive processes.

In the discussion section each age group will be treated separately as an attempt to understand from these findings what might be the cognitive organizational basis for performing the task. As in the results section, cross age comparisons will be made in order to give the findings of a particular age group a 'context of change'.

Age Groups

Age 5:

This group of subjects did not perform the task above a chance level, initially, and did not improve during 60 trials. This finding was consistent for two measures of proficiency, error score and the number of trials on which both voices were correctly identified. One possibility is that the dichotic task is too difficult for young children. However, studies with children of this age have found that they are able to repeat digits (Hiscock & Bergstrom, 1982) and syllables (Mirabile, Porter, Hughes, & Berlin, 1978) presented dichotically, suggesting that it is not the dichotic task alone which limits performance. Similarly, within the first year of life some ability to recognize voices, at least the mother's voice, has been demonstrated (DeCasper & Fifer, 1980; Spence, 1984; Tulkin, 1973). Since it appears to be neither voice recognition nor the dichotic task, it must be the way in which these two factors interact which resulted in young subjects being unable to identify both voices together. There seems to be no question that a right ear advantage can be demonstrated in young children for both nonsense syllables (Bryden & Allard, 1978) and words (Geffen & Hochberg, 1971) and

that a left ear advantage can be shown for emotional intonation (Saxby & Bryden, 1984). The direction of lateralization for processing these different types of stimuli is consistent with that found for adults. If performance on the voice recognition task requires processing which involves differentiation of these different types of stimuli, then these subjects may have been at a disadvantage if their tendency to process is holistic but undifferentiated.

Shepp (1978) in a review of four experiments concluded that young children (kindergarten and first grade) perceive dimensional combinations as integral while older children and adults perceive them as separable. He argues that until differences in perceptual structure can be perceived selective attention is logically impossible. One possibility is that children at age 5 approach voice recognition as if dimensions such as intonation, pitch and speech sounds are inseparable. They 'know' a voice based on their connecting it to the identity of the speaker. For this voice recognition task, which is perceptually difficult because it is dichotic, the ability to selectively attend to separable dimensions may be a necessary learning phase.

Selective attention to lateralization of stimuli, however, appears to be possible for young children. Several related studies (Hiscock & Bergstrom, 1982; Hiscock & Kinsbourne, 1980) have demonstrated in children ages 3-12 years a right ear advantage for naming dichotically presented digit pairs which is asymmetrical with respect to attentional factors. Subjects who were asked to report what was heard in the right ear for 36 trials followed by reporting from the left ear for 36 trials had a significant REA and had difficulty switching attention to the left ear. Those subjects who reported the digits from the left ear first did not show the same significant REA. In discussing their findings these authors suggested that lateralization is based on multiple attentional mechanisms, including a right orienting bias for attending to verbal material, the ability to voluntarily shift attention to the contralateral sensory field and a priming effect in which allocation of attention to the right ear, based on anticipation of a verbal task, early in processing establishes a priority for processing from that side which influences subsequent processing. Their finding of a priming effect for subjects who attended to the right ear first persisted after one week and was evident on a task in which subjects were free to report either ear (Hiscock & Bergstrom, 1982).

Age 10

In contrast to the age 5 group, subjects in the age 10 group improved over the course of the test in their ability to identify the voices as indicated both by their error scores and the number of trials on which both voices were named correctly. On error scores, although the difference between the right and left ears only approached significance, fewer errors were made by subjects to voices presented to the left ear. On each block more subjects had a left ear advantage, a finding which further emphasizes the consistency within this age group.

Initially the number of trials on which both voices were named correctly was at chance level, but by the last block subjects were better than chance on this measure.

When subjects were divided into two sub-groups based on initial ear advantage it was found that those subjects who began with a LEA maintained this advantage throughout the task and made significant improvement. Subjects who began with a REA shifted by block 3 to a weak LEA which was not maintained and on the last 3 blocks there was essentially no ear advantage for this sub-group.

Although the IREA sub-group improved over the task their improvement was not significant. These two sub-groups began the voice recognition task with almost identical proficiency levels but the ILEA sub-group made more improvement. One possibility is that the maintaining of laterality was effectively associated with the consistent employment of a strategy.

From the confusion matrices constructed from voice presented and named speaker it appears that there is internal systematicity, with one voice (J) resulting in many fewer confusions. Although not formally tested, there seems to be similarity in the matrices between blocks in which subjects have a REA and LEA. It appears from this finding that voice identification was not tied to a single set of features (such as speech sounds) which are lateralized, but involved multiple features which evoke processing at a higher cortical level of integration in which lateralization is irrelevant.

