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Hemispheric Perception of Modulated Rhythmic Patterns in a Dichotic Listening Task

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HEMISPHERIC PERCEPTION OF MODULATED RHYTHMIC PATTERNS IN A DICHOTIC LISTENING TASK

by

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HEMISPHERIC PERCEPTION OF MODULATED RHYTHMIC PATTERNS IN A DICHOTIC LISTENING TASK

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This study attempted to determine ear advantage in a dichotic listening task involving perception of tempo modulation (decrease or increase) within repeating rhythmic patterns at initial tempi of 80 mm or 160 mm. Ear advantage was measured by reaction times to and accuracy of modulation detection.

The subjects were thirty right-handed nonmusicians with normal hearing. The rhythms were pure tones generated in real time on an Apple II computer and presented through headphones. The subjects' task was to depress a designated computer key as soon as the modulation was detected. The computer recorded each subject's response and reaction time.

Reaction time to and accuracy of modulation detection were significant at the 160 mm initial tempo. Increases in tempi were perceived twice as accurately as decreases in tempi. Reaction time and accuracy of responses were not significant for ear and modulation or ear and initial tempo. Results showed no ear advantage for the task.

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CHAPTER I

INTRODUCTION

The music therapist is concerned with human behavior, specifically, the effects of music on change in behavior. The music therapist's tool for changing behavior is a complex one. A single musical stimulus may combine pitch, rhythm, harmony, timbre, and intensity (Gates & Bradshaw, 1977a). An understanding of how the two cerebral hemispheres perceive these elements can contribute to the scientific foundation on which the principles of music's therapeutic use are based. After much more evidence accumulates concerning cerebral perception of music and the nature of music learning, it may be possible to develop therapeutic and instructional strategies that take advantage of hemispheric dominance effects.

In 1957, Henkin found that of the various elements in music there are at least two independent factors: melody and rhythm (Lundin, 1967). Previous research indicates that the right cerebral hemisphere is superior to the left hemisphere for perceiving instrumental melodies (King, 1964, 1967) and hummed melodies (King & Kimura, 1972). Research data also indicate that the right hemisphere is dominant for recognition of musical chords (Gordon, 1970). Finally,

research data support the right hemisphere's involvement in singing melodies (Bogen & Gordon, 1971; Gordon, 1974). Research has not yet clearly established cerebral dominance for the perception of rhythm. Some research indicates that rhythm may be processed in the left hemisphere (Robinson & Solomon, 1974; Natale, 1977; Gates & Bradshaw, 1977a) while other research indicates that rhythm may be processed in the right hemisphere (Gregory, Harriman & Roberts, 1972).

The general purpose of this project is to investigate cerebral perception of the rhythmic factor in music. The background for the project is found in clinical and experimental literature involving hemispheric specialization in the four areas of: speech, vocal nonverbal sounds, environmental sounds and music. A summary of research within these four areas will be presented later.

Past research has clearly defined the basic functions of the two cerebral hemispheres. The left cerebral hemisphere, the dominant hemisphere, specializes in analytical and serial processing of incoming information. It controls the processes of verbal language, rational analysis, definition and logic. The left hemisphere is dominant for speaking, writing and mathmatical calculation. In 1878, Jackson designated the left hemisphere as the temporal or propositional hemisphere because it perceives the significance of relationships across time. In contrast, the right cerebral hemisphere--the nondominant hemisphere--

specializes in the perception of holistic and synthetic relationships, and in perceiving the totality and synthesizing information. It controls visualization, metaphor, imagery and concrete perceptual insight. The right hemisphere specializes in data whose significance come from relationships perceived across space, such as recognizing a face in the surrounding environment. In 1969, Bogen labeled this visual-spatial brain the appositional hemisphere as a parallel to Jackson's use of the word "propositional" to describe the left hemisphere.

Research in the perception of musical stimuli reveals that the left hemisphere mediates tasks requiring perception, analysis and remembrance of stimuli in a sequence of interrelated elements (Gordon, 1970, 1978). In contrast, the right hemisphere is involved when a set of stimuli are grouped and processed at once as a single unit (Gordon, 1978). For example, a task may emphasize a listening strategy centered around the relationships between adjacent notes, implying left hemisphere mediation. A different task, using the same stimuli, may emphasize a strategy in which the pattern or contour of the entire sequence of notes is important, implying a right hemisphere mediation (Gates & Bradshaw, 1977a). The musical elements of melody and rhythm may invoke different processing strategies, depending upon the task, which reflect the different specialization of the two cerebral hemispheres: holistic and

analytical (Gates & Bradshaw, 1977b).

Research in time and rhythm has also suggested that the two cerebral hemispheres do not function completely independent from each other. There may be a neutral zone in the middle of the continuum from left to right hemispheric specialization which yields bilateral results or a lack of specialization (Bradshaw, Nettleton & Geffen, 1972). Depending upon the processing strategies involved, analytical or holistic, hemispheric dominance may shift from one hemisphere, through the neutral zone, and to the other hemisphere (Bradshaw, Nettleton & Geffen, 1972; Halperin, Nachshon & Carmon, 1973). The complexity of the task or stimuli may dictate the type of processing strategy used in a given task. There may be a shift in dominance as the task grows more complex (Halperin, Nachshon & Carmon, 1973; Papcun, Krashen, Terbeek, Remington & Harshman, 1974).

The bilateral time and rhythm results cited above would seem to indicate that processing is possible by either hemisphere or both working together, each according to its specialization. It appears that hemispheric lateralization is not so much a function of the specific stimuli as it is a function of the type of processing strategy required by the task. Hemispheric dominance may be explained by the cognitive functioning required by the right and left hemispheres in order to process the stimuli. Thus, tasks designed to require holistic processing of time or rhythm

may be mediated in the right hemisphere, and those tasks requiring analysis or sequential ordering of stimuli may invoke left hemisphere involvement. The type of processing strategy required may also be a function of the elements within the stimuli that lend themselves to processing most suited for one hemisphere or the other's specialization.

Assuming that both hemispheres are involved in processing rhythm, what has not been clearly defined is the role each hemisphere plays in tasks of rhythmic perception. It is the general purpose of the present study to attempt to identify the function of each hemisphere within one specific area of rhythmic perception. The area that has been chosen for study is perception of tempo modulation. The specific purpose of this project is to investigate cerebral hemispheric processing of dichotically presented rhythm patterns that modulate in tempo as measured by accuracy of response and reaction times.

Three studies are the most germane to the theoretical basis and design of the present investigation. Kuhn (1974) and Madsen (1979) designed very similar auditory discrimination tasks in which subjects identified direction of beat modulation provided by a metronome. The 30 professional musicians used in the Kuhn study were presented with beats produced by a metronome at initial tempi of 60, 90, 120 and 150 beats per minute. After six seconds at the initial tempo, the rate modulated (decreased or

increased) or stayed the same. Data were taken on accuracy of response for direction of modulation and time required to discriminate a tempo change. Subjects accurately identified significantly more Decrease and Increase modulation examples than same (non-modulating) examples. Subjects also accurately identified more Decrease and Increase modulation examples, although not significantly more. Reaction times were significantly faster for detection of Decrease modulations than Increase modulations. Finally, reaction times attributable to the four initial tempi were not significant.

Two hundred musicians and nonmusicians were used in the Madsen (1979) study. As in the Kuhn study, subjects were presented with beats produced by a metronome at nine initial tempi ranging from 40 to 200 beats per minute. After six seconds at the initial tempo, the rate modulated (decreased or increased) or stayed the same. Data were taken on accuracy of response for direction of modulation. The results indicated that both musicians and nonmusicians accurately identified significantly more Decrease than Increase modulation examples.

Gates and Bradshaw (1977a) conducted six dichotic experiments in which a series of five notes of equal value were altered by pitch, harmony and rhythm. In the third experiment, the note pattern was altered by rhythm only. One of the five notes was lengthened or shortened by half

a beat. The task of the nonmusician subjects was to detect rhythmic changes in the five·note pattern. Data were taken for reaction time and accuracy in detecting rhythmic changes. Results indicated that subjects showed significantly faster reaction times for detecting rhythmic changes in the left ear than in the right ear. The right ear was significantly more accurate in detecting the rhythmic changes than was the left ear.

The designs and results of the three preceding studies along with the principles of hemispheric dominance found in the literature provided the theoretical basis and experimental design for the present study. Both Kuhn and Madsen found that all subjects more accurately discriminated modulations in which tempo decreased than modulations in which tempo increased. Gates and Bradshaw found that accuracy in detecting rhythm changes was greater for the right ear than the left ear. Fewer rhythm changes were missed when stimuli were presented to the right ear.

Kuhn found that reaction times were faster for modulations that decreased in tempo than for modulations that increased in tempo. Gates and Bradshaw found that rhythm changes caused by lengthening notes yielded faster left ear reaction times than the right ear. Gates and Bradshaw also found that rhythmic changes caused by shortening notes resulted in no difference between the ears for reaction time.

While lengthening or shortening a note is not the same process as decreasing or increasing tempo, it is interesting to observe the similarity of reaction time results for these two processes in the two studies. Gates and Bradshaw found that the left ear detected rhythmic changes, specifically lengthened notes, more quickly than the right ear. In the Kuhn study, decrease in tempo was detected more quickly. It was theorized that in both cases left ear/right hemisphere was faster than the right ear/left hemisphere in detecting occurrence of tempo changes. That is, the right hemisphere was faster in detecting a slowing of the entire pattern. This type of perception would be within the right hemisphere's specialization for holistic processing.

In contrast, the right ear was more accurate than the left ear in detecting specific rhythm changes. This was evidenced by the right ear missing fewer rhythm changes in the Gates and Bradshaw study. It was theorized that the right ear/left hemisphere was more accurate in analyzing that a specific change had taken place, especially when that change was a decrease in tempo as in the Kuhn and Madsen studies. This type of perception would be within the left hemisphere's specialization for analytical processing.

In all three studies, increasing tempo or shortening note values resulted in slower reaction times and less

accurate detection than decreases in tempo or lengthened note values. Based upon no difference in reaction times between ears in the Gates and Bradshaw study, it was theorized that increases in tempo did not show lateralization effects.

The present study attempted to determine the role of each hemisphere in a dichotic listening task involving perception of tempo modulation within repeating rhythmic patterns having selected initial tempi. Possible lateralization effects were measured by (1) ear advantage for reaction times to tempo modulations and (2) ear advantage for accuracy of the reported modulations.

CHAPTER II

THE PROBLEM AND ITS SETTING

The Statement of the Problem

This dichotic study attempted to determine whether ear of presentation would affect subject perception of tempo modulation within a repeating rhythmic pattern. The rhythmic patterns were based upon the temporal patterns used in the international Morse Code alphabet. Each rhythmic pattern was assigned a frequency of 750 or 1000 Hertz (Hz). In some trials, tempi remained constant or were modulated by decreasing or increasing 10 metronome markings (mm) from an initial tempo of 80 mm. In other trials, tempi remained constant or were modulated by decreasing or increasing 20 mm from an initial tempo of 160 mm. Ear advantage was measured by reaction times to the tempo modulations and by accuracy of the reported modulations in each ear.

Reaction time was assessed by the total number of elapsed seconds between the beginning of each trial and the point at which the subject heard the modulation in one of the two competing dichotic rhythms and depressed either the slower or faster key on the computer. Accuracy of response for direction of modulation (decrease or increase) was assessed by recording the total number of correct computer

key depressions (slower or faster) for stimuli presented to the left and right ear.

Predictions for the present study were based upon the results of studies by Kuhn (1974), Madsen (1979) and Gates and Bradshaw (1977a). Kuhn found that reaction times were faster for modulations that decreased in tempo while Gates and Bradshaw found that rhythm changes caused by lengthening notes resulted in faster left ear than right ear reaction times. Gates and Bradshaw also found that rhythmic changes caused by shortening notes resulted in no difference between ears for reaction time. Both Kuhn and Madsen found that subjects more accurately discriminated modulations in which tempo decreased than modulations in which tempo increased. Finally, Gates and Bradshaw found that accuracy in detecting rhythm changes was greater for the right ear than for the left ear.

On the basis of the results described above, four predictions were made. First, it was predicted that the left ear would perceive modulations that decreased in tempo more quickly than the right ear. The left ear would yield faster reaction time scores to decreases in tempo at both initial tempi than would the right ear.

