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HEMISPHERIC AND DEVELOPMENTAL FACTORS IN TIME ESTIMATION OF AUDITORY STREAMING PATTERNS

DISSERTATION

Presented in Partial Fulfillment of the Requirements For the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

Randolph Steven Tipps, B.S., M.A.T.

*****

The Ohio State University
1980

Reading Committee:
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Approved By

Adviser
Department of Education
To my grandmother, Mary Crawford,
Whose love of learning set many goals for me

And to my mother, Elaine Boatright,
Whose love has supported me in those goals

And in memory of Cindie L. Cook,
Whose friendship is stitched into many hearts.
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Chapter I
INTRODUCTION

As neuroscientists learn more about the functioning of the brain, educators interpret the findings for theory, research, and practice. The emerging concept of the brain as an active processor replaces an older record-replay model. The brain receives sensory inputs and transforms them into meanings and memories. Visual, tactile, and auditory information are directly sensed and interpreted. However, sensory information is also embedded in the fourth dimension—time. Jones (1976) called time "our lost dimension." Her point was that researchers have failed to acknowledge the fundamental role which time plays in sensing, learning, and remembering. The purpose of this study was to investigate hemispheric and developmental aspects of temporal processing. How does the brain interpret time in the creation of meaning?

An overview of the study is presented in Chapter I. Rationale and methodology are developed from neurological studies of hemispheric differences and psychological studies of time perception. The specific problem of the study concludes the chapter with research questions,
hypotheses, and definitions.

**Rationale and Methodology**

**Brain Functioning and Education**

In the last twenty years, brain functioning has become an established area of research, and educators have become aware of neurological implications for learning. Understanding the brain is a method of getting inside the closed box of cognition. Language, which served as a window to cognitive process, is a brain-based phenomenon. Speech is an obvious behavioral indicator of complex and subtle differences between the two sides of the brain. For ninety percent of the population, the main speech centers are located in the left hemisphere. Verbal-left and nonverbal-right, however, do not adequately describe the hemispheric differences in knowing and learning. In studies of persons with neurological insult or surgically separated hemispheres, as well as with normal populations under experimental conditions which limit the sensation to one hemisphere, two processing styles have been detected. The left side employs an analytic, detailed, sequential approach to experience; the right side is relational and holistic. While the differences between the hemispheres are often emphasized, the ability to integrate them for a unified understanding of the world is sometimes overlooked.
Although there are different models of brain functioning (Languis, Sanders, and Tipps, 1980; Restak, 1979), the hemispheric model has been particularly cited in a wide variety of educational recommendations. Samples (1977) called for radical transformation of curriculum and instruction; Hunter (1976) focused on the dilemma of what she termed "right-brained kids in left-brained schools." A need for balance in school program and instructional techniques based on hemispheric understanding is common (Galin, 1976; Kraft and Languis, 1977; Samples, 1975; Wittrock, 1977). Considering both sides of the brain or both types of knowing has been argued to support or improve instruction in mathematics (Wheatley, Frankland, Mitchell, and Kraft, 1978), art (Regelski, 1978; Edwards, 1979), science (Languis and Kraft, 1976), creative dramatics (Rice and Sisk, 1980), and movement (Frostig and Maslow, 1979). Rice and Languis (1979) emphasized the role of the hemispheres in interpreting teacher verbal and nonverbal messages. Basic knowledge and practical implication of hemispheric functioning are formative. Extending empirical research and developing educational applications calls for interdisciplinary work by neuroscientists, psychologists, and educators (Languis, Sanders, and Tipps, 1980).

Developmental Issues and the Brain

Development is another, albeit older, issue of importance to educators. Whether expressed as normative behaviors
by age (Gesell) or in clusters of behaviors which mark stages
(Piaget, Erikson, Kohlberg), development has been used to
determine both what is appropriate to teach and how to
teach. How does development of the brain affect basic
developmental questions? Within hemispheric studies, onto-
genetic development and lateralization of brain functioning
pose two main questions:

1. Are there periods in which the brain is particu-
larly sensitive to certain experiences?

2. Is the lateralization and integration of brain
function present at birth or does it come about as a
result of brain maturation?

Chall and Mirsky (1978) found ample reason to support
a sensitive period approach to brain development. Epstein
(1978) recorded changes in rate of brain weight gain which
coincided with Piagetian stages. MacLean (1978) speculated
that development of altruism might be linked to frontal lobe
growth. Although exact nature of internal growth of brain
structures is not fully understood, Frostig and Maslow (1979)
listed several possible explanations. Both intrahemispheric
and interhemispheric change affect lateralization and inte-
gration of functioning based on neurological substrates.
Kraft (in press) posited completion of neural connection
between the hemispheres as accounting for the development
stated that young children function much like patients
who have their hemispheres surgically separated. Galin et al. (1979) conducted tactile experiments with 3 and 5 year-olds and found that fives were much more accurate at matching tactile stimuli presented separately to the hands. He suggested this developmental change was due to increased myelination of the corpus callosum between the hemispheres.

The attentional explanation proposed by Kinsbourne (Kinsbourne and Hiscock, 1978) is in contrast with the neurological explanation of lateralization and integration of function. Based on anatomical differences of the hemisphere from birth and response to stimuli, Kinsbourne found that perceptual bias accounted for differences in processing. He used conflicting task demands and instruction to control hemispheric responses (Kinsbourne and Hiscock, 1977; Hiscock and Kinsbourne, 1977). Whether hemispheric specialization is due to inborn differences, perceptual bias, progressive maturation of neural structure, or a combination of influences, neuroscientists and educators have a strong common interest in developmental issues of the brain.

Time and the Brain

An area of hemispheric and developmental consideration which has received little empirical emphasis is that of temporal processing. Descriptions of hemispheric function point to differential time processing: linear-non-linear, sequential-gestalt, serial-parallel. Das, Kirby, and
Jarman (1979) called the time differences successive and simultaneous. In ten years of research, they employed tests which defined successive and simultaneous abilities. Das and associates do not present neurological evidence of the hypothesized difference but interpret their model in terms of Luria's functional model of the brain (1973). The tests which represent successive ability are the same tests which are typically used to describe verbal-analytic functioning of the left brain. The simultaneous factor includes spatial tasks generally regarded as right hemispheric indicators of gestalt functioning. The work of Das and associates in developing simultaneous/successive profiles of normal, learning disabled, and retarded students raises educational questions, but does not bridge the gap between educational issues and the existing knowledge of hemispheric processing of time. Empirical evidence of time processing as important to brain functioning is needed to validate the presumptive link between Luria's model and educational practice.

**Time Perception and Temporal Processing**

Time itself is a paradoxical subject for contemplation. Humans have no direct sensory apparatus for time, but most human activity, including higher order functions of memory and planning, are dependent on some awareness of "not now." Jaynes (1976) suggested "that one of the essential properties [in the development] of consciousness was the metaphor of time as a space" in which events and people could be
placed (p. 250).

The study of time includes such diverse areas as physics and philosophy. The psychological study of time parallels the growth of psychology from philosophy to introspection to quantification, from description to theory building. Recent models attempt to describe perceptual and cognitive features of time perception and temporal processing. Time perception deals with the relationships between stimuli and perceived time, while temporal processing draws inferences about underlying mechanisms.

Fraisse (1963) summarized 75 years of time perception studies. During this period, experimenters concentrated on issues of empty and filled time, intensity and rapidity of stimuli, and sensory differences in time estimation. A change in the study of time came about with cognitive psychology. Subjective differences in time estimation were taken as indicators of how people dealt with information. Processing studies found longer estimates due to increased complexity and number of stimuli (Ornstein, 1969), increased processing required (Hicks, Miller, Gaes, and Bierman, 1977), and increased attention to the time dimension (McKay, 1977; Curton and Lordahl, 1974). Shorter subjective judgments were found with easily coded stimuli (Ornstein, 1969), subjects naive to the time dimension (McKay, 1977), and increased subject response (Vroon, 1970).
Allan (1979) summarized time perception studies and found that no one theory accounted for the major findings. She found some support for a real-time model in which an "internal criterion interval" serves as the monitor for time estimations. A time mechanism is consistent with the space-time expectancy theory of Jones (1976). When events are judged in both spatial and temporal contexts, changes in one dimension also affect perceptions in the other. Using musical tones, Jones, Hahn, and Kidd (1978) found that when an extreme pitch displacement occurred within a sequence, the displaced tone was reported inaccurately. Streaming patterns are rapidly alternating high and low tones; they have extreme pitch displacement. Bregman's (1978) experiments showed that subjects do not maintain the sequential nature of the pattern. Instead, subjects split the pattern into two simultaneous streams or sequences— one high and the other low. Using streaming patterns in a time estimation task, Tipps (in press) found that they were judged shorter than a standard pattern. The perceived change in streaming patterns from sequential to simultaneous and the finding that streaming patterns induce shorter time estimation suggested a way of assessing temporal processing differences of the hemispheres.

**Hemispheric Differences in Time Estimation**

Streaming patterns produce an auditory illusion of simultaneity from sequential stimuli. The high and low
streams overlap rather than maintain strict temporal order. The successive-simultaneous change reflects differences attributed to the hemispheres. Among the many descriptions of intelligence Bogen (1977) listed, several had temporal qualities.

<table>
<thead>
<tr>
<th>Schenov (Luria)</th>
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<th>simultaneous</th>
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<td>sequential</td>
<td>multiple</td>
</tr>
<tr>
<td>Oppenheimer</td>
<td>historical</td>
<td>timeless</td>
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<tr>
<td>Lee</td>
<td>linear</td>
<td>non-linear</td>
</tr>
<tr>
<td>Bateson and Jackson</td>
<td>digital</td>
<td>analogic</td>
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<td>Dieudonne</td>
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**Figure 1.1 Types of intelligence indicating temporal qualities from Bogen (1977)**

The two types of intelligence appear related to the difference in hemispheric processing with the left hemisphere maintaining serial order and the right not being as time dependent (Bogen, 1977). Streaming patterns would cause a conflict between the linear left and the relational right. A linear perception would result in longer time estimations. The simultaneous perception of the right hemisphere would collapse the time for overlapping streams. In addition, differences in time estimation of streaming patterns for different ages would provide a clue to the developmental role of time in brain functioning.
Procedures

Use of streaming patterns depends on separating the processing of the two hemispheres. Controlling auditory input to the hemispheres is a major problem because the auditory nerves are not completely crossed to the opposite hemisphere. The dichotic procedure involves competing simultaneously-presented stimuli. With normal subjects, directly competing stimuli, such as digits or environmental sounds, are broadcast to the ears. Subjects report which stimuli were heard, and processing is inferred from the relative accuracy of the reports. When streaming patterns are used as stimuli, no directly competing stimuli are possible. The need is to occlude processing from one hemisphere while the other makes a time estimate. Recently, white noise (Aitken, 1976) has been used to block one hemisphere. The resulting technique is equivalent to the psychoacoustical techniques of monaural masking (Zwislocki, 1978). Noise was used as a mask in the study.

The actual method of time estimation is also a concern in procedure. Doob (1971) and Allan (1979) summarized the major types of time estimation by the method of response. Verbal estimation tasks required the subject to label a time in seconds or minutes. Comparison tasks were based on judgments of longer or shorter for two intervals. In reproduction tasks, the subject reproduced a specified temporal interval. In the latter method, both the standard and the
reproduced interval were experienced directly rather than mediated verbally with arbitrary units. In research, reproduction has been found to be the least variable (Fraisse, 1963). It also provides a quantitative dependent measure.

The procedure of the study combined time reproduction techniques and hemispheric-psychoacoustic methods. Streaming patterns were directed to each ear while the other was occluded with noise. Subjects listened to each streaming pattern, then reproduced the perceived duration by depressing a microswitch. Switch closings were timed and recorded yielding two measures—response time and time estimation. Time estimations were converted to accuracy scores by dividing them with actual pattern length. Both accuracy scores and response times were then analyzed using UNENAN-Harmonic Mean Analysis of Variance.

The Problem

Significance of Problem

Hemispheric and developmental differences in temporal processing have significance in hemispheric studies of the brain and time estimation research.

1. Temporal aspects of hemispheric processing, while mentioned prominently in the literature, had not been considered extensively. This study developed an instrumentation of hemispheric temporal processing.
2. Despite one hundred years of study, the phenomenon of subjective time perception has not been integrated into the mainstream of psychological research. In the past ten years, processing approaches to time study have sought to explain the interaction of sensory input, processing, memory or storage, and behavioral output resulting in subjective reports of duration or time-in-passing. This study explored neurological and developmental bases for time estimation errors.

Research Questions

The problem of the study was to determine if differences existed in time estimation of auditory streaming patterns which were directed to the left or right hemisphere. The additional question of development was explored by selecting subjects at three age levels: 6-7, 9-10, and 12-13. Ages were chosen to reflect differences in cognitive functioning suggested by Piaget, brain growth (Epstein, 1978), and neural development theory (Kraft, in press). Two major research questions were addressed in the study:

1. Do differences exist in time estimations of auditory streaming patterns when presented separately to the left and right ear?

2. Are developmental trends indicated by time estimations of streaming patterns?
Research Hypotheses

If, as has been suggested in hemispheric literature, the right hemisphere works in an analogic, simultaneous mode, the streaming pattern presented to the left ear should result in time estimations which are shorter than those presented to the right. The left hemisphere, a digital, sequential processor, would maintain events in order and resist the effect of streaming. Differential time estimates found by directing streaming patterns to each hemisphere would support different temporal strategies.

Hypothesis One:

Time estimation of auditory patterns directed to the right ear will be significantly longer than time estimation of auditory patterns for the left ear.

The question of developmental change with regard to time in hemispheric processing has not been explored. As time estimations tend to become more stable and accurate with age, both hemispheres could show equal improvement in time accuracy. Differential change would support developmental laterality in temporal processing. Neural maturation models suggested by Kraft (in press) and Galin, et al. (1979) support greater interhemispheric communication resulting in more accurate performance as the two sides integrate. Both accuracy and hemispheric differences in time estimation of streaming patterns were assessed to ascertain developmental change.
Hypothesis Two:
With increase in age, the accuracy of time estimates will improve significantly.

Hypothesis Three:
With increase in age, the time estimates for streaming patterns directed to the left and right ear will differ significantly.

Population and Sample
Subjects were selected from the student population of a unified county-wide school system in central Virginia. This population represents a predominantly white, rural environment. A volunteer sample of right-handed, normal hearing subjects was drawn from two first grade, one fourth grade, and two seventh grade classrooms. The groups drawn were 6 to 7, 9 to 10, and 12 to 13 years of age respectively.

Definitions
1. Hemispheric processing - strategies which are characteristic of the right or left hemisphere of the brain; "hemispheric differences are more usefully considered in terms of process specificity rather than material specificity." (Bogen, 1977, p. 138)

2. Dichotic listening technique - a measure of cerebral asymmetry developed by Kimura (1961) based on competing, simultaneous transmission of auditory stimuli.
3. Masking - "process by which the detectability of one sound, the signal, is impaired by the presence of another sound, the masker." (Deatherage and Evans in Studebaker, 1973, p. 362)

4. Random noise - noise for which the spectrum density is substantially independent of frequency over a specified frequency range. (Yost and Nielsen, 1977, p. 240)

5. Contralateral - relating to the opposite side; right side of body connected to left hemisphere.

6. Ipsilateral - relating to the same side; right side of body connected to right hemisphere.

7. Reproduction method of time estimation - paradigm in which the experimenter presents a timed interval and subject is asked to duplicate that interval in some manner.

8. Time accuracy score - ratio of time estimation divided by the actual interval length.

9. Pitch space - distance between tones measured in semitone intervals.

10. Streaming - sequence of discrete tones presented rapidly in high and low fashion; reported by subjects to segregate into two or more concurrent patterns. (Bregman, 1978)
11. Simultaneous processing (parallel) -
   (1) time-independent (Bogen, 1977)
   (2) "synthesis of separate elements into groups" (Das, Kirby, and Jarman, 1979, p. 49).

12. Successive processing (sequential) -
   (1) time-dependent (Bogen, 1977)
   (2) "in serial order ... not surveyable at any point in time." (Das, Kirby, and Jarman, 1979, p. 30).

13. Independent Variables - five fixed independent variables were controlled: grade level (age), order of presentation, side of presentation, length of auditory patterns, configuration of pattern.

14. Dependent Variable - two dependent measures were taken: response (delay) time and time estimation (interval).

15. Limitations - The following factors could have affected the results of this study as well as the generalizability:
a. Selection - the sample was volunteer and was further screened for handedness, hearing, and ability to complete the task.

b. Biological, cultural, and environmental variables which were not assessed in regard to individual subjects may have impact on completion of the task.

**Conclusion**

Chapter I presented a brief review of the rationale and procedures of the study concluding with research questions and hypotheses. Chapter II expands the rationale through a more comprehensive review of pertinent literature. In Chapter III, the procedures of the study are explained with support for the methodology chosen. Results are presented in Chapter IV and Chapter V continues with interpretation. Implications of the study are discussed in Chapter VI.
CHAPTER II

REVIEW OF RELATED RESEARCH

The purpose of the study was to investigate hemispheric and developmental differences in time estimation of auditory streaming patterns. In formulating the problem, several different lines of research have contributed significantly. In Chapter II, the main threads of research are drawn together to provide a background for the study.

The first section outlines hemispheric functioning—types of research, consistent differences found between the hemispheres, and current theories. The seminal work, now over twenty years old, and continuing study combine to present tentative answers and interesting new questions. The second section deals with development by comparing neurological work with cognitive and social theories. The parallels among developmental approaches hint that certain ages are particularly interesting in assessing maturational changes.