The maintaining of a left ear advantage and the improvement in performance of the ILEA sub-group may be related to an attentional strategy. In this sub-group subjects correctly named first the voice presented to the left ear significantly more than to the right ear. An attentional strategy does not necessarily suggest that

this left ear lateralization is a peripheral phenomenon. It may be that voice recognition is based on pattern perception which is more easily executed by the right hemisphere and, therefore, attention is directed to the left ear.

In a study of voice recognition in children aged 6 to 16 years, Mann, Diamond and Carey (1979) found that children at age 6 performed at chance level on their task and there was successive improvement in proficiency until age 10 when performance was at an adult level. After age 10 and until age 13 there was a decrement in performance, with a return to adult levels at age 14. As in the present study, their task involved recognition of unfamiliar voices and the identification segments were 3 word sentences. These investigators compared their findings to research in face recognition in which a similar decline in performance at ages 12-14 occurred (Carey & Diamond, 1980 for review). The improvement in recognition of photographed faces between ages 6 and 9 was attributed to a shift away from reliance on specific facial features to the development of processing a facial configuration. The similar, temporary declines in performance on face and voice recognition tasks, they suggested, may involve a common right hemisphere maturational change or may be shifts in general

information processing strategies. Other studies have supported age changes in the type of processing and right hemisphere involvement. Levine (1985) reported that a left visual field advantage for unfamiliar faces does not emerge until age 10 with a subsequent, temporary disappearance of the lateralization at 14 years. Turkewitz and Ross-Kossak (1984) found that children of 8 and 11 years appear to use a single mode of right hemisphere processing during a recognition task for unfamiliar faces but girls aged 13 and women subjects use two different types of right hemisphere processing. This finding was demonstrated by a bimodal distribution of errors for subjects with a left visual field (right hemisphere) advantage on the face recognition task and by shifts in lateralization in the female adults in which processing began as a left visual field advantage, shifted to the right, then returned to the left, and with concomitant improvement in proficiency. From the current study it appears that for some subjects at age 10 lateralization is established on the voice recognition task and for these subjects voices are identified more accurately when they are presented to the left ear. From the confusion matrix data it can be speculated that the type of processing involves a pattern recognition which is easier to effect if the input is from the left ear.

Age 15:

As a group, the age 15 subjects improved as shown by both their error scores and the number of trials in which both voices were correctly named. The left ear was better than the right ear although the difference between ears only approached significance.

When subjects were separated into sub-groups based on initial ear advantage there were differences in the rate and pattern of improvement and in lateralization. The IREA sub-group made significant improvement between blocks 1 and 2 but did not maintain this improvement. This group also shifted lateralization as shown by a significant linear trend on the EA indices. The ILEA sub-group made overall improvement on the task and generally maintained a left lateralization advantage. However, at blocks 4 and 5 there was an increase in the number of errors and this is associated with a weakening of left ear advantage (Figure 8).

On the confusion matrices (Table 26) there was a distribution of confusions almost identical to that of the age 10 group. The "J" voice was identified more often regardless of the other voice in the dichotic pair. There was no difference between blocks on which subjects

had a REA and those in which there was a LEA. The similarity of the age 10 and age 15 groups on this measure while the changes in lateralization with familiarization were different is further support for the claim that the basis for recognizing voices is a cognitive strategy which transcends peripheral acoustical analysis.

The 15 year olds with a ILEA were correct with regard to the first named speaker significantly more often when that voice was presented to the left ear than when it was presented to the right ear. This finding is similar to the age 10 group. In contrast to the younger group, in the age 15 group the IREA sub-group had a significant difference between ears for the second half of the test tape, also with the left ear better when it was named first (Table 28). For the IREA sub-group there was a difference between the first and second half of the test task. This difference has some relation to the shift in lateralization in that, when there was a REA on the EA indices there was no difference between ears on accuracy of the first named voice, while in the second half of the task when there was a weak LEA the left ear was correctly named first more than the right ear.