Second, it was predicted that there would be no lateralization effects for modulations that increased in tempo. There would be no difference in reaction time scores for perception of tempo increases at both initial tempi.

Third, it was predicted that the right ear would more accurately perceive the occurrence of tempo modulations than the left ear. The right ear would yield higher accuracy of response scores at both initial tempi.

Finally, it was predicted that initial tempi modulations that decreased in tempo would be more accurately perceived than modulations that increased in tempo regardless of ear of presentation. Tempo decreases would yield higher accuracy of response scores than tempo increases regardless of ear of presentation.

Ear advantage was taken to imply involvement of the hemisphere contralateral to the ear. Thus, right ear advantage would suggest left hemisphere lateralization. Left ear advantage would suggest right hemisphere lateralization.

The Subproblems

The First Subproblem

The first subproblem was to determine whether ear of presentation (left or right) affects reaction time scores for perceiving modulations.

The Second Subproblem

The second subproblem was to determine whether type of modulation (decrease or increase) affects reaction time

scores for perceiving modulations.

The Third Subproblem

The third subproblem was to determine whether rate of initial tempo (80 mm or 160 mm) affects reaction time scores for perceiving modulations.

The Fourth Subproblem

The fourth subproblem was to determine whether assigned frequency (750 Hz or 1000 Hz) affects reaction time scores for perceiving modulations.

The Fifth Subproblem

The fifth subproblem was to determine whether reaction time was affected by the interaction between levels of ear and modulation.

The Sixth Subproblem

The sixth subproblem was to determine whether reaction time was affected by the interaction between levels of ear and tempo.

The Seventh Subproblem

The seventh subproblem was to determine whether reaction time was affected by the interaction between levels of ear and frequency.

The Eighth Subproblem

The eighth subproblem was to determine whether ear of presentation (left or right) affects accuracy of response scores for perceiving modulations.

The Ninth Subproblem

The ninth subproblem was to determine whether type of modulation (decrease or increase) affects accuracy of response scores for perceiving modulations.

The Tenth Subproblem

The tenth subproblem was to determine whether rate of initial tempo (80 mm or 160 mm) affects accuracy of response scores for perceiving modulations.

The Eleventh Subproblem

The eleventh subproblem was to determine whether assigned frequency (750 Hz or 1000 Hz) affects accuracy of response scores for perceiving modulations.

The Twelfth Subproblem

The twelfth subproblem was to determine whether accuracy of response was affected by the interaction between levels of ear and modulation.

The Thirteenth Subproblem

The thirteenth subproblem was to determine whether accuracy of response was affected by the interaction between levels of ear and tempo.

The Fourteenth Subproblem

The fourteenth subproblem was to determine whether accuracy of response was affected by the interaction between levels of ear and frequency.

The Null Hypotheses

The First Null Hypothesis

It was hypothesized that there would be no difference in total reaction time scores for perceiving modulations between the left ear and the right ear.

The Second Null Hypothesis

It was hypothesized that there would be no difference in total reaction time scores for perceiving modulations between modulations that decrease in tempo and modulations that increase in tempo.

The Third Null Hypothesis

It was hypothesized that there would be no difference in total reaction time scores for perceiving modulations

between modulations at an initial tempo of 80 mm and modulations at an initial tempo of 160 mm.

The Fourth Null Hypothesis

It was hypothesized that there would be no difference in total reaction time scores for perceiving modulations between modulations at a frequency of 750 Hz and modulations at a frequency of 1000 Hz.

The Fifth Null Hypothesis

It was hypothesized that there would be no effect upon reaction time scores due to the interaction between levels of ear and modulation.

The Sixth Null Hypothesis

It was hypothesized that there would be no effect upon reaction time scores due to the interaction between levels of ear and tempo.

The Seventh Null Hypothesis

It was hypothesized that there would be no effect upon reaction time scores due to the interaction between levels of ear and frequency.

The Eighth Null Hypothesis

It was hypothesized that there would be no difference

in total accuracy of response scores for perceiving modulations between the left ear and the right ear.

The Ninth Null Hypothesis

It was hypothesized that there would be no difference in total accuracy of response scores for perceiving modulations between modulations that decrease in tempo and modulations that increase in tempo.

The Tenth Null Hypothesis

It was hypothesized that there would be no difference in total accuracy of response scores for perceiving modulations between modulations at an initial tempo of 80 mm and modulations at an initial tempo of 160 mm.

The Eleventh Null Hypothesis

It was hypothesized that there would be no difference in total accuracy of response scores for perceiving modulations between modulations at a frequency of 750 Hz and modulations at a frequency of 1000 Hz.

The Twelfth Null Hypothesis

It was hypothesized that there would be no effect upon accuracy of response scores due to the interaction between levels of ear and modulation.

The Thirteenth Null Hypothesis

It was hypothesized that there would be no effect upon accuracy of response scores due to the interaction between levels of ear and tempo.

The Fourteenth Null Hypothesis

It was hypothesized that there would be no effect upon accuracy of response scores due to the interaction between levels of ear and frequency.

The Delimitations

The subjects used in this study were limited to right-handed, nonmusicians. Student subjects were enrolled at Western Michigan University, Kalamazoo, Michigan, during the Summer Session 1981 and at College of Mount St. Joseph on the Ohio, Cincinnati, Ohio, during the Winter Semester 1982. Non-student subjects were from Kalamazoo, Michigan.

Since musicians were not included in the study, results may not be generalized beyond adult nonmusicians. It is known that as the amount of musical training increases, changes can occur in cerebral perception of musical stimuli.

Results may not be generalized beyond adult non-musicians who are right-handed. Left-handed persons may show a right or mixed hemispheric dominance for speech.

In tasks of rhythm that at least partially involve temporal analysis similar to that of speech, it can not be assumed that processing will be the same for the left as right-handed.

Results may be generalized only to the perception of rhythm separated from melody. It is known that rhythm may be perceived differently within the context of a melody than when separated from it.

The Definition of Terms

The definitions given below relate to the specific context in which the terms are used in the present investigation.

Nonmusician refers to a subject who is not enrolled in a college School of Music, who is not a member of a college music organization and who has had less than three years of private or group choral or instrumental music study during his/her public school experience.

Rhythm refers to the grouping of sounds according to their duration in time. Rhythm is the organization of time relationships among musical stimuli.

Tempo is a time description and refers to the rate or speed at which rhythm progresses within musical stimuli.

Contralateral refers to the ear or cerebral hemisphere on the opposite side of the body as the ear being stimulated.

Ipsilateral refers to the ear or cerebral hemisphere on the same side of the body as the ear being stimulated.

Cerebral lateralization refers to a function that is located in one specific hemisphere over the other.

Cerebral asymmetry refers to the size of difference in function between the two hemispheres.

Monaural refers to a listening task in which only one ear receives the stimuli (Sonn, 1969).

Binaural refers to a listening task in which both ears receive the stimuli (Sonn, 1969).

Dichotic refers to a listening task in which the sound stimulus presented at one ear is different from the sound stimulus presented at the other ear (Sonn, 1969).

Assumptions

The major assumption made by this researcher is that the two processes of lengthening/shortening notes and decreasing/increasing tempo are related. This assumption is made on the basis of results from three studies by Madsen (1979), Kuhn (1974) and Gates and Bradshaw (1977a). These results partially form the theoretical basis of the present investigation and give direction to the inquiry.

Additionally, it is assumed that lateralization effects indicate a specialization of function for a given hemisphere. Ear advantage, with its contralateral hemispheric involvement, can be used to measure lateralization

effects. Thus, a right ear advantage suggests a left hemisphere lateralization and possible specialization. Left ear advantage suggests a right hemisphere lateralization and possible specialization.

The Importance of the Study

A musical stimulus is composed of at least two independent factors which in themselves require certain behaviors of an individual. In the therapeutic setting, the music therapist can manipulate musical stimuli to help accomplish a specific treatment goal.

Rhythm is one of the two independent factors in music. Rhythm is part of the underlying structure, time order or temporal sequence, by which music is organized. Because rhythm makes the temporal order of music possible, it has been described as the organizer and energizer of music (Gaston, 1968).

Basic research into cerebral control of the various elements of music is in the elementary stage. Research investigating cerebral processing of rhythm is especially fragmentary. An understanding of the separate or joint functions of the two cerebral hemispheres in processing time and rhythm would contribute to the scientific foundation on which the principles of music therapy are based.

Results of the present investigation may be used in developing strategies for improved skills in producing

tempo changes within the rhythmic context of music. These skills are useful for perceiving as well as producing tempo change as dictated by the musical stimuli in the therapeutic/learning environment. Development of such strategies will be possible only after much more evidence is gathered concerning cerebral perception of music and the nature of music learning.

To the best of this researcher's knowledge, a dichotic study has not been conducted that uses repeating rhythmic patterns that modulate in tempo and that requires the subject to perceive direction of modulation.

CHAPTER III

REVIEW OF RELATED LITERATURE

Hemispheric Specialization
Three Major Lines of Investigation

Research in cerebral hemispheric specialization can be categorized into three major lines of investigation. The first two lines are composed of clinical studies involving epileptic patients requiring either a midline cerebral commissurotomy or a temporal lobectomy as a form of treatment. The third line of investigation consists of experimental studies using normal subjects. A basic description of the role of the corpus callosum in hemispheric processing is necessary to appreciate the significance of these studies.

Although the two cerebral hemispheres each have specialized processes, their functions should be thought of as different parts of a total, integrated performance rather than completely separate and parallel. Right and left hemisphere functions are integrated through a system of cerebral commissures, the most important of which is the corpus callosum. The corpus callosum connects the two cerebral hemispheres which make up the upper part of the forebrain. The nerve fibres that make up the corpus callosum form reciprocal connections between parallel centers in the right and left hemispheres. Without the corpus

callosum, there would be no communication or transfer of learning between the two hemispheres. The corpus callosum correlates the right and left halves of the field of vision, integrates sensations and coordination of both halves of paired limbs, and unifies cerebral processes of attention and awareness (Sperry, 1964). Shared learning and memory between the hemispheres is made possible by passing of information in the form of engrams via the corpus callosum. The engrams are established in the hemisphere being directly trained but are available to the other hemisphere if needed. Thus, learning is not transferred from one hemisphere to the other when the corpus callosum is cut. The two separated hemispheres can learn different solutions to the same problem depending upon which hemisphere received the triggering stimulus. Conversely, when the corpus callosum is intact, any incompatible messages from one hemisphere to the other are disregarded since one hemisphere is usually dominant at a time (Sperry, 1964). Studies by Sperry and others using patients who have had their corpus callosum sectioned as treatment for severe epilepsy form the first line of investigation into hemispheric specialization. Midline cerebral commissurotomy eliminates communication between the two hemispheres, but it leaves them otherwise intact and capable of functioning separately. This surgery allows for comparison of independent performance of the two

hemispheres in the same person. Results of these investigations supply evidence for the strong lateralization of speech, writing and calculation in the left hemisphere. After surgery, the patients seem to rely primarily on the left hemisphere to function apparently normally in daily life. However, the disconnected right hemisphere was shown to have tactual, visual and auditory aptitudes. Additionally, the right hemisphere was shown to have some rudimentary verbal comprehension although it was largely incapable of speech or writing (Sperry, cited in Milner, 1975). In summary, Sperry and others found that each hemisphere seems to process information in fundamentally different ways and that the role of the corpus callosum is to unite a single process having parts in both hemispheres.

The second major line of investigation in hemispheric specialization comes from the pioneer work of Milner and others with epileptic patients having unilateral lesions or damage to only one of the temporal lobes. It was found that a left temporal lobectomy impaired learning and retention of verbal material, but it did not affect memory for perceptual material such as faces, melodies or nonsense patterns. A right temporal lobectomy impaired the recognition and recall of visual and auditory patterns not closely connected with verbal coding (Milner, 1975). However, use of the Wada technique with these patients revealed that speech may be represented in the right hemisphere in some

right-handed cases. According to Milner, the Wada technique also showed that cerebral dominance for speech among left-handed subjects is variable with some of them showing bilateral representation.