Having established hemispheric functioning and developmental progression as coherent areas of research, time is proposed as a significant element in both. Time as an influential and underlying mechanism in hemispheric functioning
is discussed in the third section. Previous studies in temporal abilities of the brain and a temporal-based theory of intelligence are presented. Finally in section four, time as a cognitive and developmental phenomenon is highlighted. Time research has changed in the last ten years as researchers have seen temporal processing as an integral part and as an index of cognition. At the end of section four, the idea of temporal illusion is introduced as a potential way of eliciting hemispheric differences in time estimation. In Chapter III, the methodology suggested in Chapter II is fully developed.

**Hemispheric Functioning**

Humans have attempted to explain the functioning of the singular and multifaceted brain for centuries. It has been described as a bellows which blows gaseous matter through the body, a radiator which cools the blood, an engine which provides power, and a computer which programs behaviors. Each description contains some metaphoric truth although it is inadequate. In the last twenty-five years the complex, mysterious structure has been studied systematically. Technological advances have allowed neuroscientists to probe the electrical and chemical inner workings. Anthropological, medical, and psychological research added to knowledge of the brain and behavior. From basic research come theories, or models, of brain functioning; Languis, Sanders, and Tipps (1980) classified three major models:
1. Up and Down or Evolutionary Models
2. Side-by-Side or Hemispheric Models
3. Inner Connection or Program Models

All three models are based on research and have practical and educational implications; however, the hemispheric model has been particularly generative for both research and application.

One hundred years ago, doctors conducted brain research during autopsies and found that patterns of behavioral dysfunction were related to cerebral damage. Left hemisphere damage was usually associated with speech deficits and inability to sequence activity. In the 1960's, surgeons and neuropsychologists pioneered a new technique to control epileptic seizures by severing the connecting nerve fibers between the two hemispheres. In addition to assessing medical changes, Gazzaniga, Bogen, Sperry, and associates (1962, 1963, 1965) engaged in research to discern other possible effects of the split-brain operation. In a series of psychological tests, they found two different types of cognition in the two halves of the brain. "Each hemisphere seems to have its own sphere for sensation, perception, ideation, and other mental activities" (Sperry, 1968, p. 723). Galin (1975) and with Ornstein (1976) characterized the individual processes of the two hemispheres as analytic and holistic. Bogen (1969) referred to the differences as propositional and appositional.
The nature of the differences between the hemispheres was illustrated by experiments conducted with split-brain patients. The organization of the body senses and motor control opposite to the sides of the brain is important in understanding split-brain experiments. Sensory information from the right hand, ear, and visual half-field of each eye is sent primarily to the left hemisphere; the left sensors send primarily to the right hemisphere. The corpus callosum connects the two hemispheres and allows for interhemispheric transfer. Cutting the corpus callosum in split-brain patients prevented sensory information from being transferred.

By controlling the side of sensation, experimenters discerned what the two sides "knew" about an experience. If a split-brain patient was blindfolded or hands were shielded from view, objects presented to the right hand could be named verbally. The same object presented to the hidden left hand could not be named verbally, although it could be found again in an array of objects. The "verbal" ability of the left hemisphere was the same that had been established through autopsies of brain-injured patients since the middle 1800's.

Levy and Sperry (1972) had subjects learn the names and faces in eight photographs. After splitting the pictures in half and recombing the halves into "chimeric" wholes, the new pictures were flashed tachistoscopically to the patients. When asked to identify what they had seen, split-brain subjects named the picture from the left half but pointed to the picture from the right. Spatial deficits
had been found with right hemispheric injuries: disorienta-
tion, problems with face recognition, and difficulty in
drawing of patterns (Nebes, 1977). With split-brains, right-
hemisphere facility was reported in drawing spatial relation-
ships and completing block designs (Sperry, 1968) and for
assembling patterns (Bogen and Gazzaniga, 1965). The cogni-
tive capacity of the right hemisphere showed that it was only
mute, not ignorant, and could perceive and recall information,
especially pictorial.

Ingenious experiments done by many researchers supported
hemispheric differences in cognition (reviewed by Dimond and
Beaumont, 1974; Languis and Kraft, in press). The left
hemisphere which had the power of speech was predisposed to
analysis and detail. Its mode of operation seemed to be
part-by-part. The right hemisphere, which did not have
speech facility beyond a few concrete nouns, exclamations,
and expletives, appeared to have a complementary mode of
synthetic wholeness. Often referred to as gestalt, the
right hemisphere was good at total pattern recognition. A
primary contribution of the split-brain experiments was the
establishment of a definite role for the right hemisphere.

With a new view of the role and importance of the right
hemisphere, a number of investigators began to look at brain
functioning of adults and children without neurological
insult. Experimental procedures developed for split-brain
research were designed to limit sensory information to one
hemisphere via contralateral pathways. Utilizing the procedures with normal subjects required exploiting hypothesized antagonism (Levy, 1969) and competing processing modes of the two hemispheres. Tasks emphasizing one type of knowing were selected and presented simultaneously to both sides. The hemisphere which was better adapted to the task performed faster and more accurately. Visual hemifield, dichotic listening, and dichaptic touch experiments were three types of experiments carried out with subjects.

When the eyes are exposed to stimuli flashed shorter than 200 milliseconds (Woodworth and Schlosberg, 1954), they do not have time to scan the whole visual field. Therefore, the left visual hemifield of each eye transmits to the right hemisphere and right visual hemifield to the left hemisphere. The right visual field superiority for letters in words (Kimura, 1966; White, 1971), digits (Hines and Satz, 1974), single letters for children (Marcel, Katz, and Smith, 1974), and words (MacKavey, Curcie, and Rosen, 1973) supported a linguistic capacity of the left hemisphere. Dot enumeration (Kimura, 1966, 1969) and detection of slant (Kimura and Durnford, 1974) pointed to right hemisphere spatial ability although the influence of verbal coding appeared important if the alternatives were few (Berlucchi, 1974). Face recognition (Yin, 1970) and reaction times to faces (Geffen, Bradshaw, and Wallace, 1971) also showed right hemisphere superiority. Seamon (1974) proposed that
latency of response reflected proficiency to manipulate different types of information for which each hemisphere was best suited.

Dichotic studies exploited the "prepotency" (Kimura, 1967) of contralateral (opposite) auditory pathways and a resulting functional blockage of ipsilateral (same) pathways. The technique, pioneered by Broadbent (1954), involved simultaneous presentation of auditory material. Right ear advantage (REA) for verbal material has been demonstrated with digits (Kimura, 1961, 1964; Satz, 1968; Milner, 1962) with syntactic structures (Zurif and Sait, 1969), and with easily pronounced words (Curry, 1967). Melodies (Kimura, 1964), sonar signals (Chaney and Webster, 1966), and environmental noises (Curry, 1967) elicited left-ear advantages (LEA). Knox and Kimura (1970) found the same REA-LEA pattern for children age five to eight. However, Bever and Chiarello (1974) reported that the LEA for melody found with nonmusicians was not found with trained musicians. They suggested that strategy rather than stimuli per se accounted for the differences with musicians utilizing serial, coded processing.

Berlin (1978) questioned the use of dichotic listening as an index of hemispheric laterality. According to him, dichotic results could be a correlate of laterality although central processing at a lower brain level might also account for differences. He reviewed the effects of intensity,
frequency, signal-to-noise, lag time, age, and stimuli composition and concluded that dichotic listening could be used to study brain asymmetry if the competing challenges actually induce suppression of the auditory nervous system.

Another type of investigation of hemispheric specialization is the electroencephalogram (EEG). Individuals perform tasks and brainwaves are recorded for later analysis. Galin and Ornstein (1975) had subjects engage in verbal (writing) and spatial (block design) activities. Beta waves from the left hemisphere accompanied verbal tasks, while spatial tasks elicited beta in the left hemisphere. Kraft (1976) engaged children in Piagetian tasks and reading while she recorded EEG patterns. Her results documented a shift from right hemisphere to left hemisphere depending on the demands of the task. Silent reading showed greater right hemisphere activity than did answering questions. Presentation of Piagetian tasks also elicited more right hemisphere brainwaves than explaining the task.

The weight of evidence from split-brain research and studies with normals supported differences in hemispheric functioning. Interpretation of the differences, however, was not as simple as the terms would imply. Verbal-non-verbal, analytic-visuospatial, detailed-gestalt—all are dichotomous descriptors for relative differences. The difficulty experimenters have separating the processing differences with normal subjects reemphasizes the brain's
exceptional ability to process experience in both ways. Rather than right-versus-left, right-plus-left integration more accurately reflects how humans develop a unified view of reality (Languis, Sanders, and Tipps, 1980).

In fact, Sperry and associates recently conducted follow-up testing of the original split-brain patients. Five to ten years after the callosal commissures were cut, patients' responses to motor and social tasks supported differences in hemispheric functioning. However, evidence suggested the importance of the integrative role of the corpus callosum and the co-operative nature of the hemispheres. After observing right hand failure to reproduce visually presented hand signals to the right hemisphere, Zaidel and Sperry (1977) concluded that the deficit resulted for inadequate language control over volitional motor response. Likewise, problems of copying spatial figures with the right hand may point to poor spatial control over the left hemisphere motor response. Both findings argue for callosal integration of functions which require specialized abilities of the hemisphere. Simple visuomotor or well practiced movements learned prior to surgery are least disturbed in the patients which suggested lower brain or non-specialized control.

Two of the patients were studied in regard to personal and social awareness of the right hemisphere. By controlling the visual input through special contact lenses, a number of
pictures were shown to assess self recognition and affective response. Sperry, Zaidel, and Zaidel (1979) concluded that the nonverbal responses revealed consciousness equal to that of the left hemisphere. However, the interplay between the hemispheres in responding to verbal questioning revealed an amazing interdependence. One patient actually cued the left hemisphere by writing letters with the left hand on the back of the right hand. The examiners believed that the responses showed considerable memory available to each hemisphere, a verbal role for the right hemisphere in the quick identification of pictures when the word was provided, and the existence of an affective "aura" which spread to the left hemisphere even when no factual information was provided to it.

Twenty years of research into hemispheric functioning warrant few conclusions, but some generalizations are possible.

1. There appear to be fundamental differences in the way the two hemispheres make sense of experience. Each constructs meaning which is integrated with the other for a total view.

2. Observed differences are not wholly within the cortical hemispheres but also depend on lower brain structures for arousal, attention, and memory.

3. Differences are not absolute. Difficulty in detecting differences, as well as neural plasticity and redundancy, argues against simplistic hemispheric descriptions.
4. Terms used to describe the differences are inherently inadequate because they emphasize only one of many qualities.

5. The differences are not entirely due to perception, processing, or response; each of the three plays a role and confounds all studies although to different extents with different tasks and different individuals.

The generalizations reflect the limitations of any simple explanatory model for complex events. However, the field of brain functioning is formative and challenging. Existing empirical research is pre-Einstein in answering questions about the brain and behavior. What is known about the brain has been organized into theories or models which enable evaluation of new findings and planning of further investigation. Tentative models are temporary guides in an ongoing process.

Even within the hemispheric model of the brain, there are models to explain differences. Three current models of hemispheric functioning were outlined by Spirduso (1978):

1. input-output or coupling model
2. processing or specialization model
3. orientational or attentional model.

The coupling model suggests that differences are due to the contralateral neural pathways and that differences in response times reflect the time for neural connection and transfer.
The specialization model builds on neural mechanisms but adds that hemispheric specialization helps determine which connections must be made. The attentional model also acknowledges the role of neural mechanism but suggests that the real difference is not specialization but is due to alerting or priming of hemispheres to tasks. Research into the nature of hemispheric differences seeks to clarify and extend the models. Results of the study on hemispheric and developmental aspects of temporal processing were interpreted with regard to the models.

**Developmental Aspects of Hemispheric Functioning**

What is known about brain growth, and how does brain growth relate to behavioral changes of the human organism? Epstein (1978) approached the questions from an anatomic viewpoint in reporting changes in brain weight. He summarized a number of studies (1974) which showed a similar pattern of "brain growth spurts" at ages 0-1, 2-4, 6-8, 10-12, and 14-16. The exact nature of such weight changes is as yet unknown although neural cell reproduction is thought to cease soon after birth, so other structures must be assessed. Frostig and Maslow (1979) listed potential sources of growth which might account for weight change including:

1. Increase in the fine branching of dendrites and axons and bundling of the dendrites.

2. Growth and change of neuro-glial cells which support the formation of myelin sheath around axons resulting
in functional units.

In addition, Yacoylev & Lecours (1967) suggested:

3. Formation of the myelin sheaths themselves.

Does brain growth just happen or does experience affect it? Rosenweig, Bennett, and Diamond (1972); Rosenweig and Bennett (1969) reported a series of experiments in which rats were exposed to enriched or impoverished environments. They found that the ratio of weight of the cortex to the subcortex was consistently greater for the rats in the enriched environment. Weight, number of glial cells, thickness of the cortex, and cross section of neuron cell bodies in the occipital cortex were significantly greater for enriched littermates. They concluded that "there can be no doubt that many aspects of brain anatomy and brain chemistry are changed by experiences" (1972, p. 7) but caution generalization to humans. Even with due caution however, the impact of experience in establishing neural networks which undergird behavior is affirmed. Moreover, experience may be necessary for certain pathways to be shaped originally. Wiesel and Hubel (1965) sutured one eye of a cat closed and discovered that certain visual regions of the brain were functionally lost. Epstein (1978) wrote that "the role of experience is to select from alternative network possibilities which existed before the experience begins" (p. 354). These patterns of neurological connections serve as "program" for human behavior according to Young (1978).
Neuroplasticity also affirmed the role of experience within the confines of a genetic timetable. "The earlier a neural insult occurs the greater the chance of recovery of function" has been found with child language (Krashen, 1975), adult motor, visual and dysphasia (Teuber, 1975), and spatial tasks of monkeys (Goldman, 1976). Although timing appears to be a major factor in the ability of the brain to find alternative ways of establishing neural networks, location and extent of injury are also important. Rudel (1978) added that even with recovery it is probable that functioning never reaches full proficiency. In fact deficits from early damage may not appear for years. Geschwind (1975) suggested that all humans are brain-damaged to some extent but that the brain for most people manages to find appropriately adaptive ways of dealing with experience.

Development of the brain can also be considered as structural growth. The human brain develops in stages which resemble the brains of animals lower on the phylogenetic scale. The lower brain and brain stem develops early neonatally and is similar to the reptile brain. The midbrain and limbic system develops next and resembles lower mammalian brains. The cortex and hemispheres are last to develop and are common only to higher mammals and most pronounced in dolphins, apes, and man. MacLean (1978) used these parallels as well as evolutionary evidence to develop the triune brain model. In this model, evolutionary pressures brought about
the development of cortical association areas which are related to thinking, problem-solving, and intelligence. (MacLean, 1973, 1978; Jerison, 1977; Levy, 1974; Leakey, 1979). Young (1978) believed that the brain structure itself was a genetic code which guides behavior.

MacLean (1978) suggested that the newest evolutionary feature, the pre-frontal cortex, was the site of the empathy and altruism which distinguish man emotionally from other animals. He then raised the question of sensitive periods for the development of the capacity for caring. While research does not support a wholly deterministic view of brain growth and development, Chall and Mirsky (1978) believed that the timing of experience is a recurrent neurological theme. The matching of experience with a neurological structure which is primed to benefit is at the heart of learning as learning is at the core of human development.

Classical issues of human development include:

1. Role of environmental and biological factors in determining behavior
2. Interrelationship of structural and behavioral maturation.

When applied to the question of lateralization of the hemispheric functioning, the issues result in many questions:

1. Does lateralization of function exist?
2. If it exists, does lateralization of function develop?
3. Are there neural substrates which explain lateralization of function?
4. Are substrates subject to experience and/or growth?
5. Are there relationships between neural/behavioral changes?
6. Is there an optimum lateralization or can various lateralizations be equally as "good?"
7. Do genetic/experiential factors influence "goodness" of lateralization?

Rather than being separate questions, research which yields information on any one of these questions implies answers to others.

In the previous section, differences in hemispheric functioning were reviewed. Evidence from cerebral insult, split-brain, and normals is consistent in the kinds of processing which typify the two hemispheres. The question of how differences come to exist is not resolved. Asymmetry may be established at birth and maintained, may become greater with experience and/or neural maturation, or may be developed to a plateau. There is evidence to support each of the views. In this section, a number of findings in neurology and psychology are reviewed relative to their developmental implications.

Geschwind (1968, 1974) reported anatomic asymmetry of the infant brain in Wernicke's area which is associated with speech comprehension. Asymmetry of habituation to acoustical stimuli in infants also has been found (Entus, 1977). Kinsbourne and Hiscock (1977) used these and other findings of early differences to reject a developmental specialization model. Their explanation of lateralization is based on selective attention. The orientational model explained infant rightward turning as evidence for left hemisphere
Neural maturation is not an important issue in the attentional model, but it is the basis of the specialization model. Myelin is a fatty tissue which grows around nerve fibers and insulates the nerve. Growth of myelin sheath which increases conductivity of neuroelectrical impulses follows a pattern (Yacovlev and Lecours, 1967). Motor and sensory connections are begun prenatally and continued for the first two to four years of life with specific senses having different rates and periods of completion with the midbrain control centers. Although beginning before birth and lasting into adolescence, interhemispheric myelination is for the most part completed at age six or seven. After that time most myelination appears to be for intrahemispheric association areas. Myelination proceeds in a bottom-to-top and back-to-front progression paralleling MacLean's evolutionary brain models, as well as the proximodistal (close-far) developmental pattern. Increased efficiency of conduction results in proficiency of functioning for activated areas and inhibition of extraneous processing. Hebb (1949) emphasized the role of inhibition in establishing clear neural pathways which he termed cell assemblies and phase sequences.