The age 15 group gives further support to the association between measures of lateralization and attention as measured by ear first named. One possibility is that more than one strategy is used for any one trial. For example, voice recognition based on an acoustical configuration or pattern may be easier and, therefore, the left ear may be named first more often, followed by the naming of the voice in the right ear based on a comparison of acoustical features between the remaining three choices. The confusion matrices of age 10 and age 15 groups are highly similar. Since confusions are consistent within the age groups between REA and LEA blocks and also across these age groups, the same interpretation applies that these confusions represent errors in pattern recognition.

It appears that for the IREA sub-group right lateralization initially resulted in improvement but as they changed to left lateralization these subjects did not retain this improvement. It can be speculated that this group of subjects were unable to flexibly shift between two different kinds of processing.

The ILEA sub-group generally maintained a left ear advantage and an attention to the left as measured by correctly first named voices. As mentioned previously,

at blocks 4 and 5 errors increased and from Figure 8 it can be seen that lateralization was less at these blocks. As discussed in Mann, Diamond and Carey (1979) there is a related finding in face recognition. Leehey (1977) found a left visual field advantage at ages 9 and 12 and at age 14 there was diminished visual field advantage. This reduction in lateralization occurred at the same age at which Carey, Diamond and Woods (1980) found a reduction in proficiency in facial recognition as compared to younger and older subjects. Although both of these studies measure overall performance in the test task there does seem to be an association between degree of lateralization and proficiency for recognition of unfamiliar faces and this association may have similarities to the same observed association within this voice recognition task.

Young Adults:

As a group, young adults improved over the test task on measures of error score and trials on which both voices were correctly identified. There was no difference between ears on errors and improvement occurred on error score for both ears.

When the subjects were divided into sub-groups based on initial ear advantage, each sub-group, although selected for a particular direction of lateralization, changed lateralization during the task. That these shifts in lateralization characterized the sub-groups was shown by significant linear trends for each sub-group. Since there was no proficiency differences between the sub-groups it is likely that the different patterns of lateralization reflect qualitative individual differences in processing.

Correlations of degree of lateralization with error score were generally negative and significant for young adults. Younger subject groups showed a tendency in this direction but the relationship between lateralization and proficiency was less clear. Few studies have addressed this issue of the adaptive significance of lateralization (Birkett, 1978; Devenny & Turkewitz, in prep.; Ross-Kossak & Turkewitz, 1984).

The difficulty in exploring the adaptiveness of lateralization has been that evidence for lateralization is a relative proficiency difference (either in correctly identified items or reaction time) between the ears. In most studies the proficiency measure is used to describe the degree of lateralization. In the current study an

attempt has been made to separate the degree of lateralization from the proficiency measure and to associate them through tests of correlation. However, it is recognized that the measure of lateralization (EA index) is derived from error scores. The presence of an occasional positive correlation and several non-significant correlations supports the claim that, although the two measures are related, the relationship is not fully determined.

On the confusion matrices there is less correspondence between blocks on which there is a REA or LEA than for the younger age groups but still the two matrices are highly similar. Confusions involving the voice "Bri" tend to be similar while those involving the voice "T" are less so. Although the differences between the matrices are slight they may reflect differences in underlying processes.

The young adult subjects shifted lateralization during the voice recognition task while continuing to improve in their performance on the task. Subjects with greater lateralization performed better, particularly during the second half of the task, and this finding was independent of the direction of lateralization. From these findings it would seem that these subjects were

able to utilize a flexible approach to processing and to integrate learning from previous trials in order to improve.

Old Adults:

In comparison to younger subjects, the old adults showed quantitative and qualitative differences in performance on the voice recognition task. In general, they had more difficulty in identifying the voices than any of the younger age groups. Dichotic listening is unique to experimentation and none of the subjects reported having had a similar experience. Old adults have more difficulty in new learning and they, therefore, were likely at a disadvantage in learning to perform the task. If difficulty with new learning was the only factor, however, it would be expected that although overall scores might be depressed, subjects would show improvement over the course of the task. Old adults, however, did not show any change in either error score or the correct naming of both voices, suggesting other factors, in addition to difficulty with novelty, may be affecting performance.

Compared to younger age groups, old adults had more blocks in which there was a higher proportion of REA.