The Wada technique, developed in 1949, is used before temporal lobectomies or other brain surgery that may affect language mechanisms. The technique consists of injecting sodium amobarbital into either the right or left carotid artery which induces a temporary loss of function in the depressed hemisphere. In every case in which Wada and Rasmussen (1960) used the technique to determine hemispheric dominance for speech, subsequent surgery confirmed the accuracy of their finding. Thus, research has shown that although the tendency for speech function to be organized in the left hemisphere is great, handedness does play a part in this area of cerebral dominance.

The third major line of investigation into hemispheric specialization supports evidence from the first two. This line of research involves normal subjects who perform specified tasks better with one side of their bodies than the other. An example of this type of investigation is research in which reaction times are noted for performance of tasks with one hand over the other. Other studies involve the accuracy with which subjects perceive visual stimuli delivered to the right or left of a fixed point. Another type of study measures the accuracy with which subjects perceive

competing auditory stimuli. This last type of research involves the dichotic listening technique.

Hemispheric Specialization
The Role of the Dichotic Listening Technique

The dichotic listening technique was developed in 1954 by Broadbent. The need for using this technique to establish cerebral auditory function and specialization becomes apparent when the physical mechanics of audition are examined. Each ear is represented bilaterally at every stage of the auditory pathway. The auditory pathway carries impulses from the ear to the cochlear nucleus to the transverse gyrus of Heschl, the primary auditory cortex. Therefore, sound input can not be restricted to one hemisphere; either hemisphere is able to hear through either ear. However, the auditory pathways from the ears to the cerebral auditory receiving areas in the right and left hemispheres are partially crossed. The central nervous system dictates that each hemisphere receives information primarily from the opposite half of the body. This means that although each hemisphere receives input from both ears, the neutral connections from one ear to the contralateral hemisphere are stronger than the connections to the ipsilateral hemisphere (Milner & Sperry, 1968). Evidence for this phenomenon was first demonstrated through Rosenzweig's (1951) electrophysiological work with cats. By measuring

the EEG response of anesthetized cats to electrically generated clicks at each auditory cortex, Rosenzweig found that the response of the contralateral ear was significantly larger in amplitude than the response of the ipsilateral ear.

Although a sound played into just one ear will show a larger contralateral than ipsilateral response, it is not enough to obtain reliable differences between the ears. It is usually necessary to create competition by playing two different messages simultaneously, one into each ear, to reliably demonstrate ear advantage and possible cerebral dominance. Rosenzweig proposed that there is a point at which input from each ear overlaps. At this point, the input of the contralateral pathway can partially occlude or block impulses arriving along the ipsilateral path. This view is supported by Kimura (1967) and Milner, Taylor and Sperry (1968) among others. In essence, the dichotic listening technique creates auditory overlap.

The basic dichotic listening technique involves presenting two different messages, such as digits, through headphones simultaneously to the two ears, one message to the left and one to the right. Usually, three such pairs are presented in rapid succession. At the end of the six digits, the subject is asked to report all the numbers he heard in any order he recalls.

Hemispheric Specialization in Speech

The dichotic listening technique was modified by Kimura in 1961 to investigate hemispheric dominance in speech. Using the technique with patients having temporal lesions (1961a) and normal subjects (1961b), Kimura found in both populations a greater accuracy of recall for digits presented to the right ear than to the left. Broadbent and Gregory (1964) confirmed this finding using normal subjects with a recognition rather than recall task; subjects recognized more digits presented to the right ear than left. Likewise, normal subjects in the Milner, et al., (1968) study showed a significant right ear superiority for recalling dichotically presented digits. The patients having left temporal lobectomies in both the Kimura (1961a) and Milner, et al., studies showed impaired performance on the dichotic task by recalling fewer digits correctly than patients with right temporal lobectomies. The impairment of the left hemisphere decreased the efficiency of report for the ear contralateral to the lesion in a verbal task. The Milner, et al., commissurotomized patients, who were all deprived of all input from the right hemisphere, had near zero scores on recalling dichotically presented digits to the left ear. In contrast, under monaural conditions these patients showed equal accuracy with both ears in reporting digits. These findings confirm the dominance

of the contralateral over ipsilateral auditory projection system.

Using the dichotic listening technique, Satz, Achenbach, Pattishall and Fennell (1965) found that although the right ear was more efficient for recalling digits than the left ear for both right and left-handed subjects, handedness played a role in degree of asymmetry. The mean difference in scores between the right and left ears for the right-handed subjects was almost twice as large as for left-handers. These results support Wada and Rasmussen's (1960) findings that there is a relationship between handedness and hemispheric dominance for speech, especially among right-handers. Kimura (1961b) found a higher proportion of left-handers than right-handers with speech representation in the right hemisphere. Branch, Milner and Rasmussen (cited in Kimura, 1967) estimated that 90% of normal right-handers and over 60% of normal left-handers have speech functions represented in the left hemisphere. Satz, et al., (1965) suggested that the probability of left hemisphere speech representation in the right-hander is $p = .97$, whereas right hemisphere speech representation in the left hander is $p = .35$. In general, left-handed subjects tend to show a varied and less reliable pattern of speech representation.

Another factor in ear asymmetry is immediate or perceptual recall versus delayed or stored recall. Satz,

et al., found a significant difference between errors made in immediate recall of dichotically presented digits and errors made in delayed recall. In the delayed recall condition, all digits heard in a specified ear had to be reported before digits heard in the other ear. Satz, et al., hypothesized that excess verbal information could be stored and more easily accessed to the contralateral than ipsilateral ear of the speech dominant hemisphere. Their hypothesis was based upon the efficiency of crossed auditory connections. These researchers also found that creating stimulus overload greatly increased the ear asymmetry by increasing the margin of accurate recall between the two ears. The overload condition was achieved by increasing the amount of stimulus information from three to six pairs of digits.

Research indicates that attention to task is one other factor involved in ear asymmetry and cerebral dominance. Treisman and Geffen (1968) presented dichotic speech messages to normal subjects. The task required subjects to simultaneously verbally shadow one of the messages and manually tap when a target word was heard. Results indicated that the verbal response of shadowing showed right ear dominance more clearly than the manual response of tapping. Treisman and Geffen maintained that right ear dominance for verbal input is primarily a qualitative difference in distribution of attention to left

and right ear input reaching the left hemisphere speech centers.

In 1967, Curry found the expected right ear advantage for recalling dichotically presented words in normal subjects. Curry also found a right ear advantage for recalling dichotically presented nonsense syllables. In both verbal tasks, right-handers reached significance level only on the words task. Despite the absence of meaning, the nonsense syllables were processed in the same way as meaningful words. Curry proposed that this may have been because the syllables had English phonemes in common with the words. In contrast, dichotically presented environmental nonverbal sounds, such as a car starting or a toilet flushing, yielded a left ear advantage for both right and left-handers, but significance was reached only for right-handers. Knox and Kimura (1970) also found that primary school children showed a left ear advantage for nonverbal environmental sounds, such as a clock ticking, phone dialing and animal sounds.

King and Kimura (1972) found that voice quality alone is not enough to engage left hemisphere processing. Their data indicated that vocal nonverbal sounds, such as crying, laughing and sighing, resulted in a significant left ear advantage. This would indicate right hemisphere processing for these normal subjects. Additionally, this study found that hummed melodic patterns yielded a left ear advantage.

Hemispheric Specialization in Music

Left ear/right hemisphere dominance for melodies was first shown by Kimura. Kimura's (1964) pioneer study used normal subjects and contrasted right ear advantage for dichotically presented digits with left ear advantage for classical solo instrumental passages. This study instigated scores of dichotic research experiments in the area of cerebral processing of musical functions. McCarthy (1969) replicated Kimura's study with two exceptions. The first exception was the use of recognition instead of recall for reporting. Secondly, McCarthy used organ tones rather than solo melodies played on string and woodwind instruments in an attempt to control for differences in timbre, rhythm, pitch and intensity. McCarthy's results supported Kimura's in that the normal right-handed subjects recognized more dichotically presented tones in the left ear and more digits in the right ear. Under dichotic stimulation conditions, Sidtis (1978) also found right ear advantage for speech sounds and left ear advantage for tones in normal subjects. As the tones progressed in complexity from pure tones to overtone laden square waves, Sidtis found increasingly right hemisphere advantage in accuracy and latency of response. Further support for these right/left asymmetries has been found in infants. Glanville, Bradley, Best and Levenson (1977) habituated cardiac

responses of three month old babies to dichotically presented speech syllables and piano and brass tones. When a novel stimulus (a reed tone) was introduced dichotically with the habituated speech stimulus, the infants showed a greater left than right ear response as measured by heart rate recovery. These results were taken to support the auditory asymmetries seen in older children and adults.

A 1976 study by Calderon-Teran investigated whether the established right/left ear asymmetries would remain strong under conditions of simultaneous processing of verbal and tonal information. The four dichotic testing conditions consisted of: simple dichotic tonal patterns, dichotic digits, spoken digits superimposed on piano notes in dichotic competition, and sung digits competing with tonal patterns. Calderon-Teran found that in immediate recall the expected right and left ear advantages occurred in concurrent verbal and tonal processing. Results from a delayed report condition supported the Satz, et al., (1965) findings cited earlier. Information seems to decay less rapidly in its dominant hemisphere. That is, verbal material was more easily recalled in the left hemisphere and tonal material in the right.

Further evidence for right hemisphere dominance for tonal material is provided by a Sidtis and Bryden (1978) study in which piano tones and English nouns were dichotically presented to normal subjects. After an initial

right ear advantage for tones and left ear for words, the effects reversed and the expected asymmetries appeared. Practice effects seemed to be differential in this study. Left ear performance improved only when tones were presented, and right ear improvement was dependent upon presentation of words. Like Calderon-Teran (1976), Sidtis and Bryden suggested that dichotic stimulation, at least to some degree, promotes independent processing in the two hemispheres. It might be argued that in processing complex stimuli the two hemispheres select the component for which each is dominant to process (Calderon-Teran, 1976). However, Jellison (1976) found that musically trained and untrained subjects showed a right ear rather than left ear advantage for song input in three out of four experimental conditions. The subjects listened to dichotically presented digits under verbal/song and right/left ear conditions. In general, song seemed to facilitate digit recall in all subjects, especially the trained musicians. Jellison suggested this effect may be due to the existence of two types of storage codes used in recall.

Reaction times have been used in many dichotic and a few monaural experiments to provide support for right hemisphere processing of musical stimuli. The Sidtis and Bryden (1978) study previously cited used reaction times as well as accuracy of recall to demonstrate right/left asymmetries in dichotic listening. In a monaural listening

task, Kallman (1977) instructed normal subjects to indicate whether a consonant/vowel syllable or an instrumental note was a specified target sound. Reaction times were recorded and results paralleled the usual dichotic stimulation results. Using monaural reaction times to consonant/vowel/consonant syllables and tones, Haydon and Spellacy (1973) found reaction times were faster for the right ear when tones and speech sounds were presented at random. In contrast, expected order of presentation of the tones and speech sounds produced no difference in reaction time between the ears. Haydon and Spellacy attributed these results to attentional rather than language processes.

Bradshaw, Nettleton and Geffen (1971) studied right and left hemispheric asymmetries using delayed auditory feedback (DAF) under conditions of dichotic input. The disruptive DAF was presented in competition with nondisruptive feedback while the subjects played the piano, read prose or read a word list. The right-handed, musically trained subjects were more affected (reading times increased) by disruptive DAF presented in the right ear than the left ear while reading prose or the word list. While playing the piano, the subjects were more affected (playing times increased) by the DAF presented to the left than right ear. These results support the expected asymmetries, and the researchers attributed them to the attentional process as a function of the requirements of the task.

Further evidence for hemispheric lateralization in linguistic and musical tasks is provided by the 1973 study of McKee, Humphrey and McAdam. Alpha activity was measured over the right and left temporal lobes during a series of four tasks: recognizing a musical theme and three increasingly difficult linguistic tasks based on identifying a target word. Results indicated that the normal subjects produced more alpha activity over the right hemisphere than the left whatever the task. Additionally, left/right ratios were highest for the musical task and decreased as the linguistic tasks became more difficult. The largest degree of asymmetry was seen for the music task and less asymmetry was shown as the linguistic tasks became more difficult.

