THE PERCEPTION OF PATTERN REGULARITY
IN TONAL SEQUENCES

By

Thomas Henry Simpson

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Audiology and Speech Sciences

1984

ABSTRACT

THE PERCEPTION OF PATTERN REGULARITY
IN TONAL SEQUENCES

By

Thomas Henry Simpson

Wood (1980) developed a calculus for the quantification of temporal redundancy in tonal sequential stimuli. His Index of Relative Redundancy (IRR) described a monotonic relationship between ascending IRR magnitudes and percent-correct ABX discrimination of rhythm.

The present study was designed to extend the range of knowledge regarding IRR as an _a priori_ predictor of perceived pattern regularity in tonal sequences. Magnitude estimates of pattern regularity (REMEs) were gathered from 20 normal hearing listeners. REMEs were examined as a function of 7 IRR magnitudes in 4 accent modes to determine: (1) the nature of IRR-REME relationships, and (2) whether differences in perceived pattern regularity occurred as a function of accent mode.

Prior to the REME experiment, subjects were screened and then trained to: (1) discriminate sequence pairs exhibiting gross levels of IRR (2) produce reliable magnitude estimates in a simple visual task, and (3) differentiate between "regular" and "irregular" tonal patterns. REME stimuli were eight-element tonal sequences exhibiting binary accents in (1) frequency, (2) amplitude, (3) duration, and (4) combination frequency and amplitude accent modes. Seven IRR accent patterns were held constant across the 4 accent modes.

Thomas Henry Simpson

Dependent variables for the REME experiment included (1) log geometric mean REMEs across trials for 7 IRR magnitudes in 4 accent modes, and (2) slopes of the least squares lines of best fit describing log IRR-log REME functions. Results of the REME experiment indicated: (1) high reliability for both derived dependent variables, (2) nonmonotonic log IRR-log REME relationships, and (3) nonsignificant differences in estimated pattern regularity as a function of accent mode.

These results suggest IRR is flawed as an a priori predictor of pattern regularity. The analysis of accent mode effects was judged to be inconclusive, however. Real differences in the relative resolvability of the tonal stimuli as a function of accent type may not have been detected by the magnitude estimation experiment. Results were judged to be sufficiently encouraging, however, to warrant additional research for the purposes of (1) refining the IRR calculus, and (2) establishing normative data for eventual clinical application of tonal sequential stimuli in the assessment of central auditory processing problems.

Dedicated
to the memory of
Norma Jean Richards

ACKNOWLEDGEMENTS

I wish to extend my gratitude and appreciation to members of my dissertation guidance committee: Dr. Michael R. Chial, Dr. Paul A. Cooke, Dr. Andrew C. Porter, and Dr. Linda L. Smith. Their collective expertise and constructive comments were invaluable to the completion of this thesis. Thanks are also extended to Dr. Leo V. Deal, Dr. Edwin Keller and Dr. Steven C. White for their help and guidance during my academic preparation.

A special vote of thanks goes to Dr. Michael R. Chial for serving as academic advisor and chair of my dissertation committee. His friendship, support, and encouragement helped each step along the way, and his dedication to excellence provides continued inspiration.

A debt is owed to Dr. Robert W. Wood, whose assistance in preparation of stimulus tapes in the Digital Music Laboratory at the University of Western Ontario enabled this project to get off the ground—and to his wife, Shara, whose hospitality, grace, and humor enabled the project to stay off the ground.

My gratitude is expressed to Carol Abood, who prepared the proposal manuscript. Thanks go to all those who served as subjects and provided support during hard times—to my parents, Clifford and Agnes Simpson, family and friends for their unflagging devotion. And special thanks to Cindy Jacobi-Grant and Tony, who helped in so many ways.

But most of all I wish to express my love and gratitude to my fiance Lynne, for her unconditional faith, gentle understanding, and loving kindness from beginning to end.

TABLE OF CONTENTS

CHAPTER PAGE

CHAPTER PAGE

APPENDIX...PAGE

APPENDIX PAGE

LIST OF TABLES

TABLE PAGE

TABLE PAGE

TABLE PAGE

TABLE PAGE

TABLE PAGE

LIST OF FIGURES.

FIGURE PAGE

FIGURE PAGE

FIGURE PAGE

FIGURE PAGE

CHAPTER I

INTRODUCTION

Man extracts information from temporally transient acoustic signals. Little is known, however, about how temporal factors of acoustic stimuli are perceptually processed. This study examined the perceptual processing of temporal structure in tonal sequences.

Background

Experimental examination of auditory temporality has developed along two major avenues: an atomistic approach to the study of the ear's absolute resolving power; and a more wholistic approach taken up in studies of auditory pattern perception.

Absolute resolving power refers to minimum detectable durations of stimuli and inter-stimulus intervals. Experimental evidence suggests that the ability of the human ear to resolve time varies both as a function of stimulus type and psychophysical paradigm (Hirsh, 1959; Divenyi and Hirsh, 1975; Patterson and Green, 1970). It is generally accepted that "over-learned" stimuli such as speech and music are more readily resolved than unfamiliar classes of stimuli (Cutting, 1973; Neisser and Hirst, 1974; Thomas and Fitzgibbons, 1971; Warren, et al., 1969).

Studies of auditory pattern perception have observed temporal phenomena from a more wholistic, Gestalt approach. Typically, subjects have been asked to name the elements of an auditory sequence or to tell their serial order of occurrence. Again, learned classes of stimuli such as speech and music give subjects a better opportunity to make correct serial judgments (Broadbent and Ladefoged, 1959; Deutsch, 1975; Hirsh, 1967; Warren et al., 1969; Peters, 1975). Researchers interested in speech perception have suggested that temporal cues involved in both the production and reception of speech may be governed by some higher-order neural mechanisms sensitive to the characteristic rhythms in the speech signal (Lashley, 1951; Hirsh, 1967; Liberman, et al., 1967; Martin, 1972). Other researchers in the field of music have generated experimental data suggesting that rhythm in the form of musical accents is categorically perceived (Deutsch, 1975; Raz and Brandt, 1977). Indeed, much of the psychophysical literature reflects systematic attempts to isolate and identify relevant temporal features of auditory sequences as they influence perception.

But simple identification of temporally salient features of auditory sequences falls short of the ultimate goal of psychophysical examination of auditory pattern perception: the description of isomorphous relationships between the temporal characteristics of auditory stimuli and the temporal processes involved in the resolution of these stimuli. Peters (1975) sums up the major issues facing the problem of quantifying temporal factors in auditory perception:

> Measurement is thus the link between data and concept fields. Within this framework, the temporal properties of acoustic signals need to be controlled in ways that seem to relate to auditory perception. Also the consequences of these systematic controls and variations on behavioral responses need to be measured, and the results need to be related to general theories of temporal auditory perception. (p. 160)

Goals

The goal of this study was to extend the range of knowledge of a mathematical index that purportedly quantifies relative temporal redundancy in tonal sequences (Wood, 1980). This index of relative redundancy (IRR) evolves from a more general model developed by R. W. Wood and M. R. Chial that attempts to describe how "redundancy reduction" influences the perception of temporal sequences (Wood, 1980).

The definitions, assumptions, and features of this model provided a lexical, conceptual, and practical framework for the examination, interpretation, and discussion of the complex issues involving temporal auditory perception. The ultimate goal of this study was to suggest specific research strategies for the examination of IRR within the more general conceptual framework of the Wood-Chial model.

REVIEW OF THE LITERATURE

Many complex variables impinge upon the study of temporal factors in auditory perception. Auditory stimuli which vary in time are difficult to classify and measure, and behavioral responses to these stimuli are difficult to interpret. In general, the interaction of psychological variables inherent to the study of perceptual processes far exceeds that usually associated with studies of sensation.

Two classes of temporal auditory stimuli which have probably received the most attention in the literature are speech and music. Consequently, many general hypotheses of auditory temporality emanate directly from theories of speech and music perception. The following discussion represents an attempt to avoid direct reference to theories of either speech or music perception. Rather, the commonalities in the literature will be discussed from the more general standpoint of psychoacoustics. This narrower focus will more directly identify information pertinent to this study.

First, discussion will be devoted to significant factors affecting the study of temporal auditory perception. These factors include:

1. Stimulus variables
2. Behavioral variables
3. Psychological variables

Next, relevant theoretical constructs of auditory temporal perception will be discussed in order to establish a conceptual groundwork for the presentation of the Wood-Chial model. These contructs have been organized into the following general categories:

1. Gestalt theory
2. Associative chain theory
3. Concatenation versus temporal order

Finally, the Wood-Chial model will be presented. Underlying definitions and assumptions will be explained, and relevant features of the model will be discussed.

Stimulus variables

One commonality of all auditory temporal stimuli is that certain tonal patterns and certain speech sounds are more easily identified or repeated than other patterns of sounds. A unifying concept pertaining to this perceptual phenomenon is that of redundancy (Shannon and Weaver, 1949). When considered as being a property of an acoustic stimulus, redundancy describes that portion of the stimulus which is structured. Highly resolvable (i.e., identifiable or repeatable) acoustic sequences tend to be highly structured and are therefore considered to be highly redundant. Unstructured acoustic sequences exhibit low levels of redundancy and are therefore difficult to resolve.

Two general strategies have emerged by which experimenters tend to identify redundant features of auditory sequences: (1) the *a posteriori* approach, which seeks to discover stimulus-response (cause-effect) relations in a largely descriptive manner, and (2) the *a priori* approach, a more prescriptive technique, which attempts to discover stimulus-response relations through application of a theory or model.

Because the *a posteriori* approach need not presuppose theory, it is relatively free from the conceptual and experimental limitations of particular paradigms. Nor are there any of the definitional problems posed by formal theoretical constructs. The *a posteriori* strategy is flawed, however, because progress in identifying significant effects requires exhaustive enumeration of potential causes. Consequently, the approach suffers in precision and efficiency.

An advantage of the *a priori* approach is efficiency, particularly in the specification of stimulus variables and particular values for those variables. In addition, the *a priori* approach is better suited to experimental study of "latent" relational issues such as equivalency, ordinality, additivity, extensiveness, and strength. The central difficulties of this approach are those associated with paradigmatic specificity: any particular theory or model will establish a conceptual map which may or may not be an adequate representation of the phenomenological territory.

The majority of auditory temporal order studies have employed a posteriori techniques. These studies have identified several systematic relationships between stimulus features and perceptual effects.

Warren, et al., (1969) reported that resolution of nonspeech sounds was more difficult than speech sounds. In a series of experiments, subjects were asked to correctly name the order of both speech and nonspeech stimuli. All auditory sequences were 800 msec in total duration, each consisting of four contiguous 200 msec elements. The four nonspeech elements consisted of: (1) a 1000 Hz tone, (2) a 2000 Hz octave band noise, (3) a 796 Hz tone, and (4) a square wave buzz. Speech elements were the spoken digits: one, three, eight, and two. Subjects were not able to correctly name the temporal order of the nonspeech stimuli but could easily identify the order of the spoken digits, despite the fact that more than four phonemic elements were probably perceived in the pattern. Element durations for nonspeech stimuli in the order of 700 msec were necessary for correct-order judgments.

Thomas, et al., (1970) conducted a study very similar in form to Warren's. Subjects were asked to name the correct order of four continuous speech sounds: /i/, /e/, /a/, and /u/. Care was taken to asssure that the fundamental frequency of each vowel was 125 Hz plus or minus 2 Hz and that the intensity of each vowel was plus or minus 1 dB. Untrained subjects could correctly name the order of these four speech sounds when individual vowels were 125 msec in duration. The authors suggested that these vowels, although lacking semantic cues, represent a "learned" class of stimuli-that because vowels are highly familiar sounds subjects should be expected to resolve them at shorter durations than other nonspeech sounds (i.e., tones or buzzes). Cutting (1973) showed that resolution of both speech and nonspeech sounds was enhanced when formant-like transitions were inserted between elements of an auditory sequence.

Other a posteriori studies have identified stimulus response relationships which distinguish between different types of nonspeech stimuli. These studies have systematically avoided linguistic content in auditory sequences and have focused primarily on the measurable physical characteristics of nonspeech sequence elements.

Watson et al., (1975) investigated the discriminability of "temporally complex" ten-tone sequences. Each sequence element was 40 msec in duration, and the ten tonal elements ranged from 256 to 900 Hz ("low" patterns) or from 500 to 1500 Hz ("high" patterns) in equi-log intervals. Subjects were asked to detect changes in the frequency of a single tonal element in a same-different task. These just detectable differences were much smaller for higher frequency sequence elements occurring later in the pattern than for lower frequency, earlier occurring tones. Also, discriminability of earlier component tones was increased by the occurrence of a brief silent interval (80 to 120 msec) after the tone in the sequence. In an interpretation of these results, the authors stated:

> if we were to consider these results in designing a communication system, we might apply them in three ways. First, major information would be encoded in the high frequency components of the sounds forming the primary meaning-units of the system. Second, if we wanted to produce a slight change in the meaning of one of these units (as to vary number or tense) by adding a small amount of acoustic energy, the most easily identifiable addition would be placed at the end of the sound. Finally, if we wanted to make an early component particularly clear, we would add a brief silent period immediately after it (p. 1184).

Royer and Garner (1966) used eight-element sequences exhibiting two levels of physical accent in the form of different pitched buzzes. They used all possible permutations and combinations of the two accent levels, and hence drew from a pool of 256 sequential stimuli. The auditory sequences were presented in a cyclic, continuous fashion, and the subjects were asked to "mimic" the patterns by tapping two telegraph keys. Only a small portion of the 256 different patterns were easily resolved by the normal hearing subjects. Sequences with concatenations of like accents were more easily resolved, and subjects tended to organize these concatenations (as measured by the point at which they began tapping) at either the beginning or the end of each eight-element cycle. The presentation rate of these sequences was two elements per second. In a later study (Garner and Gottwald, 1968) it was found that the small number of "preferred" paterns did not change significantly over a range of presentation rates from 0.8 to 8 elements per second.

Studies of the a posteriori type have identified spectral and temporal characteristics of auditory sequences relating to how easily particular sequences are resolved by human subjects. Fewer of the a priori type studies exist, however, for it is suggested here that experimental questions for these studies were generated from hypotheses assumed to reflect theories of auditory pattern perception, and as Peters (1975) stated:

> there are no systematic, overall bodies of knowledge or theories that treat temporal properties of perception at acoustic, physiological, or behavioral levels. (p. 157)

A priori determination of sequence type comes primarily from the work of Martin (1972) and his associates. Their work is founded upon precepts originally stated by Lashley (1951) that all serial behavior is manifested in an hierarchical temporal order in the nervous system. That is, evaluation of any type of behavior cannot only consider serial order but some higher level of organization contributing to that order. Martin (1972) developed the concepts of "relative accent" and "relative timing" to formulate rules for the generation of tonal sequences of varying temporal redundancy. These tonal sequences were later used to provide preliminary evidence that auditory patterns could be ordered in terms of their relative temporal redundancy (Sturges and Martin, 1974).