This finding is consistent with some previous dichotic listening studies (Johnson, Cole, Bowers, Foiles, Nikaido, Patrick & Woliver, 1979; Clarke & Knowles, 1973) in which old adults showed a greater decline in reporting digits presented to the left ear. These authors interpret their results as a relative decline in right hemisphere processing with aging. In the Johnson, et.al. study, the decline in left ear/right hemisphere performance occurred within an old adult subject group. In their two experiments the test task was held constant while performance across age was compared. In a study with young and old adults, Obler, Woodward & Albert (1984) found that when task difficulty was made equivalent by increasing the exposure times on tachistoscopic presentation there was no difference in the relative hemispheric advantages of the older and younger subjects. In relation to the findings previously described, it suggests that either there is a difference between auditory and visual modalities with respect to change in hemispheric efficiency of processing with aging, or that performance on tasks is multiply determined with aging having uneven effects on the various factors involved in processing.

Correlations of error scores with the EA indices were generally negative but, similar to the three

youngest age groups, were significant on only a few blocks (Table 25).

When old adult subjects were divided into initial ear advantage sub-groups, both IREA and ILEA sub-groups shifted lateralization although the shift occurred later in the task than it did for young adults.

For old adult subjects there does not seem to be a difference between ears on accuracy of naming one ear first, with the exception of the first half of the task for the IREA sub-group where naming the right ear first resulted in more correctly identified voices presented to that ear (Table 28). One factor of interest when discussing order of reporting for old adults is the role of memory for the second named voice. Clark and Knowles (1973) controlled for order of report of ear of presentation by instructing half of subjects in each age group to report a specific ear first. They found that for each of four age groups ranging from 15 to 74 years, that on naming 3 pairs of digits the second ear reported was poorer and the difference between first and second ears reported was essentially the same for all age groups. Memory, then, does not appear to be a significant factor in producing differences between old and young adult subjects on a dichotic task.

If naming a voice from a particular ear first is a measure of attention, then old adults did not appear to have difficulty in the control of attention. The IREA sub-group reported more accurately, first, voices presented to the right ear while the ILEA sub-group reported the left ear first. Both sub-groups were consistent in their lateral preferences throughout the task.

Clark and Knowles (1973) have suggested that their findings of age related decrements in performance, particularly involving the left ear/right hemisphere, are best interpreted as a decrease in perceptual processing. On the confusion matrices of the current study, it appears that all voices were equally confused. This suggests that there was a lack of systematicity in executing the task which could be related to perceptual deficits. Other findings indicate a shift away from a left ear predominance on this task and it may be that pattern recognition may be impaired because of perceptual difficulties.

General Discussion:

Since all measures of performance used for these studies derive from a single score of number of correct voice identifications, the measures are expected to be highly interrelated. The finding that there is some dissociation of the measures suggests that the different measures reflect processing differences. For example, naming both voices correctly very likely reflects an ability to integrate while a large EA index suggests that attention is being allocated to one side. The details of processing, however, are only speculation but considering the alternatives can lead to testable hypotheses. With respect to the naming of both voices, one possibility is that, as Pollak, Pichett and Sumby (1954) suggest, combinations of voices can form patterns and the relationship between voices assists in the identification of the separate voices. Another possibility is that identifying both voices involves attention sharing in which there is either rapid, alternate allocation of attention, or attention division between the ears. The integrating force for attention allocation would be memory while for pattern recognition it would be perception. Similarly, strong lateralization can be either the result of attention to a peripheral sensory field on one side, or a cognitive strategy which utilizes

perceptual information which is laterally biased, resulting in hemispheric processing differences. This type of analysis of possible processing mechanisms is consistent with an information processing approach.

Information Processing

Synthesis of information can occur in at least two ways: in processing simultaneously, such as in pattern recognition, or processing sequentially and incorporating previous information into a representation. Although both kinds of synthetic processing are part of performing any complex task, during learning the task there may be advantages to selectively using one or the other (Ross-Kossak & Turkewitz, 1984). It has also been pointed out that attention to detail, an analytic type of processing, can be separate from synthetic processing but the distinction between these two modes of processing is artificial as they are interdependent (Brownell & Gardner, 1981; Marshall, 1981).

There were time-dependent changes in lateralization which are better described within an information processing approach than a structural model. If previous work in lateralization is used to assist in the description, then it can be suggested that processing in

the left hemisphere is largely connected to language and speech sounds and in the right hemisphere to the melodic aspects of voice such as intonation and pitch. Over the course of the task with some subjects there are changes in lateralization suggesting that both language and melody are attended to sequentially.