Using the documented maturation of the brain, neuroscientists have looked for corresponding behavioral changes.
Four of Epstein's (1978) brain growth spurts occur at times which coincide with Piagetian cognitive stages. However, the last brain growth spurt at 16 is not matched, lending support to Arlin's (1975) projected problem-finding stage of cognition. The relationship of a neural maturation pattern to a specific cognitive theory suggested a form-function relationship which changes over time.

Piaget described the early cognitive period as sensorimotor during which time children know things through direct experiences rather than through language; this observation could be interpreted as right and left hemispheric function. In fact, Kraft and Languis (1977) and Brown and Jaffe (1975) suggested early activation of the right hemisphere. Harris (1975) interpreted rightward turning of infants as a postural adjustment so that more information could be received via the left ear and left visual hemifield (right hemisphere). Brown (1976) and Witelson (1977) suggested that language is based originally on sensory experience which is reorganized into verbal codes. As visuo-spatial experience is organized into verbal linear codes, it is transferred to the left side. The left hemisphere becomes a more attuned receiver of coded language. Krashen (1975) reported that lateralization for language production was virtually complete at age five.

If the young child thinks like a split-brain patient (Gazzaniga, 1970), developing myelination of nerve fibers in the corpus callosum between the hemispheres would enable
whole-brain thinking by the age of 6-7. Kraft's finding (in press) of change in EEG activity from right during silent reading and presentation of Piagetian tasks to left during response supported functional transfer. Furthermore, the discovery that the more successful conservers and comprehenders showed less switch to left during response supported greater interhemispheric functioning for higher processing skills. High degree of shift may indicate immature functioning. Deaf children (Neville, 1977), illiterate adults (Wechsler, 1976), and illiterate preadolescents (Khadem, 1970) are reported less lateralized than normals. Failure to lateralize adequately may actually prohibit integration of function. Another indication of lateralization and integration might be deduced from Berlin et al. (1973). On a verbal dichotic listening task, responses from the right ear were stable from age 5 to 13 and left ear accuracy declined slightly, but total correct for both ears increased.

The idea of integration of functioning being related to increased accuracy over age was explored by Galin, Johnstone, Nakell, and Herron (1979). They asked 3 and 5 year olds to touch small samples of fabric and classify them as same or different. Two conditions for comparison were used—same hand and different hands for the two textures. Younger children had significantly more errors in the "crossed" condition than when the same hand was used. The authors concluded that interhemispheric communication due to...
myelination of the callosal fibers was responsible for the difference. Previously, Galin, Diamond, and Herron (1975) had used a tactile localization task in crossed or uncrossed position with children aged 5 to 11. Both conditions showed an age related improvement, but the difference between the conditions was strongly age dependent; younger children made more crossed errors.

Galin and colleagues have presented intriguing evidence of behavioral change related to hemispheric maturation. However, one explanation of improved performance could be improved language ability which could also be due to neurological development. Although syntactic development is completed by age 5 (Krashen, 1975), the role of language as a mediator of higher processes is suggested by Kendler and Kendler (1970), Bruner, Goodnow and Austin (1962), and Vygotsky (1962). Vygotsky emphasized transformation of overt social speech to covert inner speech which guides behaviors. The coordination of action through internal mediators after age seven suggests coordination of right and left processing.

Differences in lateralization and neural maturation were also implicated in Goldman's (1974) research with rhesus monkeys. Deficits in rotated object identification and delayed response accuracy were found among male rhesus monkeys with surgical lesions as early as fifty days, but not in females. Deficits in operated females were not apparent
until fifteen or eighteen months, suggesting early maturation of certain cortical regions for males. McGuiness and Pribram (1979) in a lengthy review of sensory and neurological sex differences proposed that earlier maturation resulted in superior male visuo-spatial performance. While males were rehearsing spatial information, females relied on frontal commissure communication allowing more proficient sequencing. "As more information, both in the input and output domains, becomes coded and efficiently ordered (chunked), higher level processing (cognition) can be more readily achieved." (p. 38) Early activation of right hemisphere may make males more vulnerable to injury prenatally and during the birth process. Later the disadvantage in verbal ability may actually result in a cognitive advantage with males having strong lateralized abilities. Bilateral language may be responsible for the spatial deficits reported in females (Harris, 1976).

Developmental questions in brain research are a way of investigating behavioral issues. Epstein's brain growth, Piaget's cognitive levels, language development, and even psychosocial stages of Erikson are consistent in ages of significance (Figure 2.1). Certain ages coincide with the advent of qualitative differences in cognitive and social behavior and with Epstein's brain growth and myelination cycles. Research focused on those ages promises fruitful results in unraveling the brain and behavior questions.
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<th>BRAIN GROWTH SPURTS-EPSTEIN</th>
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Figure 2.1 Comparison of age-related events from neurological and psychological theories.
At the present time, however, only tentative answers are possible to the questions posed earlier about lateralization, behavior, and the brain.

1. Functional differences between the hemispheres do exist. Whether these differences are due to specialization or orientation or some other reason is not known.

2. Lateralized functioning exists from birth but is also subject to change.

3. Maturation of neural structures subserves behavior manifested in lateralized functioning.

4. Neural structures are affected by experience. Experiences which coincide with neural growth have the possibility to affect the nature of lateralization.

5. Interhemispheric communication established at age six or seven coincides with a constellation of language, cognitive, and social behavior changes. Changes at ages two to four and eleven to thirteen may lead to a neurological based schema of significant developmental times.

6. No single lateralization is inherently better than others. Evolutionary pressures manifested in population parameters indicate that right-handed, left-speech dominant may have or have had some advantage in cerebral organization. Group and individual differences may be linked to different lateralization patterns.

7. There is speculation that lateralization is a precursor to integration of function.
Developmental evidence provides information about the nature of behavior and learning, brain functioning and lateralization. Developmental evidence may also provide information about the perceptual processing features which determine brain functioning. In the following section, time is suggested as a salient feature which may be part of the underlying dimension of cognitive differences.

**Time and the Hemispheres**

Despite the fact that verbal information and speech production are associated with the left hemisphere for over ninety percent of right-handers and approximately two-thirds of left-handers (Zangwill, 1960; Wada & Rasmussen, 1960), the verbal-nonverbal dichotomy has largely been rejected by brain researchers. Instead of looking at stimuli, investigators have looked at the processing which is necessary to deal with different types of information.

Looking for the underlying mechanisms of the brain is one approach to the brain mystery. What quality of stimuli and processing results in specialized or attentional asymmetry? The suggestion made in this section is that time plays an important role in the process. Joseph Bogen (1977) wrote that "what may well be the most important distinction between the left and right hemisphere modes is the extent to which a linear concept of time participates in the ordering of thought." He continued, "The right hemisphere is specialized for processing time-independent stimulus
configurations and the left hemisphere for time-ordered stimulus sequences" (p. 141). Bogen's contention that hemispheric differences are due to differences in dealing with information in time is explored in this section. First, a number of studies with auditory stimuli are reported which pertain to a time explanation of brain functioning. Finally, a processing model based on time and Luria's brain model is discussed.

Right ear, therefore left hemisphere, superiority has been noted in a number of studies which have an implied time dimension. Language—a coded, sequential, bit-by-bit phenomenon—typifies left hemisphere processing. Kraft (in press) suggested that finely tuned motor processes of speech production required a sequential controller. The consistent right ear advantage (REA) for verbal information in dichotic studies supported the time dependent description of left processing. Right ear advantage was also found for stop consonants (Studdert-Kennedy and Shankweiler, 1970) called categorical rather than continuous sounds and for syntax (Zurif and Sait, 1969).

Left hemisphere lesions reduced accuracy in temporal order discrimination with visual (Efron, 1963) and auditory stimuli (Carmon and Nachson, 1971; Swisher and Hirsh, 1972); however, Albert (1972) failed to replicate temporal sequencing deficits with left side damage. Kim (1976) found temporal ordering deficits for left-lesioned patients versus
right-lesion or normals with auditory and visual stimuli regardless of configuration—digits, words, or forms. Right-lesioned patients were inferior to normals on sequencing.

Temporal sequencing was also investigated with Morse code. Both experienced and inexperienced subjects had right ear advantage to dichotic Morse code signals (Papcun, Krashen, Terbeek, Remington and Harshmann, 1974). Bever and Chiarelli (1974) reported a consistent REA for melodies with experienced musicians who may focus on individual notes in a coded manner; nonmusicians showed a left ear advantage and may have attended to the melodic contour.

Lackner and Teuber (1973) used an auditory fusion technique in which subjects were asked to report when they hear separate clicks and when they hear only one continuous stimulus. The interval between the two clicks was varied until a fusion threshold was found. Left-lesioned subjects required a longer interval between the clicks to separate them than did right damaged patients or controls. This supported Efron's (1963) suggestion of left hemisphere decision for simultaneity and order. Mills and Rollman (1980) divided the two clicks by putting one in each ear and varying interstimulus intervals. When the right ear received the first click, the threshold of fusion was significantly shorter. They attributed the difference to inter-hemispheric transmission time as the left ear click was sent
to the right hemisphere then to the left hemisphere for a temporal decision.

Mills and Rollman (1979) asked subjects to respond as soon as variable pulse sequences were terminated. Inter-pulse intervals less than 50 milliseconds yielded significantly faster reaction times for the right ear. The 50 millisecond limit was consistent with phonemic durations but considerably shorter than syllables, verbal sequences, and sentences which also elicit right ear advantages.

Haggerty and Stamm (1979) also utilized auditory fusion techniques. Right handers and controls had lower fusion levels for clicks than mixed handed and learning disabled subjects. Higher auditory fusion scores correlated significantly with language dysfunction scores. They concluded that higher auditory fusion may indicate left hemisphere differences or dysfunction in processing. Although Murphy and Venables (1970) reported left ear discrimination for inter-stimuli intervals as small as 2 milliseconds, Mills and Rollman (1980) contended that the task called for judgments based on pitch rather than timing.

Efron and Yund (1976; Yund and Efron, 1975) found two contributing factors to observed differences in temporal processing: a temporal element and an ear dominance factor for pitch or spectral information. Divenyi and Efron (1979) separated them in a dichotic listening task in which subjects who displayed right ear dominance for pitch also had REA for
all dichotic sounds. Subjects who had left ear dominance for pitch maintained LEA for dichotic comparison based on pitch but acquired REA for speech sounds differing primarily in temporal features. Divenyi and Efron argued that the left hemisphere is specialized for speech because it is superior in dealing with "temporally-complex auditory stimulus."

Another explanation of left hemisphere language superiority is codeability. As events become more familiar, they are more easily retained in sequential, analytic code. According to Harrison (1974), a written or verbal communication system is a digital code which is arbitrary and discrete; a nonverbal system is a continuous, natural, and analogic representation. Bogen (1977) denoted the capacity of the left for syntax, semantics and logic and the right for gestalt, appositional thought. Bosshardt and Hormann (1975) investigated temporal precision in coding on the basis of laterality. In reanalyzing previous data reported by Mainta and Hormann (1975) they found a significant superiority of the left hemisphere for accurate serial recall of dichotically presented words. Albert (1972) contended that left language dominance was due to acoustic sequencing, however, the results reported for sequences of words suggest another level of sequencing. Bever (1971) worked with sentence chains and found the right ear presentation resulted in fewer errors in repeating correct order. Based on his
findings, Bever argued for asymmetry based on learning—a position similar to the attentional model of Kinsbourne.

Consistent with an attentional model of brain functioning were findings of sensitivity to temporal groupings using auditory patterns (Chang and Trehub, 1977) and cross-modal sequences (Allen, Walker, Symonds, and Marcell, 1977). Both of these studies used a habituation paradigm with children under six months of age. Hemispheric difference to temporal patterns associated with speech were also reported using auditory evoked potentials (Molfese, 1973; Molfese, Freeman, and Palermo, 1975), EEG (Davis and Wada, 1977), and heart rate habituation (Glanville, Best, and Levenson, 1977). Auditory evoked potentials were found by Molfese and Molfese (1979) which differentiated between the hemispheres for specific speech cues. Also, left hemisphere sex differences were found among neonates in perception of speech.

Research with temporal-based stimuli does show hemispheric differences. Studies using a number of methods support the left hemisphere as being instrumental in time ordered judgments, especially in dealing with language as a sequential event. The relevance of these findings to learning has not been established, but a model of intelligence proposed by Das, Kirby, and Jarman (1979) rests on a temporal processing concept. In developing their model of intelligence based on standard psychometric instruments, they cited the brain model of Luria.
Luria (1970), the noted Soviet neuroscientist, had suggested that simultaneous and successive described two types of processing and intelligence. His brain model consisted of three broad functioning areas—the reticular system and limbic system, the occipital-parietal regions, and the temporal-frontal regions—which are responsible for arousal, coding, and planning respectively. Within each of these functional blocks, three levels of complexity exist—primary sensory projection, secondary projection-association, and tertiary integration. Das, et al. placed particular emphasis on the tertiary zones which function through "transforming successively arriving stimuli into simultaneously processed groups" (p. 39). The lower zones were more modality specific; higher zones of "overlapping" function were called supramodal. While Luria's brain model is not specifically hemispheric, he acknowledged that lateralization occurred in block two at the secondary and tertiary levels which control higher thought processes.

Das, Kirby, and Jarman believed that "diminishing specificity" and "increasing lateralization" in the second block was responsible for coding of information in either successive or simultaneous manners. They developed a model which shows the relationship between input, processing, and output (Figure 2.2). Input itself may be simultaneous or successive and in any mode. A sensory register acts as a buffer which gates incoming information through threshold,
Figure 2.2 Simultaneous/successive processing model adapted from Das, Kirby, and Jarman (1979) to show relation to brain functioning
arousal, and attentional mechanisms. The central processor then codes input regardless of its mode or condition into either a successive or simultaneous form. Successive processing demands serial order in which sequential relationships are of primary importance. The code is discrete and analyzable. Simultaneous processing integrates each element into groups so that significance is derived from its relationship to the whole. The code is whole and "spatial" in nature so that all parts must be considered in the meaning. The central processor also utilizes codes in making decisions and taking action (Das, Kirby, and Jarman, 1975).

Das and associates used many standard psychometric tests. Factor analysis revealed three factors which they called simultaneous, successive, and speed. Tests which were consistently factored into the three groups were:

**Simultaneous**

- Raven's Coloured Progressive Matrices
- Figure Copying
- Memory-for-Designs

**Successive**

- Serial Recall
- Visual Short-Term Memory
- Digit Span Forward

**Speed**

- Word Reading
- Color Naming

Studies of school achievement, learning disability, reading problems, and mental retardation, based on the battery of
tests show different simultaneous-successive profiles.

Das and Molloy (1975) compared first and fourth graders on the battery. Simultaneous and successive factor scores for both groups were similar except for Visual Short-Term Memory which did not load on successive for the first graders. Students with high simultaneous/high successive scores also had higher scores on reading vocabulary, comprehension, and verbal and nonverbal intelligence tests (Kirby and Das, 1977). School achievement appeared to be related to both types of processing, although Das, et al., (1979) concluded that higher reading and mathematics achievement was more dependent on simultaneous processing. However, when the battery was analyzed with standard achievement tests, a separate achievement test factor was found (Das, 1973). The simultaneous/successive tests have been consistent for retarded (Jarman, 1978), reading disabled (Leong, 1974), and hyperactive subjects (Williams, 1976) although loadings have varied across the groups.

The empirical evidence for two processing styles amassed by Das and associates is impressive even though "rudimentary" (p. 190). The research is exciting for several reasons. The model which they presented is a direct attempt to incorporate levels of temporal processing within a cognitive model. Second, the model draws from the functional brain model developed by Luria. Third, the assessment of children based on the model has developmental, cultural,
and educational implications.

At the same time, the model is disappointing. The tests which were used have no direct relationship to any empirical understanding of temporal brain functioning. The factors are a relabeling of tests which have been previously used to describe verbal and spatial functioning. No attempt has been made to draw from the hemispheric-time studies to support the simultaneous and successive labels. Das, et al., erred in stating that hemispheric studies were mostly concerned with content rather than process. Underlying mechanisms of brain functioning have been the focus of hemispheric research for the past decade. If time is an important dimension in learning and development, continued research is needed to explore temporal differences in hemispheric functioning and to relate them to cognition. The next section reviews psychological time studies with a developmental and cognitive emphasis.

**Time Perception, Time Estimation, and Cognitive Processes**

The history of research in psychological time follows the history of psychology as a whole. Through the 18th century, philosophical issues were debated comparing sensory experiencing theories to inner construction theories. Kant rejected both extremes and suggested that time was an idea "drawn not from some sensation of objects (for sensations provide the substance but not the form of human knowledge)
but from the operation of the mind itself in accordance with
the constant law governing the sensations of the mind" (quoted in Fraisse, 1963, p. 5). In the last half of the
19th century, development of laboratory methods enabled the
empirical study of time estimation, while the Wurzberg
school attempted unsuccessfully to systematize introspective
reports of time.