Martin's concepts of relative accent and relative timing, however, provided only gross descriptions of temporal redundancy in tonal sequences. A calculus was later developed by Wood (1980) allowing for a more precise quantification of relative temporal redundancy in tonal sequences. Wood found that for the limited range of calculated redundancy levels used in his experiment, his Index of Relative Redundancy (IRR) corresponded monotonically with percent-correct judgments in an ABX matching paradigm. Furthermore, Wood noted that the temporal characteristics of his highly redundant patterns (high IRR) were similar in nature to the highly concatenated ("preferred") patterns subjectively described by Garner and his associates (Wood, 1980, pp. 21-22).

Behavioral variables

Several identifiable issues emerge from the literature regarding difficulties with the interpretation of behavioral data in studies of temporal auditory perception. Fundamental questions arise about the specific behavioral task: does it reflect lower-order sensory processes, or higher-order perceptual processes? Other questions address issues of task-subject interaction: are data confounded by the differential listening abilities subjects may bring to the specific behavioral task?

A study by Ptacek and Pinheiro (1971) addressed the first of these questions. Their behavioral task required subjects to correctly name the order of three-element temporal sequences in a method of limits paradigm. Two "loud" bursts of white noise and one "soft" burst of white noise were in each sequence, and all permutations of elements were presented. The intensity level of the soft burst was systematically controlled by the experimenter. Subjects were able to correctly name the order of the bursts 50 percent of the time when the intensity difference between soft and loud bursts was 10 dB. The authors concluded that because the jnd for intensity of white noise in only 0.5 dB, that pattern recognition is a higher order task than simple discrimination of intensity differences. Thus perceptual rather than sensory processes were implicated in the judgment of serial order.

Similar interpretations were made by Hirsh and Sherrick (1961) in a cross-modality study in which subjects were required to judge the correct temporal order of visual, auditory, and tactile stimuli. These authors were interested in the difference between: (1) minimum detectable interstimulus intervals necessary for correct judgment of the occurrence of two stimulus events, and (2) minimum interstimulus intervals necessary for correct judgment of the temporal order of two stimuli. Stimulus pairs were either: (1) an auditory tone and a visual flash, (2) a tone and a tactile vibration, or (3) a flash and a vibration. Subjects were able to name which stimulus occurred first (75% correct-order judgment criterion) when interstimulus intervals were approximately 20 msec. These interstimulus intervals were similar to those of previous experiments conducted by Hirsh and Sherrick (also reported in the 1961 publicaton) in which subjects were asked to judge the correct temporal order of stimulus pairs occurring in the same sensory modality. The authors suggested that the interstimulus intervals necessary for correct temporal order judgments (both within and between modalities) were so much larger than those describing the "temporal two-point limen" for audition, taction, and vision, that a "time organizing system...independent of and central to the sensory mechanisms..." mediated judgments of temporal order (p. 431).

Examination of studies employing longer temporal sequences (more than four elements) suggests that perceptual inferences of a specific behavioral task may be confounded with another factor: differential listening abilities among subjects.

Neisser and Hirst (1974) were interested in practice effects on the task of pattern perception. Subjects were asked to report the order of occurrence of four sounds: (1) a high tone (3400 Hz), (2) a low tone (500 Hz), (3) a hiss (broad-band white noise), and (4) a "scratch" (filtered noise peaks). The four-element sequences were presented in spaced, cyclic, and "one-shot" fashion. Durations of individual sounds was gradually decremented from 360 to 20 msec over the course of six experiments lasting a total of four weeks. Significant practice effects were found for all subjects across all presentation modes; however, performance of one subject (who reported musical training and experience) was markedly superior throughout the series of experiments. The authors suggested that overall performance on the pattern recognition task varied not so much as a function of stimulus variables as it did with individual abilities of the listener.

Watson et al., (1975) used highly trained subjects in a same-different procedure. Stimuli were auditory sequences consisting of ten tonal elements ranging in frequency from 256 to 1500 Hz in equi-log intervals. Each tonal element was 40 msec in duration, and the frequency of only one sequence element was varied during the presentation of each "stimulus event" (i.e., standard sequence and comparison sequence). Although subjects were not selected because of musical abilities, some reported instrumental or vocal training. The authors reported a "weak direct" relation between musical training and subject performance in the listening experiments, although "no systematic attempt was made to investigate the role of such training" (p. 1176).

Wood (1980) was more directly concerned with the effects of musical training on auditory pattern recognition. He used an ABX matching paradigm. Experimental stimuli were eight-element tonal sequences exhibiting two levels of physical accent in one of two accent modes. High and low levels of frequency accents were 200 msec tonal elements of 3000 Hz and 1000 Hz, respectively; sequence elements receiving high and low levels of durational accent were 1040 Hz tones of 80 msec duration, which were temporally "isolated" by inter-element intervals of 160 and 40 msec, respectively. Significant performance differences were found between groups of subjects as a function of musical training. Percent-correct discrimination scores were systematically higher for subjects reporting higher levels of formal musical training.

An experiment by Royer and Garner (1966) may have been confounded not only by subject differences in musical aptitiude, but by subject differences in motoric ability as well. Experimental stimuli were auditory sequences (eight elements each) exhibiting two levels of frequency accent. Sequence elements exhibiting these binary accent levels were generated by two doorbell buzzers shown to have "perceptually resolvable" spectral characteristics. The subjects' task was to mimic the cyclically presented sequences by tapping two telegraph keys (each key represented one accent level). The authors, however, reported no systematic assessment of either musical abilities or motoric abilities in their subject sample.

In designing a study of auditory temporal perception, the experimenter must first assure that his behavioral task "fits" the particular perceptual process to be studied and must then allow for the differential listening abilities subjects may bring to the specific task.

Psychological variables

Watson *et al.*, (1975) suggested that such psychological variables as "... stimulus and response uncertainty, attention, motivation, and memory..." play an important role in the processing of temporally complex auditory stimuli (p. 1175).

Effects of stimulus and response uncertainty have been examined indirectly by several studies. Peters (1964, 1967) examined perceptual distortions that occurred when frequency components of tonal elements in a sequence extended beyond certain limits. He suggested that misjudgments might have been caused at frequency extremes because subjects were trying to resolve two "distinct perceptual sets". Several other studies have reported effects of stimulus and response uncertainty when auditory sequences were presented in a cyclic or repeating fashion (Royer and Garner, 1966; Neisser and Hirst, 1974; Watson, et al. , 1975).

The psychological effects of memory and attention have also been reported in the literature. Neisser and Hirst identified what they called a "backward masking" effect when extraneous signals were introduced after the target sequence but before the subject response. These irrelevant signals, which the subjects were told to ignore, significantly lowered performance scores, whereas several seconds of silence introduced before a response did not lower performance. Divenyi and Hirsh (1975) noted a similar effect by adding a fourth tone to three-tone sequences. They preferred to call the effect "memory blanking", however, and suggested that "blanking" affected memory processes more than sensory processes (p. 251). Watson, et al. , (1975) noted a "recency" effect on the perceptual resolution of ten-tone sequences wherein later occurring tones were more easily resolved. He noted no "primacy" effect, however.

The distinction between pattern "learning" and pattern "perception" was made by Garner and Gottwald (1968). They varied presentation rate for nonspeech (buzzes) auditory sequences from 0.8 to 8.0 elements-per-second and found that "preferred" patterns (i.e., easily resolvable patterns with like-accent, concatenated elements) did not significantly change as a function of presentation rate. They did note, however, that slower presentation rates (below 2 sequence elements-per-second) caused subjects to exhibit "active", "intellectualized" response behaviors; at presentation rates above 2 elements-per-second, subjects were more passive in their response behavior (a key-tapping procedure). Garner and Gottwald characterized the former behavior as "pattern learning" and the latter behavior as "pattern perception" and suggested that presentation rates above 2 elements-per-second were necessary to facilitate the perception of temporal patterns in auditory sequences (p. 97).

Relevant constructs

The following discussion is devoted to several theories of auditory pattern perception which emerge from more general theories of perception. They differ from the "psychological variables" just discussed primarily by matter of degree: the authors here have attempted in greater detail to describe perceptual strategies that might be taking place in the resolution of temporal sequences. Although falling short of what could be called full-fledged temporal-perceptual models, these theories are generally well-developed. Some are accomodated by the Wood-Chial model, which will be discussed shortly.

Gestalt theory

Hirsh (1967) drew parallels between auditory pattern perception and the Gestalt concept in visual figure-ground perception, and several others have since borrowed quite heavily from Hirsh's analogy. Studies making reference to auditory figure-ground concepts are significant in that they typically have examined longer acoustic sequences. These experimenters have chosen to look at larger "chunks" of data, and hence their generalizations are broader in scope.

Garner (1974) developed a theory based upon his previous work (Royer and Garner, 1966, 1970) using seven and eight-element temporal sequences of buzzing sounds. Two levels of physical accent were used (high and low pitch), and subjects were asked to listen to the sequences as they were presented, one pattern at a time, in a continuous cycle. Subjects were asked to "trace" the pattern motorically by a key-tapping procedure and could begin tapping whenever they felt comfortable with the task.

Subjects tended to adopt one of two key-tapping strategies. Garner suggested that auditory figure-ground concepts were implicated by these strategies, as tapping behavior tended to organize the sequences so that (1) either the most number of concatenated "figure" elements occurred first, or (2) the most number of concatenated "ground" elements occurred last. Figure-ground relationships thus depended upon concatenation of similar physical accent levels, and subjects became more unsure of themselves when two accent levels tended to alternate or occur randomly within the seven and eight-element sequences. Thus performance dropped when subjects could not separate the sequences into identifiable auditory figure and ground. Longer response latencies were also noted when similar accents were not concatenated (Garner, 1974).

Associative chain theory

Associative chain theories of temporal auditory perception evolve from ideas that all serial behavior can be thought of as a string of concatenated events. These theories imply that perceptual processing of incoming stimuli takes place serially in time-that the meaning extracted from a temporal sequence is governed by the order of occurrence of elements within that sequence (Lashley, 1951). These theories, when applied directly to the perception of temporal order, suggest that distinct concatenations of sequence elements provide distinct perceptual meanings to the overall sequence-that information is stored and processed in serial fashion similar to the way in which computers manage serial strings of data.

Many studies employing subjective strategies of sequence description (discussed earlier in this text) ascribe either directly or indirectly to associative chain theories in that the authors were attempting to identify which specific orderings of temporal sequence elements were most easily resolved. In particular, the work of Garner and his associates showed that subjects could mimic auditory sequences quite well when specific concatenations of similarly accented elements were presented (Garner, 1974).

Concatenation versus temporal order

Lashley (1951) took issue with the associative chain theories of behavior. He felt that evaluation of any type of behavior should not only consider serial order but some higher level of organization contributing to that order. And this higher level of organization, Lashley suggested, related to temporal characteristics of behavior and also to the neural mechanisms underlying behavior. He felt that the link between behavior and neural processing could be attributed to rhythm or cadence.

Drawing from Lashley's precepts, Martin (1972) developed the concepts of "relative timing" and "relative accent" to explain the temporal ordering of auditory sequences as they exist in nature. Martin felt that inherent temporal regularity in auditory sequences such as speech and music is governed by invariant rules which determine physical accent levels not only for adjacent sequence elements (relative accent) but for the entire sequence as well (relative timing). Highly regular auditory sequences, therefore, exhibit an overall pattern of physical accent levels which subdivide longer sequences into perceptually meaningful subunits. Furthermore, according to Martin, temporal perceptual processes are predisposed to accept stimulus regularity in terms of relative accent and relative timing. Thus auditory sequences which exhibit temporal regularity tend to be perceptually resolvable, whereas temporally irregular auditory sequences are less resolvable.

Sturges and Martin (1974) generated seven and eight-element sequences according to the "rules" of relative accent and relative timing. Two general classes of stimuli were produced: (1) "good" sequences exhibiting high levels of temporal regularity; and (2) "poor" sequences exhibiting low levels of temporal regularity. In a same-different task, subjects were able to resolve the highly regular sequences with greater ease than the irregular ones. The authors concluded that the "rules" of relative accent and relative timing described auditory sequences in ways that were perceptually meaningful.

The Wood-Chial Model

This model is conceptual in nature and attempts to show how a process called "redundancy reduction" may operate in the perception of temporal auditory patterns (Wood, 1980, p. 81). Martin's concepts of relative accent and relative timing are incorporated and are considered to be auditory sequence attributes. Ideally, this model is suggested as a means of identifying "... the processes and subprocesses involved in the perception of rhythmic auditory patterns" in order to motivate "predictions of outcomes susceptible to experimental inquiry" (Wood, 1980, p. 82).

Definitions

The following definitions are intended to establish a general lexical framework to facilitate discussion of the Wood-Chial model. These same terms will be used extensively in the "method" section of this document.

An <u>element</u> is any auditory event. Elements may exhibit forms of <u>physical accent</u> which are manifested as physically describable characteristics (eg., frequency). Several successive elements make up a <u>temporal sequence</u> of elements, which may be either concatenated or patterned. <u>Concatenated</u> sequences are successive only, whereas <u>patterned sequences</u> exhibit greater or lesser degrees of temporal regularity in the form of <u>relative timing</u> , which describes the relative temporal placement of all physical accents present in a particular sequence.

Transmissive redundancy is a characteristic of *patterned* temporal sequences and is determined by the degree of relative timing exhibited by that sequence. the amount of transmissive redundancy for any temporal sequence can be computed (see Wood, 1980, pp. 58-81) and expressed in terms of *relative redundancy* . Relative redundancy levels can be used to compare the degree of transmissive redundancy among temporal sequences having the same number of elements.

Receptive redundancy , on the other hand, is a listener characteristic and depends upon the past experience of the listener. The perceptual resolution of any class of temporal auditory sequences (eg., the ability to repeat a melody or understand French) is thus dependent upon both *transmissive redundancy* (a signal property) and *receptive redundancy* (a listener property).

Assumptions

The Wood-Chial model makes several assumptions regarding the perceptual system and perceptual processing. Some are based on fact; others are included to allow for a more complete explanation of certain concepts.

This model assumes that neural activity is continuous in an hierarchically organized perceptual system. Fibers increase in numbers toward the cortex in two distinct groups of parallel afferent pathways. Some simply relay information to cortical centers while others pass more rapidly from the periphery as "alerting" signals. Memory is both short-term and long-term: Long-term memory stores information from the past; short-term memory is implicated more with the immediate interaction with the environment. Incoming information is encoded, decoded, and recoded at increasingly higher perceptual levels. These three processes are not necessarily serial in real time, but can occur simultaneously, as "alerting" signals can reach higher cortical levels before informational signals. These alerting signals can initiate "search programs", which interact with both short and long term memory "expectancies" regarding temporal features of incoming auditory stimuli. Finally, random neural activity can produce random perceptual errors at any hierarchical level.