There does seem to be a contradiction between the findings on error score which show lateralization, and the confusion matrices which are generally symmetrical with respect to ears. If the basis for confusing two voices is a single feature, such as pitch, then ear differences would be expected. If, however, voices are recognized as a pattern it would be predicted that if the pattern is undifferentiated the right hemisphere would process more efficiently, if the pattern is complex then the entire cortex would contribute to the processing. At each age the confusion matrices appear symmetrical suggesting that voice recognition is largely pattern recognition. At age 10 those subjects in the ILEA subgroup were consistently lateralized. Underlying this consistency could be the persistent use of an undifferentiated holistic pattern recognition or the use of right hemisphere processing of intonation and pitch. Since this group improved over the course of the task it

is more likely that processing of melodic features was refined.

Direct Access Theory

A structural theory of hemispheric lateralization, such as the direct access theory (Kimura, 1967), would predict that if subjects were using speech sounds, and specifically consonants, as the basis for distinguishing between speakers, then lateralization would be towards the right ear/left hemisphere. The acoustical properties of speech sounds, except when controlled by experimenters, are context dependent (Lieberman, 1972). Listeners 'normalize' the speech they hear so that a single consonant, although varying with speaker and adjacent vowels is heard as representative of a category for that particular consonant. The physiological mechanisms involved in this type of acoustical analysis have not been definitively identified. If speaker recognition is achieved through identification of differences in the speaker's articulation, then listeners are attending to individual differences at the same time as they are processing similarities for the identification of a particular sound.

From the current studies it appears that since there was an absence of a general REA, listeners were not defining this voice recognition task as predominantly a speech identification task. It is speculated, then, that because a substantial number of subjects who were 9-10 years and 14-15 years had consistent LEAs, they did not primarily use phonetic cues for speaker identification. Young adults demonstrated a REA with some subjects showing this advantage initially while others shifted to a REA later in processing. That these subjects showed continuous improvement for both ear advantages suggests that they were able to make use of processing in either hemisphere. With aging there is often phonemic regression, that is, a decrease in the ability to perceive speech sounds which is separate from a peripheral hearing loss. The old adult subjects, although showing a REA, probably did not make effective use of speech and this contributed to their lack of improvement on the task.

Individual Differences

Since these studies are concerned with the functional use of the cerebral hemispheres which have structural differences for processing, it is not surprising that individual differences are found. The

particular differences described are the outcome of examining cortical organization within a right/left dichotomy. When each age group was examined as a whole, lateralization, as measured by the EA indices, was negligible. This was reflected in ANOVAs which had large variability and were non-significant. However, when the age groups were divided on the basis of initial ear advantage it was apparent that real differences within the groups had been masked by lateralization in opposite directions. Interactions of sub-group with block on the the indices were significant for every age group except age 10, indicating important differences between the sub-groups in lateralization across time.

Although there was no proficiency difference between sub-groups, for those age groups which showed improvement over the task (age 10, age 15, and young adults), only for the ILEA sub-group was the improvement significant. The basis for individual differences likely changes across ages. For the young adult it is suggested that cognitive strategies in approaching the task influence the patterns of lateralization and these strategies are, in part, under conscious control. Old adults may have attentional biases which are unrelated to the specific demands of the task and may shift lateralization based on fatigue or some unspecified factors. If the only factor

in success on this task was employment of a left ear/right hemisphere strategy, then correlations between proficiency and indices on blocks on which there is a LEA should be high, particularly for the ILEA sub-groups of age 10 and age 15 which appear to maintain a left ear advantage. Since having a LEA, per se, does not appear to result in relatively better performance it is probable that proficiency is related to a time-dependent, overall cortical organization.

Subjects in the ILEA sub-group consistently named first, correctly, the voice to the left ear suggesting an attentional bias towards the left which, for this sub-group may have been beneficial. Subjects in the IREA sub-group varied with age but, except for old adults, named first correctly voices to the left ear during the second half of the task. This measure is associated with an output mode. If this voice recognition task, because it involves listening to speech and identifying speakers based on naming, simply had a differential arousal effect on the left hemisphere it would be expected that attention would be focused towards the right ear. Since the findings tend to be contradictory to this prediction, hemispheric arousal for the voice recognition task was associated with processing rather than output.

The division of subjects into sub-groups suggests overall organizational differences which are related to processing. The other measure which reveals individual differences is the correlation between error score and degree of lateralization. Although the correlations are primarily negative for all ages indicating that greater lateralization is associated with better performance, only for the young adult group is the association statistically significant on most blocks. That this association changes over blocks is consistent with the finding of Ross and Turkewitz (1982) that correlations of proficiency with lateralization change with familiarization. They suggest that the employment of a strategy is reflected in greater lateralization and transitions in lateralization mark shifts in strategy.