In the twentieth century with the predominance of
behaviorism, "consciousness" was not an acceptable arena for
research. The approach was to describe how external stimuli
changed time estimation. Fraisse (1963) summarized the time
estimation and perception research of 1900-1950 under the
headings: perception of empty time, perception of filled
time, filled and empty time, and changing threshold of the
perception of succession. The results were often confusing
and contradictory. Methodological differences were respons­
able for part of the inconsistency. However, exclusion of
an active role of human beings in perception may have also
contributed to the confusion.

Looking at time as a developmental phenomenon led to­
ward cognitive study of time. Normative studies such as
those by Sturt (1925), Harrison (1934), Bradley (1947), and
Ames (1946) sought to describe development of ideas such as
day, month, and hour from childhood to adulthood. Rather
than dealing with verbal time labels, Piaget (1969) began
studying time as a logico-mathematical mental structure
which developed from a child's interaction with distance and movement. Studies in the 1950's and 1960's supported much of his cognitive development theory. Ornstein (1969) interpreted time estimation as an index of what people knew and the experiences they had had. Numerous studies conducted in the past decade have concentrated on time as a dimension of information processing. In this section, studies of time estimation and temporal processing are reviewed. Developmental issues in time and connection to neural models are emphasized.

Ames (1946) was interested in how children come to understand common time units. Her approach was typical of the Gesell method in which children were observed in natural settings and interviewed. Age-related statements are then made about the attainment of certain skills. Information was collected about the spontaneous use of time-related words in children's play and the ability to correctly answer specific questions about time for children 21 to 48 months over a two-year period. A second series of questions was posed to children age 5, 6, 7, and 8. Ames gathered verbalizations about time of day and clock time, age concepts, past and future, duration and order of events. She noted that the children appeared to go through three stages with each time word-concept: ability to respond appropriately; ability to use spontaneously; ability to answer questions. Specific time concepts dealing with personal
experiences developed before generalized concepts. The normative data showed a tremendous improvement in ability to answer questions dealing with time at ages 5, 6 and 7. Vocabulary learning and memory may account for the improvement.

Piaget (1969) would classify the Ames' questions as verbal information—social knowledge. He was interested in a different class of time concepts—those which a child constructed from interaction with the world. He attempted to discover structures of logic about the sequence, duration, simultaneity, synchronous duration, measurement of time, concept of age, and inner sense of duration. Lovell and Slater (1960) replicated the Piagetian tasks (water flow, doll race, and co-ordinated emptying-filling of two containers) to investigate simultaneity, equality of synchronous intervals, and order of events. The ability to perform the tasks increased with age. Recognizing starting and stopping simultaneity with water flow preceded recognition of equal duration. Simultaneous and synchronous time appears to be a developing characteristic of the 8 and 9 year old normal population. For a retarded group, these abilities do not appear until age 15.

Montroy, McManis, and Bell (1971) agreed that pre-operational children use perceptual aspects to answer time questions. For time tasks, the greatest improvement was
between the ages of 6 and 9 for normal children with a delay until 9-11 for retardates. Davis (1972) found that 7 and 9 year olds were time nonconservers; only 11 year olds could conserve simultaneity and order. He found no significant differences between the black and white subjects at each age level. Dempsey (1971) did find differences between Anglo-American, Mexican-American, and American Indian groups on time concepts. Although none of the groups or ages (7, 9, 11 years) reached 75 percent criterion, he concluded that cultural differences favored Anglo, Chicano, and Pima groups.

Despite individual and cultural differences, the sequence of knowing time in Piagetian terms has been found to be consistent. Although Piaget does not assign ages to the stages of understanding, ages have been found to be fairly consistent with normal populations. Copeland (1974) summarized Piaget's sequence of "logic" as a child attempts to co-ordinate events in time:

1. A child equates time and speed (4-6 years).
2. A child equates distance and time regardless of speed (6-7 years).
3. A child recognizes simultaneous starts and stops but not equivalence of duration (8-9) if distracted by other perceptual aspects.
4. A child correctly understands the relationships of time, speed, and distance (age 10+).

Piaget was also interested in subjective apprehension of time due to activity level. If a child works rapidly, the child feels that a metronome must also move faster. Lovell and Slater (1970) asked children to compare durations
in which they were involved in different tasks. Younger children and the retarded group reported that sitting still was longer in time than reading and that marking lines rapidly was longer in time than carefully drawing with a ruler. Older children (age 10) recognized that the time intervals were equivalent regardless of the activity.

Events influence time perception through the mediation of cognitive processes according to Ornstein (1969). The time illusion which Piaget reported is also true for adults although the relationship is much more complex. In nine experiments reported by Ornstein, perceived duration was longer when more information was presented, when more was retained, and when the complexity was greater and required more coding. He hypothesized that duration depended on:

1. a register which could accept more or less input;
2. processing of information into meaningful organization and its storage; and
3. the type of reporting or use to be made of the transformed information.

Ornstein emphasized the processing and storage determinants of duration. However, his three-part model—input register, process and storage, and use—paralleled the simultaneous/successive model of temporal processing of Das, Kirby, and Jarman (1979). Luria's functional model and the up-and-down models (Languis, Sanders and Tipps, 1980) suggest similar levels of arousal, coding, and planning in describing the brain.
One group of time studies has concentrated on input and arousal; the amount of input and the openness of a "register" to receive input are important. A positive relationship between the number of stimuli and the judged duration has been found repeatedly (Fraisse, 1963; Goldfarb and Goldstone, 1963; Frankenheuser, 1959; Lhamon and Goldstone, 1974; Ornstein, 1969; Vroon, 1970). Likewise the complexity of the stimuli resulted in increased time judgments (Fraisse, 1963; Ornstein, 1969; Schiffman and Bobko, 1977). These effects occurred when processing was not required of subjects. Stimulus intensity also resulted in longer estimates (Berglund, Berglund, Ekman, and Frankenheuser, 1969).

The increase in temporal judgments has also been found with stimulants (Frankenheuser, 1959) and ethanol (Leigh and Tong, 1976). Sedatives reduced time judgments (Frankenheuser, 1959), as did cigarette smoking (Leigh and Tong, 1976). Cahoon (1969) found a relationship between basic brain alpha wave patterns (EEG) and time estimation but not with induced arousal. Ornstein (1969) rejected attempts to explain time as a function of biological clocks such as pulse, body temperature, or cell metabolism. Instead, he interpreted any such findings as artifacts of changing access to the input register. Physiological state and stimuli nature are implicated as important in time estimation.

Neurological and processing models consider arousal to stimuli as basic to the coding and storage. Ornstein (1969)
emphasized that storage of experience was critical in changing remembered time. Subjects remembered a dance seen in six parts as longer than the dance viewed in two parts. When subjects were given a cue as to how to interpret a complex pattern, time estimations were shortened. By influencing the way in which the stimuli could be coded, Ornstein allowed the subject to vary how input was processed. He concluded that not just the stimuli, but the amount of stored stimuli accounted for time estimation.

In Ornstein's experiments the subjects were uninformed of the time component as time estimates were taken following the cognitive task. In such retrospective paradigms, increased processing and remembered information appeared to increase time estimates (Ornstein, 1969; Block, 1974). If subjects were informed prior to the task that time judgment would be taken, the opposite results were found. As processing demands increased, time estimates actually decreased (Hicks and Brundige, 1974; Vroon, 1970; Curton and Lordahl, 1974).

This apparent contradiction was explained by Thomas and Weaver (1975) as indicating that there were two separate elements in remembered duration--attention to time and attention to process. When attention to time was high as in prospective judgments, increased processing interfered with time and resulted in decreased time estimates. Retrospective judgments have little attention to time so that remembered duration depends on processing input and storage only. Curton and Lordahl
(1974) suggested that some inconclusive results regarding arousal on time estimation had been the result of an erroneous equation of arousal with attention.

Subjects engaged in a variety of tasks reported different time estimates as interest in or demands of the task increased. Gulliksen (1927) reported a sequence of time estimates for resting, holding out arm, pressing a point to skin, reading, taking dictation, and arithmetic computation. In the first tasks, the limited cognitive demands allowed much attention to be placed on time. Subjects actually had time on their hands and minds. With increased processing, more attention was placed on the task decreasing attention to time and consequently time estimates. At some point, however, attention to task (input, processing, and storage) may again result in higher time estimates. Describing the time/task trade-off has been a major focus of information processing studies. Hicks, Miller, and Kinsbourne (1976) had subjects sort cards into one, two, or four stacks—all cards, by color, or by suit. As uncertainty of response increased, prospective judgments showed the expected decline. Retrospective judgments were much shorter for the no processing task but approximated prospective judgments as processing increased. Miller, Hicks, and Willette (1977) used a word rehearsal task to differentiate duration based on remembered content from duration based on remembered process. They found that the number of words remembered from rehearsals did not change,
however, time estimation decreased over repeated rehearsal periods. They concluded that "retrospective duration judgments appear to depend on the amount of processing S remember having completed" (p. 7). Hicks, Miller, Gaes, and Bierman (1977) summarized past findings on time estimation due to directed attention. Among the generalizations were:

1. Time seems longer when attention is directed to it, as in prospective judgment condition.
2. When attention to time is disrupted by processing requirements, time seems shorter.
3. Complexity of input has inconsistent effects on time estimation possibly depending on the subjective "chunking" or groupings of events.

These conclusions supported an attentional model of the brain. The idea of use or intention, the third stage of processing models, is inherent in research with attentional changes. Whether information is to be remembered, whether time is to be indexed, how content is to be reported— all affect attention to content, process, and time and change time estimation. Separating the variables is extremely difficult. Block and Reed (1978) compared event-memory, attentional, informational, and processing change explanations. Duration was found to be a function of changing levels of cognitive processing rather than input, attention, or storage. In an experiment by Vroon (1970), subjects had to respond to random tones by pushing a button when either a high or low note was heard. Increased response actually decreased interval estimation.
The parallel between neurological and time processing models is provocative. The orientation model was implicated in the division of informational and temporal attention. The arousal aspect of temporal processing was consistent with a gating explanation of brain function. The information processing model coincided with the temporal processing model of Das, et al. However, a direct relationship between time estimation and hemispheric functioning has not been made. Fundamental to finding a difference between ways of temporal processing is finding a stimulus which is ambiguous enough to be coded in different ways.

Bregman's research (1978; Dannenbring and Bregman, 1978; Bregman and Campbell, 1971) with streaming patterns offers such an ambiguous temporal stimuli. Streaming patterns are rapidly alternating patterns of tones. The tones are actually a repeated sequence of high-low-high-low, however, Bregman and colleagues found that subjects failed to report the actual serial nature of the high and low notes. Instead, two parallel or simultaneous patterns were heard. Bregman attributed the streaming phenomenon to the Gestalt law of continuity so that a high stream became a continuous pattern at the same time the low pattern was apprehended. Bregman investigated thresholds of streaming. Streaming can be achieved by increasing the pitch space between consecutive notes or by decreasing the time between notes. A critical ratio of space and time is necessary to change the perception
of successive notes into simultaneous patterns.

The auditory illusion of streaming patterns can be explained by a comprehensive space-time relativity theory proposed by Jones (1976). Jones' Rhythmic Theory differs from theories which depend on memory, storage, or external time referents. Instead, Jones hypothesized an internal time expectancy which is sensitive to pattern and changes in both rhythm and space. If world events occur in a four-dimensional reality, Jones reasoned that human ability to know about the events must also reflect spatial and temporal components. People know things through their expectancies of when and where events occur.

Individual expectancies are used to perceive "world events." If expectancies are matched by events, processing continues undisturbed. However, if the unexpected occurs, the expectancy must be revised. Extrapolation from Rhythmic Theory suggests a learning cycle:

1. Rudimentary, possibly innate, expectancy.
2. Recognition of patterns of regularity of events which tentatively match expectancy.
3. Intermediate expectancy and rechecking against reality.
4. Confirmation, rejection or revision of expectancy which then serves as rudimentary expectancy for new learning.

If events are matched exactly with expectancies, events become
boring and repetitious. They fail to elicit interest or further learning; habituation has occurred. If the event is too far away from expectancy, no perception may take place.

Jones used velocity in space and time to describe events which are beyond the threshold of perception and formulated mathematical relationships which suggest the possibility of three regions of perception (Figure 2.3). Events which have a space-time relationship near that of the expectancy are said to occur in the Serial Integration Region (SIR). The events do not match exactly but are close enough to be perceived and understood. Further away from the expectancy are two areas of distortion where events may be perceived but are changed in time or place.

In the distortion area above SIR, called the Parallel Representation Region (PRR), Jones suggested that changes in spatial position of events per unit of time are greater than expectancies would assimilate. As Jones' research utilized musical tones and rhythm, it may be useful to describe space as pitch space—the distance in musical semitones between successive tones. In the PRR, large pitch spaces between successive tones destroy temporal order. The tones are heard in overlapping or parallel strands. In the lower distortion area, the relationship between time and space is so low that "chunking" or grouping occurs. Chunking represents a forced temporal grouping in order to make a pattern.

The two regions of particular interest in this study are
Figure 2.3 Two views of space-time integration from Jones (1976).
Serial Integration and Parallel Representation because they are similar to successive and simultaneous concepts alleged to describe brain functioning. Temporal processing abilities of the brain determine whether to accept, code, and/or store stimuli as co-occurring or separate. According to Jones, when stimuli events do not match space/time expectancies, errors of attention, perception, or learning may result. Jones, Hahn, and Kidd (1978) found that the pitch of tones which were extreme deviations within a musical pattern were misjudged in pitch. Tipps (in press) used auditory streaming patterns in a comparison task of temporal duration. The alternating tone patterns were judged significantly shorter than regular ascending or continuous patterns.

Streaming patterns constitute a temporal illusion similar to Escher's visual illusions. Both ways of apprehending are possible. If the hemispheres are sensitive to temporal qualities of stimuli, streaming patterns offer the possibility of being coded in two ways—either successively or simultaneously. The processing mode of the left hemisphere has been called linear, sequential, and digital. The serial aspect of streaming patterns should appeal to left hemispheric processing. The right hemisphere is gestalt, simultaneous, and analogic. The continuous, co-occurring quality of streaming patterns matches the parallel right hemisphere.

If the same streaming patterns are processed by the left and the right sides and the processing styles are different,
the left should hold the time dimension in a more linear form while the right would collapse the time dimension. Tipps found that streaming patterns were estimated shorter than standard patterns. If the left hemisphere resists streaming, longer time estimates would result than those for the right hemisphere which is amenable to streaming. A time estimation differential for streaming patterns directed separately to the left and right hemispheres would provide support for time as a fundamental element in the processing mechanisms of the brain.

**Summary of the Argument**

In Chapter II, research from the fields of developmental neuropsychology and psychophysiology has been cited in building a case for a temporal dimension in brain functioning. Before proceeding to a review of methods and procedures in Chapter III, a review of the points establishes the reasoning for the study.

1. Differences which have been found between the hemispheres are thought to be based on process rather than content.
2. The left hemisphere operates with a strong sequential component in reception and response. Language serves as an example of this linear specialization.
3. The right hemisphere operates in a holistic, relational style. Visuo-spatial abilities described as right hemisphere are simultaneous in that all the
information is surveyable at the same point in time.
4. Time is suggested as a fundamental difference between the processing of the hemispheres.
5. Time estimation has recently been used as an index of temporal processing.
6. Streaming patterns are sequential tones which are heard as simultaneous.
7. The temporal "illusion" of streaming patterns results in shortening of time estimation.

By directing streaming patterns to the right and left hemisphere, differences in temporal processing were investigated for children at three grade levels. Chapter III presents both the rationale for procedure and description of the specific method used in the study.
CHAPTER III

METHODOLOGY

In Chapter II, neurological and psychological studies were reviewed in relation to the premise that time has a role in hemispheric processing. Hemispheric differences, developmental theory and research, and temporal processing were cited in building a rationale for the study. A method of administering auditory streaming patterns to the left and right hemispheres as a way of examining hemispheric and developmental differences was also suggested using a time estimation technique.

In the first section of Chapter III, specific methodological issues are discussed. Four main issues were involved in the adaptation of a methodology:

1. Selection of subjects
2. Development of auditory patterns
3. Presentation of patterns

Each of the issues is discussed separately with related literature presented to support the approach adopted. The second section of Chapter III describes implementation of the study including population and sample, instrumentation,
training, and testing procedures. Finally, the statistical design and hypotheses are presented in the last section. Results and interpretation are found in Chapters IV and V.

Rationale for Methodology

Selection of Subjects

Subjects for the study were selected on the basis of three criteria:

1. Parental permission
2. Right handed by behavior and family history

Parental permission was required by The Ohio State University Human Subject Review Committee. Permission to conduct the study was granted by the committee in December, 1979 (Appendixes A and B).

Right-handed subjects were chosen because they have shown a more consistent pattern of cerebral organization. Wada and Rasmussen (1960) in sodium amytal studies have shown that when right-handed subjects have the left hemisphere anesthetized, over ninety percent show loss of speech. Results of left-handers is less definitive, although over half also show left speech dominance. Although laterality is a behavioral indicator of cerebral organization rather than an absolute measure, White (1969) noted its frequent use as a first screening technique. A number of laterality measures have been developed for hand preference (Hull, 1936; Humphrey, 1951; Annett, 1970) as well as for eye and foot preference (Friedlander, 1971; Kovac, 1973).
More recent attempts by Dean (1978), Raczkowski, Kalat, Nebes (1974), and Coren and Porac (1978) have sought to establish reliability and validity of laterality measures.