Features

A graphical representation of the model is given in Figure 1. Incoming stimuli are considered to be temporal sequences exhibiting measurable amounts of relative redundancy. The peripheral multistage transducer is intended to represent the middle ear and cochlea, where the analog stimuli are transduced to neural impulses.

Neural signals are first processed by encoding

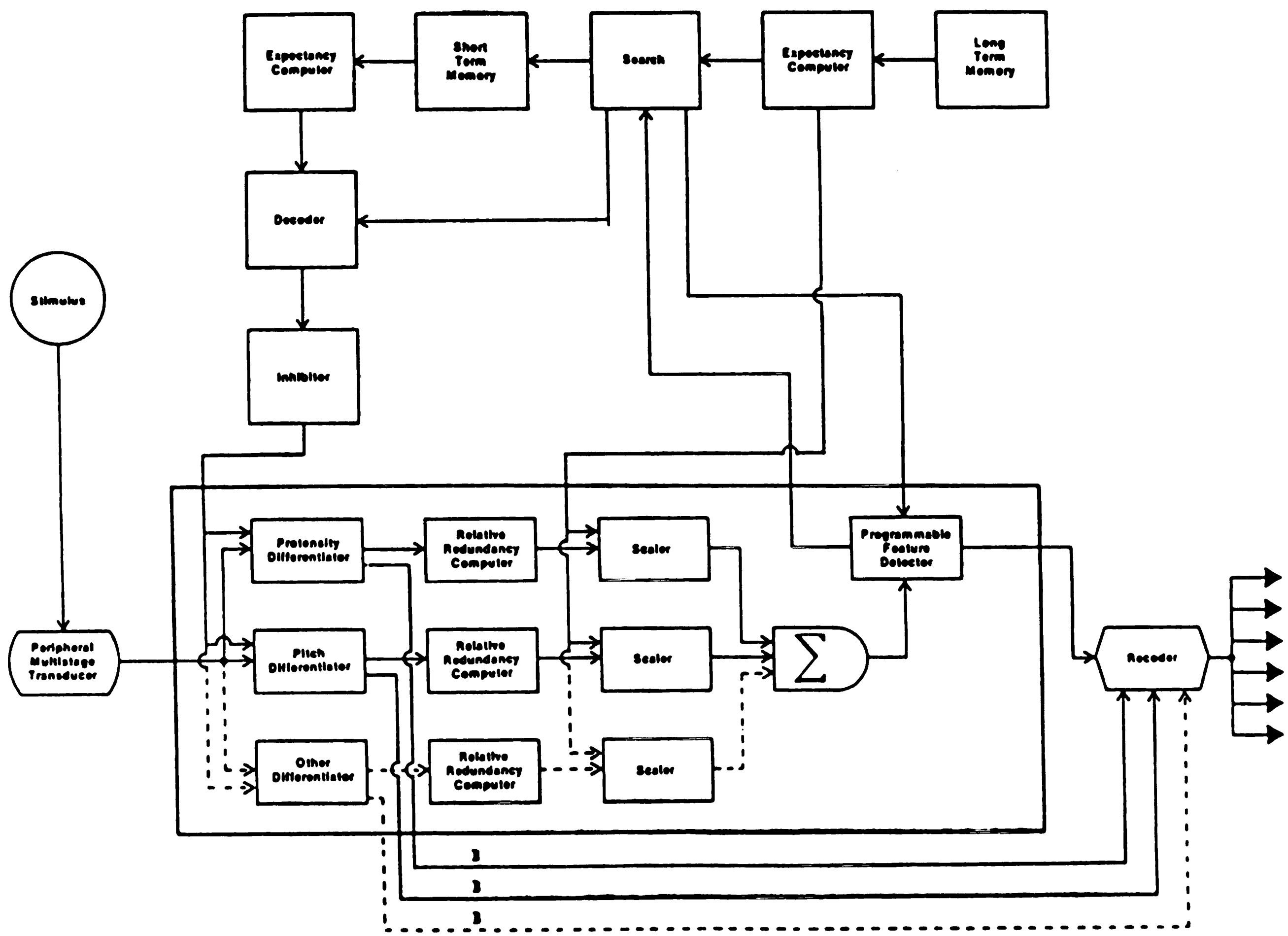


Figure 1. Graphic representation of the perceptual model (from Wood, 1980).

functions, which are considered to be precognitive operations directly or indirectly controlled by a search mechanism. Five-stage parallel processing on the transduced signal here includes: (1) feature differentiation, where temporal changes in the signal are sorted and deciphered; (2) computation of relative redundancy, where information regarding temporal regularity is extracted from the signal; (3) selective scaling or weighting of temporal signal characteristics; (4) summation (or combination) of scaled temporal features; and (5) feature detection, where summed temporal information is processed and acted upon by higher-level mechanisms.

The search component (perhaps cognitive) controls the encoding process directly through interaction with the feature detector, and indirectly through the inhibition of signal differentiators. In addition, the search mechanism interacts with both short and long-term memory, which account for receptive redundancy storage.

Information from short and long-term memory is sent by the search program to the decoder, which coordinates inhibitor activity. The inhibitor in turn restricts the transmission of redundant temporal data directly to the recoder. This "redundancy reduction" increases the informational capacity of a set of alternate differentiator outputs which progress to the recoder. Thus temporally redundant information is passed on to he recoder only after a process of "redundancy reduction" mediated by the interaction of the search program with memory, the inhibitor, and the programmable feature detector. The five-channel output of the recoder suggests an increase in neural radiations to some higher level (Wood, 1980, pp. 90-95).

Summary

A problem central to the study of temporal aspects of auditory perception is one of quantification. Temporally complex auditory stimuli are difficult to measure, and behavioral data, though more amenable to measurement, are difficult to interpret. The concept of redundancy has emerged from the literature to suggest: (1) that temporally redundant auditory signals tend to be perceptually resolvable, and (2) that "neural redundancy" in terms of parallel processing provides humans with an inherent ability to integrate or resolve temporally complex signals.

An analytical model exists that addresses the apparent link between transmissive and receptive redundancy (Wood and Chial, in Wood, 1980, pp. 36-95). A feature of the model suggests that transmissive temporal redundancy in tonal sequences can be quantified in terms of relative redundancy.

The IRR metric evolves directly from the ideas of Lashley (1951) and Martin (1972) and therefore represents an a priori attempt to quantify stimulus characteristics. Some evidence exists from a posteriori studies, however, to support IRR as a descriptor of temporal redundancy. Garner's (1974) notion of "temporal balance" is akin to Martin's idea of relative timing. That is, perceptual resolution of tonal sequences is enhanced not only by the concatenation of like-accents, but by the relative temporal placement of these concatenations as well. Concatenations of like-accents which give an identifiable beginning, middle, and end to a sequence increase the perceptual resolvability of that sequence (Garner, 1974, p. 54). Garner suggested that the temporal placement of like-accent concatenations organizes tonal sequences into an auditory figure and ground (pp. 62-63).

Thus rationale for the IRR metric receives support from several general theories of auditory temporal perception. Computational characteristics of the IRR calculus evolve more directly from Martin (1972), but computational features of IRR also accomodate the notions of concatenation (associative chaining) and auditory figure-ground relationships (Gestalt theory).

Wood's (1980) IRR metric represents a refinement of Martin's concepts of relative timing and relative accent.

Martin's generative grammar described gross levels of temporal redundancy in tonal sequences (Sturges and Martin, 1974). Wood's concept of relative accent level (RAL) suggests, however, that transmissive temporal redundancy can be scaled with at least ordinal power, and some experimental evidence exists to support this notion (Wood, 1980).

Appendix A discusses Martin's original grammar, concepts relating to RAL, and procedures for the computation of IRR. Basically, RAL represents an invariant set of "rules" which govern temporal regularity among elements of tonal sequences. To the extent that the temporal arrangement of accents in a sequence (i.e., the relative timing of that sequence) "obeys" RAL rules, a particular IRR level can be calculated for that sequence. Wood (1982 personal communication) has generated IRR levels for all permutations and combinations of binary physical accent in eight element sequences. These 256 sequences are rank-ordered as a function of IRR, with minimum IRR = 0.30 and maximum IRR = 1.00.

PROBLEM STATEMENT

The Wood-Chial computational index of relative redundancy (IRR) has been shown to correspond monotonically with percent-correct discrimination of temporal sequences for a limited range of IRR levels (Wood, 1980). Wood's results suggest at least an ordinal relationship between IRR and temporal resolution of tonal patterns when IRR magnitudes are above median value. The entire range of IRR values (that is, minimum to maximum temporal regularity) must be examined in tonal sequences of the type used by Wood (1980) before IRR concepts are generalized to other classes of auditory stimuli.

Components of the Wood-Chial model allow for the assessment of differential effects of various physical accent modes on the perceptual process. Wood found resolution for frequency accent modes to be consistently superior to duration accent mode stimuli. He did not, however, investigate other accent modes, such as amplitude, nor did he examine the perceptual effects of combinations of accent modes present in the same sequence.

In general, more knowledge of the relationship between IRR and the perceptual resolution of tonal sequences is necessary to address issues of ordinality, and more knowledge of the differential effects of physical accent modes (and combination of accent modes) is necessary to address issues of relative potency, equivalency, and additivity in the perceptual resolution of different "types" of temporal redundancy allowed for in the conceptual framework of the Wood-Chial model.

PURPOSE

The goal of this study was to extend the range of knowledge of the Wood-Chial IRR metric by employing temporal sequences exhibiting the entire range of IRR levels. Physical accents in experimental sequences were in frequency and duration modes (to continue Wood's work), as well as amplitude, and a combination of frequency and amplitude modes. Significant relationships between IRR and perceived regularity would suggest that IRR is a useful index for the quantification of temporal redundancy in tonal sequences and would justify examination of tonal sequences having different numbers of elements and (perhaps) more complex auditory sequences. If IRR adequately describes abstracted temporal features of tonal sequences, it might be useful in isolating temporal redundancy in speech or speech-like auditory sequences. Thus IRR would become a useful "tool" for the separation of linguistic and nonlinguistic cues from the speech signal (Peters, 1975; Watson, et al. , 1975).

If significant relations are found between IRR and perceived regularity for the four accent modes, comparisons could be made among different modes. This would allow for evaluation of different types of temporal regularity as they relate to perceptual processes. The Wood-Chial model suggests that temporally redundant characteristics of the auditory signal are sorted, differentially weighted, summed, and decoded. Evaluation of frequency, amplitude, and duration accent modes would, within the conceptual framework of the general model, allow for assessment of the relative contributions of pitch, loudness, and protensity to the perceptual resolution of temporal redundancy. The combination accent mode (frequency plus amplitude) further allows for questions relating to additivity in physical accents.

Methodological issues

The issues of IRR and differential accent mode effects were addressed by a scaling procedure known as magnitude estimation (Stevens, 1975). It is suggested that a magnitude estimation paradigm provided a more direct measure of the perceptual phenomena of interest than ordinal scaling techniques such as AB or ABX discrimination. Ratio scaling (i.e., magnitude estimation) allowed for more powerful comparisons among different IRR levels within accent modes and among the overall perceptual effects of different accent modes.

Experimental questions

The following questions were formalized to suggest tests of statistical significance regarding the Wood-Chial IRR formulation. Where possible, these questions conformed to the postulates mandated by a ratio-scaling procedure (Stevens, 1975).

1. How consistently do subjects scale perceived regularity within and between experimental sessions?

2. Do stimuli with different IRRs produce significantly different perceptions of pattern regularity as indexed by magnitude estimates?

3. Is there a statistically significant trend for perceived regularity to be influenced by changes in IRR?

4. If a statistically significant trend is present, what is the lowest order mathematical function required to provide a statistically significant fit to the stimulus-response functions?

5. Do the stimulus-response functions (slopes) differ in strength of association across accent modes?

6. Do the slopes of the functions differ significantly across accent modes, across experimental session, or across combinations of the two?

7. Is the slope of the combination frequency-amplitude function significantly greater than that for the frequency accent mode? For the amplitude accent mode? For the sum of the two?

CHAPTER II

METHOD

Subjects

Audiometric criteria

Twenty normal hearing adult females served as subjects in this study. They demonstrated normal hearing by:

(1) exhibiting hearing threshold levels (HTLs) better than 15 dB (re: ANSI S3.5-1969) for 250, 500, 1000, 2000, 4000, and 6000 Hz;

(2) exhibiting inter-ear HTL differences no greater than 5 dB;

(3) exhibiting normally shaped tympanograms indicating normal middle ear pressure (Jerger, 1970);

(4) exhibiting acoustic reflex thresholds at hearing levels greater than 60 dB and less than 110 dB (re: ANSI S3.6-1969) at 500, 1000, and 2000 Hz;

(5) exhibiting stable acoustic reflexes for 10 seconds at 500 and 1000 Hz (Anderson, Barr, and Wedenberg, 1970);

(6) exhibiting monosyllabic word discrimination scores of 90% or better on the C.I.D. Auditory Test W-22 PB word list presented at 40 dB above the two-tone average threshold (Fletcher, 1950);

(7) reporting no history of otologic surgery, familial hearing loss, recent upper respiratory problems, vertigo, tinnitus, noise exposure, or

hearing loss;

(8) reporting no use of pharmacological agents for at least one week prior to the experiment.

In addition, all experimental subjects met screening criteria relating to: (1) percent-correct discrimination judgments between gross levels of temporal regularity, (2) reliability of performance in a visual magnitude estimation task, and (3) pattern regularity magnitude estimation training.

Auditory discrimination criteria

Each experimental subject demonstrated 90% correct discrimination judgments between gross levels of temporal regularity as determined by IRR in a same-different matching task. All combinations of four levels of IRR (levels 1, 3, 5, and 7) were presented for each of 3 accent modes (frequency, amplitude, and duration). Each retained subject therefore correctly discriminated a total of at least 27 out of 30 possible sequence combinations. Refer to Appendix B for a more detailed description of the pattern discrimination task.

Visual magnitude estimation criteria

Subjects demonstrated general understanding of the experimental paradigm to be used in this study by generating reliability coefficients equal to or greater than 0.9 in a visual magnitude estimation task (Lawson, 1980, pp. 179-196). Refer to Appendix D for reliability and validity data regarding this visual training task.