Physiological Correlates of Performance

Larsen's proposal (1984) that the principle of hemispheric specialization precedes the principle of unity appears to have some support from the voice recognition studies. At age 10 and age 15 there was an overall LEA for voice recognition with those subjects who began the task with a LEA generally maintaining this direction of lateralization throughout the task and improving more than those subjects who began the task

with a REA. At age 5 subjects did not improve in performance on the task although they showed shifts in lateralization while young adult subjects continued to improve on the task while shifting their lateralization. Larsen has speculated that for his youngest subjects (age 9) there was a transmission loss due to an immature corpus callosum which resulted in a greater degree of lateralization on a test task of dichotically presented monosyllables for this age than for age 15. If the voice recognition task is best performed by integrating information from both hemispheres then the shifts in lateralization for the young adults could be indicative of an integrated, cerebral unity. This interpretation of the data is consistent with Larsen's proposal: for a complex task, at age 5 there is relatively little transfer of hemispheric information; with development there is hemispheric differentiation around the performing of the task and consistent use of a single hemisphere has a proficiency advantage; in young adults their cerebral hemispheres have flexible integration of the specialized functioning of each hemisphere.

Developmental Trends

The argument has been made that each age group should be described separately by virtue of having

subjects who differ, because of age, in degree of maturation of the corpus callosum and who vary in experience. In describing the findings of the voice recognition task some distinctions have been made between findings of shifts in lateralization, suggesting changes in attention and strategy of approach to the task and the finding that there were no differences between voices presented to either ear on the confusion matrices. The finding on the confusion matrices is consistent across ages while the pattern of lateralization changed within the task, with individuals within an age group and across ages. It is possible that attention and strategy represent a level of analysis which could be identified with perception while performance, measured by the confusion matrices, could be identified with cognition. The distinction between cognition and perception is never clear but there is also a tradition in psychology of describing changes with age in the relationship between cognition and perception (Luria, 1976; Vygotsky, 1933/1978; Werner, 1957).

Findings of lateralization in early development do appear to be tied to perceptual activity and, therefore, have been demonstrated primarily in response to stimulus categories such as speech and music. For shifts in lateralization to be utilized in enriching a

representation it would require a cognitive system which can integrate over time input from an active perceptual system which is providing changing information. For age 10 and age 15 children they were able to utilize perceptual information most efficiently when that information was less varying, that is, when lateralization was left ear/right hemisphere. Young adults showed the flexibility of lateralization with increasing proficiency which has been identified in the studies of Ross and Turkewitz. Old adults, while also shifting lateralization, did not evidence hemispheric integration as measured by a lack of improvement in performance.

Ross-Kossak and Turkewitz (1986) have discussed their findings in relation to Werner's theory of development. Briefly, in Werner's theory development, in general, and development of perception, in particular, follows a sequence which is orderly and systematic. Development proceeds from a state of relatively global undifferentiation through increasing differentiation and articulation to a state of hierarchic integration. Changes in processing which occur as a general developmental sequence over several years in early development (macrogenesis) are repeated within the time it takes to learn a new task (microgenesis).

The voice recognition studies can be interpreted within the macrogenic analysis but it is not clear if a microgenic analysis also applies. The differentiation of perceptual information based on hemispheric advantage seemed most apparent with the age 10 group. There is no evidence, however, that they started the task with undifferentiated perception. The argument has been made that young adults, by virtue of continuing to improve while shifting lateralization, demonstrated both differentiation and integration. From the analyses of lateralization across the course of the task there is no reason to believe that differentiation occurs before integration. Old adults appeared to have retained differentiation in that they could utilize perceptual information based on one ear/hemisphere but no longer could integrate two sources of information. As a first step, based on extensive previous studies of lateralization, types of processing have been inferred from previously established associations between hemispheric specialization and stimulus categories. A microgenic analysis, for this task, would require being able to specify the type of processing associated with a direction of lateralization and with early and late stages of processing for the voice recognition task.