Coren and Porac used eight of the hand items from Raczkowski, et al. and obtained twelve month agreement of one hundred percent for five items and ninety-six percent for the three others. The hand laterality items have also been found by Raczkowski, et al. to show high agreement between questionnaire answers and actual performance. A ten item laterality test was developed adapting six high-agreement items from Raczkowski, et al. (1974). Four additional items were added to the measure. The six adapted items were writing, drawing, erasing, dealing a card, tooth brushing, and throwing. Four added items were cutting with scissors and three involved making a cup of lemonade—opening, stirring, and pouring. The scissors item was chosen because it is a common school task which is highly identified with handedness by teachers and students. The last three items were used as naturalistic observation of handedness in which the focus of attention was on a task rather than the hand. Laterality was determined by right-hand response to eight of the ten items. The laterality index is shown in Appendix D.

The role of heredity in cerebral organization has also been a concern of hemispheric investigators. Levy (1974) believed that direction (right or left) and degree
(complete or partial) of cerebral specialization have genetic components. The incidence of familial left-handedness may affect the degree of cerebral difference for behavioral right-handers. She suggested family history of laterality to support classification of subjects as right-handed.

A questionnaire of family laterality was sent with the permission letters. Handedness of father, mother, all grandparents and siblings was requested. (Appendix C.) Subjects were eliminated if either parent were reported as left-handed or if more than two left-handers were reported in other categories on the questionnaire.

Another screening technique used was an audiometric test. A Bell-and-Howell audiometer was set at twenty-five decibels for frequencies of 2000, 1000, 500, and 250 Hertz for each ear. Children were asked to raise either their right or left hand to indicate the side they heard the tone. Screening for hearing loss was necessary to ensure that children had normal acuity in each ear across the frequencies used in the streaming patterns.

In summary, subjects were selected who had parental permission, were right-handed by observation and family history, and had normal hearing. In addition, children were chosen from three grade levels—first, fourth, and seventh—to assess developmental trends in early and middle childhood. Brain growth, cognitive, and social changes have been cited from the ages of six to thirteen as children move through
childhood to adolescence. Three years between groups was used to span the period of interest. As the study was conducted late in the school year, children in the first grade were ages 6-7, in fourth ages 9-10, and in seventh ages 12-13.

Development of Auditory Patterns

Auditory streaming patterns made up of alternating high and low notes have been investigated by Bregman and his associates for the last ten years. Bregman and Dannenbring (1973) found that the splitting of tone sequences into separate streams was increased when the pitch space between high and low subgroups was greater and when the tempo of the notes was faster. Interval between high and low streams and rapidity of tone sequence were important in determining streaming. Bregman (1978) found that 150-msec tones were a threshold for streaming patterns. Three configurations of auditory patterns were developed for the study:

2. Alternating pattern of 150-msec tones with 10 semitones between high and low streams—marginal streaming.
3. Alternating patterns of 150-msec tones with 20 semitones between high and low streams—streaming.

Presentation of Patterns

Using streaming patterns to assess hemispheric difference rests on controlling transmission to the hemispheres. Dichotic listening has been used in hemispheric studies to determine differences in the type of stimuli which each
hemisphere processes best. Stimuli are presented to each ear at the same instant and subjects report what they have heard. Taken as a whole, the studies support the generalization of a linear, successive style for the left hemisphere and a style for the right hemisphere dependent on the relationships between stimuli.

However, dichotic listening is not without limitations in assessing hemispheric differences, as Berlin (1978) noted. He stated that dichotic listening was only a correlate of differential lateral processing and was dependent on interference at a central processing point rather than indicating lateral processing solely. Despite cautions about the nature of competing stimuli, intensity and frequency of stimuli, stimuli onset, as well as concerns about interpretation of hemispheric processing, Berlin expected the method "to continue to unravel parts of the lateralization puzzle" (p. 334). Two recommendations were made, however, for dichotic listening; use of response time measures and attention to developmental changes were suggested as ways of strengthening conclusions based on dichotic paradigms.

The competitive premise of dichotic listening is if both hemispheres are required to perform the same kind of task the side which is better equipped to do the task will take the lead (reaction time) and perform more accurately. Thus stimuli which are most alike in processing demands result in the most consistent laterality indication. However, use of
streaming patterns differs from typical dichotic procedures in that no directly competing stimuli exist. Hemispheric differences have been found in other experiments without exactly matched probes. Berlin (1978) reported a study (Cullen, et al., 1975) in which background noise was added to the signal of one ear resulting in lower accuracy scores. Aitken (1976) listed ten studies which reported ear asymmetries with monaural stimulation, against two which failed to demonstrate them.

Although asymmetries have been shown without competing stimuli, control of hemispheric activity may be enhanced by blocking the sensory pathways with noise. Aitken's (1976) experiments provided support for use of white noise as a mask. First, he established that uncrossed input and response resulted in shorter reaction times with white noise contralateral to the tone. Then he used white noise only on half the trials and found that without white noise the differences in latency were not maintained. The technique of monaural masking is used frequently in psychoacoustics to block one ear while testing the other ear (Zwislocki, 1978). Such a procedure is necessary because the sensory pathways are not totally contralateral. About sixty percent of auditory nerves are connected to the opposite hemisphere while the remainder are ipsilateral.

For the purpose of this study, noise was used on the opposite channel to the streaming pattern. The intent was
to occupy one hemisphere while the opposite one made time estimations. On the channel opposite the trial pattern, noise was recorded.

Method of Time Estimation

A number of different methods have been utilized to obtain time estimations. Doob (1971) and Allan (1979) summarized the major methods and compared them. Verbal estimation and production techniques rely on subjects' knowledge of arbitrary time units—seconds, minutes. With the reproduction method, however, both the standard and the reproduced intervals are experienced without labels. A stimulus is presented for a period and the subject responds by reproducing that period through tapping or some other response. Gilliland and Humphreys (1943) and Fraisse, et al. (1962) found that overall error was less for reproduction than for verbal estimation or production. Fraisse (1963) concluded that "the reproduction method is the most reliable" (p. 214) although was best for durations less than thirty seconds. Also, he found reproduction method to be more stable with children as verbal methods are highly variable depending on interpretation of time names. The method of reproduction was chosen for the study because it has been shown to be most reliable. Response times and time estimation intervals were recorded as subjects pushed a microswitch after each pattern.
Summary

Methodological concern determined selection of subjects, organization and presentation of stimuli pattern, and method of time estimation. Decisions were made to be consistent with current procedures and to control extraneous variables. In the next section of this chapter, implementation of methodological decisions is described.

Implementation of Study

Subjects

Population: A rural school district in central Virginia provided the subjects for the study. The school district is a unified county-wide district with a school enrollment of slightly more than 1600 students in three schools. All schools are located on a common site with grades K-3 in the primary school, 4-7 in the elementary, and 8-12 in the high school. Although unemployment and public assistance in the county are low (2% and 4%), the general economic level is not high. Almost fifty percent of the school population participates in free or reduced lunch programs.

Sample: Between thirty and forty requests for permission were originally sent home for each grade level. The elementary supervisor selected two first grade classes, one fourth, and two seventh grades. Students were heterogeneously grouped in home rooms. Additional permission letters were sent to first grade and seventh grade to obtain enough subjects. Sixty permission letters were returned.
Screening: Screening took place during March, 1980. For the sessions, a small conference room in the primary school was used. The room was not soundproof, but was quiet except when the hall outside was an access to the cafeteria. Testing was not scheduled during those times.

The screening session consisted of an audiometer test and a laterality observation using a 10 point test adapted from Raczkowski, et al. (1974) (Appendix D). Subjects were screened individually with sessions lasting about ten minutes. At the end of the session, subjects drew a playing card from the deck they used on the laterality test and kept it. Subjects who had passed the screening were told that their role in the study would be to listen to songs and push a button. Subjects were screened until at least twelve at each grade level were qualified for testing. Table 3.1 shows the number of subjects who returned permission slips and the number who were eliminated in screening by grade. Some students had both family history and observed left-handedness.
Table 3.1
Number of Subjects Screened for Study by Grade

<table>
<thead>
<tr>
<th>Grade</th>
<th>Permission Received</th>
<th>Left-handedness Observed</th>
<th>Left-handedness Familial</th>
<th>Hearing</th>
<th>Qualified for Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>19</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>12</td>
</tr>
</tbody>
</table>

Description of Sample: The subjects' average ages were 6 years, 11 months for first grade, 9 years, 11 months for fourth grade and 13 years, 0 months for seventh grade. Sixteen males and twenty females were selected; in the fourth grade twice as many females as males qualified for the study.

Table 3.2
Age and Sex of Subjects

<table>
<thead>
<tr>
<th>Grade</th>
<th>Age (year-month)</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Range</td>
</tr>
<tr>
<td>1</td>
<td>6 - 11</td>
<td>HI 7-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LO 6-4</td>
</tr>
<tr>
<td>4</td>
<td>9 - 11</td>
<td>HI 10-11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LO 9-6</td>
</tr>
<tr>
<td>7</td>
<td>13 - 0</td>
<td>HI 13-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LO 12-4</td>
</tr>
</tbody>
</table>
Although no attempt was made to select one particular achievement group, the academic records of the subjects show that there was a large proportion of high achievers. Both reading group and available test scores show a high academic pattern.

Table 3.3

Academic Level of Subjects

<table>
<thead>
<tr>
<th>Grade</th>
<th>Reading Group/Level</th>
<th>Standardized Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High 7</td>
<td>Above Average a</td>
</tr>
<tr>
<td></td>
<td>Middle 1</td>
<td>Average 6</td>
</tr>
<tr>
<td></td>
<td>Low 4</td>
<td>Below Average 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not Available 1</td>
</tr>
<tr>
<td>4</td>
<td>High 5</td>
<td>75%-99% b</td>
</tr>
<tr>
<td></td>
<td>Middle 7</td>
<td>50%-74% 3</td>
</tr>
<tr>
<td></td>
<td>Low 0</td>
<td>25%-49% 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0%-24% 0</td>
</tr>
<tr>
<td>7</td>
<td>High 9</td>
<td>Not Available c</td>
</tr>
<tr>
<td></td>
<td>Middle 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low 0</td>
<td></td>
</tr>
</tbody>
</table>

a1st grade - Primary Mental Abilities - Kindergarten level.
b4th grade - Iowa Test of Educational Development - 4th grade.
c7th grade - Test scores destroyed in explosion of county courthouse.

Another indication that the sample was not representative of the population was the number of subjects on school lunch program. While fifty percent of the school population were on the lunch program, less than one-fourth of the subjects in each grade level were involved.
Instrumentation

Equipment: Two systems of equipment were required for the study. A cassette tape player, amplifier, and headphones were needed to present the tones to subjects. Second, mechanisms for responding and recording responses were required.

The equipment used for presentation of the stimuli was a Kenwood 4600 amplifier, AIWA Model M100U cassette tape deck, and Pioneer SE205 headphones. The response manipulandum was a microswitch with light-touch response mounted in a handheld box. Both the response manipulandum and tape deck were connected to the recording device—the Traffic Data Acquisition System (TDAS) of the Virginia Highway Research Council. Appendix E shows photographs of the equipment. The TDAS recorded switch closures at the onset and offset of the trial pattern and the onset and offset of response on a magnetic tape. The magnetic tape was read at the University of Virginia Academic Computing Center with a program which computed stimulus time, response time, and estimated time for each trial.

Stimuli: Trials were constructed to represent three configurations of tones and two lengths with four repetitions each. The 24 resulting trials were randomly ordered and generated on a Wavetek Model 1500 sine wave tone generator controlled by a Cromemco micro processor. Rise and fall time for each of the 150-msec tones was 10-msec with no
silence between tones. Continuous tones were generated at the specified frequency for the equivalent time of the separate tones. Each trial consisted of a warning tone, a pause of two seconds, a trial pattern, and a pause for time estimation of the trial pattern of eight seconds. The trial patterns are shown in Appendix F with random order. Two lengths of patterns were used. Shorter patterns consisted of 8, 10, 12, or 14 alternating tones. Longer sequences had 16, 20, 24, or 28 tones. The total time for shorter patterns was 1500 to 2400-msec; longer patterns were designed to be 3000 to 4800.

Developing two lengths of patterns, three configurations, and four repetitions resulted in a total of twenty-four patterns.

Training and Testing

All testing was done by the experimenter. The same small conference room was used for testing as for screening. Testing was done in April and May, 1980. A complete schedule of testing is shown in Appendix G. Originally only two sessions were planned—one for screening and one for training/testing. Due to electrical failure, only five of the first twenty-six subjects were completed on the first training/testing session. Twenty-one subjects had a second testing session.

Training and testing sessions were conducted either in pairs or individually. The older children were able to work without distracting each other; however, first graders
could not. Two fourth and two seventh graders were tested alone due to scheduling conflicts. Six first graders who had previously been trained and tested during the equipment failure were tested in pairs.

Training Session: Training sessions consisted of three tapes of tone sequences. During training tape 1, subjects listened to a continuous tone and practiced pushing the microswitch. At first, each would hold down the switch simultaneously with the tone. Then subjects were asked to listen to the tone, to remember how long it lasted, and at the end of the tone to push the button down for the time they remembered it. A visual display of the sequence was introduced and explained. After several more trials, training tape 2 was started.

Tones on training tape 2 were 2-msec long and arranged in ascending, descending, and alternating patterns. None of the patterns were streaming patterns. The warning tone was introduced for each trial. After six or eight practice trials, headphones were placed on the subjects' heads. All of the children learned the procedure, could describe the task, and perform it by the end of training tape 2. Training tape 3 contained 12 of the actual test trials. These were randomly ordered and broadcast to both ears. Testing conditions were maintained for training tape 3 as a final check-out. Training procedures lasted about twenty minutes.
Testing: Complete text of instructions and copy of the visual display are in Appendix H. Actual testing took ten minutes. Fifteen subjects completed both training and testing in one session, while 21 subjects had a second testing session. In each testing session, the subject had two sets of 24 trials. One set was presented to the right ear; one to the left. Order of presentation was counter balanced within each grade level, so that half of the subjects heard right, then left; the other six heard left, then right. The manipulandum with the microswitch was held in the hand ipsilateral to the side of presentation. This arrangement resulted in an uncrossed response so that right ear/right hand were together and left ear/left hand were paired. Subjects were monitored during the trials to ensure they were following the test procedure. Three first graders demonstrated lack of attention to the task, while all others followed the testing sequence with only minor problems, e.g., responding to the warning tone. At the end of the testing session, students were thanked and given a pencil or an orange.
Research Design

Trials were constructed with two lengths (short and long), three configurations (continuous, marginal streaming, and streaming), and four repetitions within each configuration.

<table>
<thead>
<tr>
<th>Length</th>
<th>Short</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>S1</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>S1</td>
</tr>
<tr>
<td>Trials</td>
<td>XXXX</td>
<td>XXXX</td>
</tr>
<tr>
<td></td>
<td>XXXX</td>
<td>XXXX</td>
</tr>
</tbody>
</table>

Figure 3.1 Design of trials.

Each set of 24 trials was repeated twice—once to the right ear and once to the left ear.

<table>
<thead>
<tr>
<th>SIDE</th>
<th>RIGHT</th>
<th>LEFT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short</td>
<td>Long</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>S1</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 3.2 Repeated design of trials.

The four trials within each cell were divided by the actual length of the pattern presented and averaged to give a single data point for each cell. This procedure compensated for missing trials without interfering with the degree of freedom of the design. Subjects were nested within three grade levels and in addition were blocked for order of
presentation. The research design shown in Figure 3.3 shows a repeated measures design with two between-subjects and three within-subjects variables.

Statistical analysis was conducted with UNENAN Harmonic Mean Analysis of Variance Program at the University of Virginia Academic Computing Center (Main and Engelke, 1979).

Hypotheses

Analysis of variance of the complete research design in Figure 3.3 afforded 31 tests of significance: five for main effects, 10 first-order interactions, 10 second order, five third order, and one fourth order interaction. Thirty-one null hypotheses are outlined in Figure 3.4.

Not all of the possible null hypotheses pertain to the research hypotheses stated in Chapter I. The research hypotheses with appropriate statistical hypotheses follow.

Hypothesis One: Time estimation of auditory patterns directed to the right ear will be significantly longer than time estimation of auditory patterns for the left ear.

Statistical Test: There will be no significant difference between the time estimation accuracy scores for auditory pattern presented to the left and right ear (Ho 4, $p < .05$).

Hypothesis Two: With increase in age, the accuracy of time estimates will improve significantly.