Pattern regularity magnitude estimation training criteria

Subjects demonstrated understanding of the concept of "pattern regularity" by correctly distinguishing between two example pattern types: (1) a twenty element sequence whose accent pattern was "regular", and; (2) an "irregular" pattern where accent levels occurred randomly in the twenty-element sequence. Refer to Appendix I (instructions and response sheet for the listening task) for a more detailed description.

Stimulus materials

Introduction

Twenty-eight tonal sequences exhibiting seven levels of temporal regularity were developed for a magnitude estimation experiment. Sequences consisted of eight tonal elements, each of which exhibited either high or low magnitudes of physical accent. Physical accent modes were variations in (1) frequency, (2) amplitude, (3) duration, and (4) a combination of frequency and amplitude modes. The relative temporal placement of binary accents within a sequence was determined by the index of relative redundancy (IRR) for that sequence (Wood, 1980).

Ratio scaling procedures require between five and nine levels of the independent variable (Stevens, 1975). Seven levels of IRR were chosen for tonal sequences in each mode to (1) achieve adequate descriptions of independent - dependent variable relationships, and (2) minimize subject fatigue factors.

The modulus-free magnitude estimation task required subjects to: (1) enumerate the temporal regularity of a standard sequence (this value became the "free" modulus, determined by each subject), (2) "internalize" the modulus value, and (3) evaluate the regularity of a comparison sequence in relation to the internalized modulus value. Each stimulus presentation (see Figure 2) therefore consisted of a standard sequence, a comparison sequence, and a response interval. Seven stimulus presentations were generated for each accent mode, making a total of 28 stimulus presentations.

Tonal elements. All sequence elements were considered as auditory events. That is, they exhibited measurable physical properties (see definitions of the Wood-Chial model, Chapter I). Each element was a gated sinusoid. Element durations (except for low-magnitude durational mode accents) were held constant at 100 msec to facilitate temporal judgments by subjects with little or no prior training (Hirsh, 1959; Warren, et al ., 1969; Divenyi and Hirsh, 1975; Watson, et al .,1975) and also to avoid potential problems related to incomplete loudness summation (Scharf, 1978). Inter-element intervals of 50 msec were

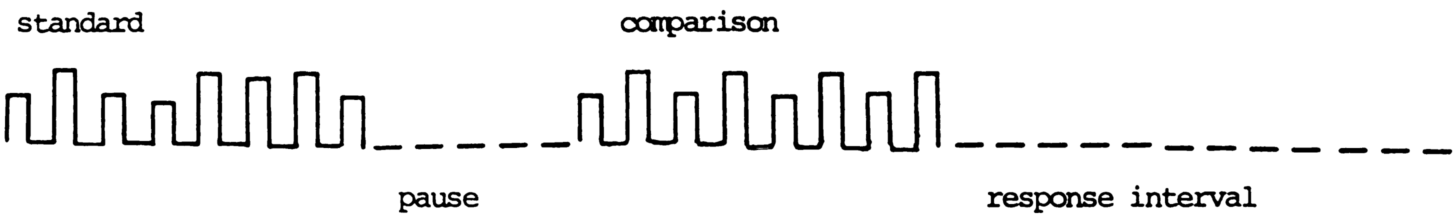


Figure 2. Time-domain depiction of a stimulus presentation, consisting of (1) an eight-element standard sequence, (2) a 1 second pause, (3) an eight-element comparison sequence, and (4) a five second response interval. Voiced labels (i.e., "item one, standard") announced each taped stimulus presentation.

maintained to minimize auditory fatigue factors (Jerger and Jerger, 1966) and to assure each element's discrete perceptual entity (Garner, 1974). All sequence elements exhibited rise-fall times of 10 msec to minimize acoustic transients while assuring a distinct "beginning" and "end" for each element. Rise times of this magnitude had little effect on the perceived loudness of tonal elements (Gjaevenes and Rimstad, 1972).

Levels of physical accent. Each tonal element in a sequence received either a high or low level of physical accent. Binary accents in each mode were chosen to accomodate the body of data supporting the Wood-Chial IRR metric (Royer and Garner, 1966, 1970; Sturges and Martin, 1974; Wood, 1980). Specific values of physical accent were chosen to : (1) facilitate comparisons among accent modes, (2) minimize confounding instrumental effects on stimulus generation and presentation procedures, and (3) resolve confounding perceptual effects relating to pitch, loudness, and protensity resolution. Detailed discussion of specific accent magnitudes will occur below for each accent mode.

Sequence duration. The number of sequence elements and overall sequence duration was chosen to accomodate a body of data supporting the Wood-Chial IRR metric (Royer and Garner, 1966, 1970; Sturges and Martin, 1974; Wood, 1980). All sequences consisted of eight elements (see Figure 3). Sequences in frequency, amplitude, and combination frequency-amplitude modes were 1150 msec in

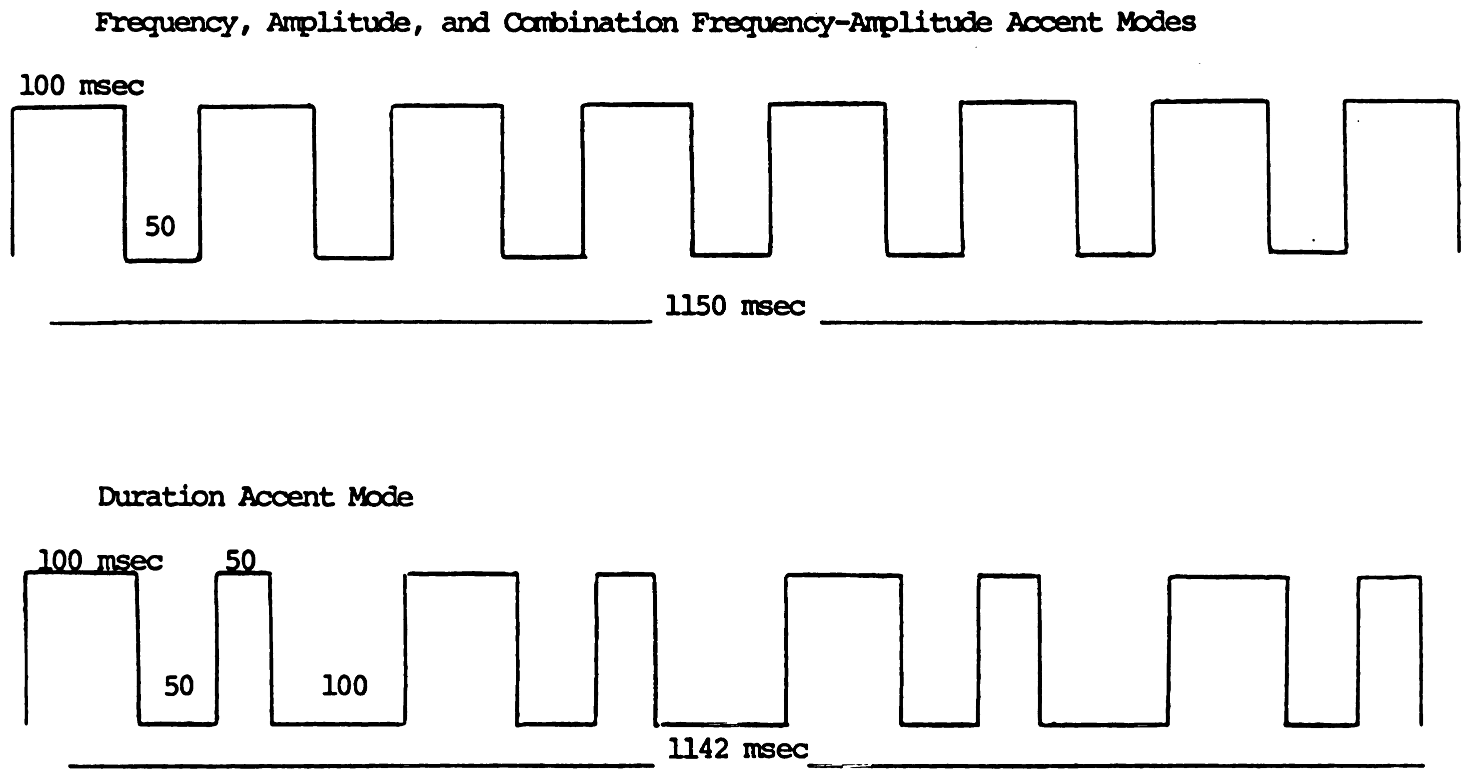


Figure 3. Time-domain depiction of total sequence durations. Sequences in the frequency, amplitude, and combination frequency-amplitude modes were 1150 msec in duration. Mean sequence in the duration accent mode was 1142 msec.

duration. Mean sequence duration in the durational accent mode was 1142 msec. Shorter overall sequence durations in the durational accent mode were necessary to accomodate two levels (short and long) of element durations while keeping the total number of elements per sequence (8) constant across all four accent modes. Wood (1980) used two types of physical accents (frequency and duration) in a pattern discrimination study and described these accents in terms of musical notation, which defines absolute stimulus durations (of tonal elements or "notes") with less rigor than it defines the relative temporal placement of tonal elements within a sequence. Consequently, tonal sequences in his study differed across accent modes in terms of overall sequence duration and presentation rate (in elements per second). In the present study, overall sequence durations agreed within 99% to facilitate specific comparisons between accent modes.

Levels of temporal regularity. Seven levels of temporal regularity as defined by IRR were chosen for each accent mode. Figure 4 illustrates relative temporal placements of high and low magnitudes of physical accent for each IRR level. Sequences exhibiting IRR level 1 were defined as having minimal levels of temporal redundancy. Sequences exhibiting IRR level 7 were defined as having maximal levels of temporal redundancy. These seven IRR levels represented approximately equilog intervals from minimum to maximum "raw" IRRs (Wood, 1982, personal

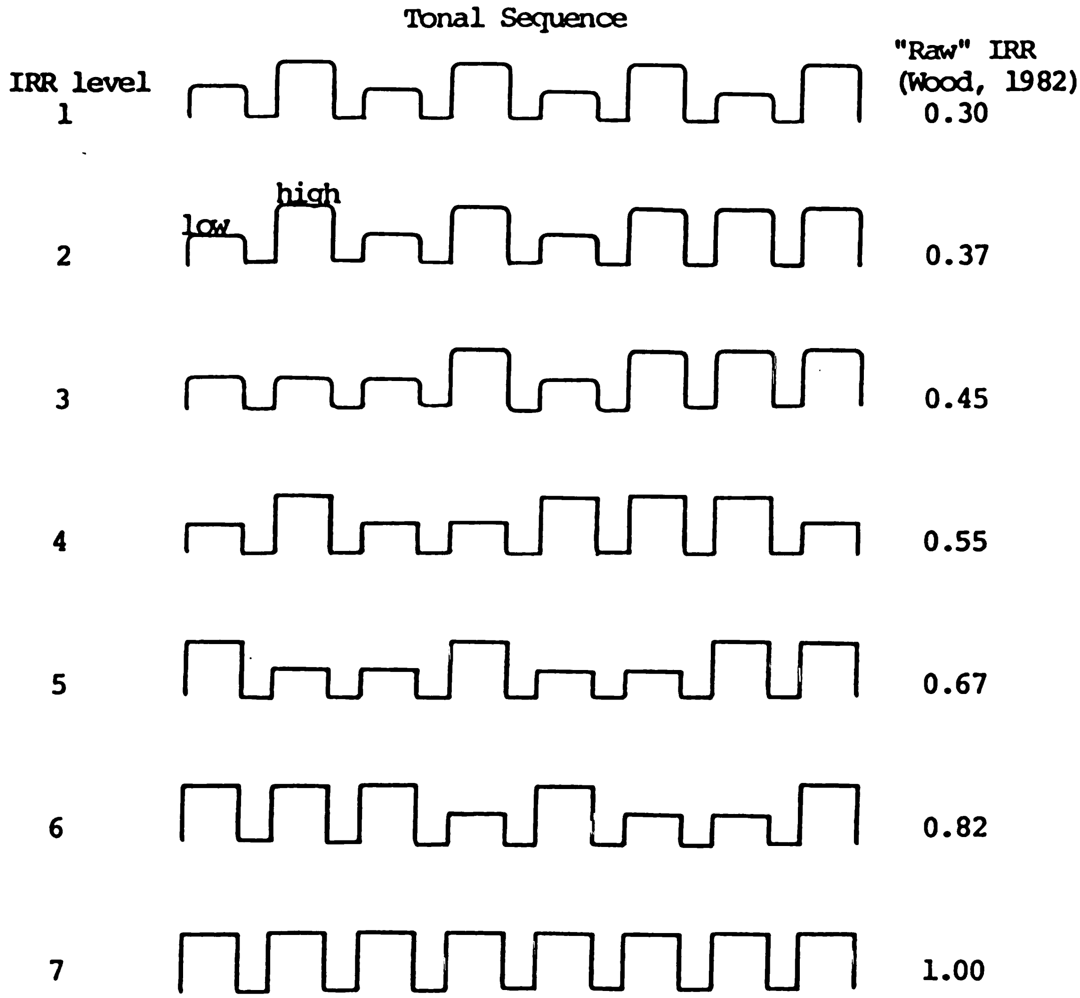


Figure 4. Time domain depiction of seven tonal sequences exhibiting approximately equilog intervals of IRR, from minimum to maximum temporal regularity (Wood, 1982, personal communication). Accent magnitudes (high and low) are depicted by the relative heights of sequence elements. Level 1 sequences are defined as exhibiting minimum temporal regularity, while level 7 sequences are defined as exhibiting maximum regularity. Level 4 sequences served as standard stimuli. Sequences exhibiting all IRR levels (1-7) served as comparison stimuli.

communication) as mandated by the ratio scaling procedure (Stevens, 1975). Level 4 became the "standard" stimulus in each accent mode. All IRR levels (1-7) served as "comparison" stimuli.

Presentation rate. Tonal sequences in frequency, amplitude, and combination frequency-amplitude modes were presented at a rate of 6.96 elements per second. Sequences in the duration accent mode were presented at a mean rate of 7.01 elements per second. These rates of presentation were employed in order to facilitate perception of the overall temporal pattern of accent within a particular sequence while also maximizing the ease of the magnitude estimation task for relatively naive subjects (Garner and Gottwald, 1968, p. 102). Overall percentage of agreement (99%) among presentation rates across accent modes facilitated specific comparisons between accent modes.

Presentation level. Stimulus sequences were presented at 40 dB SL (re: each subject's threshold at 1000 Hz). A sensation level criteria was adopted to minimize intramodal magnitude estimation variance associated with absolute levels of stimulus presentation. Frequency response curves of earphones were matched to ensure equal signal levels for diotic presentation, and differences in response as a function of frequency were taken into account to ensure equal loudness for accents of different frequency. Also, equal loudness contours were taken into consideration to ensure equal loudness for 1024 Hz and 3001 Hz accents.