Turning to studies which place a greater emphasis on musical rather than verbal processing, clinical evidence from Shankweiler (1966) and Bogen and Gordon (1974) support Kimura's (1964) position that certain musical functions are right hemisphere processes. Shankweiler found that perception of dichotically presented melodies was impaired in patients who had undergone right temporal lobectomies. However, Shankweiler maintained that the dominance of the right temporal lobe for nonverbal stimuli is weaker than the corresponding dominance of the left lobe for speech. Shankweiler (1966) stated that:

> In cases of right temporal lobe damage the presence of an epileptogenic lesion without surgical excision often shifts the balance in favor of the right ear on the melodies test, whereas on the digits test right ear superiority is found in spite of the interfering effects of an epileptogenic lesion of the dominant left hemisphere. (p. 118)

Although Gordon and Bogen (1974) found that a right carotid injection of sodium amobarbital impaired singing of melodies while leaving speech intact, the opposite was not true. After a left carotid injection, singing was much less disturbed than speech was impaired. This result supports Shankweiler's (1966) position of weaker right hemisphere dominance effects.

Cook (1975) dichotically presented musical phrases to musically trained subjects. Unlike other experiments which used recall tasks involving tonal memory, Cook required the subjects to visually recognize the phrase from several notated choices. Once again, the results indicated a left ear advantage in processing musical stimuli.

Additional support for right hemisphere processing of nonlinguistic tasks is found in the Taub, Tanguay, Doubleday and Clarkson (1976) study. Taub, et al., found that quasi-randomly presented chords evoked a significantly larger EEG response amplitude over the right than left hemisphere when the chords were presented to the contralateral (left) ear. In a very similarly designed study, Taub, Tanguay and Clarkson (1976) found that reaction

times to randomly presented chords were faster for the left ear stimuli.

Not all hemispheric asymmetry research using musical stimuli has yielded clear-cut results following the expected lateralizations. Variables such as degree of musical training, task requirement, interstimulus interval and processing strategies complicate generally held expectations. Kallman and Corballis (1975) found that reaction times for recognition of dichotically presented instrumental tones showed the expected left ear advantage during the first test block, but the advantage disappeared during the remaining three test blocks. Spellacy (1970) also found that ear asymmetry disappeared during prolonged testing. Like Spellacy, Kallman and Corballis hypothesized that the left hemisphere might be able to process musical sounds as efficiently as the right once a strategy to do so is established.

Spreen, Spellacy and Reid (1970) used only the first section of the solo violin music used in the 1970 Spellacy study to avoid dissipation of asymmetry effects. The violin music was dichotically paired with pure tone patterns. The study yielded the expected left ear advantage for musical stimuli. The results also indicated that the degree of difference in scores between ears for music and tonal patterns decreased as the length of interstimulus interval increased. Significant results were obtained at the five

second interval, but no significant difference between ears was found at the 12 second interstimulus interval.

Bartholomeus (1974) found that when different tasks were based on the same acoustical stimuli, shifts occurred in hemispheric dominance. Normal right-handed subjects were presented a series of dichotic trials. Each trial involved two different sequences of letters sung to two different melodies by two singers. Results indicated a definite left ear superiority for melody recognition. There was no difference between ears for recognition of sung voices. Bartholomeus suggested that the laterality effects in audition may be dependent upon task as well as stimulus characteristics.

Degree of musical training among subjects is another variable in the processing of musical stimuli. A Bever and Chiarello (1974) study indicated that musically trained subjects perceive dichotically presented melodies better in the right than left ear, indicating left hemisphere involvement. The reverse was shown among the musically naive subjects. Using Spellacy's 1970 solo violin music in a dichotic listening task, Johnson (1977) found significant differences between musicians and nonmusicians. Supporting the Bever and Chiarello results, Johnson found that musicians obtained more correct recognition scores with the right than left ear.

Two studies measuring alpha wave production indicate

that musicians process music differently than nonmusicians. McElwain (1979) found that dichotic listening tasks elicit more alpha wave production over the right temporal lobe in nonmusicians while musicians produced more alpha wave over the left temporal lobe. McElwain also found that musicians increase alpha wave production over time while there is a decrease for nonmusicians. Whitten (1979) measured alpha wave production during three conditions: silence, free listening to music, and listening with musical tasks. There were no significant differences in alpha wave production among tasks, but age and musical training did show differences. Overall, children showed greater asymmetry between hemispheres in alpha wave production than adults. Musically untrained adults showed more asymmetry than musicians. Since less asymmetry was shown in musically trained adults, Whitten hypothesized that music is such a complex stimulus that it involves the full response of both hemispheres to process it.

In conflict with the research just presented, Gaede, Parsons and Bertera (1978) presented some evidence indicating that processing differences might be due to musical aptitude rather than training. Aptitude of trained musicians having five or more years of lessons was determined by the Drake Musical Aptitude Test. Aptitude of the musically untrained subjects was determined by the same instrument. Experimental conditions for the tests of laterality

were the chord analysis and memory sequence analysis taken from the Wing Standardized Tests of Musical Intelligence. Disagreeing with the results of Bever and Chiarello (1974), Gaede, et al., found that both trained and untrained high aptitude subjects had significantly lower ear error scores on both tests. Experience and aptitude affected the general level of performance, but only aptitude related to ear advantage or hemispheric differences. High aptitude subjects showed minimal ear differences while low aptitude subjects had significant ear difference scores on both tests. Gaede, et al., suggested that low aptitude for music might be the result of a rigid hemispheric strategy of processing whether it be analytically or holistically oriented. In contrast, high aptitude for music might be the result of using both types of strategies flexibly depending upon the need.

Hemispheric Specialization in Time and Rhythm

The research discussed thus far indicates that although the body of literature concerning hemispheric processing of musical stimuli is growing, research in the area of musical cognition and.cerebral specialization is still fragmentary. This is especially true of research in the area of time and rhythmic processing. Existing research in the area of time and rhythm yields some seemingly conflicting

results. Some evidence exists suggesting a right or left hemisphere involvement; however, other research supports a bilateral or lack of lateralization theory. It appears that neither the right nor left hemisphere alone exhibits an unequivocal specialization for rhythm.

Some of the evidence for left hemisphere processing of rhythm is based on Lashley's (1951) exploration of temporal order in speech. Lashley theorized that left hemisphere dominance for speech is closely related to processing of the rhythmic patterns in speech. Lashley felt that speech is the best example of temporally ordered behavior. Martin (1972) added that the rhythmic patterns in speech carry a heavy information load useful in perceiving speech in and of themselves, separate from phonemes. Based on these theories, Robinson and Solomon (1974) hypothesized that nonspeech rhythm patterns would be processed by the speech hemisphere even though no phonic information was involved. Twenty-four normal, right-handed subjects were involved in a dichotic listening task requiring a forced choice recognition of pure tone rhythmic patterns. The subjects were able to accurately identify more rhythmic patterns presented to the right ear than to the left which supported the experiment's hypothesis of left hemisphere involvement.

The clinical studies of M. Gordon (1967), Needham and Black (1970) and Carmon and Nachshon (1971) provide support

for left hemisphere involvement in judgements of duration and temporal ordering of aural stimuli. M. Gordon (1967) found that patients with lesions in the dominant (left) hemisphere were not able to discriminate tone durations as accurately as patients with right lesions or control (normal) subjects. The left hemisphere lesion patients could not tell which tone of a pair was longer or shorter than the test tone with as much accuracy as the other two groups. In the 1970 Needham and Black study, aphasic subjects with left hemisphere impairments were not able to discriminate differences in pure tone durations as accurately as nonaphasic subjects. Again, the aphasics were not able to tell whether the second tone was longer or shorter than the first tone as well as the right hemisphere impaired patients or the control subjects. In the Carmon and Nachshon (1971) study, patients having left hemisphere lesions were not able to identify the order of a sequence of three, four or five audiovisual stimuli (colored lights, tones and clicking sounds) as accurately as the right lesion patients or control subjects.

A study by H. Gordon (1978) used normal college level musicians and nonmusicians in a melodies recognition task. Results showed a right ear advantage for all subjects for recognizing melodies whose changes were rhythm cued. Neither group showed a difference in ear scores for recognition of melodies whose changes were pitch cued. These

results indicate a left hemisphere involvement in recognizing rhythmic changes at least within the context of a melody. However, Gates and Bradshaw (1977b) have noted that research shows that rhythm may be processed differently when in the context of a melody than when it is separated from melody and consists only of temporal patterned stimuli.

Gregory, Harriman and Roberts (1972) presented evidence suggesting that the right hemisphere may be involved in processing the element of time. Five normal subjects listened to stimuli of 70 msec pure tones which were presented alternately to each ear. The near auditory threshold stimulus tone was paired with white masking noise in the nonstimulated ear. The experimental condition task required the subject to adjust the precise timing of incoming stimuli in the right ear so that the tones appeared regular. The timing of the tones in the right ear could be adjusted by the subject over a range of 430 to 570 msec after hearing the left ear tones which were presented every 1000 msec. Results yielded a significant difference of about four msec between the control condition and the experimental condition described above. The stimulus in the right ear was delayed relative to the stimulus in the left ear. The efficiency of the contralateral auditory pathway was taken to account for the right cerebral dominance. The right hemisphere was superior for perceiving

time of arrival of tones.

Many studies examining the two temporal aspects of auditory stimuli (time and rhythm) yield results indicating a lack of lateralization or bilateral involvement. In an early study, Milner (1962) tested a group of 27 patients having unilateral temporal lesions on the six Seashore Measures of Musical Talents tests. The tests were administered before and two weeks after temporal lobectomies were performed, 16 operations on the left and 11 on the right. On the test of rhythm, Milner found no dlfferences in scores before or after operations for either right or left lobectomy patients. On the Seashore time test, there was no before and after operation difference in scores for left lobectomy patients; however, depressed scores created a small but significant difference for right lobectomy patients (Milner, cited in Mountcastle, 1962).

The 1971 Bogen and Gordon study examined the functions of patients undergoing a right carotid artery injection of sodium amobarbital which temporarily depressed the right hemisphere's functioning. It was found that singing familiar, simple songs was grossly disturbed, being off-key or monotonic, while the intelligibility and rhythmicity of speech were not. The patients were able to maintain correct rhythms even though they were not able to produce the correct pitch. Discussing this study in a later report, Gordon and Bogen (1974) stated that the right hemisphere

depression resulted in correct rhythms although they were somewhat slowed. A separate study revealed that left hemisphere depression after sodium amobarbital did not affect rhythm either (Gordon & Bogen, 1974). Sturgis and Martin (1974) support these results stating that simple musical tunes remain recognizable when pitches are varied as long as timing relationships are left intact. The evidence seemed to indicate that rhythmic production is possible by either hemisphere independent of the ability to sing or pitch.

Schulhoff and Goodglass (1969) designed a dichotic experiment in which normal control subjects, left lesion (aphasic) and right lesion subjects were required to count the number of clicks heard in each ear. The control subjects did not show any difference in scores between ears for the task. The laterality effects in both groups of brain injured subjects were due to site of injury. There was a marked decrease in performance in the ear contralateral to the injury. This was superimposed on a marked bilateral impairment for counting clicks in both brain injured groups.

Hicks and Brundige (1974) investigated the temporal element of duration with a group of normal subjects. The experiment required the subjects to estimate the lapse of time at given intervals under three conditions: staring at a blank piece of paper, sorting cards with words into

familiar and unfamiliar stacks, and sorting cards with pictures of faces into familiar and unfamiliar stacks. Since recognition of faces is mediated by the right hemisphere and recognition of words by the left, lateralization effects were expected. However, there was no difference in scores among any of the conditions, although the experimental subjects had shorter time judgements than the control subjects who stared at the paper. Hicks and Brundige theorized that the tasks took the subjects' attention away from temporal cues. A 1970 Gordon study yielded no laterality effects on a dichotic task in which recognition of melodies played on a recorder was required. These results are in contrast to the results of the 1978 Gordon study cited earlier in which a dichotic melodies task showed left hemisphere dominance effects. One difference between the two studies that may have affected the results is that the 1970 study used college level musicians, and the 1978 study used both musicians and nonmusicians. The 1970 study also showed a significant left ear/right hemisphere dominance for distinguishing chords. Gordon concluded that the chords task involved only one cue, pitch, whereas the melodies task involved two cues, pitch and rhythm. Since pitch is a right hemisphere, nontemporal quality and rhythm is a temporal, possibly left mediated quality, Gordon proposed that these two cues confounded the results and accounted for the lack of laterality.