Statistical Test: There will be no significant difference in time estimation accuracy scores over three grade levels (Ho 1, $p < .05$).
**Figure 3.3** Data matrix for complete research design showing five factors.
<table>
<thead>
<tr>
<th>Statistical Hypothesis</th>
<th>Source of Variance</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ho1</td>
<td>A Grade</td>
<td>.05</td>
</tr>
<tr>
<td>Ho2</td>
<td>B Order of Presentation</td>
<td>.05</td>
</tr>
<tr>
<td>Ho3</td>
<td>AB Grade x Order</td>
<td>.05</td>
</tr>
<tr>
<td>Ho4</td>
<td>C Side of Presentation</td>
<td>.05</td>
</tr>
<tr>
<td>Ho5</td>
<td>AC Grade x Side</td>
<td>.05</td>
</tr>
<tr>
<td>Ho6</td>
<td>BC Order x Side</td>
<td>.05</td>
</tr>
<tr>
<td>Ho7</td>
<td>ABC Grade x Order x Side</td>
<td>.05</td>
</tr>
<tr>
<td>Ho8</td>
<td>D Length</td>
<td>.05</td>
</tr>
<tr>
<td>Ho9</td>
<td>AD Grade x Length</td>
<td>.05</td>
</tr>
<tr>
<td>Ho10</td>
<td>BD Order x Length</td>
<td>.05</td>
</tr>
<tr>
<td>Ho11</td>
<td>ABD Grade x Order x Length</td>
<td>.05</td>
</tr>
<tr>
<td>Ho12</td>
<td>CD Side x Length</td>
<td>.05</td>
</tr>
<tr>
<td>Ho13</td>
<td>ACD Grade x Side x Length</td>
<td>.05</td>
</tr>
<tr>
<td>Ho14</td>
<td>BCD Order x Side x Length</td>
<td>.05</td>
</tr>
<tr>
<td>Ho15</td>
<td>ABCD Grade x Order x Side x Length</td>
<td>.05</td>
</tr>
<tr>
<td>Ho16</td>
<td>E Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho17</td>
<td>AE Grade x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho18</td>
<td>BE Order x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho19</td>
<td>ABE Grade x Order x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho20</td>
<td>CE Side x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho21</td>
<td>ACE Grade x Side x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho22</td>
<td>BCE Order x Side x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho23</td>
<td>ABCE Grade x Order x Side x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho24</td>
<td>DE Length x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho25</td>
<td>ADE Grade x Length x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho26</td>
<td>BDE Order x Length x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho27</td>
<td>ABDE Grade x Order x Length x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho28</td>
<td>CDE Side x Length x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho29</td>
<td>ACDE Grade x Side x Length x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho30</td>
<td>BCDE Order x Side x Length x Configuration</td>
<td>.05</td>
</tr>
<tr>
<td>Ho31</td>
<td>ABCDE Grade x Order x Side x Length x</td>
<td>.05</td>
</tr>
</tbody>
</table>

Figure 3.4 List of statistical hypotheses with source of variance and significance level.
Hypothesis Three: With increase in age, the time estimates for streaming patterns directed to the left and right ear will differ significantly.

Statistical Test: There will be no significant difference in time estimation accuracy scores over three grade levels for streaming patterns directed to the left and right ear (Ho 5, \( p < .05 \)).

There will be no significant difference in time estimation accuracy scores for different streaming patterns directed to the left and right ear over three grade levels (Ho 21, \( p < .05 \)).
CHAPTER IV

DATA ANALYSIS AND RESULTS

To examine hemispheric and developmental differences, auditory patterns were presented separately to the left and right ears of children ages 6-7, 9-10, 12-13. Following each auditory pattern, subjects were required to make time estimates by reproducing the intervals immediately. Three configurations of patterns were used: continuous tones, marginal streaming, and streaming. Streaming patterns are alternating high and low sequences of tones which are heard not in actual sequential order but as overlapping and simultaneous. The dual nature of streaming patterns suggested descriptions of the two hemispheres, the left being sequential and the right being simultaneous. Relationships between the streaming patterns, left and right processing, and age differences were assessed in the study. The results of the experiment are presented in Chapter IV and interpreted in Chapter V.

Analysis of Variances for Time Estimation Accuracy Scores

Thirty-six subjects were grouped in three grade levels and further divided within each grade level for order of presentation. Half heard trials in the right ear first followed by the left side; the other half heard left then
right. Three independent variables were considered in the
design and presentation of trials: side, length, and con-
figuration. The data matrix used for analysis was shown in
Figure 3.3. Forty-eight observations per subject were re-
duced to twelve accuracy scores. This procedure meant that
missing observations did not result in empty cells for
analysis. Scores of 1.00 indicated accurate judgments of
trial patterns while scores less than 1.00 are estimates
shorter than actual and above 1.00 are longer than actual.

A five-factor analysis of variance (Grade x Order x
Side x Length x Configuration; 3 x 2 x 2 x 2 x 3) was con-
ducted with UNENAN-Harmonic Mean Analysis of Variance.
Results are shown in Table 4.1. Four significant F-tests
were found: main effects for Length of pattern (F = 82.93,
$p < .001$) and Configuration of pattern (F = 6.79, $p < .01$)
and interactions for Grade x Length (F = 4.72, $p < .05$) and
for Grade x Order x Side x Configuration (F = 4.86, $p < .05$).

The means and standard deviations (Table 4.2) for
Length of patterns and for Grade x Length reveal that short
patterns were estimated longer than actual and long intervals
were shorter. A Tukey's post hoc comparison (HSD = .159)
confirmed the significant difference in each of the grade
scores. The Grade x Length interaction resulted from the
scores of the youngest group who had a similar but exaggerated
pattern of longer and shorter estimates. In fact, the dif-
ference between first grade short pattern estimates (1.341)
<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Ss</td>
<td>35</td>
<td>15.150</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>A (Age)</td>
<td>2</td>
<td>.120</td>
<td>.060</td>
<td>.13</td>
</tr>
<tr>
<td>B (Order)</td>
<td>1</td>
<td>.025</td>
<td>.025</td>
<td>.05</td>
</tr>
<tr>
<td>AB</td>
<td>2</td>
<td>.973</td>
<td>.487</td>
<td>1.04</td>
</tr>
<tr>
<td>S/AB</td>
<td>30</td>
<td>14.040</td>
<td>.468</td>
<td></td>
</tr>
<tr>
<td>Within Ss</td>
<td>396</td>
<td>27.214</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C (Side)</td>
<td>1</td>
<td>.078</td>
<td>.078</td>
<td>1.70</td>
</tr>
<tr>
<td>AC</td>
<td>2</td>
<td>.028</td>
<td>.014</td>
<td>.31</td>
</tr>
<tr>
<td>BC</td>
<td>1</td>
<td>.062</td>
<td>.062</td>
<td>1.36</td>
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<td>ABC</td>
<td>2</td>
<td>.073</td>
<td>.036</td>
<td>.80</td>
</tr>
<tr>
<td>SC/AB</td>
<td>30</td>
<td>1.366</td>
<td>.046</td>
<td></td>
</tr>
<tr>
<td>D (Length)</td>
<td>1</td>
<td>8.143</td>
<td>8.143</td>
<td>82.93***</td>
</tr>
<tr>
<td>AD</td>
<td>2</td>
<td>.927</td>
<td>.463</td>
<td>4.72*</td>
</tr>
<tr>
<td>BD</td>
<td>1</td>
<td>.000</td>
<td>.000</td>
<td>.00</td>
</tr>
<tr>
<td>ABD</td>
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<td>.187</td>
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<td>.95</td>
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<tr>
<td>SD/AB</td>
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<td>2.946</td>
<td>.098</td>
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<tr>
<td>CD</td>
<td>1</td>
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<td>.001</td>
<td>.03</td>
</tr>
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<td>ACD</td>
<td>2</td>
<td>.017</td>
<td>.009</td>
<td>.36</td>
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<tr>
<td>BCD</td>
<td>1</td>
<td>.038</td>
<td>.038</td>
<td>1.56</td>
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<td>ABCD</td>
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<td>.082</td>
<td>.041</td>
<td>1.70</td>
</tr>
<tr>
<td>SCD/AB</td>
<td>30</td>
<td>.721</td>
<td>.024</td>
<td></td>
</tr>
<tr>
<td>E (Configuration)</td>
<td>2</td>
<td>.644</td>
<td>.322</td>
<td>6.79**</td>
</tr>
<tr>
<td>AE</td>
<td>4</td>
<td>.168</td>
<td>.042</td>
<td>.89</td>
</tr>
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<td>BE</td>
<td>2</td>
<td>.212</td>
<td>.106</td>
<td>2.24</td>
</tr>
<tr>
<td>ABE</td>
<td>4</td>
<td>.107</td>
<td>.027</td>
<td>.57</td>
</tr>
<tr>
<td>SE/AB</td>
<td>60</td>
<td>2.845</td>
<td>.047</td>
<td></td>
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<td>CE</td>
<td>2</td>
<td>.108</td>
<td>.054</td>
<td>2.24</td>
</tr>
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<td>ACE</td>
<td>4</td>
<td>.150</td>
<td>.037</td>
<td>1.55</td>
</tr>
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<td>BCE</td>
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<td>.059</td>
<td>.029</td>
<td>1.22</td>
</tr>
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<td>.470</td>
<td>.118</td>
<td>4.86*</td>
</tr>
<tr>
<td>SCE/AB</td>
<td>60</td>
<td>1.451</td>
<td>.024</td>
<td></td>
</tr>
</tbody>
</table>
Table 4.1 (Cont'd.)

<table>
<thead>
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<th>Source</th>
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<th>SS</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE</td>
<td>2</td>
<td>.094</td>
<td>.047</td>
<td>1.06</td>
</tr>
<tr>
<td>ADE</td>
<td>4</td>
<td>.323</td>
<td>.081</td>
<td>1.82</td>
</tr>
<tr>
<td>BDE</td>
<td>2</td>
<td>.145</td>
<td>.073</td>
<td>1.64</td>
</tr>
<tr>
<td>ABDE</td>
<td>4</td>
<td>.106</td>
<td>.026</td>
<td>.59</td>
</tr>
<tr>
<td>SDE/AB</td>
<td>60</td>
<td>2.664</td>
<td>.044</td>
<td></td>
</tr>
<tr>
<td>CDE</td>
<td>2</td>
<td>.013</td>
<td>.007</td>
<td>.15</td>
</tr>
<tr>
<td>ACDE</td>
<td>4</td>
<td>.116</td>
<td>.029</td>
<td>.64</td>
</tr>
<tr>
<td>BCDE</td>
<td>2</td>
<td>.040</td>
<td>.020</td>
<td>.44</td>
</tr>
<tr>
<td>ABCDE</td>
<td>4</td>
<td>.089</td>
<td>.022</td>
<td>.48</td>
</tr>
<tr>
<td>SCDE/AB</td>
<td>60</td>
<td>2.741</td>
<td>.046</td>
<td></td>
</tr>
</tbody>
</table>

TOTAL        | 431| 42.364|

* * *p .001

* * p .01

* p .05
Table 4.2

Means and Standard Deviations of Time Estimation Accuracy Scores for Length of Pattern and Age x Length

<table>
<thead>
<tr>
<th>Grade</th>
<th>Length of Pattern</th>
<th>Short</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>Mean</td>
<td>1.341</td>
<td>.935</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>.441</td>
<td>.288</td>
</tr>
<tr>
<td>Fourth</td>
<td>Mean</td>
<td>1.210</td>
<td>.998</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>.233</td>
<td>.220</td>
</tr>
<tr>
<td>Seventh</td>
<td>Mean</td>
<td>1.204</td>
<td>.998</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>.221</td>
<td>.196</td>
</tr>
<tr>
<td>All</td>
<td>Mean</td>
<td>1.252</td>
<td>.977</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>.265</td>
<td>.217</td>
</tr>
</tbody>
</table>
and the older group (1.210, 1.204) approaches the critical interval.

Means and standard deviations for Configuration and for the third-order interaction (Configuration x Grade x Order x Side) are shown in Table 4.3. The means of the three configurations were compared using a Tukey post hoc comparison (HSD = .061). Although continuous configuration was shown to be significantly shorter (1.06) than either marginal (1.152) or streaming (1.129), the four-way interaction which includes configuration precludes any further comment. Description and interpretation of the complex interaction are reserved for Chapter V.

In summary, analysis of variance for time estimation accuracy scores for the three age groups led to rejection of the null hypothesis in four instances: Ho 8 for Length, Ho 9 for Grade x Length, Ho 16 for Configuration, and Ho 23 for Grade x Order x Side x Configuration. All other null hypotheses presented in Chapter III were accepted.

Analysis of Variance of Response Scores

A second dependent measure was taken for each trial. The time from offset of trial to onset of time estimate was recorded to monitor responses indicative of hemispheric functioning as suggested by Berlin (1978). The response times were subjected to the same five-factor analysis as the time estimation accuracy scores. However raw response
<table>
<thead>
<tr>
<th></th>
<th>Configuration</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-Continuous</td>
<td>2-Marginal</td>
<td>3-Streaming</td>
<td></td>
</tr>
<tr>
<td><strong>All Subjects</strong></td>
<td>Mean</td>
<td>1.061</td>
<td>1.152</td>
<td>1.129</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.285</td>
<td>0.331</td>
<td>0.396</td>
</tr>
<tr>
<td><strong>Grade First</strong></td>
<td>R-L Mean</td>
<td>1.044</td>
<td>1.075</td>
<td>1.179</td>
</tr>
<tr>
<td>Order</td>
<td>SD</td>
<td>0.298</td>
<td>0.342</td>
<td>0.334</td>
</tr>
<tr>
<td></td>
<td>L-R Mean</td>
<td>1.235</td>
<td>0.990</td>
<td>1.109</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.523</td>
<td>0.326</td>
<td>0.321</td>
</tr>
<tr>
<td><strong>Fourth</strong></td>
<td>R-L Mean</td>
<td>1.115</td>
<td>1.005</td>
<td>1.078</td>
</tr>
<tr>
<td>Order</td>
<td>SD</td>
<td>0.180</td>
<td>0.243</td>
<td>0.280</td>
</tr>
<tr>
<td></td>
<td>L-R Mean</td>
<td>1.018</td>
<td>0.935</td>
<td>1.224</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.160</td>
<td>0.244</td>
<td>0.230</td>
</tr>
<tr>
<td><strong>Seventh</strong></td>
<td>R-L Mean</td>
<td>1.143</td>
<td>1.218</td>
<td>1.132</td>
</tr>
<tr>
<td>Order</td>
<td>SD</td>
<td>0.277</td>
<td>0.285</td>
<td>0.201</td>
</tr>
<tr>
<td></td>
<td>L-R Mean</td>
<td>0.988</td>
<td>0.970</td>
<td>1.143</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.189</td>
<td>0.146</td>
<td>0.194</td>
</tr>
</tbody>
</table>
times were used so that there were four observations in each cell. In three instances, the grand mean of response time was substituted for missing observations.

Results show four significant F-tests in Table 4.4. Three main effects were found: Grade ($F = 8.94, \rho < .001$), Length of pattern ($F = 13.97, \rho < .001$), and Configuration ($F = 3.52, \rho < .05$). A three-way interaction of Grade x Order x Length ($F = 4.67, \rho < .05$) was also revealed.

Response times for the three grade levels showed a decrease with age (1077-msec, 781-msec, 699-msec) which was significant between first and fourth grades (Tukey's HSD = 338 msec). Response to length of pattern was longer for short patterns (884-msec) than for longer patterns (820-msec). Response to configuration was longer for the continuous pattern (891-msec) than for marginal streaming (858-msec) which was longer than streaming (808-msec). However a critical interval of 152-msec (Tukey's HSD) did not locate differences. Means and standard deviations for the Grade x Order x Length interaction are in Table 4.5.
Table 4.4
Analysis of Variance of Response Times by Age, Order, Side, Length, and Configuration

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between Ss</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A (Grade)</td>
<td>2</td>
<td>22,794,199</td>
<td>8.94***</td>
</tr>
<tr>
<td>B (Order)</td>
<td>1</td>
<td>433,580</td>
<td>.17</td>
</tr>
<tr>
<td>AB</td>
<td>2</td>
<td>1,301,399</td>
<td>.51</td>
</tr>
<tr>
<td>S/AB</td>
<td>30</td>
<td>2,548,735</td>
<td></td>
</tr>
<tr>
<td><strong>Within Ss</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C (Side)</td>
<td>1</td>
<td>913,379</td>
<td>1.29</td>
</tr>
<tr>
<td>AC</td>
<td>2</td>
<td>774,868</td>
<td>1.09</td>
</tr>
<tr>
<td>BC</td>
<td>1</td>
<td>2,765,440</td>
<td>3.90</td>
</tr>
<tr>
<td>ABC</td>
<td>2</td>
<td>1,894,772</td>
<td>2.67</td>
</tr>
<tr>
<td>SC/AB</td>
<td>30</td>
<td>709,066</td>
<td></td>
</tr>
<tr>
<td>D (Length)</td>
<td>1</td>
<td>1,759,885</td>
<td>13.97***</td>
</tr>
<tr>
<td>AD</td>
<td>2</td>
<td>201,487</td>
<td>1.60</td>
</tr>
<tr>
<td>BD</td>
<td>1</td>
<td>33,093</td>
<td>.26</td>
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<tr>
<td>ABD</td>
<td>2</td>
<td>588,581</td>
<td>4.67*</td>
</tr>
<tr>
<td>SD/AB</td>
<td>30</td>
<td>125,945</td>
<td></td>
</tr>
<tr>
<td>CD</td>
<td>1</td>
<td>74,971</td>
<td>.61</td>
</tr>
<tr>
<td>ACD</td>
<td>2</td>
<td>181,957</td>
<td>1.47</td>
</tr>
<tr>
<td>BCD</td>
<td>1</td>
<td>483,272</td>
<td>3.92</td>
</tr>
<tr>
<td>ABCD</td>
<td>2</td>
<td>106,598</td>
<td>.86</td>
</tr>
<tr>
<td>SCD/AB</td>
<td>30</td>
<td>123,414</td>
<td></td>
</tr>
<tr>
<td>E (Configuration)</td>
<td>2</td>
<td>1,018,460</td>
<td>3.52*</td>
</tr>
<tr>
<td>AE</td>
<td>4</td>
<td>87,944</td>
<td>.30</td>
</tr>
<tr>
<td>BE</td>
<td>2</td>
<td>158,979</td>
<td>.55</td>
</tr>
<tr>
<td>ABE</td>
<td>4</td>
<td>54,241</td>
<td>.19</td>
</tr>
<tr>
<td>SE/AB</td>
<td>60</td>
<td>289,321</td>
<td></td>
</tr>
<tr>
<td>CE</td>
<td>2</td>
<td>184,875</td>
<td>1.11</td>
</tr>
<tr>
<td>ACE</td>
<td>4</td>
<td>66,355</td>
<td>.40</td>
</tr>
<tr>
<td>BCE</td>
<td>2</td>
<td>168,114</td>
<td>1.00</td>
</tr>
<tr>
<td>ABCE</td>
<td>4</td>
<td>46,950</td>
<td>.28</td>
</tr>
<tr>
<td>SCE/AB</td>
<td>60</td>
<td>167,298</td>
<td></td>
</tr>
<tr>
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<td>df</td>
<td>MS</td>
<td>F</td>
</tr>
<tr>
<td>--------------</td>
<td>----</td>
<td>----------</td>
<td>------</td>
</tr>
<tr>
<td>DE</td>
<td>2</td>
<td>270,994</td>
<td>1.37</td>
</tr>
<tr>
<td>ADE</td>
<td>4</td>
<td>64,264</td>
<td>.33</td>
</tr>
<tr>
<td>BDE</td>
<td>2</td>
<td>7,719</td>
<td>.04</td>
</tr>
<tr>
<td>ABDE</td>
<td>4</td>
<td>102,930</td>
<td>.52</td>
</tr>
<tr>
<td>SDE/AB</td>
<td>60</td>
<td>197,187</td>
<td></td>
</tr>
<tr>
<td>CDE</td>
<td>2</td>
<td>133,223</td>
<td>.89</td>
</tr>
<tr>
<td>ACDE</td>
<td>4</td>
<td>206,309</td>
<td>1.37</td>
</tr>
<tr>
<td>BCDE</td>
<td>2</td>
<td>377,729</td>
<td>2.51</td>
</tr>
<tr>
<td>ABCDE</td>
<td>4</td>
<td>225,669</td>
<td>1.50</td>
</tr>
<tr>
<td>SCDE/AB</td>
<td>60</td>
<td>150,370</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>431</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p < .05
*** p < .001
Table 4.5
Means and Standard Deviations for Response Times in Milliseconds: Grade x Order x Length Interaction