Refer to Appendix H for a more complete description of the procedures undertaken to ensure the integrity of stimulus levels.

Accent modes

Frequency and duration modes were included to compliment Wood's (1980) original ABX discrimination experiment. He found a monotonic relationship between IRR level and percent-correct discrimination judgments for eight-element sequences in both frequency and duration accent modes. This experiment employed a greater range of IRR levels for each of these accent modes. Inclusion of amplitude and combination frequency-amplitude modes in the present study reflected an attempt to assess possible additivity effects on perceived regularity when tonal elements were similarly accented in more than one mode (i. e., both frequency and amplitude).

Frequency accent mode. Figure 5 shows a highly redundant tonal sequence in the frequency accent mode. Specific frequency parameters of 1024 Hz and 3001 Hz were chosen here because:

(1) 1 KHz is a standard reference calibration signal;

(2) both 1 KHz and 3 KHz fall in the range for which frequency response curves for TDH 49 earphones are fairly flat;

(3) the pitch difference between 1 KHz and 3 KHz

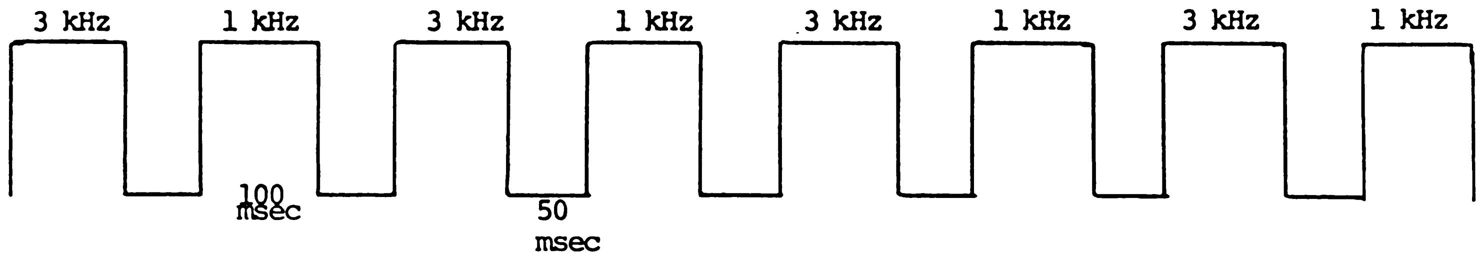


Figure 5. Time-domain depiction of a highly regular tonal sequence in the frequency accent mode. High magnitude accents were 3001 Hz tones. Low magnitude accents were 1024 Hz tones. On and off-times of tonal elements were 100 and 50 msec, respectively. Presentation level for all tonal elements was 40 dB SL (re: threshold for 1000 Hz).

is easily resolvable (Shower and Biddulph, 1931) in terms of jnd's, and exceeds the critical band. Frequency differences greater than a critical band (Scharf, 1970) have been shown to enhance temporal pattern resolution (Thomas and Fitzgibbons, 1971; Watson <u>et al</u> ., 1975);

(4) at presentation levels of 40 dB SL, both frequencies fall within a range where equal loudness contours are fairly flat (Robinson and Dadson, 1956);

(5) the frequency ratio between these two pure tones does not correspond to a musically "turned" interval (Roederer, 1975).

<u>Amplitude accent mode.</u> Figure 6 gives a time-domain example of highly redundant tonal sequence in the amplitude accent mode. A relative difference of 20 dB was adopted for high and low magnitudes of accent because:

(1) intensity differences of this magnitude are easily resolvable at 1 kHz (Jesteadt, <u>et al</u> ., 1977);

(2) in SPL, they are both below intensity levels (at 1000 Hz for the specified durations at criterion sensation levels) which might cause complete loudness summation or auditory adaptation (Scharf, 1978; Jerger and Jerger, 1966);

(3) intensity levels of these magnitudes are unlikely to elicit the acoustic reflex (Metz, 1952).

<u>Duration acent mode.</u> Figure 7 depicts a time-domain example of a highly redundant tonal sequence in the duration accent mode. Highly accented elements were 100 msec in duration, and elements receiving low levels of durational accent were 50 msec in duration. These specific durations were chosen because at 1000 Hz, pitch resolution is not significantly affected for tone pulses over 100 msec

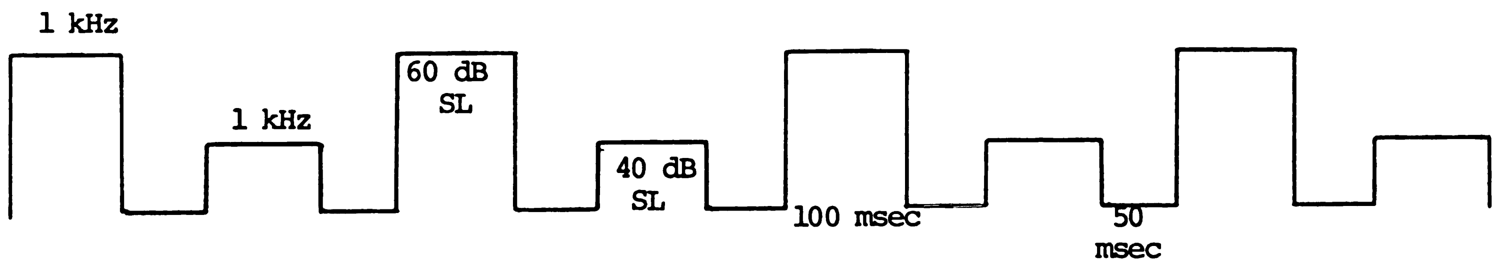


Figure 6. Time-domain depiction of a highly regular tonal sequence in the amplitude accent mode. All sequence elements were 1024 Hz tones. High magnitude accents were presented at 60 dB SL. Low magnitude accents were presented at 40 dB SL. On and off-times of tonal elements were 100 and 50 msec, respectively.

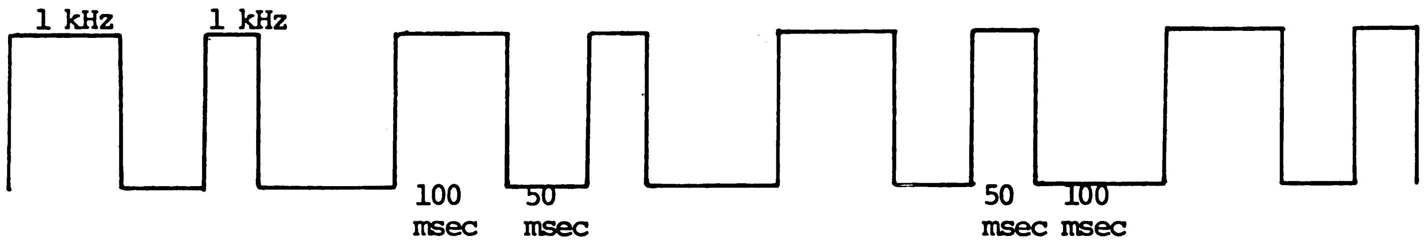


Figure 7. Time-domain of a highly regular tonal sequence in the duration accent mode. All tonal elements were 1024 Hz tones presented at 40 dB SL. High magnitude accents were 100 msec tones followed by 50 msec off-times. Low magnitude accents were 50 msec tones followed by 100 msec off-times.

in duration (Chih-an and Chistovich, 1960), and also because at 1000 Hz, duration differences between "high" and "low" levels of duration accent are greater than the difference limen for duration (Stott, 1935).

This method of durational accenting was a departure from that of Wood (1980), who defined accents in terms of musical notation (pp. 108-110). The present method was employed to maximize equivalency among intramodal sequence durations and assure for approximately equal numbers of elements (8) to occur per unit of time across accent modes. Thus, direct comparisons across accent modes was less subject to confounding.

Combination frequency-amplitude accent mode. Figure 8 gives an example of a highly redundant tonal sequence in the combination frequency-amplitude accent mode. Accented elements of sequences in this mode received emphasis in both frequency and amplitude. Absolute magnitudes of physical accents in this mode represented a direct and consistent combination of accent levels from the frequency mode and the amplitude mode.

Stimulus generation and control

All stimulus sequences were generated by a Synclavier II polyphonic synthesizer (New England Digital Corporation, White River Junction, Vermont, 05001). The Synclavier II provided digital synthesis and control of (1) signal levels, (2) rise-fall times of tonal elements, (3)

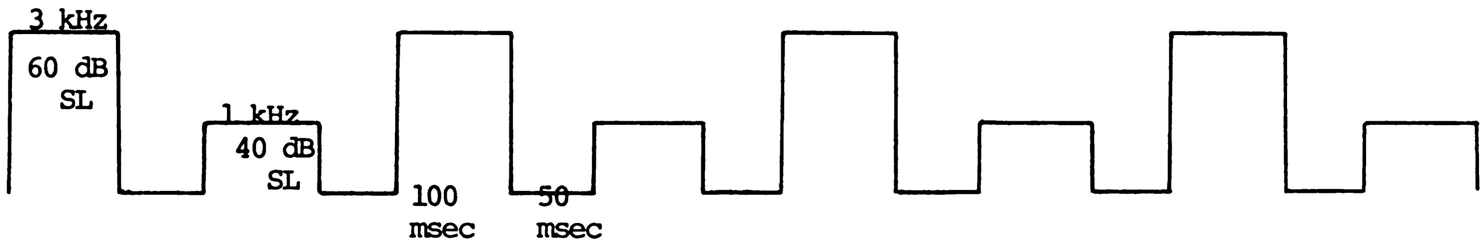


Figure 8. Time-domain depiction of a highly regular tonal sequence in the combination frequency-amplitude accent mode. On and off-times of tonal elements were 100 and 50 msec, respectively. High magnitude accents were 3001 Hz tones presented at 60 dB SL. Low magnitude accents were 1024 Hz tones presented at 40 dB SL.

inter-element and inter-sequence intervals, and (4) response intervals. High and low accents were routed from seperate channels of the Synclavier II (Figure 9) to tracks 1 and 3 of a reel-to-reel tape recorder (Teac. A2340 SX). Calibration tones were first recorded on magnetic tape (Ampex 406) for each accent level on the appropriate track. All calibration tones were recorded at zero VU, thus equating the peak to peak amplitudes of sequence elements to that of their corresponding calibration tones.

Stimulus sequences were then re-recorded (Figure 10) to achieve criterion differences in relative accent. This was accomplished by adjusting the calibration tones on tracks 1 and 3 such that peak to peak amplitudes of sequence elements reflected (1) frequency response characteristics of matched pairs of TDH 49 earphones with MX 41/AR cushions, and (2) equal loudness contours (refer to Appendix H).

Frequencies of sequence elements were verified by an external frequency counter (Tektronix DC 503 A), and signal levels and temporal characteristics were monitored on a dual channel storage oscilloscope (Tektronix T 912). After relative differences in accent magnitude were verified, verbal labels (i. e., "trial one, item one") were synchronized on track 4 using the aid of a "click track" generated by a metronomic device (Musical Technological Industries, Inc., Newark, New Jersey). High and low accent magnitudes were mixed together on the same track; verbal

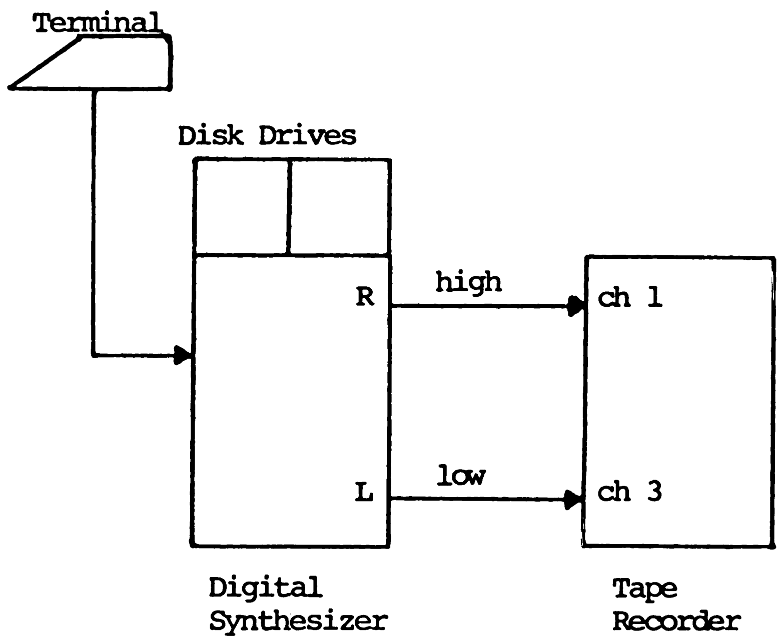


Figure 9. Block diagram of stimulus generation apparatus.

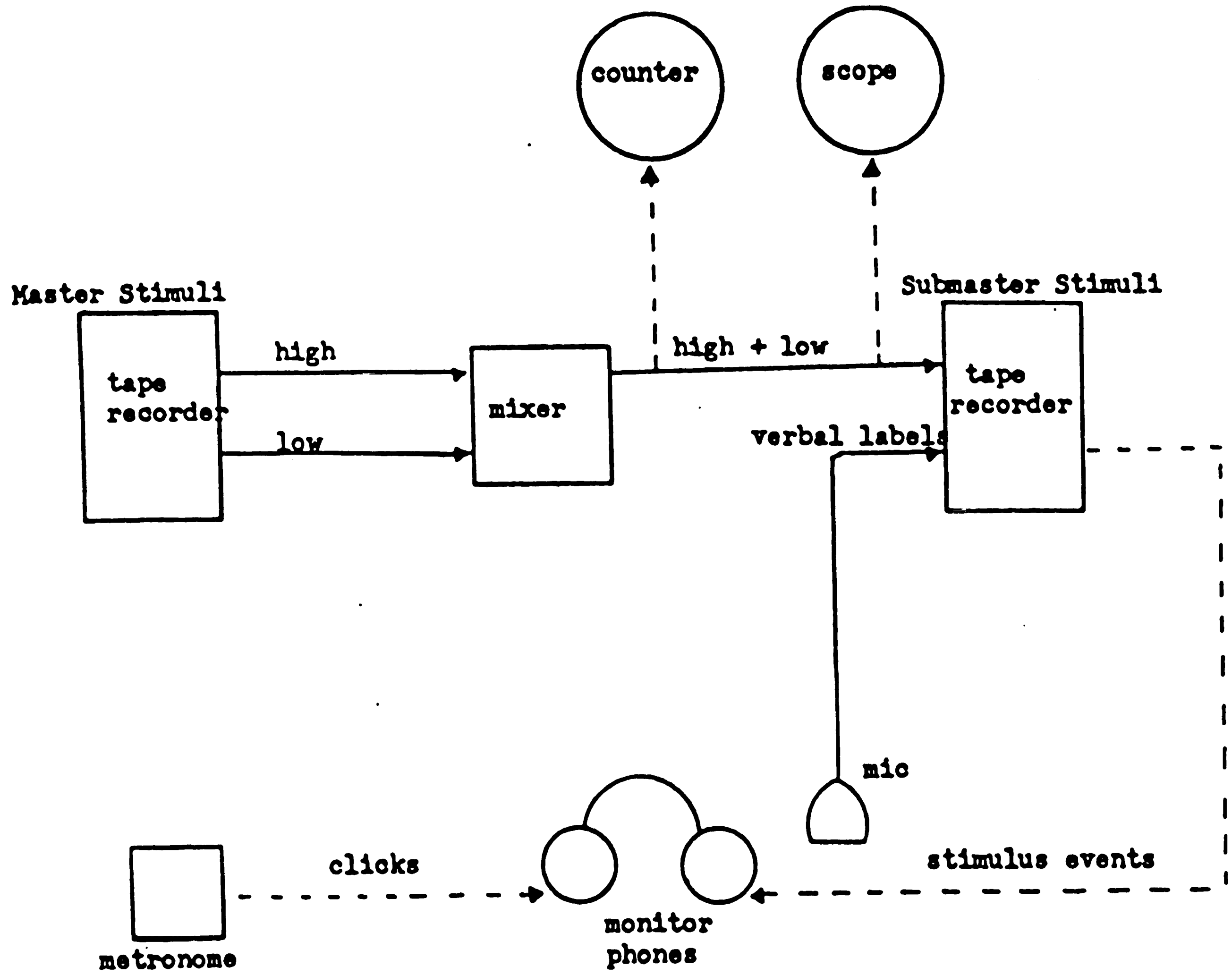


Figure 10. Block diagram of apparatus used to generate submaster recordings from the master tapes.

labels, however, remained on a discrete track.