Gates and Bradshaw (1977a) conducted six dichotic experiments in which a series of five notes were altered by pitch, harmony and rhythm. In the third experiment, the note pattern was altered by rhythm only, and subjects were able to perceive rhythm changes faster with the left ear. The right ear was more accurate in analyzing the rhythmic changes. Faster perception of rhythmic changes by the left ear would appear to support the Gregory, Harriman and Roberts (1972) study cited earlier in which the right hemisphere was involved in perceiving the time of arrival of tones. More accurate perception of rhythm changes by the right ear would seem to support the Robinson and Solomon (1974) study cited earlier in which the left hemisphere perceived pure tone rhythmic patterns more accurately than the right.

The 1970 Spellacy study discussed earlier partially involved a task requiring recognition of tone pulse patterns either five or 12 seconds after their dichotic presentation. No lateralization effects were found for either the five or 12 second conditions. Among three other dichotic experimental conditions (music, frequency and timbre), only music showed a dominance effect and that was for the right hemisphere at the five second interval. The 12 second interval did not yield lateralization under any condition.

In an experimental task requiring subjects to

binaurally tap out rhythms to speech and musical stimuli, Vrtunski (1977) found that contralateral relationships were stronger than ipsilateral ones as revealed by EEG measures. However, no lateralization was found during stimulation. Tapping responses did not show any phase or linear relationship differences in motor activities between tasks. This study indicated that rhythm may be processed by either hemisphere.

Bradshaw, Nettleton and Geffen (1972) designed a series of experiments involving delayed auditory feedback (DAF). The task in experiment four required subject responses ranging from purely verbal, nonrhythmic responses to nonverbal, rhythmic responses. The subjects were required to complete five tasks under DAF conditions: read a prose passage, repeat a meaningful rhythmic refrain ("there was a nice little old armchair"), repeat a meaningless rhythmic sequence ("da" and "di" syllables), whistle on a recorder, and manually tap out the "armchair" refrain (Bradshaw, Nettleton & Geffen, 1972, p. 237). Results showed a significant right ear effect for the prose passage and a lesser right ear effect for the armchair phrase. Thus, a greater and lesser degree of left hemisphere involvement was implied. Significant left ear effects were observed for whistling without thinking the words of the "armchair" refrain and, to a lesser extent, whistling while covertly thinking the words. These results were taken to

imply right hemisphere involvement to a greater and lesser extent. Significant right hemisphere effects were shown by the manual tapping without covert thinking condition. Covertly thinking the words while tapping reduced the magnitude of the left ear effect and implied a lesser degree of right hemisphere involvement. Bradshaw, et al., concluded that cerebral asymmetry can be described as a continuum which extends from left to right hemisphere with a neutral or undifferentiated zone in the middle. They did not theorize whether or not the center zone represents joint participation by the two hemispheres.

Halperin, Nachshon and Carmon (1973) used temporally patterned nonverbal stimuli to demonstrate a shift from left to right ear advantage as the experimental task requirements became more complex. The normal subjects were given two dichotic listening tasks which required them to identify sets of sounds differing in their sequential complexity of frequency (combinations of high and low sounds) or complexity of duration (combinations of long and short sounds). Results showed a left ear/right hemisphere superiority at zero transitions for both frequency (e.g., High-High-High) and duration (e.g., long, long, long) trials. At one transition, subjects showed a tendency toward left ear superiority for frequency trials (e.g., High-Low-High) and a tendency toward right ear superiority for duration trials (e.g., long-short-long).

The magnitude of difference between ears was greater for frequency than duration trials at all number of transitions. Data showed that as the number of transitions progressed from zero to two, a shift from left ear to right ear superiority took place. The researchers concluded that the direction of ear superiority for the reports varied as a function of the complexity of the temporal pattern.

Natale (1977) tested right-handed college students on a series of handedness measures and on dichotically presented repeated, nonverbal, rhythmic sequences. The handedness measures included manual tasks as well as a self report instrument. Analysis revealed that the manual handedness tasks were positively related to the degree of left hemisphere asymmetry for recognition of the dichotic rhythmic sequences. The data also showed a significant left hemisphere superiority for recognition of the rhythmic stimuli. Similar to the results of Halperin, et al., (1973), Natale found increased left hemisphere asymmetry for complex rhythmic trials as opposed to easy trials. As a group, subjects showed a greater right ear lateralization for the hard rhythms.

Papcun, Krashen, Terbeek, Remington and Harshman (1974) conducted a dichotic listening experiment in which Morse code signals were presented to Morse code operators and Morse code naive subjects. The dot and dash signals were composed of units: a dot was one unit, a space was

one unit, and a dash was three units. Morse code operators showed a right ear advantage for perceiving signals of all lengths or number of units. The Morse code naive subjects also showed a right ear advantage for perceiving signals up to seven units long, but they showed a left ear advantage for signals over seven units long. This shift in dominance from left to right hemisphere would seem to concur with the Halperin, et al., (1973) results suggesting that shift in hemispheric dominance may be a function of complexity of task or stimuli. Papcun, et al., were not able to determine whether it was the temporal length restriction or the number of units that brought about the shift in ear advantage. The researchers hypothesized that seven may represent a threshold for processing information. Seven units may be the limit of the immediate memory span for transmitting information. Thus, the naive subjects may have been able to process the stimuli with seven or fewer units by noting the individual elements in the signal and by lateralizing the shorter signals to the left hemisphere. However, the longer signals of more than seven units may have forced the naive subjects to adopt strategies taking into account the holistic qualities of the signals and thus lateralize them to the right hemisphere.

Summary

The old assumption that the type of stimulus material, verbal, nonverbal or music, is the only index of which ear gives a better performance has been questioned (Critchley, 1977). Research has shown that a lack of the verbal component is not enough to insure right hemisphere superiority (Gordon, 1978). If under certain conditions, such as temporal patterning, nonverbal stimuli can be mediated by the left hemisphere, then the old assumptions do not hold (Halperin, Nachshon & Carmon, 1973). Nonverbal temporal sequences and speech may be processed in the same hemisphere not because of two independent processes but because of one basic underlying process: temporal analysis (Carmon & Nachshon, 1971). It has been suggested that the division of labor between the two hemispheres may not have so much to do with the specific musical stimuli as with different perceptual dimensions or mode of response (Carmon & Nachshon, 1971; Gordon, 1978).

Accumulated evidence seems to indicate that the left hemisphere can be involved in accurately perceiving rhythmic changes (Gates & Bradshaw, 1977a; H. Gordon, 1978; Robinson & Solomon, 1974; Natale, 1977), judging duration (M. Gordon, 1967; Needham & Black, 1970), and order of sequence (Carmon & Nachshon, 1971). In all of these tasks, processing strategies involve comparison or analysis of

elements within the sequence, a process most suited for left hemisphere mediation.

Other research has shown that the strategies involved in processing temporal patterns of nonverbal stimuli may be a function of complexity of task (Halperin, Nachshon & Carmon, 1973; Natale, 1977) or of complexity of stimuli (Papcun, Krashen, Terbeek, Remington & Harshman, 1974).

There is less research available investigating possible right hemisphere involvement in processing time and rhythm. Gregory, Harriman and Roberts (1972) found the right hemisphere to be superior in judging the time of arrival of pure tones. Gates and Bradshaw (1977a) found the right hemisphere was able to detect rhythm changes faster than the left hemisphere when note values were lengthened. There was no difference between ears for notes whose values were shortened. Bogen and Gordon (1974) found that right hemisphere depression induced by sodium amobarbital injection did not impair rhythmic accuracy in singing a familiar song, but it did slow the rhythms down. In the first two cases, the time of arrival of stimuli seems to be the critical factor in producing right hemisphere involvement. In the last case, right hemisphere depression left the duration and sequential aspects of rhythmic production intact, but the overall tempo was impaired by slowing down, a possible indication of right hemisphere involvement.

CHAPTER IV

METHOD

The Subjects

The subjects consisted of 30 nonstudent and college student volunteers. Nonstudent volunteers were from Kalamazoo, Michigan. Student volunteers were from Western Michigan University, Kalamazoo, Michigan, and College of Mount St. Joseph on the Ohio, Cincinnati, Ohio. The subjects' ages ranged from 19 to 26 years old with a mean age of 20.8 years. The 26 female subjects had a mean age of 20.4 years while the four male subjects had a mean of 23.0 years. All subjects were right-handed, nonmusicians and had normal hearing. The subjects were not enrolled in a college school of music, were not members of a music organization at Western Michigan University or College of Mount St. Joseph on the Ohio and had less than three years of private or group choral or instrumental music study during their public school experience. The criteria for the definition of nonmusician are the same as used by Madsen (1979).

Musicians were not included in this experiment because it is known that musicians perceive musical stimuli, in many cases, differently than the nonmusician (Bever &

Chiarello, 1974). It is not clearly known whether the difference in perception is a function of training, a different processing strategy or other variables as yet unidentified.

All subjects were right-handed to reduce the probability of confounding the results due to right hemisphere or mixed hemispheric dominance for speech patterns (Satz, Achenbach, Pattishall & Fennell, 1965; Wada & Rasmussen, 1960). Mixed speech representation may be an indication of mixed patterns of perception for musical stimuli, especially time and rhythm which are so closely related to speech. Handedness of the subjects was assessed by the Edinburg Inventory for Handedness (Oldfield, 1971). (See Appendix A)

Normal hearing within the range needed for this experiment was assessed by a hearing interview (See Appendix B) and three audiometric tests (See Appendix C). The subjects were first screened by a pure tone air conduction sweep check for their ability to detect pure tones of 250, 500, 750, 1000, 2000, 4000 and 8000 Hz delivered monaurally at a hearing threshold level of 15 dB. After passing this initial screening, the pure tone air conduction hearing threshold level of each ear at 750 Hz and 1000 Hz was determined for all subjects. This hearing threshold level was defined as the lowest intensity at which a 750 Hz and 1000 Hz pure tone could be perceived 50% of the time it was

introduced (Carhart & Jerger, 1959). Finally, each subject received a tone decay test. Pure tones of 750 Hz and 1000 Hz were presented for 60 seconds at 20 dB hearing threshold level to the left ear and the right ear. The tone decay test was used to check for damage to the auditory portion of Nerve VIII.

Apparatus

The subjects were tested individually and were seated at a desk in the experimental room. The experimenter was seated out of the subject's range of vision. Testing at Western Michigan University was conducted in a double-walled sound isolation room in a sound suite (IAC 1200 series). An isolated, sound attenuated listening room was used for testing at College of Mount St. Joseph on the Ohio. The absolute level of ambient noise was 29 dB at 1000 Hz and 32 dB at 800 Hz. The background noise measurements (See Appendix D) were taken under actual test conditions with an Ivie Electronics (Model 1E-30A) Audio Analyzer placed on the desk where the subject was seated.

Equipment in both testing rooms included a 48K Apple II Plus computer and monitor, demographic questionnaires (See Appendix E), audiometric examination forms, handedness inventories, and a pen. A Grason-Stadler 1701 audiometer and headphones was used for testing at Western Michigan University. A Tracor RA115A Rudmose clinical audiometer

with headphones was used at College of Mount St. Joseph on the Ohio for testing.

Description of Stimuli

The acoustic signals for the constant and modulated rhythmic patterns in this experiment were computer generated. A special computer program was developed for the experiment. The program was run on a 48K Apple II Plus with a special circuit board containing oscillators that output to the two audiometer channels and into the headphones.

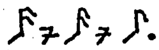
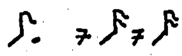
Each trial in the experiment consisted of two different rhythmic patterns presented dichotically. One pattern was the experimental item, and the stimuli in this item consisted of a repeating, pure tone temporal pattern which increased or decreased in tempo. The other pattern was the competing dichotic input item. The stimuli of the competing input item consisted of a repeating pure tone whose temporal pattern remained constant in tempo. Both patterns in the dichotic pair had the same initial tempo marking. After five seconds of remaining at a constant tempo, the experimental pattern modulated in tempo (decrease or increase) or remained constant. The competing input pattern remained constant at the initial tempo for all trials.