<table>
<thead>
<tr>
<th>Grade</th>
<th>Order 1 (R-L)</th>
<th>Order 2 (L-R)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short</td>
<td>Long</td>
<td>Short</td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>First</td>
<td>1096</td>
<td>926</td>
<td>1147</td>
</tr>
<tr>
<td></td>
<td>227</td>
<td>209</td>
<td>584</td>
</tr>
<tr>
<td>Fourth</td>
<td>844</td>
<td>775</td>
<td>801</td>
</tr>
<tr>
<td></td>
<td>159</td>
<td>176</td>
<td>153</td>
</tr>
<tr>
<td>Seventh</td>
<td>679</td>
<td>698</td>
<td>740</td>
</tr>
<tr>
<td></td>
<td>119</td>
<td>153</td>
<td>127</td>
</tr>
</tbody>
</table>

Inspection of the means indicates that both the main effects showing response time by Grade and for longer patterns (Length) are sustained except for first graders in the left first order of trials who had large response times of nearly 1150-msec. A Tukey's HSD of 362-msec shows that the response times were significantly higher than those for older groups.

In summary, analysis of response times shows improvement over age and shorter response for longer patterns with the exception of the second set of trials for the first graders. No pairwise comparisons were found significant in post hoc analysis for response to configuration which had been found with the omnibus F-Test.
Chapter V presents interpretation of the statistical results. The four-way interaction for time estimation accuracy scores is of particular interest.
CHAPTER V

INTERPRETATION OF RESULTS

In Chapter IV, the statistical results of the time estimation study were given. The study involved auditory patterns administered separately to the left and right ears for three age levels. The intent was to investigate hemispheric and developmental trends in a time estimation task using patterns which might elicit different responses from the two hemispheres.

The null hypotheses which dealt directly with the research hypotheses could not be rejected on the basis of the analysis. Main effects for Side (Ho 4) and Grade (Ho 1) were not found. Interaction for Grade x Side (Ho 5) and for Grade x Side x Configuration (Ho 21) were not significant. However, the significant four-way interaction of Grade x Order x Side x Configuration contains three elements of interest in the study and requires additional explication. The purpose of this chapter is to examine the interaction.

Results in the form of an interaction should not be surprising. Complexity of the brain, difficulty in isolating and describing integrated functions, and the developing state of research methodology—all may have predestined results to be hidden rather than to be alone and salutary at the level of main effects or first order interaction.
interactions is difficult. The danger exists that simplification of results to show one relationship may obliterate another. For that reason, the interaction is viewed wholly while isolating certain patterns.

**Qualitative Interpretation of the Interaction**

Prior to considering quantitative differences certain qualitative aspects of the interaction are described.

The cell means for Grade x Order x Side x Configuration from Table 4.3 are plotted in Figure 5.1. The face of each graph shows the Order x Side accuracy scores of each grade over three kinds of patterns—continuous, marginal streaming, and streaming. Time estimation accuracy scores on the vertical axis were calculated by dividing raw estimates by actual time intervals. Cell means less than 1.00 are estimates less than actual. Over 1.00, scores indicate intervals were estimated over their actual length.

Order x Side lines show on which side the pattern was heard and whether that side was heard first or second. Half of the subjects in each group heard right side, then left side; the other half heard left, then right. Each pair of lines represents the mean scores of six subjects for their two Order x Side combinations. Also shown in horizontal lines are the non-significant age averages.

By following each Order x Side combination across grade levels, the right-first order shows that both right
Figure 5.1 Time estimation accuracy scores showing Grade x Order x Side x Configuration; configuration within each grade.
side and left side means tended to increase relative to age level means. For 6-7 year olds, scores were below the average; for 9-10, they approximate the average; for 12-13, scores are above average. The opposite trend is noted for left-first order for both sides. The youngest had left side scores generally higher and the oldest had scores generally lower than the age means. Although the graph for Grade x Order x Side (Figure 5.2) appears to be disordinal, the test for significance (Ho 7) was not significant (F = .80, p > .10) Only when configuration of different patterns is also considered does a significant interaction result.

The differences between left-first order and right-first are an important starting place in comparing configuration responses. In Figure 5.1, there are three main observations for subjects who heard patterns the left-side first:

1. Estimates are responsive to different patterns. Five times the scores are accurate for continuous, increase for marginal streaming, and drop again for streaming patterns.

2. The right-side scores tend to follow the form of the left-side scores for the two older groups.

3. First grade right-side scores do not parallel left-side scores.

In contrast, right-first order for both left and right-side are not as responsive to different auditory patterns and do not show a consistent form. It would be possible to interpose
Figure 5.2 Time estimation accuracy scores showing non-significant Grade x Order x Side interaction.
straight lines for four of the six right-first Order x Side plots.

The differences between left-first and right-first order of presentation lead to interpretations of the interaction which are related to the hypotheses of the study. Over age and configuration, time estimation by Order and Side scores become less variable. Although overall accuracy for ages do not differ, accuracy does vary within the interaction. For instance seventh grade Order x Side responses are not as changeable across configurations. Also the standard deviation for first graders (.423) is almost double that of fourth (.250) and seventh graders (.233). Inspection of standard deviations in Table 4.3 supports the difference in variability for the ages and configuration.

Side differences appear in concert with order of presentation. When the left-side is heard first, the following right-side estimates are similar to the previous left-side estimates. The parallel between right-side and left-side for both seventh and fourth graders would suggest that left side (right hemisphere) primed the right side (left hemisphere) to hear the patterns in the same way. This inference supports an attentional model of hemispheric functioning. In this case right hemisphere influence over left would be suggested. The general increase in time estimates over age for the right-first presentation suggests the opposite kind of priming by the right-ear (left hemisphere). For the seventh
right-first order resulted in longer estimates for both sides and left-first order resulted in shorter estimates for both sides. Rather than a simple side difference, however, priming through order of presentation is a better explanation of the interaction.

The effectiveness of this supposed priming also provides a clue to possible developmental changes. Looking at response to different auditory patterns, streaming patterns were not judged shorter than continuous patterns as had been reported (Tipps, in press). However, both a difference in population (college-age) and method (comparison) might account for the failure to replicate the previous finding. What is apparent is the accuracy for the continuous pattern for left-first presentation—except for the youngest children's right-side score. Possibly, the left-side priming of the right was poor for the first grade but well established by fourth grade. The rather flat lines for the right-first Order x Side responses might also indicate that the left-hemisphere influence over the right was established prior to age 6-7. This would be reasonable from language studies and conclusions of Krashen (1977). A new suggestion for attentional and developmental hemispheric functioning would be the later establishment of right hemisphere priming or orientational ability. If another group of subjects of ages 15-16 had also participated in the study and if their pattern of response was stable, high estimates for the right-first order with
stable, low estimates for left-first estimates, speculations about developmental, attentional, and hemispheric response would be stronger.

Quantitative Analysis of the Interaction

With 36 cell means, over 600 pairwise post hoc comparisons are possible. Tukey's critical interval for all possible comparisons is .446, however Tukey's is a conservative test and not all comparisons are of equal interest. In this case, Kennedy (1977) suggested use of Dunn's test for fewer than half of the possible comparisons. Dunn's test controls the alpha level of .05 by distributing it over the number of comparisons required to be tested. For 125 comparisons, Dunn's critical interval is .237. While few comparisons meet the required interval, it does serve as a guide for determining which of the cell means are substantially different.

In Figure 5.1, the left-first left-side estimates for first and fourth grade increase significantly from continuous to marginal streaming patterns. The fourth-grade, left-first right-side estimate also approaches the criterion. In these three instances the differential response to configuration for left-first order previously noted is statistically supported.

Note. One hundred twenty-five comparisons allows each cell mean to be compared with the others in its ordered sets of Grade x Configuration (54); Grade x Order x Side (36); and Order x Side x Configuration (36).
The apparent right to left side difference for the 
youngest group in estimation of the left-first continuous 
pattern is also significant (1.235 to .988). None of the 
right-first patterns meets the criterion, although the 
accuracy (1.018) of the left-side estimates for continuous 
pattern of fourth graders stands in sharp contrast to the 
high estimate for the seventh graders (1.218). Perhaps 
the attentional impact of the right first presentation is 
still increasing from ages 9-10 to ages 12-13.

Finally in the oldest group, a statistical difference 
is found between left and right-first presentations. Left­
side estimates when heard after right-side trials are higher 
than when heard first. For continuous patterns, the dif­
ference is significant (1.218 to .97) while for marginal 
and streaming the differences approach the criterion.

Another graph may serve to consolidate the interpre­
tation (Figure 5.3) by placing the ages within configuration. 
Most of the significant differences are included in the 
continuous pattern. Left-first, left-side scores create an 
accuracy floor for all estimates. Decreasing left-first, 
right side estimates and increasing right-side first are 
apparent with the continuous pattern. For marginal and 
streaming patterns, the significantly improving estimates 
over age for left-first, left side are isolated. This 
developmental pattern is echoed in the left-first, right
side scores for the streaming pattern.

In conclusion, while the interaction resists definitive interpretation, there are suggestions of an attentional focus due to order of presentation, short time estimations by right-hemisphere focused and long time estimates by left-hemisphere focused listeners at ages 12-13, less right-hemispheric attentional focus for the younger children, and established but improving left hemisphere focus over the three ages investigated.

The interpretations relate to the research hypotheses of the study. Hypothesis One suggested longer estimates for right-side than left and Hypothesis Three suggested estimation difference would have an age component. The differences found are longer for right-primed estimates and shorter ones for left-primed estimates regardless of side. The trend is most apparent for the oldest children and least stable for the youngest. Hypothesis Two posited increased accuracy with age. Improved accuracy was found for the left-first presentation groups only (Figure 5.3). Right-first presentation (left-hemisphere primed) maintained a level of inaccuracy over age in the range of 10-15 per cent.

Other Interpretations

The Grade x Order x Side x Configuration interaction has been interpreted at some length for two reasons. First, the variables were of most interest in the study. Second,
Figure 5.3 Time estimation accuracy scores showing Grade x Order x Side x Configuration; grades within each configuration.
other statistical results were reasonably apparent in interpretation. The Length and Age x Length for time estimation show that the short patterns were overestimated and long patterns were underestimated by all groups but especially by the youngest. These results seem to be a regression toward the mean. The response time main effect for Length could be interpreted in an allied way. As the length of the pattern increased, response time decreased showing recognition that it was long and had to end soon. Both indicate an overall expectancy of pattern lengths.

The decrease in response time over age (main effect for Grade) is expected with increased attention to the task as well as better co-ordination by older children. The interaction of Grade x Order x Length for response times supports the separate Length and Order main effects except first graders on left-right order of presentation. Why the left-first presentation should result in longer response times for long patterns is not clear. However, if the left-priming premise from time estimation is applied to the response times for the youngest children some clues are found. The cell means for the first graders inside the Grade x Order x Side x Length interaction shows that left-first, left-side response are very high (1325 for short, 1304 for long) and lower for left-first, right-side (970 and 974). While any analysis of the cell means is unjustified, they are illustrative of another difference.
When the left side is presented first, first graders were not as responsive to long-short pattern length expectancy. Another explanation for the difference would be fatigue for the second set of trials, although no such fatigue is apparent with right-first presentation.

The final main effect for response time was Configuration. However the reduced response times for continuous to marginal to streaming pattern was not upheld in post hoc tests nor does it appear in any interaction. The absolute difference is less than 100-msec. For these reasons no interpretation is made.

Summary

The major interpretation of results deals with the suggested attentional focus or priming which is most apparent for left-first presentation. Time estimates are most accurate for the left-first left-side continuous patterns. Attentional and developmental impact is inferred from the increased accuracy over age of right-side scores following the left. Discussion and implications of the results conclude the study in Chapter VI.
CHAPTER VI

DISCUSSION AND IMPLICATIONS

Discussion of the study takes several forms—critique, relationships to other research, tentative projection, and personal speculation. In Chapter VI, all these elements are mixed, however there are three foci:

1. Relationship to brain research and theory
2. Relationship to time research
3. Relationship to education and instruction.

Conclusions and implications are necessarily limited from a study of small scope, but when this study is placed in context of ongoing experimentation and theorizing, it contributes to all three areas.

The purpose of the study was to find if the two sides of the brain would attend to and process ambiguous auditory information in different ways. The rationale and method were developed around descriptions of the right and left hemispheres being, respectively, simultaneous and successive processors. Streaming patterns are alternating high and low patterns of tones which are actually sequential but are reported as simultaneous. Streaming patterns were directed
separately to the left and right hemispheres via the contra-
lateral ear with noise in the ipsilateral ear. Subjects 
at three grade levels were asked to estimate the duration 
of three types of auditory patterns. Estimates were analyzed 
with a five factor analysis of variance design (Grade x Order 
x Side x Length x Configuration). Despite acceptance of 
the null hypotheses which dealt directly with the research 
hypotheses, a Grade x Order x Side x Configuration inter-
action allowed interpretation which had bearing on the 
research questions.

Relationship to Brain Research

The lowest estimates for all age groups were for left-
first, left-side, continuous patterns. Variations from this 
standard revealed both developmental and attentional differ-
ences which were interpreted as evidence of hemispheric 
functioning subject to types of pattern and order of pre-
sentation. In fact, order of presentation appeared to be a 
primary factor. The left-first order was more responsive to 
configuration and showed more age differences.

Specifically, left-first left-side estimates of marginal 
and streaming patterns improved with age. Right-side 
estimates following left-side estimates for continuous and 
streaming patterns also became more accurate. With continuous 
patterns, first grade estimates for right after left were much 
longer than the left. The only significant difference 
involving the right-first presentation was for the
continuous patterns. Seventh graders had longer estimates for left after right than for either left-first estimates. The results were interpreted as evidence of hemispheric difference due to both attentional and developmental factors. The left-first presentation appears to prime the right hemisphere to control the manner in which the following right-side trials were estimated. The suggested priming or attentional focus was most evident for all age groups with the streaming patterns, least consistent with the first graders, and most consistent with seventh graders.

Whether there is a match between simultaneous perception of streaming and simultaneous process of the left hemisphere is difficult to decipher, although the seventh grade scores would lend credence to the idea. If the study had included older subjects and the pattern was sustained, more support would be possible. Bregman (1978) proposed a neural "parsing" mechanism which allows humans to differentiate many simultaneous stimuli into intelligible streams. Some streams are important while others are unimportant—a figure-ground discrimination due to neural selective attention. The parsing of rapid speech into sequential acoustical information would involve segmenting, even expansion. This process is opposite the compression necessary to group relatively slow musical information into melodies and harmonies. Differences in time processing, or parsing, could be an explanation for the results found with dichotic listening with verbal and musical
information. The relationship between Bregman's neural parser and the hemispheres is more intriguing than conclusive. However different time estimates by configuration and order are suggestive of possible connections and deserve further consideration.