Recording procedure

A repeated measures design in which all subjects receive all experimental treatments requires that presentation order of treatments be counterbalanced to minimize systematic learning effects (Campbell and Stanley, 1963). Furthermore, the ratio scaling procedure mandates that comparison stimuli be presented in random order (Stevens, 1975). Final run tapes used in this experiment therefore accomodated randomization of stimulus presentations within a counterbalancing of accent modes.

Subjects responded to a total of 336 stimulus presentations (refer to Table 1). Seven stimulus presentations (one pairing of standard and comparison sequences for each level of IRR) made up one stimulus trial. Four stimulus trials (one for each accent mode) comprised a stimulus block. Three stimulus blocks (one practice and two experimental) were administered in each experimental trial, and two experimental trials were held in each of two experimental sessions. Because counterbalancing of final run tapes took place at the experimental trial level, each final run tape accomodated 12 randomizations of stimulus presentations (4 randomizations for REME practice, and 8 randomizations for the REME experiment).

Generating all randomizations of stimulus presentations for a given accent mode at one time

TABLE 1. Summary of hierarchical stimulus delivery terms.

Term	Number	Contents
Experimental Session	2	2 Experimental Trials
Experimental Trial	4	3 Stimulus Blocks (1 practice, 2 experimental)
Stimulus Block	12	4 Stimulus Trials (one for each accent mode)
Stimulus Trial	48	7 Stimulus Presentations (one for each IRR level)
Stimulus Presentation	336	1 Standard Sequence and 1 comparison sequence

facilitated both control of tonal parameters and also counterbalancing of accent modes (which was accomplished by a splicing technique).

Master reel-to-reel recordings. Table 2 lists the contents of the 4 master tapes. Each tape was recorded directly from the stimulus generation equipment described above. Voiced labels were recorded on a seperate track of the four track recorder (Teac A2340SX) to "cue" subjects for the beginning of each "stimulus trial" (i. e., seven randomized pairs of standard and comparison stimulus presentations within a given accent mode). Additional voiced labels announced each stimulus presentation ("item") within each stimulus trial. These voiced labels aided subjects in recording their magnitude estimates (REMEs) on response sheets.

Each master tape consisted of:

(1) a 30-second, 1000-Hz level calibration tone,

(2) twelve stimulus "trials" for one of four accent modes, and

(3) one randomization of seven stimulus presentations ("items") for each stimulus trial.

The configuration of the four master tapes was such that stimulus trials from these tapes could be spliced in serial fashion for recording final run tapes.

Final run tapes. Four final run tapes were prepared by splicing timing (leader) tape and stimulus trial segments from the master tapes. Table 3 shows the serial

Table 2. Summary of reel-to-reel master recordings.

Master Tape No.	Contents	Number
1	Stimulus Trials, frequency accent mode	12
2	Stimulus Trials, amplitude accent mode	12
3	Stimulus Trials, duration accent mode	12
4	Stimulus Trials, frequency-amplitude accent mode	12

Table 3. Summary of final run tapes A, B, C, and D.

TAPE A (subject group 1)

Stimulus Trial*	Accent Mode	Number of Stimulus Presentations		Random Order No.
1	amp	7		1
1	freq	7	(practice)	2
1	freq-amp	7		3
1	dura	7		4
1	freq	7		5
1	freq	7		6
1	amp	7		7
1	amp	7	(experimental)	8
1	dura	7		9
1	dura	7		10
1	freq-amp	7		11
1	freq-amp	7		12

TAPE B (Subject group 2)

Stimulus Trial	Accent Mode	Number of Stimulus Presentations		Random Order No.
1	freq	7		13
1	amp	7	(practice)	14
1	dura	7		15
1	freq-amp	7		16
1	amp	7		17
1	amp	7		18
1	freq	7		19
1	freq	7	(experimental)	20
1	freq-amp	7		21
1	freq-amp	7		22
1	dura	7		23
1	dura	7		24

*Each final run tape consisted of 1 practice Stimulus Block and 2 experimental Stimulus Blocks. Thus REME practice consisted of 1 Stimulus Trial for each accent mode. Two Stimulus Trials for each accent mode were presented in the REME experiment.

Table 3. Continued.

TAPE C (Subject group 3)

Stimulus Trial	Accent Mode	Number Stimulus Presentations		Random Order No.
1	freq-amp	7		25
1	dura	7		26
1	amp	7	(practice)	27
1	freq	7		28
1	dura	7		29
1	dura	7		30
1	freq-amp	7		31
1	freq-amp	7	(experimental)	32
1	freq	7		33
1	freq	7		34
1	amp	7		35
1	amp	7		36

TAPE D (Subject group 4)

Stimulus Trial	Accent Mode	Number of Stimulus Presentations		Random Order No.
1	dura	7		37
1	freq-amp	7		38
1	freq	7	(practice)	39
1	amp	7		40
1	freq-amp	7		41
1	freq-amp	7		42
1	dura	7		43
1	dura	7	(experimental)	44
1	amp	7		45
1	amp	7		46
1	freq	7		47
1	freq	7		48

configuration of final run tapes A, B, C, and D. Each final run tape consisted of:

(1) a 30-second, 1000-Hz calibration tone,

(2) spoken instructions to the subject,

(3) one stimulus block of practice events (i. e., 28 stimulus presentations), and

(4) two stimulus blocks of experimental events (56 stimulus presentations).

The four first-generation final run tapes were re-recorded for back-up purposes. The spliced versions (first generation) served as experimental tapes.

Stimulus presentation apparatus

Figure 11 shows a block diagram of stimulus presentation apparatus. Tonal stimuli and verbal labels were routed from tracks 1 and 3 of a reel-to-reel tape recorder (Teac Tascam Series 40-4), respectively, to an audio mixer (Teac Model 2 with an MB 20 meter bridge). Instructions for the REME task were similarly routed to the mixer from a cassette recorder (Eumig FL-1000). At this point, signals were combined and routed to right and left channels of a speech audiometer (Grason Stadler GS 162) for purposes of calibrated attenuation. Attenuated signals were then routed to two sets of earphones (TDH 49 with MX 41/AR cushions) for diotic presentation to either one or two subjects.

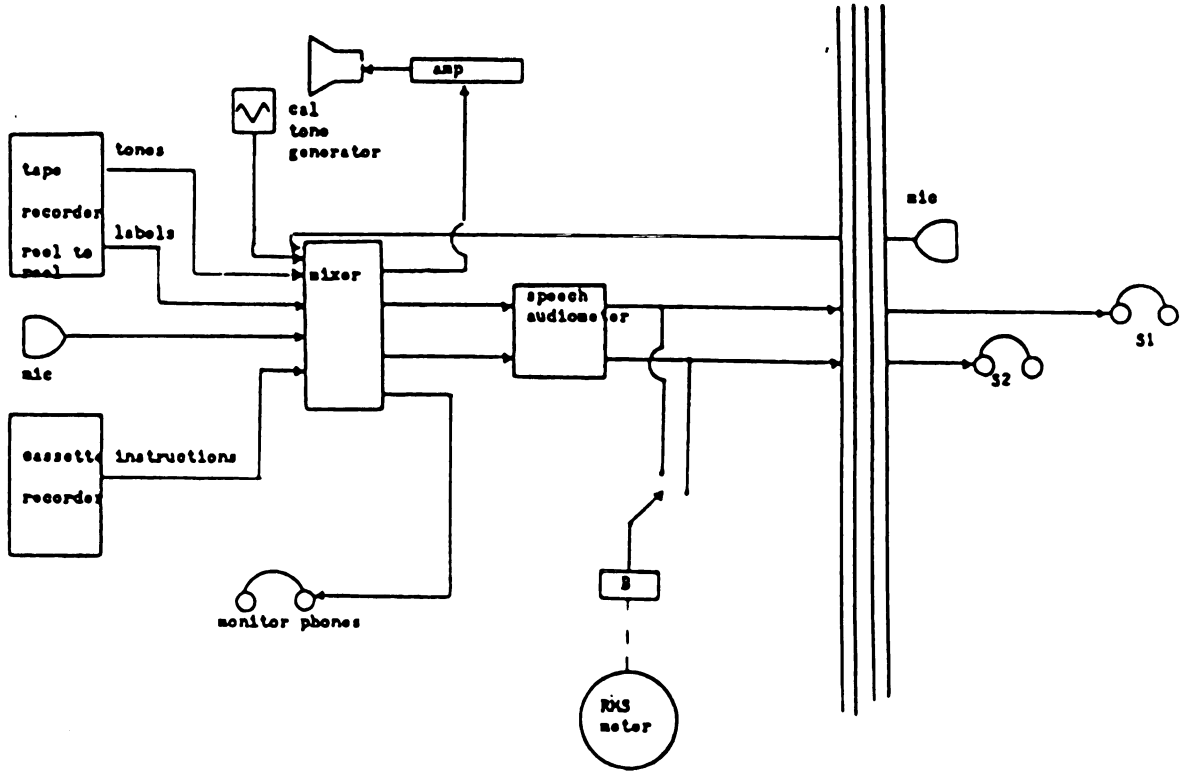


Figure 11. Block diagram of stimulus presentation apparatus.

Calibration procedures

System calibration was performed on the stimulus presentation apparatus and earphones to ensure criterion levels of accent magnitude. Refer to Appendix H for a complete description of system calibration procedures and appropriate frequency response curves. Running calibration was performed before each testing session by monitoring voltages at the level of each earphone terminal by a switching network (B, Figure 11) and an RMS voltmeter (Heath Schlumbarger SM-5225). Voltages were measured for the 1000 Hz taped calibration tones, and the integrity of the system was monitored daily with a test-tone generator (Teac Model TD-122 A).

Experimental procedures

Experimental procedures are summarized in Figure 12. Approximate time for each event is summarized in Table 4. Subjects were adult females with a mean age of 24.7 years. Subjects reporting normal hearing were asked to sign an informed consent release form (Appendix E) before commencing screening and training activities. All screening and training activities were administered in a chronological order reflecting supposed difficulty. That

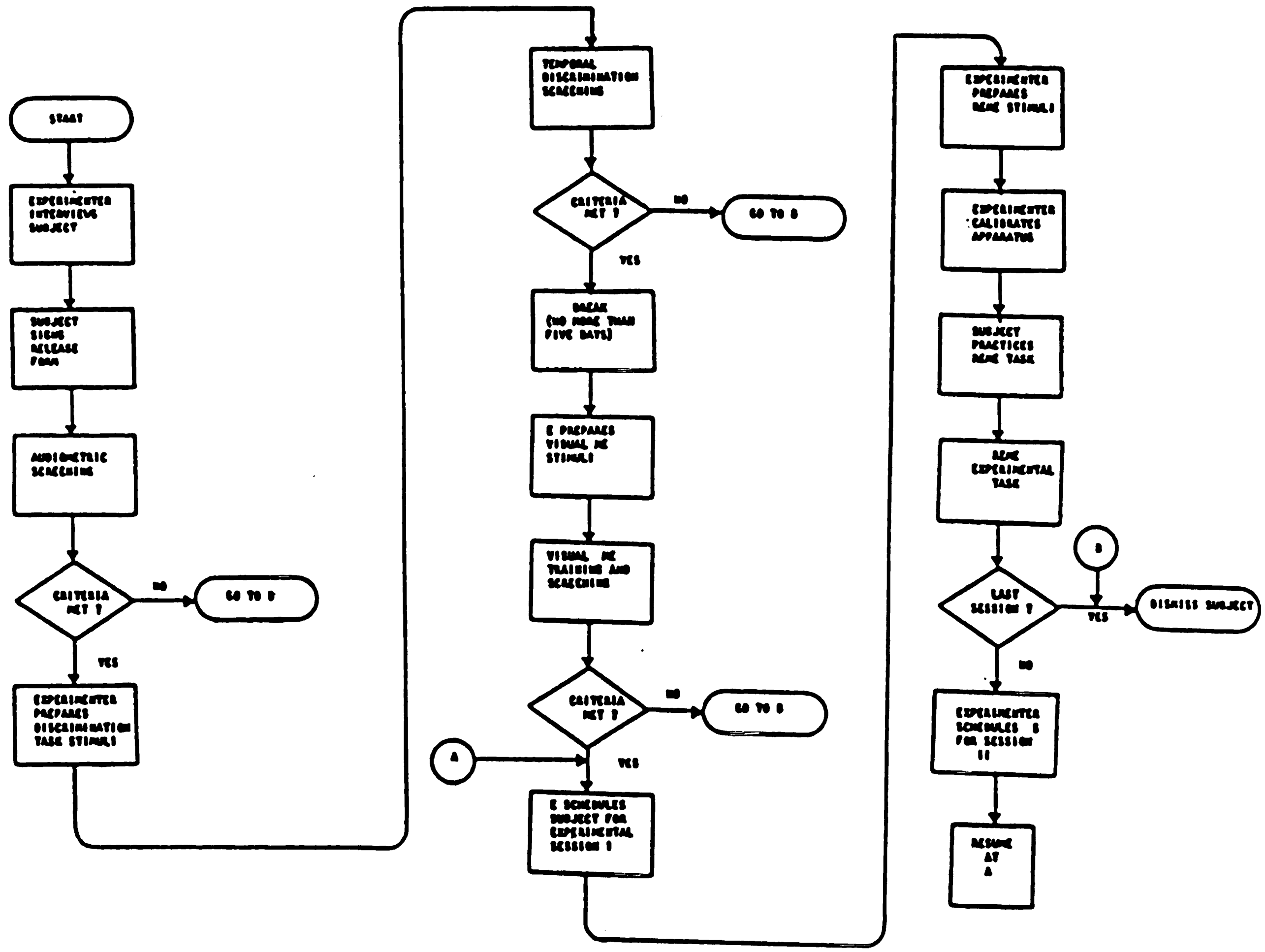


Figure 12. Procedural flowchart.