Computer generated pure tone acoustic signals were chosen for the rhythmic patterns to avoid confounding

effects of overtones (Papcun, Krashen, Terbeek, Remington & Harshman, 1974). Temporal patterns separated from melody were chosen to avoid the effects of intensity, timbre and pitch (Gordon, 1970, 1978). In a task of temporal perception such as this, continuously repeating patterns represent one way of eliminating effects of memory and order of report (Carmon & Nachshon, 1971; Warren, Obusek, Farmer & Warren, 1969). Both patterns in each trial were synchronized to prevent subjects from detecting modulations through differences in onset and offset of the patterns.

Each pattern in the dichotic pair was assigned a different frequency (750 Hz or 1000 Hz) to maximize discrimination (Spellacy, 1970). The choice of 1000 Hz was consistent with previous dichotic research (Halperin, Nachshon & Carmon, 1973; Needham & Black, 1970; Papcun, Krashen, Terbeek, Remington & Harshman, 1974; Spellacy, 1970). The 750 Hz tone was paired with 1000 Hz to approximate the 707 Hz and 1000 Hz signals used by Papcun, et al., for their Morse code study (1974).

The repeating, rhythmic patterns were based upon the time relationships used in Morse code. Each letter of the Morse code is represented by some combination of dots, spaces, and/or dashes. In the converted rhythmic form, each dot was equal to a sixteenth note, each space a sixteenth rest, and each dash a dotted eighth note. The

durational relationship of dots to dashes (1:3) is the same as sixteenth notes to dotted eighth notes (1:3). The Morse code units in the letters "u" and "d" were the basis for the two rhythmic patterns used in the experiment. The letter "u" in Morse code is written as " . . - " and is composed of a dot, space, dot, space and dash sequence. The rhythmic pattern derived from the letter "u" is written as  and is a sixteenth note, sixteenth rest, sixteenth note, sixteenth rest, and dotted eighth note sequence. The letter "d" is written as " - . . " in Morse code and as  in the converted rhythmic pattern.

The sixteenth note rest representing a space was not only proportional but served to inhibit illusory continuity of the sounds. When successive sounds are heard without pauses, auditory induction can cause one sound to appear to continue even though the physical sound has been discontinued (Warren, 1974b). Nábělek, Nábělek and Hirsh (cited in Warren, 1974b) found that brief silent pauses between short tone bursts help reduce the tones' tendency to run together.

The experimental test item in each trial was a repeating, rhythmic pattern. At an initial tempo of 80 mm, the pattern stayed at a constant tempo for five seconds and then modulated at the rate of one mm (Malzel's metronome marking) per second. A precedent for modulating at this

rate was set by Kuhn (1974) and Madsen (1979). The amount of change was 10 mm in either direction. The rhythmic patterns at an initial tempo of 160 mm stayed at a constant tempo for five seconds and then modulated at the rate of two mm per second. The amount of change was 20 mm in either direction. Thus, the patterns at both initial tempi lasted 15 seconds: five seconds at a constant tempo and 10 seconds modulating in tempo.

Two initial tempi were selected for use in this study as a conservative answer to the issue of tempo effects. Kuhn (1974) used four initial tempi (60, 90, 120, 150 mm), and Madsen (1979) used nine (40, 60, 80, 100, 120, 140, 160, 180, 200 mm). Although neither Kuhn nor Madsen found significant main effects or interactions due to tempo, the conservative approach of two initial tempi, 80 mm and 160 mm, was chosen since the present study involved a dichotic rather than binaural listening task and used only nonmusicians.

The initial tempi, expressed in beats per minute, and the ranges of modulation (decrease or increase) were as follows: 80 to 70 or 90 mm and 160 to 140 or 180 mm.

The 16 modulating trials in the experiment were completely counterbalanced. The "u" rhythmic pattern was assigned to channel one of the audiometer and the "d" pattern was assigned to channel two. The ear of presentation, direction of modulation, initial tempo, and frequency were

randomly assigned. Eight modulations were presented in the left ear and eight in the right ear. The modulations in eight trials decreased in tempo while eight increased in tempo. Eight trials modulated from an initial tempo of 80 mm and eight from 160 mm. The frequency assigned to ear of modulation was 750 Hz in eight trials and 1000 Hz in eight trials.

The four constant trials used both initial tempi and both frequencies. The order of presentation for the constant and modulating trials was randomly assigned. All subjects received the 20-trial test in the same order; however, the headphones were reversed for every other subject so that half of the subjects received the trials in the original ear of presentation order, and half of the subjects received the trials in a reversed ear of presentation order.

Procedure

Upon entering the testing room, each subject completed a demographic questionnaire which included questions about the subject's musical background and a statement of consent to participate in the research project. The handedness inventory was then completed and scored according to Oldfield's (1971) procedure. The hearing interview was conducted, and finally, normal hearing was ascertained according to the three previously described procedures.

The experimental testing was done with the subject wearing headphones and sitting at a table containing the computer and monitor. The audiometer and computer were interfaced, and the entire experiment was presented through headphones.

The acoustic stimuli were presented through headphones at 35 dB above hearing threshold level in each ear for each subject (Rintelmann, 1979). This individualized method was chosen rather than a single level of presentation, such as 62 dB, to insure that the perceived loudness of the dichotic stimuli was approximately equal for all subjects. This procedure controlled for dichotic effects due to any slight interaural differences in sensitivity (Natale, 1977).

The experimenter verbally gave the directions while the subject read a printed copy (See Appendix F). After the subject received the directions, the rest of the experiment was subject directed at the prompting of the computer program.

The program required the subject to type his/her last name on the computer keyboard. The name was used to identify subject files. Prompts were flashed on the monitor screen at every step of the experiment, giving directions and indicating the beginning of practice or test trials. After hearing the two practice examples, the subject was given the chance to ask the experimenter any questions

he/she might have before beginning the 20 test trials. The subject depressed any key on the keyboard to begin the test trials. Once the test trials began the experimenter did not interact with the subject and sat out of the subject's range of vision.

The subject's task was to listen to the dichotic rhythmic patterns until he/she heard the modulation and then to depress either the "slower" or "faster" key on the computer keyboard. For example, trial 10 had an initial tempo of 80 mm with a frequency of 750 Hz assigned to the constant, repeating rhythmic pattern in the left ear and a frequency of 1000 Hz assigned to the modulating, repeating rhythmic pattern in the right ear. After five seconds of constant tempo, the pattern in the right ear gradually decreased in tempo from 80 mm to 70 mm. As soon as the subject detected the modulation, the subject would depress the "slower" computer key. The computer then recorded the number of elapsed seconds between the beginning of the trial and the point at which the key was depressed. The computer also recorded whether the subject response was slower or faster. If the subject did not hear a modulation, he/she did nothing and simply waited for the trial to end. The computer would then record the reaction time as 15 seconds and the subject response as "constant."

After completing the test trials, each subject was debriefed. The experimenter asked three questions:

(1) Was it easier to hear changes that got faster, changes that got slower, or was there no difference? (2) Was it easier to hear changes when the original speed was fast, the original speed was slow, or was there no difference? (3) Describe in your own words the strategy you used to deal with this task

CHAPTER V

RESULTS

The major purpose of this study was to investigate the effect of ear of presentation on perception of modulation as measured by reaction time and accuracy of response. Reaction time was assessed by the total number of elapsed seconds between the beginning of each trial and the point at which the subject heard the modulation and depressed either the slower or faster key on the computer. Accuracy of response for direction of modulation (decrease or increase) was assessed by recording the total number of correct computer key depressions (slower or faster) for stimuli presented to the left and right ear.

Main effects for ear of presentation (left/right), direction of modulation (decrease/increase), level of tempo (80 mm/160 mm), and frequency (750 Hz/1000 Hz) were analyzed for their effect upon reaction time and upon accuracy of response. In addition, the interaction effects of ear by modulation, ear by tempo, and ear by frequency were analyzed for their effect upon reaction time and accuracy of response. Although other interaction analyses were possible, the present study did not hypothesize about them, and they were not included in the analysis.

Four constant trials were included in the experiment to discourage subjects from randomly guessing modulations. During these four trials, modulation did not occur in either direction. Although data were taken on the constant trials, they were not part of the hypotheses and were not included in the analysis.

Reaction Time

Main Effects

Reaction time scores had a possible range of .01 to 14.99 seconds since each trial lasted 15 seconds. Although each trial remained at a constant tempo for five seconds before modulation, it was possible for the subject to depress the slower or faster computer keys before five seconds had elapsed. If neither computer keys were depressed before the end of the trial, the response was recorded as 15 seconds.

Left and right ear reaction time mean and standard deviation scores are reported in Table 1. Mean reaction times for perception of modulations were 10.98 seconds for the right ear and 11.05 seconds for the left ear. A multivariate analysis of variance found no significant difference between left ear and right ear reaction times, $F(1, 58) = .063$, $p > .05$.

Table 1

Reaction Time Means and
Standard Deviations for Ear

	Ear	
	Left	Right
Mean	10.98	11.05
Standard Deviation	3.26	3.07

Note. Reaction times reported in seconds

Reaction time mean and standard deviation scores for perception of decreased and increased modulations are reported in Table 2. Modulations that decreased in tempo resulted in a mean reaction time score of 11.08 seconds while modulations that increased in tempo resulted in a mean of 10.95 seconds. A multivariate analysis of variance found no significant difference between increased modulation and decreased modulation reaction times, $F(1, 58) = .225$, $p > .05$.

Table 2

Reaction Time Means and
Standard Deviations for Modulation

	Modulations	
	Decrease	Increase
Mean	11.08	10.95
Standard Deviation	3.41	2.91

Note. Reaction times reported in seconds

Reaction time mean and standard deviation scores for rhythmic patterns having initial tempi of 80 mm and 160 mm are reported in Table 3. The mean reaction time for the perception of modulation in rhythmic patterns at an initial tempo of 80 mm was 11.89 seconds. However, rhythmic patterns at an initial tempo of 160 mm yielded a mean reaction time of 10.14 seconds, and a multivariate analysis of variance found a sifnificant difference between 80 mm and 160 mm tempi reaction times, $\underline{F}(1, 58) = 36.87$, $\underline{p} < .001$. Reaction times were significantly faster for perception of modulations in rhythmic patterns having an initial tempo of 160 mm. Subjects were able to hear modulations more quickly when the initial tempo was fast than when the initial tempo was slow.

Table 3

Reaction Time Means and
Standard Deviations for Tempi

	Tempi	
	80 mm	160 mm
Mean	11.89	10.14
Standard Deviation	3.05	3.04

Note. Reaction times reported in seconds

Reaction time mean and standard deviation scores for rhythmic patterns with frequencies of 750 Hz and 1000 Hz are reported in Table 4. Rhythmic patterns presented at 750 Hz yielded a mean reaction time of 10.92 seconds for perception of modulation. Rhythmic patterns presented at 1000 Hz yielded a mean reaction time of 11.11 seconds. A multivariate analysis of variance found no significant difference between 750 Hz frequency and 1000 Hz frequency reaction times, $\underline{F}(1, 58) = .484$, $\underline{p} > .05$.

Table 4

Reaction Time Means and
Standard Deviations for Frequencies

	Frequencies	
	750 Hz	1000 Hz
Mean	10.92	11.11
Standard Deviation	3.10	3.24

Note. Reaction times reported in seconds

Interactions

Reaction time means and standard deviations for levels of ear and modulation, ear and tempo, and ear and frequency are reported in Tables 5, 6 and 7 respectively. A multivariate analysis of variance found no significant interaction effect on reaction times between ear and modulation (F [1, 58] = .590, $p > .05$), ear and tempo (F [1, 58] = .022, $p > .05$), and ear and frequency (F [1, 58] = .604, $p > .05$).