When the results are compared to attentional and developmental theories of hemispheric functioning, the study raises an interesting new conjecture. The relatively stable right-first estimates might indicate that left hemispheric priming is already established by age 7. The slight, non-significant increase in right-side estimates over three ages might also indicate that the left hemisphere becomes more controlling from 7 to 13. The developmental change inferred from the left-first presentation is more complex. For continuous patterns left-first presentation, the right-side inaccuracy of the first graders suggests that right hemisphere control over the left is not established at age 7. The parallel left and right side responses for left-first order with the older groups implies that right hemisphere priming is being established during the years from 7 to 13. Perhaps the study indicates that hemispheric specialization due to priming is a developmental process which progresses on different schedules for left to right than for right to left.

How the attentional focus occurs is not actually addressed in the study but progressive inhibition of
alternative processing appears to be the most reasonable explanation. Levy (1980) succinctly stated the role of neural inhibition in learning:

At birth, each hemisphere apparently possesses a primary program of specialization that becomes progressively refined and more competent with maturation and a capacity for integrating behaviors normally programmed by the other half-brain. This capacity in the normal child seems to become increasingly restricted with development, under the influence of inhibition via the corpus callosum from the other half-brain. (p. 263)

The situation found in this study is that the inhibition due to attention may also block any primary program of specialization which exists. Kinsbourne (1980), the leading spokesperson for the attentional model of hemispheric asymmetry, also emphasized inhibition of preprogrammed or prior learnings as important in adaptive behavior and creative problem solving. Alerting or suppressing different perceptual, processing, and planning schemas becomes more efficient and more exclusive through excitation and inhibition of neural pathways. What we presently refer to as abilities might more accurately be referred to as "inhibilities."

Before any of these speculations could be considered more seriously, additional research is required. First, replication and improvement of the present design is warranted. Subjects that are older and more representative
of particular age groups, as well as more subjects at additional levels, would be necessary before results could be generalized. Present experimental techniques could also be improved with more accurate volume control, better recording and delivery of auditory stimuli, and use of additional streaming and contrast patterns. After development of normal time estimations were established, other groups could also be tested. Only in this way would an adequate test of simultaneous/successive processing with hemispheric basis be developed to support Das, Kirby, and Jarman's (1979) model of intelligence.

Another method which could also be used to understand temporal processing as the basis of learning is that of auditory fusion. Haggerty and Stamm (1979) reported different fusion levels for normal, learning disabled, and poor readers. Normals had lower thresholds of fusion than did learning disabled or reading disabled students across the volumes and frequencies used by McCroskey and Kidder (1980). They suggest fusion be used as a diagnostic test for auditory temporal deficits. Their results may actually be a symptom of a larger neurological phenomenon based on response to time patterns.


**Relationship to Time Research**

Results of the study are also pertinent to time research. The effect for length of pattern showing that shorter patterns were reported longer while longer patterns were shorter than actual is a regression to the mean called Vierordt's Law. Bobko, Schiffman, Castino and Chiapetta (1977) discussed this central tendency of temporal judgment. The failure to find significant improvement in time estimation was surprising, but the error rate of 10-20 per cent was consistent with time estimation studies using reproduction techniques. The trends for the two orders of presentation show differences in direction. Right-first estimates are close to typical error rates also. The improvement in accuracy for left-first patterns does show the expected improvement, so much so that the oldest group is more accurate than usual. The fact that different error rates were found for different patterns and orders of presentation raises questions about typical time estimation techniques.

Time estimation tasks may call on different perceptual or processing strategies which result in the variation and conflict found in duration studies. In a hemispheric time estimation task, Hicks and Brundige (1974) had subjects estimate while sorting word cards or picture cards. No time estimation or accuracy differences were found. The method seems extremely crude to elicit hemispheric differences. However, other time tasks may inadvertently tap hemispheric
differences either through stimuli or response requirements. The findings of the study strongly suggest more concern for brain functioning issues in future time research. The failure to replicate the previous finding of shorter estimates for streaming patterns (Tipps, in press) could be due to left hemisphere attention to the standard patterns and right hemisphere response to the streaming patterns.

**Educational Implications**

Finally, educational implications of the study are addressed. Brain functioning has served the investigator as a way of expanding knowledge of child development for application to curricular and instructional questions. In the context of facilitating total development, the brain may suggest both what it learns and how it learns. Knowledge of the brain may then imply what schools should foster and how teaching should proceed, although societal pressures often seem more important in those decisions. Languis, Sanders, and Tipps (1980) presented several classroom goals which summarize major contributions of neurological research to education:

1. Acceptance of different ways of knowing and different ways of demonstrating knowledge
2. Motoric base of language learning and variety of experience to support learning
3. Integration of two ways of thinking as a model of creativity and intelligence
4. Supportive, non-threatening yet stimulating learning atmosphere
5. Personal causation as an important determinant in learning.

The results of the study are most directly related to the first three points.

Piaget's theory of learning involved the cooperative and counterbalancing forces of assimilation and accommodation, or accumulation and reorganization of information. If the brain can be taught to attend certain ways or be alerted to certain types of processing, as the attentional model suggests, then the potential to extend the brain's capabilities is great. However use of only one set of instructional goals and modes could also diminish the capabilities or reduce flexibility of functioning.

The residual effects of time estimation dependent on order of presentation, if time estimation is an index of processing, implies that habitual use of one mode could limit the use of other learning approaches. Experience served to select those neural pathways which are useful and inhibit those which are not. When schools operate on a model of instruction based predominantly on task analyzed behavioral objectives, modular scheduled, discipline discrete, lock-step, grade-wise learning, they imply that there is one way of thinking and learning.
Das, Kirby, and Jarman (1979) concluded that students who were high successive and high simultaneous were the best readers. Kinsbourne (1980) noted that problem solving was the ability to hold alternative plans of action simultaneously and to try them out mentally. The trying out process would include an ordered, sequential set of mental actions. This definition also describes the development of conservation abilities which Kraft (in press) related to interhemispheric communication. Frank Smith (1979) called reading comprehension the act of making sense out of nonsense—discerning the wholeness in separate bits of information. In each case the necessity of dual processing and integrative learning is highlighted. Linear, verbal instructional modes without due attention to non-verbal, synthetic and simultaneous capacity and capability in learning may result in children who expect fractionated information and have impaired ability to learn in the real, continuous world.

One example of the instructional dilemma is technology in the form of television. The media is vivid, multi-modal, simultaneous, and stimulating, however the message may be passive, successive, and isolated from the real world constraints of time, gravity, and personal consequences. We now have flickering pictures of the flickering images on the wall of the cave. What this means in terms of learning and teaching is unclear. The power of imagery in learning is being rediscovered (Wittrock, 1980), but whether television
enhances or destroys generative ability can be debated and needs to be researched. Wittrock has used imagery to facilitate learning, but Worthington (1977) found that providing film versions of short stories actually limited students' abilities to create their own images. The allure of technology is so real that teachers complain of becoming entertainers. A personal conviction is that both media and typical instruction fail to engage students in first-hand, functional, "comprehensive" learning. If learning in terms of neural facilitation is as susceptible to focusing by stimuli as is suggested by this study, it is imperative that school programs balance instructional modes, activities, and expectations.

Concluding Remarks

Attentional focus subject to external stimuli and task demands and to internal decision making has additional personal importance as a result of this investigation. Information may elicit processing which when established has residual impact on how new information is processed. Learning set and functional fixity take on new and expanded meaning for teaching.

The study suggests that time can be a salient dimension in the attentional process. Time can be measured in milliseconds, minutes, days, or years. A growing awareness of micro and macro structures of time has been another result of the study. The awareness has been accompanied by a growing
confusion about the levels of time which were being dealt with. Whether successive and simultaneous abilities per se exist or whether the hemispheres are neural sites of any such processes no longer seems as important. They are simply convenient ways of considering temporal, neurological, and developmental relationships. Those relationships provide a continuing challenge to understanding learning and teaching.
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Swisher, L., & Hirsch, I. J. Brain damage and the ordering of two temporally successive stimuli. Neuropsychologia, 1972, 10, 137-152.


Dear Parents,

I am asking you to help me with a study about how long children remember musical notes. Children in the first, fourth, and seventh grades will listen to some musical notes then hold a button down for a few seconds. They will hear notes in one ear first, then in the other ear. From the time they remember the tones, I hope to find out which side of the brain is better at remembering the length of tones.

In order for your child to participate in the study, you will need to sign the permission form attached. Then the child will be given a short hearing test and a right or left hand laterality test. I also will need to know whether members of your family (blood-kin only) are left handed or right handed.

Your help will allow me to finish a degree at Ohio State while I am teaching at the University of Virginia. If you have any questions, you may call Mrs. Lucille Morris at the primary school (985-2580). She will answer your questions, or I will call you back. We will also arrange a meeting one night so that you can talk to me. Thank you for your assistance.

Sincerely,

Steve Tipps

RUFFNER HALL  CHARLOTTESVILLE, VIRGINIA 22903  804-924-3736/3739/3730
APPENDIX B
— THE OHIO STATE UNIVERSITY —

CONSENT FOR PARTICIPATION IN
SOCIAL AND BEHAVIORAL RESEARCH

I consent to participating in (or my child's participation in) a study entitled Hemispheric Differences in Time Estimation: Simultaneous and Successive Abilities of the Human Brain.

(Investigator/Project Director or his/her authorized representative) has explained the purpose of the study and procedures to be followed. Possible benefits of the study have been described as have alternative procedures, if such procedures are applicable and available.

I acknowledge that I have had the opportunity to obtain additional information regarding the study and that any questions I have raised have been answered to my full satisfaction. Further, I understand that I am (my child is) free to withdraw consent at any time and to discontinue participation in the study without prejudice to me (my child). The information obtained from me (my child) will remain confidential and anonymous unless I specifically agree otherwise.

Finally, I acknowledge that I have read and fully understand the consent form. I have signed it freely and voluntarily and understand a copy is available upon request.

Date: _____________________ Signed: _____________________

(Participant)

Steve Tipps/Marlin Languis

(Investigator/Project Director or Authorized Representative) (Person Authorized to Consent for Participant - If Required)

PA-027 (2/79) — To be used only in connection with social and behavioral research for which an OSU Human Subject Review Committee has determined that the research poses no risk to participants.
APPENDIX C

FAMILY HISTORY OF HANDEDNESS

Please tell me whether each member of your family (blood kin only) is

<table>
<thead>
<tr>
<th>Right-handed only</th>
<th>Left-handed only</th>
<th>Uses Both or mixed.</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>L</td>
<td>B</td>
</tr>
</tbody>
</table>

The things which you should think about include which hand is generally used for:
- Writing
- Drawing
- Holding a toothbrush
- Eating with a spoon
- Hammering
- Sewing
- Throwing a ball

Circle the letter of your answer for each person listed below.

<table>
<thead>
<tr>
<th>Child's Name</th>
<th>R</th>
<th>L</th>
<th>B</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>FATHER</th>
<th>R</th>
<th>L</th>
<th>B</th>
</tr>
</thead>
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<tr>
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<td>R</td>
<td>L</td>
<td>B</td>
</tr>
<tr>
<td>GRANDMOTHER</td>
<td>R</td>
<td>L</td>
<td>B</td>
</tr>
<tr>
<td>GRANDMOTHER</td>
<td>R</td>
<td>L</td>
<td>B</td>
</tr>
<tr>
<td>GRANDMOTHER</td>
<td>R</td>
<td>L</td>
<td>B</td>
</tr>
</tbody>
</table>

Thank you,

Signed ____________________________
APPENDIX D

LATERALITY QUESTIONNAIRE AND AUDIOMETRIC TEST

FOR SCREENING

NAME _______________________________ CODE _________

DATE INTERVIEW _______

DATE TEST _______

AUDIOGRAM

<table>
<thead>
<tr>
<th>Freq.</th>
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<td></td>
<td></td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td></td>
</tr>
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</table>

LATERALITY QUESTIONNAIRE

1. Write name        L  R  B
2. Throw ball       L  R  B
3. Use toothbrush    L  R  B
4. Draw a picture    L  R  B
5. Cut with scissors L  R  B
6. Use an eraser on paper L  R  B
7. Remove top card of a deck of cards L  R  B
8. Open jar lid     L  R  B
9. Stir a liquid in a glass with a spoon L  R  B
10. Pour from pitcher L  R  B
APPENDIX E

DISPLAY OF EQUIPMENT USED

COMPLETE ARRANGEMENT

PRESENTATION
  Amplifier
  Cassette Player
  Relay Sensor
  Headphones

RECORDING
  Manipulandum Switch
  Traffic Data
  Acquisition System

TRAFFIC DATA
  ACQUISITION SYSTEM
  Control Panel
  Magnetic Computer Tape Recorder
  Power Source
# APPENDIX F

## COMPOSITION OF TRIAL PATTERNS

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<thead>
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<th>PATTERN NUMBER</th>
<th>CONFIGURATION</th>
<th>RANDOM NUMBER</th>
<th>ACTUAL TIME</th>
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</thead>
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<td>24</td>
<td>1430</td>
</tr>
<tr>
<td>2</td>
<td>continuous</td>
<td>1</td>
<td>1700</td>
</tr>
<tr>
<td>3</td>
<td>continuous</td>
<td>11</td>
<td>1996</td>
</tr>
<tr>
<td>4</td>
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<td>2282</td>
</tr>
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**APPENDIX G**

**SCHEDULE OF STUDY IMPLEMENTATION**

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<td>Notice of Alumni Research Grant</td>
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<tr>
<td>December, 1979</td>
<td>Human Subjects Committee Approval</td>
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<tr>
<td>February, 1980</td>
<td>Approval by school district</td>
</tr>
<tr>
<td>January-April, 1980</td>
<td>Development of equipment</td>
</tr>
<tr>
<td>March, 1980</td>
<td>Screening</td>
</tr>
<tr>
<td>April-May, 1980</td>
<td>Testing</td>
</tr>
<tr>
<td>February 13</td>
<td>Initial meeting with principal and elementary supervisors</td>
</tr>
<tr>
<td>February 28</td>
<td>Permission letter to parents</td>
</tr>
<tr>
<td>March 6,7,12,13,14,19,20,25,26</td>
<td>Screening</td>
</tr>
<tr>
<td>April 16</td>
<td>Install equipment</td>
</tr>
<tr>
<td>April 17,18,23,24,25</td>
<td>Testing--results lost due to equipment failure</td>
</tr>
<tr>
<td>April 30</td>
<td>Install equipment</td>
</tr>
<tr>
<td>May 1,2,5,6,7</td>
<td>Testing</td>
</tr>
<tr>
<td>May 21</td>
<td>Exit interview with principal and elementary supervisor</td>
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APPENDIX H

TRAINING PROCEDURES AND INSTRUCTIONS TO PARTICIPANTS WITH VISUAL DISPLAY

I. Training Phase with Audible Signals on Speakers

I am interested in how long you think that things last in time. You are going to show me how long they last by pushing down the button with your right or left index finger.

SUBJECT WILL TRY OUT MICROSWITCHES WITH EACH INDEX FINGER.

Now listen to this tone. When the tone begins, push down the button with the right/left finger and hold it down until the tone goes off. Now try other finger

SUBJECT WILL PRACTICE SYNCHRONIZING BUTTON PUSHING WITH MUSICAL TONE (2-5 SEC) WITH EACH FINGER.

You have held the button down the same amount of time as the tone lasted. Now you will try something different. At first you will hear a pattern of musical notes which go up and down. Listen to the notes but do not count. You may want to close your eyes and just listen. Next, when the musical tone begins, you will push down the button for as long as you think the pattern lasted. Let's try that now.

SUBJECT WILL LISTEN TO TRAINING PATTERN AND FOLLOW INSTRUCTIONS BY PUSHING BUTTON DURING CONTINUOUS TONE. (4-6 trys)

II. Training Phase with Headphones

Now you will hear the musical notes and the tone through the headphones. But you will hear it only on one side or the other. There will be a short beep to tell you which side to listen to and which hand to answer with. If you hear the beep in this ear
you will hear the notes here and answer with the finger on the same side. If you hear the beep in this ear, you will hear the notes with this ear and answer with this finger.

INVESTIGATOR WILL POINT TO CORRESPONDING EAR AND FINGER.

Put the headphones on and listen to the first patterns of notes. When the tone begins, push the button down as long as you think that the first pattern lasted. Are there questions about what to do? First let's check to see if the sound is the same loudness in both ears.

INVESTIGATOR WILL ADJUST VOLUME CONTROLS.
SUBJECTS WILL RESPOND TO 12 PATTERNS FOR TRAINING TRIALS.

AFTER THE TRAINING TRIALS, A QUICK ASSESSMENT OF RESPONSE TIMES AND EXAMINATIONS WILL SHOW IF SUBJECT IS FOLLOWING INSTRUCTIONS.

SUBJECTS WHO ARE NOT FOLLOWING THE EXPERIMENT WILL BE THANKED AND DISMISSED. SUBJECTS WHO ARE RESPONDING TO THE TASK WILL TAKE A SHORT REST BEFORE CONTINUING.

III. First Block of Trials

Now you will hear a series of notes and tones. The beep will tell you which ear and finger you will use. Listen to the pattern of notes, then wait for the tone. When the tone starts, hold the button down for as long as you think the pattern lasted. You will do the same for each new pattern of tones. Are you comfortable?

SUBJECT WILL LISTEN TO 24 PATTERNS. AFTER A SHORT STRETCH, THE SECOND BLOCK WILL BEGIN WITH HEADPHONES REVERSED.
IV. Second Block of Trials

You will listen to another series of notes and tones. Hold the button down for as long as you think the pattern of notes lasted. Do you have any questions?

SUBJECT WILL RESPOND TO 24 PATTERNS.

Thank you.

VISUAL DISPLAY OF INSTRUCTIONS