Table 4. Summary of events and their approximate time requirements.

Event	Time required (minutes)	
SCREENING AND TRAINING ACTIVITIES		
Subject interview	5	
Audiometric Screening		
history	5	
PT, AC testing	10	
reflex tone decay testing	5	
discrimination testing	10	
tympanometry	10	
Temporal Regularity Discrimination Screening	12	
Visual ME Training and Screening	12	
EXPERIMENTAL SESSIONS (two)		
*REME Instructions	5	
REME practice block	10	
(break)	2	Trial 1
REME Experimental Block 1	10	
(break)	2	
REME Experimental Block 2	10	
(break between experimental trials 1 and 2)	5	
REME practice block	10	
(break)	2	Trial 2
REME Experimental Block 1	10	
(break)	2	
REME Experimental Block 2	10	
ALL EVENTS	237	

*Second experimental session began with REME instructions.

is, screening activities thought to eliminate the most subjects were administered first.

Audiometric screening

Audiometric screening data for the twenty experimental subjects are summarized in Appendix C. All hearing tests were administered bilaterally to accomodate diotic stimulus presentation. Pure tone thresholds were assessed using a Tracoustics Program III audiometer conforming to ANSI S3.6 specifications and employing a test protocol which closely matches that described in ANSI S3.21-1978. The audiometric test environment conformed to ANSI S3.1-1977 specifications. Tympanometric and acoustic reflex decay assessment was accomplished on a Grason Stadler Middle-Ear Analyzer (model 1723), an automated device designed to yield middle ear measurements described by Jerger (1970) and Anderson, et al .,(1970).

Each subject passed a pure tone screening test by exhibiting hearing levels of 15 dB at 250, 500, 1000, 2000, 4000, and 6000 Hz (re: ANSI S3.5-1969). In addition, each subject exhibited inter-ear hearing threshold level differences no greater than 5 dB (to accomodate diotic presentation of experimental stimuli). Reflex decay testing was administered at 10 dB SL (re: acoustic reflex threshold), and tympanograms were plotted (automatically) for each subject at pressure increments of 100 mm H20. Speech discrimination testing (C. I. D. Auditory Test W-22

PB word list) was administered at 40 dB SL (re: two-tone threshold as computed by Fletcher, 1950). Subjects failing audiometric screening criteria were dismissed. Subjects passing audiometric criteria were screened for temporal regularity discrimination ability.

Pattern discrimination screening

Each subject demonstrated correct discrimination judgments between gross levels of temporal regularity as determined by IRR in a same-different matching test. Tonal sequences exhibiting IRR levels 1, 3, 5, and 7 were presented in pairs for frequency, amplitude, and duration mode sequences. All pair-wise combinations of IRR levels were presented in each mode. Subjects who correctly discriminated at least 27 out of the 30 test items participated in a visual magnitude training task.

Visual magnitude estimation screening

Each subject demonstrated ability to perform consistently in a visual magnitude estimation training task. This task was developed by Chial and Lawson (Lawson, 1980) to instruct subjects in ratio scaling strategies. Subjects were asked to estimate the apparent magnitude (size) of various squares and circles which were projected on a rear-screen slide viewer equipped with a synchronized tape player (Singer Caramate II SP). Each subject yielded a reliability coefficient (Pearson r) greater than or equal to 0.90 between estimates for second and third trials.

Information regarding the development of this visual training task is in Appendix D. Subjects meeting visual magnitude estimation criteria were scheduled for the temporal regularity magnitude estimation experiment (i. e., experimental Session I).

REME practice

Subjects first listened to taped instructions designed to teach the concept of "pattern regularity" and review the task of magnitude estimation (refer to Appendix I). Subjects then practiced the regularity magnitude estimation (REME) task prior to the gathering of experimental data in Trials 1 and 2 of experimental Session I. One block of practice stimuli was presented (i. e., seven stimulus presentations for each of four accent modes). Approximately 10 minutes were required for subjects to respond to the 28 stimulus presentations in a stimulus block. To minimize listening fatigue, a two minute rest period followed each stimulus block.

Response mode. Subjects responded to each stimulus presentation by writing numeric estimates of temporal regularity (REMEs) on response sheets (Appendix I). Because the scaling procedure was modulus free (Stevens, 1975), each stimulus trial required subjects to enumerate the regularity of a standard sequence (exhibiting IRR level 4) before responding to seven stimulus presentations (each in the same accent mode). Three response sheets were filled out by each subject in each experimental Trial: response sheet 1 accomodated REMEs to stimulus practice block 1; sheets 2 and 3 accomodated REMEs to experimental stimulus blocks one and two, respectively.

Counterbalancing strategy. The configuration of the four final run tapes (refer to Table 3) was such that stimulus presentations were randomized within counterbalanced accent modes. The presentation order of the four final run tapes maintained this counterbalancing strategy (see Figure 13). Experimental subjects were assigned (randomly) to one of four groups. Each group received a different counterbalancing of final run tapes A, B, C, and D.

REME experiment

Two experimental stimulus blocks were presented in Trial 1 of experimental Session I. Each subject therefore yielded 56 REMEs per Trial and 112 REMEs per Session. Again, a two minute break followed the presentation of each stimulus block. Experimental Trial 1 was followed by a five minute rest period. After experimental Trial 2 of Session I, subjects were scheduled to return within 10 days for a second listening session.

Second listening session. Experimental Session II also consisted of two experimental Trials (refer to Figure

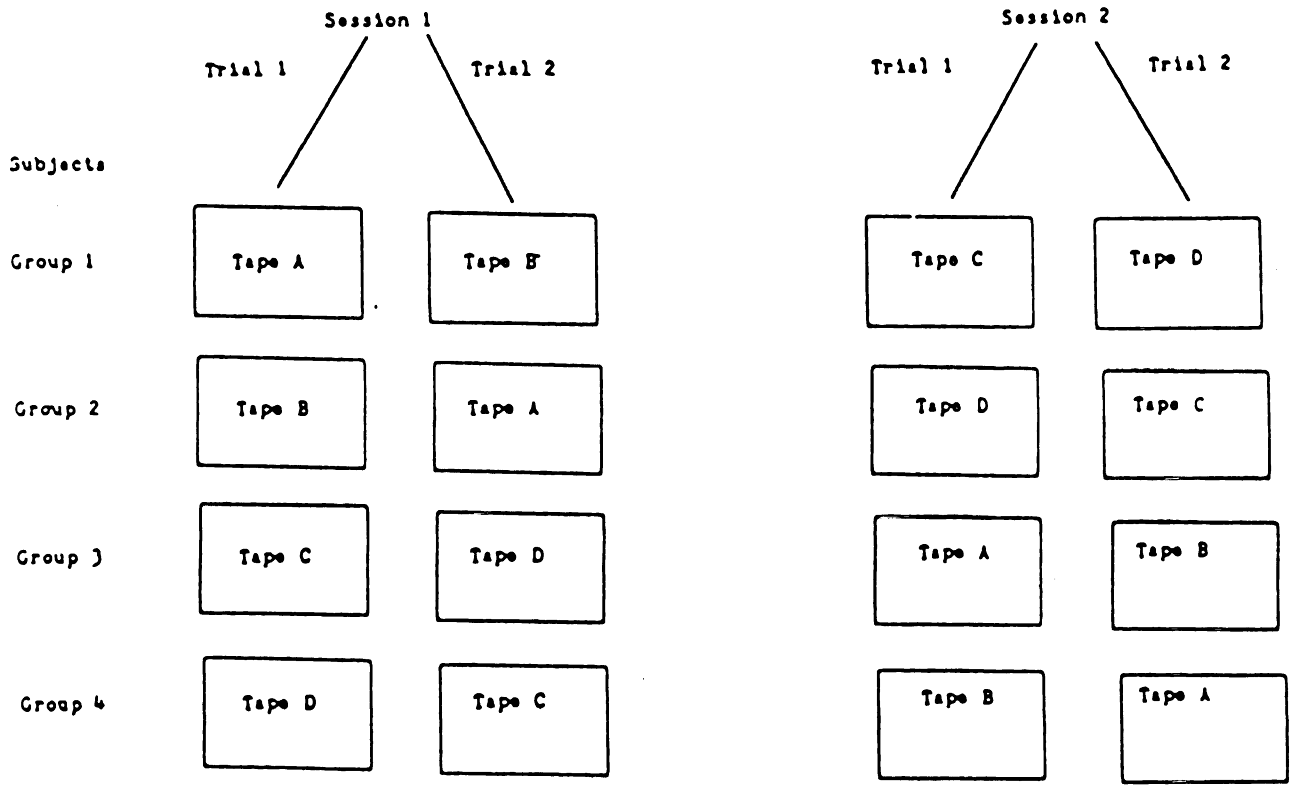


Figure 13. Counterbalancing strategy across experimental trials. Final run tapes A, B, C, and D were presented in counterbalanced fashion for 4 subject groups. Serial content (refer to Table 3) and different presentation orders of these tapes assured for (1) randomization of stimulus presentations within accent mode, and (2) counterbalancing of accent modes across experimental trials.

13). Each Trial in Session II also yielded 56 REMEs per subject (or a total of 112 REMEs per subject in experimental Session II). A total of 224 magnitudes estimates were therefore yielded by each subject across experimental Sessions I and II. Subjects were dismissed after Trial 2 of Session II.

CHAPTER III

RESULTS

Introduction

The purpose of this study was to examine the effect of relative temporal accent placement and accent type on the perception of pattern regularity in tonal sequences. To this end, pattern regularity magnitude estimation (REME) functions were generated by twenty trained subjects with normal hearing and similar listening ability. The REME functions were obtained for seven *a priori* indices of relative redundancy (IRR) in each of four accent modes, or types.

Initially, each subject met listening ability criteria by correctly judging at least 27 out of 30 items (i.e., 90%) on a same-different pattern discrimination task. Subjects were then trained in the use of ratio scaling by performing visual magnitude estimates of square and circle size. They were then instructed in magnitude estimation of pattern regularity and presented with 28 practice stimuli (seven levels of IRR for each of four accent modes). Practice stimuli were followed by 112 experimental stimuli (two presentations of seven levels of IRR in each of four accent modes for two trials). Both the practice and the experimental stimuli consisted of tonal sequences accented by pitch, loudness, duration, and a combination of pitch and loudness.

Twelve subjects were randomly selected to participate in a second experimental session. The second session was conducted in the same manner as the first, beginning with instruction in pattern regularity magnitude estimation.

Log geometric mean REMEs obtained over trials were plotted as a function of log stimulus magnitude (i.e., log IRR). Both the log-transformed data and the log-log functions were examined to answer the following experimental questions:

1. How consistently do subjects scale perceived regularity within and between experimental sessions?

2. Do stimuli with different IRRs produce significantly different perceptions of pattern regularity as indexed by magnitude estimates?

3. Is there a statistically significant trend for perceived regularity to be influenced by changes in IRR?

4. If a statistically significant trend is present, what is the lowest order mathematical function required to provide a statistically significant fit to the stimulus-response functions?

5. Do the stimulus-response functions (slopes) differ in strength of association across accent modes?

6. Do the slopes of the functions differ significantly across accent modes, across experimental sessions, or across combinations of the two?

7. Is the slope of the combination frequency-amplitude function significantly greater than that for the frequency accent mode? For the amplitude accent mode? For the sum of the two?

Data reduction

Because the experimental questions dealt with derived dependent variables (i.e., log geometric means and slope terms), it was necessary to reduce individual magnitude estimates to log geometric mean magnitude estimates and slope functions. Thus, raw REMEs were first tabulated from individual response sheets for each subject under each listening condition. Geometric means were then computed across presentations and trials for each IRR level in each of the four accent modes. The geometric mean (G.M.) is defined as:

$$G.M. = \sqrt[N]{(X1)(X2)\ldots(Xn)},$$

where Xn is the nth score. Stevens (1975) suggested that the geometric mean is the preferred index of central tendency because (a) it is consistent with the underlying scale of measurement (ratio), and (b) it is relatively insensitive to the effects of modulus differences across subjects and trials.

Log values were then computed from each geometric mean REME. Slopes of the log stimulus-log response (i.e., log IRR-log REME) functions were obtained from CURVE FITTER (Warme, 1980), a BASIC computer program designed to fit a variety of curves to experimental data using either least squares or interpolation solutions. Inputs to CURVE FITTER were (1) log stimulus values (2) individual log geometric mean REMEs for each subject, and (3) mean log geometric mean REMEs across trials and sessions. Outputs of CURVE FITTER included slopes, intercepts, and coefficients of determination for individual subjects and for all combinations of accent modes and sessions.

Statistical procedures

Within-subject analyses were performed on log geometric mean REME data and slopes. A significance criterion of 0.05 was adopted for all statistical tests. Interpolations for critical values (where needed) were computed by a method described by Glass and Stanley (1970, pp. 361-362). Strength of associations measures and specific comparison tests were carried out where appropriate.

<u>Pattern discrimination data</u>

Mean raw scores, standard deviations, and ranges were computed for wholescale and subscale responses. Reliability was assessed by computing (1) an ANOVA-based reliability coefficient for a test consisting of 30 dichotomous items (Winer, 1971, p. 294) and (2) percent-correct discrimination judgments for "control" test items (i.e., where stimulus pairings were correctly judged the same). In addition, a one-way analysis of variance (Winer, 1971, pp. 261-268) was performed to examine mean raw scores as a function of subscales (accent modes).

<u>Visual magnitude estimation data</u>

Reliability of log geometric mean visual magnitude estimates was assessed with Pearson coefficients of correlation. Mean log geometric mean responses were plotted as a function of log stimulus magnitudes (circle area in square inches). Lines of best fit describing log stimulus-log response functions were obtained for individual and group data using least squares solutions. Mean slope, standard deviation, and range were also computed. Analysis procedures on the log data included (1) ANOVA of log geometric mean visual magnitude estimates as a function of circle size (2) test for linear trend in log visual magnitude estimates to be influenced by changes in circle size, and (3) specific comparison tests between all pairs of mean log geometric mean visual magnitude estimates.