Table 5

Reaction Time Means and Standard Deviations for Ear and Modulation

	Modulation			
	Decrease		Increase	
Ear	Mean	St. Dev.	Mean	St. Dev.
Left	11.23	3.31	10.90	3.09
Right	10.94	4.25	10.98	3.00

Note. Reaction times reported in seconds

Table 6

Reaction Time Means and Standard Deviations for Ear and Tempo

	Tempo			
	80 mm		160 mm	
Ear	Mean	St. Dev.	Mean	St. Dev.
Left	11.86	2.87	10.19	3.09
Right	11.83	3.64	10.13	3.07

Note. Reaction times reported in seconds

Table 7

Reaction Time Means and Standard Deviations for Ear and Frequency

	Frequency			
	750 Hz		1000 Hz	
Ear	Mean	St. Dev.	Mean	St. Dev.
Left	11.09	2.96	11.04	3.21
Right	10.77	3.18	11.18	3.24

Note. Reaction times reported in seconds

Accuracy of Response

Main Effects

Accuracy of response scores had a possible range of zero to eight correct responses. Because the study was completely counterbalanced, eight modulations were presented in the left ear and eight in the right ear. The modulations in eight trials decreased in tempo while eight increased in tempo. Eight trials modulated from an initial tempo of 80 mm and eight from 160 mm. A frequency of 750 Hz was assigned to the ear of modulation in eight trials and 1000 Hz to the ear of modulation in eight trials.

Left ear and right ear accuracy of response mean and standard deviation scores are reported in Table 8. Mean

accuracy of response scores for perception of modulations were 3.37 for the right ear and 3.03 for the left ear. A multivariate analysis of variance found no significant difference between left ear and right ear accuracy scores, $F(1, 29) = 1.09$, $p > .05$.

Table 8

Accuracy of Response Means and Standard Deviations for Ear

	Ear	
	Left	Right
Mean	3.37	3.03
Standard Deviation	1.05	1.47

Note. Accuracy scores reported in number correct out of eight possible

Accuracy of response mean and standard deviation scores for perception of decreased and increased modulations are reported in Table 9. Modulations that decreased in tempo yielded a mean accuracy of response score of 2.07 while modulations that increased in tempo yielded a mean of 4.33. A multivariate analysis of variance found a significant difference between increased modulation and decreased modulation accuracy scores, $F(1, 29) = 39.26$, $p < .001$. Accuracy of response scores were significantly higher for

perception of modulations that increased in tempo. Subjects were able to more accurately hear modulations that got faster than modulations that got slower.

Table 9

Accuracy of Response Means and Standard Deviations for Modulations

	Modulation	
	Decrease	Increase
Mean	2.07	4.33
Standard Deviation	1.21	1.49

Note. Accuracy scores reported in number correct out of eight possible

Accuracy of response mean and standard deviation scores for rhythmic patterns at initial tempi of 80 mm and 160 mm are reported in Table 10. Rhythmic patterns at an initial tempo of 80 mm yielded a mean accuracy of response score of 2.57 for perception of modulation. However, rhythmic patterns at an initial tempo of 160 mm yielded a mean of 3.83. A multivariate analysis of variance found a significant difference between 80 mm tempo and 160 mm tempo accuracy scores, $\underline{F}(1, 29) = 19.42$, $\underline{p} < .001$. Accuracy of response scores were significantly higher for perception of modulations in rhythmic patterns having an initial tempo

of 160 mm. Subjects were able to more accurately hear modulations from a fast initial tempo than from a slow initial tempo.

Table 10

Accuracy of Response Means and Standard Deviations for Tempi

	Tempi	
	80 mm	160 mm
Mean	2.57	3.83
Standard Deviation	1.23	1.21

Note. Accuracy scores reported in number correct out of eight possible

Accuracy of response mean and standard deviation scores for rhythmic patterns with frequencies of 750 Hz and 1000 Hz are reported in Table 11. Rhythmic patterns at 750 Hz yielded a mean accuracy of response score of 3.53 for perception of modulation. Rhythmic patterns at 1000 Hz yielded a mean of 2.87. A multivariate analysis of variance found no significant difference between 750 Hz and 1000 Hz frequency scores, $F(1, 29) = 3.26$, $p > .05$.

Table 11

Accuracy of Response Means and Standard Deviations for Frequencies

	Frequencies	
	750 Hz	1000 Hz
Mean	3.53	2.87
Standard Deviation	1.41	1.33

Note. Accuracy scores reported in number correct out of eight possible

Interactions

Accuracy of response means and standard deviations for levels of ear and modulation, ear and tempo, and ear and frequency are reported in Tables 12, 13 and 14 respectively. A multivariate analysis of variance found no significant interaction effect upon accuracy of response between ear and modulation ($F[1, 29] = 2.33$, $p > .05$), ear and tempo ($F[1, 29] = .155$, $p > .05$), and ear and frequency ($F[1, 29] = 1.41$, $p > .05$).

Table 12

Accuracy of Response Means and
Standard Deviations for Ear and Modulation

	Modulation			
	Decrease		Increase	
Ear	Mean	St. Dev.	Mean	St. Dev.
Left	1.00	.77	2.37	.84
Right	1.07	.81	1.97	1.09

Note. Accuracy scores reported in number correct out of eight possible

Table 13

Accuracy of Response Means and
Standard Deviations for Ear and Tempo

	Tempo			
	80 mm		160 mm	
Ear	Mean	St. Dev.	Mean	St. Dev.
Left	1.40	.76	1.97	.89
Right	1.17	.90	1.87	.96

Note. Accuracy scores reported in number correct out of eight possible

Table 14

Accuracy of Response Means and
Standard Deviations for Ear and Frequency

	Frequency			
	750 Hz		1000 Hz	
Ear	Mean	St. Dev.	Mean	St. Dev.
Left	1.93	.81	1.43	.76
Right	1.60	1.05	1.43	.92

Note. Accuracy scores reported in number correct out of eight possible

Summary

The difference in mean reaction time for the two levels of tempo was significant at the .001 level. Subjects were able to hear modulations more quickly when the initial tempo was 160 mm than when the initial tempo was 80 mm. Reaction times for all other main effects of ear, modulation and frequency were not significant. Reaction times for all interactions between ear and modulation, ear and tempo, and ear and frequency were not significant.

Accuracy of response scores were significantly affected by the main effects of modulation and tempo. Subjects were more than twice as accurate in detecting modulations that got faster than modulations that got slower. Subjects

were also able to more accurately identify the modulations when the initial tempo was 160 mm than when the initial tempo was 80 mm. Accuracy of response scores for the main effects of ear and frequency were not significant. Accuracy of response scores for all interactions between ear and modulation, ear and tempo, and ear and frequency were not significant.

The null hypotheses tested were divided into four main categories: (1) Main effects for ear of presentation, direction of modulation, level of tempo, and frequency upon reaction time were tested in hypotheses one, two, three and four. (2) The effects of interactions between ear and modulation, ear and tempo, and ear and frequency upon reaction time were tested in hypotheses five, six and seven. (3) Main effects for ear of presentation, direction of modulation, level of tempo, and frequency upon accuracy of response scores were tested in hypotheses eight, nine, ten and eleven. (4) The effects of interactions between ear and modulation, ear and tempo, and ear and frequency upon accuracy of response scores were tested in hypotheses twelve, thirteen and fourteen.

Following is a list of each null hypothesis tested and the results.

(1) It was hypothesized that there would be no difference in total reaction time scores for perceiving modulations between the left ear and the right ear. Not

rejected.

(2) It was hypothesized that there would be no difference in total reaction time scores for perceiving modulations between modulations that decrease in tempo and modulations that increase in tempo. Not rejected.

(3) It was hypothesized that there would be no difference in total reaction time scores for perceiving modulations between modulations at an initial tempo of 80 mm and modulations at an initial tempo of 160 mm. Rejected.

(4) It was hypothesized that there would be no difference in total reaction time scores for perceiving modulations between modulations at a frequency of 750 Hz and modulations at a frequency of 1000 Hz. Not rejected.

(5) It was hypothesized that there would be no effect upon reaction time scores due to the interaction between levels of ear and modulation. Not rejected.

(6) It was hypothesized that there would be no effect upon reaction time scores due to the interaction between levels of ear and tempo. Not rejected.

(7) It was hypothesized that there would be no effect upon reaction time scores due to the interaction between levels of ear and frequency. Not rejected.

(8) It was hypothesized that there would be no difference in total accuracy of response scores for perceiving modulations between the left ear and the right ear. Not rejected.

(9) It was hypothesized that there would be no difference in total accuracy of response scores for perceiving modulations between modulations that decrease in tempo and modulations that increase in tempo. Rejected.

(10) It was hypothesized that there would be no difference in total accuracy of response scores for perceiving modulations between modulations at an initial tempo of 80 mm and modulations at an initial tempo of 160 mm. Rejected.

(11) It was hypothesized that there would be no difference in total accuracy of response scores for perceiving modulations between modulations at a frequency of 750 Hz and modulations at a frequency of 1000 Hz. Not rejected.

(12) It was hypothesized that there would be no effect upon accuracy of response scores due to the interaction between levels of ear and modulation. Not rejected.

(13) It was hypothesized that there would be no effect upon accuracy of response scores due to the interaction between levels of ear and tempo. Not rejected.

(14) It was hypothesized that there would be no effect upon accuracy of response scores due to the interaction between levels of ear and frequency. Not rejected.

CHAPTER VI

DISCUSSION

Based on previous research by Kuhn (1974) and Madsen (1979), it had been predicted that, at both initial tempi, modulations that decreased in tempo would be more accurately perceived than modulations that increased in tempo regardless of ear of presentation. The data did not support this prediction. Subjects were able to accurately perceive twice as many modulations that increased in tempo as modulations that decreased in tempo. In addition, subjects were significantly more accurate in perceiving the direction of modulation at an initial tempo of 160 mm, and were faster in doing so as well.

Anecdotal feedback gathered from each subject following testing supported the results. The debriefings revealed a tendency for subjects to perceive themselves as more easily hearing modulations that increased in tempo than modulations that decreased in tempo. Eighteen subjects thought they were able to hear modulations that increased in tempo more easily; three thought they were able to hear decreases more easily. Seven thought they could hear increases and decreases equally as well while two subjects could not discriminate which type of modulation was easier or if both

were of equal difficulty.

The subjects may have been able to respond more quickly and accurately to modulations at the 160 mm tempo because there were more repetitions of the rhythmic patterns at the faster tempo than at the slower tempo. Mean reaction time was 10.14 seconds at 160 mm and 11.89 seconds at 80 mm. Subjects identified 116 modulations correctly at the fast tempo but only 76 modulations at the slow tempo. Also, because the decrements and increments were two mm per second at the 160 mm tempo and one mm per second at the 80 mm tempo, the change may have been more easily discerned at the fast than slow tempo. This would have allowed the subjects to respond more quickly and accurately to decrease as well as increase modulations at the fast tempo. There were 79 increasing modulations and 37 decreasing modulations correctly identified at 160 mm as opposed to 51 increasing and 25 decreasing modulations correctly identified at 80 mm. Finally, during each trial, the rhythmic patterns started in phase, went out of phase, came back into phase during modulation, and went out of phase once again. Coming into phase during modulation occurred more quickly at the 160 mm tempo than at the 80 mm tempo, and this may have resulted in faster reaction times by providing a basis for comparison of the two rhythms that was not available as quickly at the slower tempo.

Results of the study did not yield any significant interactions between ear and modulation, ear and tempo or ear and frequency for either reaction time or accuracy of response. It had been predicted that there would be a right ear advantage for accurate perception of modulations. It had also been predicted that there would be a left ear advantage for reaction time to modulations that decreased in tempo. Finally, it had been predicted that there would be no difference in reaction time between ears for modulations that increased in tempo. The last prediction was supported by the data. However, the lack of interaction between ear and decrease/increase modulations for accuracy of response and reaction time indicated an overall lack of lateralization for the task in the present study.

The issue of task difficulty was examined as a possible explanation for the lack of lateralization effects. The mean accuracy scores for detecting modulations of 3.37 for the left ear and 3.03 for the right ear out of a possible eight would indicate that the task was a difficult one. However, both accuracy scores were above the random guessing level. Since the subject had three response choices (decrease, increase and constant) in every trial, random guessing would have yielded a mean of approximately 2.67 correct out of eight.

Further, random guessing by the subjects as an explanation for the lack of lateralization effects was not

supported by the results of three of the main effects. First, subjects correctly identified a mean of twice as many modulations that increased (4.03) as modulations that decreased (2.07). Second, subjects were able to accurately detect a mean of 3.83 modulations at the fast tempo as compared to a mean of 2.57 at the slow tempo. Third, subjects heard modulations significantly faster at the 160 mm tempo (mean of 10.14 seconds) than at the 80 mm tempo (mean of 11.89 seconds). The data would not have yielded these patterns had the subjects been randomly guessing.