A Theory of Cognitive Systems

In a most general way, it is possible to understand the dichotomy of analytic/holistic as a metaphor for two modes of thinking. Bruner (1986) has suggested that modes of thought can be characterized as the logical and the narrative. It is not possible to tie such general concepts to neurophysiological data. However, modes of thought must arise from the employment of underlying cognitive processes. At the most complex of the levels of processing, cognitive organization can be viewed as consisting of the dynamic use of many cognitive processes (such as perception, attention, memory, strategies). Depending on the task requirements, some of these processes may be lateralized and, in the view of Moscovitch (1979), once an asymmetry emerges in input, all subsequent processing of the input will retain the asymmetry. From the studies recognizing shifts in lateralization with familiarization to the task, it is clear that task requirements can change. A 'mode' of thinking can be considered to be a system of dynamic processes which are organized for processing in a particular way. It is this possibility of a cognitive system which will be discussed within the theory of Nelson and Nelson (1978).

According to this theory cognitive systems develop with periods of flexibility alternating with periods of rigidity, much as a pendulum oscillates. Initially a system is open and flexible with only a few general rules. With subsequent development these rules become better defined but more rigidly and inflexibly applied. Later in development there is an integration and consolidation of the rules which, at maturity, enables flexible application of the rules. Since Nelson and Nelson discuss their theory in relation to language as a system, the description of the characteristics of the system with reference to 'rules' is appropriate. When the theory is applied to a system such as a mode of thinking, then instead of rules governing the association between elements the association is contained in ways of processing, such as the analytic/holistic distinction.

In the studies of voice recognition it is possible to examine the performance of subjects from the perspective of a developing cognitive system for learning and use the general theory to describe the system. The ILEA sub-groups of the age 10 and age 15 groups perform the task with a consistency of lateralization which fits the description of a stage of relative rigidity in the application of a strategy. The IREA sub-groups, however, do not fit this interpretation and may represent an

example of individual difference in cognitive style. Certainly, at the level of processing of this theory, one assumes that strategies of approach to a task have a determining influence on the performance of the task and that individual histories will influence the strategies used. Support for a flexible application of cognitive processes in maturity is seen in the young adult group where it appears there is an ability to use both hemispheres, albeit sequentially, in performance of the task. This theory of cognitive systems does not address developmental changes in old adults but, using language systems as an example, Nelson and Nelson suggest a progression in acquisition which is not reversible. If old adults demonstrate a lack of hemispheric integration it is not likely to be qualitatively the same as a lack of integration observed in young subjects.

Conclusion

Cognitive organization can be described as the relative employment of different ways of processing. Since the cerebral hemispheres are often distinguished by modes of processing with the left hemisphere identified with verbal/analytic processing and the right hemisphere with non-verbal/synthetic processing, cognitive organization can also be described as the relative employment of hemispheric differences. The changes in lateralization which were found over the course of the voice recognition task for some of the subjects were probably related to changes in underlying processing with familiarity to the voices. Findings of linear trends support a claim that these shifts in lateralization were systematic.

It appears that lateralization on this task is beneficial. For young adults better performance is correlated with greater lateralization. For age 10 and age 15 subjects maintaining a LEA was associated with improvement.

Voice recognition can now be considered to be an activity for which lateralization has been demonstrated

but only if individual differences in initial direction of processing are taken into account. Within age groups there were individual differences with respect to the utilization of hemispheric differences. At age 10 and age 15 subjects who initially had a LEA tended to maintain this advantage while subjects beginning the task with a REA shifted lateralization. Young adults, regardless of the direction of their initial ear advantage shifted lateralization. Old adults shifted lateralization but did not improve, suggesting that for this age these shifts are not associated with processing.

When individual differences are considered, the basis on which the task was performed appeared to change with age. Young adults consistently improved over the task while shifting hemispheric advantage, suggesting effective sequential utilization of hemispheric differences. For younger subjects, maintaining a hemispheric advantage, and specifically a right hemispheric advantage was most effective. It is not known from these studies if those subjects who had a left hemispheric advantage did not improve because they did not maintain the advantage or because it is less effective than a right hemispheric advantage for this task. It appears, however, that younger subjects did not utilize hemispheric processing differences in a way

similar to young adults. Old adults also did not make effective use of hemispheric differences on this task, in that they neither maintained a single hemispheric advantage nor did they utilize additional information that can be gained from shifting processing.

These were a series of descriptive studies of changes in cognitive organization across most of the life span. Contained within the results are both individual differences which suggest a contribution of experience to cognitive organization and lateralization which suggests hemispheric differences in processing. Differences between age groups in the performance of the task are the result of the interaction of a maturing nervous system with experience, resulting in qualitative and quantitative developmental differences in cognitive organization.

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