It is also reasonable to assume that if the subjects had been randomly guessing, some of the mean accuracy scores would have fallen well above and some well below the 2.67 correct out of eight guessing level. Mean accuracy scores for the main effects did not show such a pattern. Mean accuracy scores ranged from 2.07 for the decrease modulation condition to 4.33 for the increase modulation condition. Accuracy standard deviation scores ranged from 1.21 for the decrease modulation condition to 1.49 for the increase modulation condition.

Finally, if the task were too difficult, the reaction time scores would have either fluctuated widely due to random guessing or hovered around the 15 second mark because of subject inability to hear the modulations. The data did not support either alternative. The mean reaction time scores for the main effects ranged from 10.14 seconds

for the 160 mm tempo condition to 11.89 seconds for the 80 mm tempo condition. The standard deviation scores ranged from 2.91 seconds for the increase modulation condition to 3.41 seconds for the decrease modulation condition.

After examining the pattern of results for the main effects for reaction time and accuracy scores, it was concluded that although the task was a difficult one it was not an impossible one. Task difficulty or random guessing did not confound possible lateralization effects.

It might be theorized that lateralization effects were confounded by insufficient familiarity with the stimuli and too few practice trials. In the present experiment, subjects listened and responded to two practice trials before beginning the test trials. In a similar repeating rhythm, dichotic listening task, subjects received 30 trials of binaural presentation of the acoustic stimuli to familiarize them with the stimuli (Natale, 1977). The binaural presentation was followed by 15 practice trials of dichotic presentation of the stimuli. It could be argued that subjects in the present experiment may have been overwhelmed by the unfamiliar stimuli, despite the two practice examples, and may have taken several trials to formulate a listening strategy to deal with the task's requirements. The data only partially support this idea. Fifteen out of a possible 90 responses were

correct for the first three test trials. It should be noted, however, that the first two trials were decrease modulations from an initial tempo of 80 mm, and the third trial was a decrease from 160 mm. The number of correct responses per trial for the remaining 17 trials reflected a varying pattern of accuracy due to experimental conditions rather than a pattern of increasing accuracy due to practice effects. For example, there were 21 correct responses for trial seven, an increase modulation/160 mm tempo condition. In contrast, there were only 12 correct responses for trial 19, a decrease modulation/160 mm tempo condition. Similarly, there were 12 correct responses for trial 17 and 12 correct responses for trial eight. Both trial eight and trial 17 were increase modulation/80 mm tempo conditions.

It was concluded that insufficient familiarity or too few practice trials did not confound possible lateralization effects. Because cerebral asymmetries are frequently small, ear advantage is often measured by a few percentage point difference in accuracy scores or a few milliseconds in a reaction time scores (Springer & Deutsch, 1981). If a pattern of increasing accuracy due to practice effects had been shown, the insufficient familiarity may have been an important factor in the lack of ear advantage. However, the evidence did not support such a conclusion. It might be theorized that increased familiarity and practice trials

would improve overall accuracy scores, but improved scores would not automatically lead to lateralization effects.

Another consideration in the lack of expected lateralization effects might be the issue of handedness. The Edinburg Handedness Inventory used in the present experiment may not have been sufficient to insure left hemisphere speech dominance among all subjects. There is some evidence (Natale, 1977; Shankweiler & Studdert-Kennedy, 1975; and Satz, Achenbach & Fennell, 1967) that indicates manual motor tasks predict the magnitude of speech laterality more effectively than self-report measures (cited in Natale, 1977). The motor tasks, such as cutting with scissors or tracing, are done with both hands and are assessed by time needed to complete the task and accuracy in performing the task. Following this theory, a combination of a self-report measure and manual tasks would have provided stronger evidence of right-handedness and left hemisphere speech dominance among the subjects in the present study.

However, a number of time and rhythm studies have shown significant lateralization effects without having used manual tasks to assess handedness. Evidence for left hemisphere involvement in accurately perceiving rhythmic changes was shown by Gates and Bradshaw (1977a), H. Gordon (1978) and Robinson and Solomon (1974) as well as Natale (1977). None of these researchers except Natale used

manual tasks in addition to self-report measures. M. Gordon (1967), Needham and Black (1970) and Carmon and Nachshon (1971) all showed left hemisphere involvement in judging duration or determining order of sequence, and none of those studies used manual tasks. In view of the number of these studies, it would appear that insufficient measurement of handedness was not an important factor in the lack of lateralization effects.

Having considered and rejected several alternate theories, the researcher concluded that lateralization effects may not be present rather than confounded in this experimental task. The two cerebral hemispheres may not differ in their capacities to perceive tempo modulations; they may be equally efficient at processing the rhythmic information in this dichotic task. Both hemispheres may process the information involved in rhythm patterns getting faster or slower equally as well.

Alternately, the two cerebral hemispheres may have been equally as efficient within their respective specialized modes and worked together rather than independently to process the information. The present task required the subject to first recognize that a change, a tempo modulation, had occurred in the overall pattern. Recognition of change in the whole pattern may be within the right hemisphere's holistic mode of processing. The task next required the subject to analyze what that change was, a

tempo decrease or increase. This type of decision would be within the left hemisphere's analytical mode of processing. The two hemispheres may have processed the complex stimuli equally as efficiently within their respective modes in a cooperative effort.

When lateralization effects are not shown in a study, it is difficult to determine whether they do not exist for the task, whether they simply were not shown in that particular sample or whether the experiment's design was faulty. Because the design of the present experiment was tightly controlled and carried out, the researcher would recommend that the study be replicated to see if the same results would be obtained.

If the study were replicated, the researcher would recommend the addition of binaural trials to familiarize the subjects with the stimuli as well as the addition of several more dichotic practice trials. The additional trials may improve the overall accuracy of response rate. As pointed out earlier, an increased accuracy rate would not automatically lead to laterality effects; nor was that the purpose of the suggestion.

The field of music therapy can benefit from the continued research in cerebral hemispheric processing of rhythm. Since rhythm is one of the basic elements of music, understanding how the brain processes rhythm may lead to therapeutic uses of rhythm that take advantage of

cerebral dominance and lateralization effects. However, before such therapeutic uses and instructional methods can be devised much more original research and replication of existing research must be done. In addition, much more must be known about rhythm's role in music perception as well as the overall nature of music perception before effective strategies capitalizing on cerebral dominance can be created.

APPENDIX A

EDINBURG HANDEDNESS INVENTORY

NAME______________________ DATE______________

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent, put + in both columns.

Some of these activities require both hands. In these cases, the part of the task, or object, for which hand preference is wanted is indicated in the brackets.

Please try to answer all questions, and only leave a blank if you have no experience at all with the object or task.

	Left	Right
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking a match (match)		
10. Opening a box (lid)		

L. Q. ______________ Please leave this space blank

Subject #____________

Taken from:
Oldfield, 1971

APPENDIX B

HEARING INTERVIEW

Subject #_____ Name__________________ Date________

1. Do you consider yourself to be in good general health?

   No_____ Yes_____

2. Do you consider yourself to have normal hearing?

   No_____ Yes_____

3. Do you hear better with one ear than the other?

   No_____ Yes_____

   If so, which? Right_____ Left_____

4. Do you have a history of ear infections, high fever or upper respiratory problems? If so, describe.

   No_____ Yes_____

5. Do you experience hissing, buzzing or ringing (tinnitus) in your ears? If so, describe.

   No_____ Yes_____

6. Do you experience dizziness (vertigo) frequently?

   No_____ Yes_____

7. Are you currently on medication? If so, describe.

   No_____ Yes_____

8. Are you a heavy smoker? If so, how many packs daily?

   No_____ Yes_____

   (How many packs daily?_______________)

9. Do you consume large amounts of caffine daily, such as tea, coffee or colas? If so, describe.

   No_____ Yes_____

10. Do you work in a very noisy environment requiring hearing protective devices, such as ear plugs or ear muffs? If so, describe.

    No_____ Yes_____

APPENDIX C

AUDIOMETRIC TESTS

Subject #__________ Date____________________

Pure Tone Air Conduction 15 dB Screening Test

	1000 Hz	2000 Hz	4000 Hz	8000 Hz	1000 Hz	750 Hz	500 Hz	250 Hz
RE	_______	_______	_______	_______	_______	_______	_______	_______
LE	_______	_______	_______	_______	_______	_______	_______	_______

Pure Tone Air Conduction Hearing Threshold Level (HTL) Test

RE 750 Hz________ HTL LE 750 Hz________ HTL

RE 1000 Hz_______ HTL LE 1000 Hz________ HTL

Olsen-Noffsinger 20 dB Tone Decay Test (Present tone 60 sec. 20 dB HTL)

RE 750 Hz at__________dB__________

RE 1000 Hz at__________dB__________

LE 750 Hz at__________dB__________

LE 1000 Hz at__________dB __________

APPENDIX C
(cont'd)

Stimuli Presented at:

Left Ear__________ dB HTL

Right Ear_________ dB HTL

__✓__ indicates subject passed item

__O__ indicates subject did not pass item

APPENDIX D

AMBIENT BACKGROUND NOISE LEVELS
COLLEGE OF MOUNT ST. JOSEPH ON THE OHIO

Frequency Band Analysis

Center Frequencies	Decibels	Center Frequencies	Decibels
25	47	800	32
31.5*	44	1000*	29
40	38	1250	29
50	38	1600	29
63*	38	2000*	29
80	38	2500	29
100	35	3150	26
125*	35	4000*	26
160	35	5000	26
200	35	6300	26
250*	35	8000*	26
315	32	10,000	26
400	32	12,500	26
500*	32	16,000*	26
630	32	20,000	

*Indicates standard octave band center frequencies

Testing room ambient background noise level measurement at College of Mount St. Joseph on the Ohio taken with an Ivie Electronics (Model 1E-30A) Audio Analyzer by George Pallage, Sound Technology, Inc.

APPENDIX E

DEMOGRAPHIC QUESTIONNAIRE

Subject #_________ Date___________

NAME____

AGE_________ SEX_______________

Please check (✓) the correct answer for each question.

1. Are you currently a student at Western Michigan University or College of Mount St. Joseph on the Ohio?

   Yes_____ No_____

2. Do you consider yourself to be right-handed?

   Yes_____ No_____

3. Are you a member of a music organization at Western Michigan University or College of Mount St. Joseph on the Ohio?

   Yes_____ No_____

4. How much formal, private or group, music instruction have you had in high school and college?

   0 through 2 years_____ 3 or more years_____

CONSENT TO PARTICIPATE

I agree to participate in this research project. I understand that all information collected in this project will be treated as confidential. Further, I understand that all information collected will be used only for the express purpose of this research project.

Signed ___________________________

Date ___________________________

Witness ___________________________

APPENDIX F

EXPERIMENT DIRECTIONS

The purpose of this experiment is to explore how we hear changes in rhythm and how the brain processes those changes.

There will be two examples and twenty trials in this experiment. Each trial will last 15 seconds. The computer screen will prompt you when trials are about to begin.

In each trial, you will hear two different rhythms at the same time, one rhythm in your right ear and a different one in the left ear.

For the first five seconds of each trial, both rhythms will stay at the same speed. After five seconds, one of three things will happen.

(1) In some of the trials, one of the rhythms will gradually get faster.

(2) In some of the trials, one of the rhythms will gradually get slower.

(3) In some of the trials, both rhythms will stay at the same speed for the entire trial. Neither rhythm will get faster or slower.

Your task will be to listen to the rhythms until you can hear the change and identify whether the change is faster or slower. If the change is faster, press the key marked "F" with your right hand index finger. If the change is slower, press the key marked "S" with your right hand middle finger. Please keep your fingers close to the keys for the entire experiment. If you make a mistake and hit a key other than the "F" or "S" keys, the computer screen will prompt you by telling you how to correct the mistake. Please, practice pressing the keys now.

APPENDIX F
(cont'd)

If neither of the rhythms change (get faster or slower), do nothing. Simply wait for the computer screen to prompt you that the next trial is about to begin.

Do you have any questions?

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