REME data

Reliability procedures . Pearson product-moment correlation coefficients (Linton and Gallo, 1975, pp. 347-352) were computed to assess reliability both within and between sessions. Within-session analyses were performed on the raw REME responses. Between-session analyses were performed on the log geometric mean REMEs and slopes of the log stimulus-log response functions.

Within-session correlation coefficients were obtained for raw REME responses in Session I and Session II. Correlation coefficients were obtained between each subject's Trial 1 and Trial 2 REMEs for each accent mode. Coefficients were transformed to Fisher Z scores (Hays, 1963, pp. 680-681), which were summed and divided by the appropriate number of scores to determine mean Z scores. The mean Z scores were then transformed to correlation coefficients to obtain "average" coefficients for each accent mode in each session.

Between-session correlation coefficients were computed on each subject's log geometric mean REMEs (7) and slope terms (log IRR-log REME functions) for each of the four accent modes between Sessions I and II. "Average" between-session correlation coefficients were determined by interpolating Z to r transformations from mean Fisher's r to Z transformations.

Analysis procedures for REME data. Perceptions of pattern regularity were examined first by analyzing the log geometric mean REMEs as a function of log stimulus magnitudes, and second, by analyzing the slopes of the log-log functions.

Session I log geometric mean REMEs were examined separately for each accent mode. This plan called for four one-way fixed-effects analyses of variance (ANOVA) with repeated measures on the seven levels of IRR within an accent mode (Winer, 1971, pp. 261-268). These analyses made it possible to determine if mean log geometric mean REMEs differed as a function of IRR level. If statistically significant differences were noted among mean log geometric mean REMEs, Newman-Keuls' tests of specific comparison were performed to assess differences between all possible pairs of mean log geometric mean REMEs within a specific accent mode (Linton and Gallo, 1975, pp. 324-327).

All specific comparison tests were followed by alternative tests for trend to determine the lowest order mathematical function providing a statistically significant fit to the log-log data in each accent mode (Winer, 1971, pp. 296-300). These tests for trend included first, second, and third degree polynomial "fittings" to the stimulus-response data.

Individual slope terms were obtained for each subject for the lowest order polynomial "fit" to the group data, where the best-fitting equation was defined as:

1. providing a statistically significant function, and

2. accounting for more than 50% of the variance shared by stimulus and response magnitudes.

The percentage of shared variance accounted for by a particular equation was estimated roughly by the formula:

% Variance = 100(SS trend-type/SS IRR levels) .

Although specific comparison tests among mean log geometric mean REMEs for each accent mode and among log geometric mean REMEs collapsed across accent modes suggested an insufficient number of data points for meaningful slope determination, individual and group slopes were obtained for the purpose of discussing the following in Stevensonian terms:

1. the effectiveness of IRR as an *a priori* predictor of perceived pattern regularity,

2. the reliability of the percept (i.e., "pattern regularity"), and

3. the differences of the percept among tonal sequences exhibiting different types of physical accents.

Mean slope terms, standard deviations, and ranges were obtained for each accent mode. In addition, mean coefficients of determination, standard deviations, and ranges were obtained. Coefficients of determination were taken as indices of relative potency (i.e., strength of association measures) for the stimulus-response functions in each accent mode.

Slope terms for the log-log functions were examined for statistically significant differences as a function of accent mode, experimental session, and interactions of modes and sessions. This plan called for a two-way ANOVA (2 x 4) with repeated measures on accent modes and experimental sessions (Winer, 1971, pp. 518-526). Coefficients of determination were examined in this way also.

PATTERN DISCRIMINATION DATA

Description

Mean raw scores, standard deviations, and ranges for the pattern discrimination task are summarized in Table 5. Summary statistics were computed for wholescale and subscale responses. The distribution of wholescale raw scores could be described as negatively skewed and platykurtic (Glass and Stanley, 1970, pp. 88-92).

Table 5. Mean raw scores, standard deviations and ranges for twenty subjects on the pattern discrimination task.

ACCENT MODE/SUBSCALE									WHOLESCALE		
frequency			amplitude			duration					
M	SD	R	M	SD	R	M	SD	R	M	SD	R
9.8	0.41	1	9.85	0.48	2	9.19	0.89	3	28.9	0.89	3

Reliability

An ANOVA-based reliability coefficient for a test of 30 dichotomous items of 0.93 was computed for wholescale discrimination data (Winer, 1971, p. 294). Also, the percent-correct judgments of "control" test items was calculated to be 98%.

Analysis

Table 6 summarizes the results of a one-way analysis of variance in raw discrimination scores as a function of accent modes (i.e., subscales). A significant F ratio was obtained, and a strength of association measure (eta-squared) indicated that approximately 19% of the variance in raw discrimination scores could be accounted for by accent modes (frequency, amplitude, and duration). Specific comparisons of subscale means (Table 7) indicated that mean scores for both the frequency and amplitude subscales were significantly greater than that for the duration subscale, but not significantly different from each other.

Quantitative comparisons were not made between pilot and experimental groups for the pattern discrimination task because eight subjects were common to both groups. Also, only subjects meeting the 90% correct judgment criteria were included in the study.

Table 6. Summary of analysis of variance of raw scores for the pattern discrimination task as a function of accent mode.

Source	SS	df	MS	F	F for alpha=0.05	alpha F Obs.
Blocks/ Subjects	6.849	19				
Accent Modes	5.233	2	2.616	6.175	3.24*	0.005
Error	16.100	38	0.423			
Total	28.183	59				

* From F distribution table (Winer, 1971, pp. 864-869)

Table 7. Results of the Newman-Keuls specific comparison test on pairs of mean correct raw scores for each accent mode in the pattern discrimination screening task. Critical values are given for all possible ranges spanning from two to three means. A difference between any two means is significant when it exceeds the appropriate critical value (CV) for alpha = 0.05. The number of means is equal to k.

Accent Mode (means)	Amp (9.85)	Fre (9.80)	Dur (9.19)	CVk	
Amp		0.05	0.66*	CV3	0.50
Fre			0.61*	CV2	0.42

* Denotes a significant difference between a pair of means.

VISUAL MAGNITUDE ESTIMATION DATA

Description

Figure 14 summarizes mean log geometric mean fixed-modulus visual magnitude estimates of circle size as a function of circle area (inches-squared). The mean slope, standard deviation, and range for twenty subjects are summarized in Table 8. Figure 15 was created to visually compare the visual magnitude estimation functions of this study to that of Lawson (1980, p. 54). Slope comparisons were only qualitative, however, because Lawson used a free modulus, whereas this study employed a fixed modulus (i.e., subjects were asked to assign the same magnitude to all presentations of the standard stimulus). Lawson reported a mean slope of 0.717 for an n=12 (p. 55). The mean slope of this study was 0.708 for an n=20.

Reliability

Table 9 lists reliability coefficients (Pearson r) between Trial 2 and Trial 3 log visual magnitude estimates of circle size for the twenty subjects used in this study. All subjects met reliability criterion ($r >= 0.90$).

Analysis

Analysis of the visual screening data indicated (a) statistically significant differences among mean log geometric mean visual estimates as a function of circle

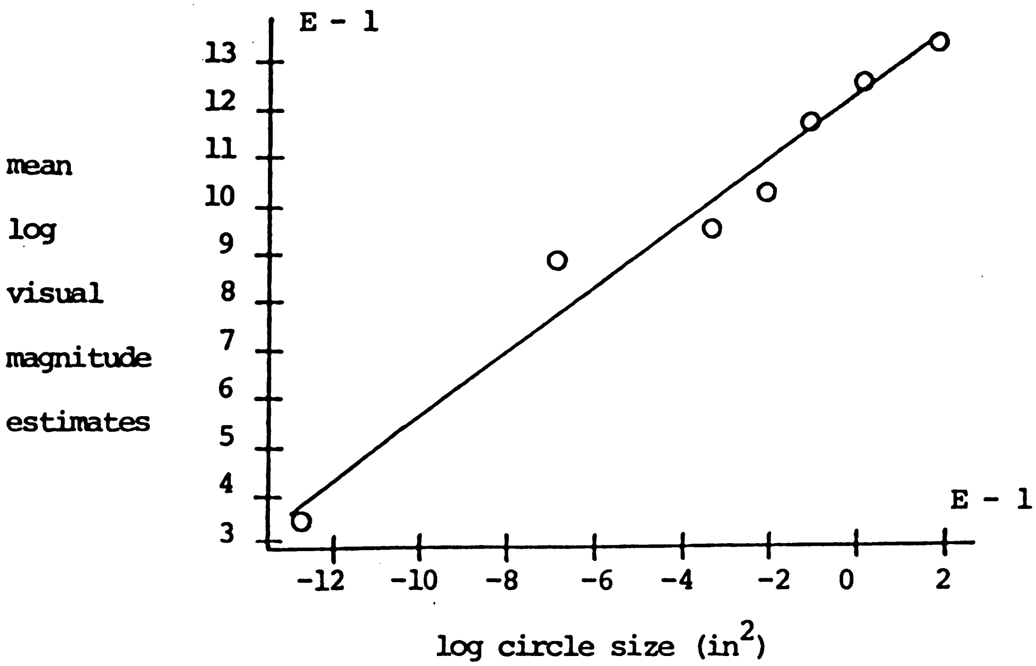


Figure 14. Mean log geometric mean fixed-modulus visual magnitude estimates of circle size plotted as a function of log circle area (in^2). The line of best fit was obtained from a least squares solution.

Table 8. Mean slope, standard deviation and range for twenty subjects on the visual screening task. Slopes were obtained from least squares solutions for log geometric mean visual magnitude estimates as a function of log circle size (inches-squared).

	Mean	Standard Deviation	Range
N = 20	0.708	0.107	0.401

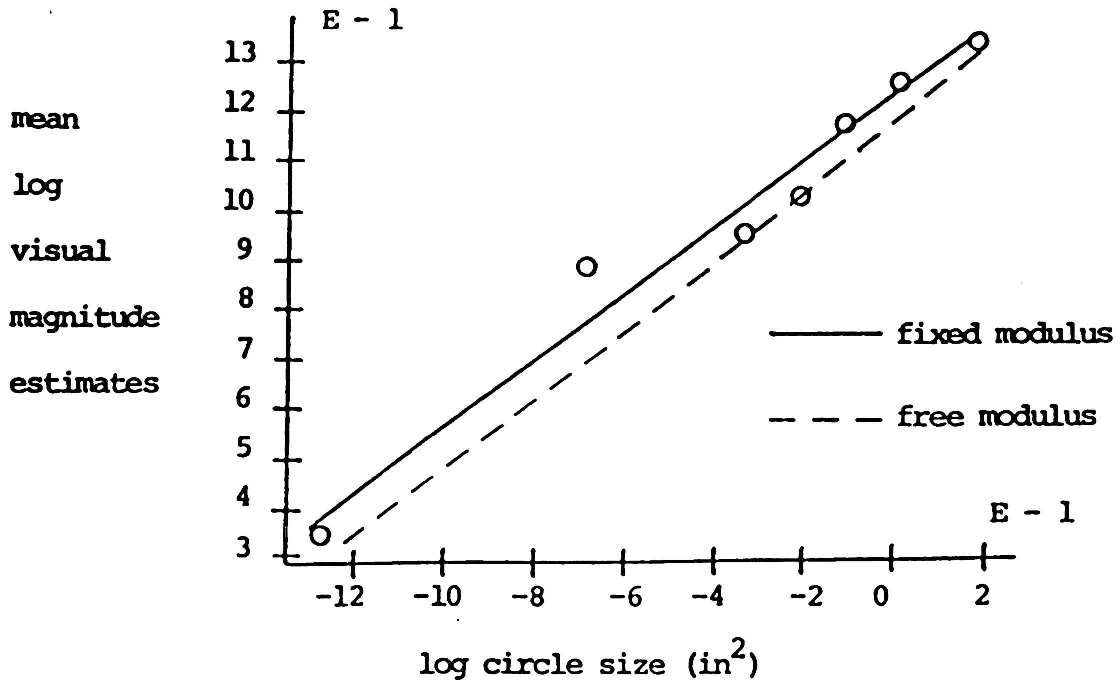


Figure 15. Mean log geometric means of fixed-modulus (solid line) and free-modulus (dashed line) visual magnitude estimates of circle size plotted as a function of log circle area (in^2). Twenty subjects in this study responded with fixed moduli. Twelve subjects responded with free moduli (Lawson, 1980). Lines of best fit were obtained from least squares solutions.

Table 9. Pearson product-moment correlation coefficients (r) between the log visual magnitude estimates of circle size (inches-squared) for each subject's trial 2 and trial 3 stimuli. All coefficients were significant for alpha = 0.05 (df = 18 ; critical r = 0.444).

Subject	r
1	1.00
2	0.99
3	0.98
4	1.00
5	0.96
6	0.99
7	0.99
8	1.00
9	1.00
10	1.00
11	0.91
12	0.98
13	0.99
14	1.00
15	0.98
16	1.00
17	0.99
18	0.97
19	0.99
20	0.91

area (Table 10), (b) a statistically significant linear trend in the log stimulus-log response function (Table 11), and (c) statistically significant differences between all pairs of mean log geometric mean visual magnitude estimates (Table 12).

AUDITORY MAGNITUDE ESTIMATION DATA

Raw REME Data

Descriptive statistics were not computed for raw REME responses. Within-subject analysis of raw REMEs was confined to reliability assessment within Sessions I and II.

Session I reliability. Table 13 lists individual subject and group (n = 20) "average" correlation coefficients between REMEs for the first and second trials in Session I. Group "average" correlations are shown graphically in Figure 16. Significant coefficients were those which equalled or exceeded 0.444. Only three subjects exhibited nonsignificant coefficients for a particular accent mode. These nonsignificant coefficients occurred in only one accent mode per subject, and in a different mode for each subject. Average coefficients across accent modes ranged from 0.82 (for duration stimuli) to 0.89 (for amplitude stimuli). The average coefficient for all Session I REMEs was 0.86. These averages suggest high within-subject reliability of REMEs for all accent

Table 10. Summary of analysis of variance in log geometric mean visual magnitude estimates as a function of circle size (inches-squared).

Source	SS	df	MS	F	F for alpha=.05	alpha for F obs.
Blocks/ Subjects	19.016	19				
Visual Magnitude Estimates	15.26	6	2.543	333.975	2.174*	0.001
Error	0.868	114	0.007			
Total	35.145	139				

* From F distribution table (Winer, 1971, pp. 864-869).

Table 11. Summary of test for linear trend in log geometric mean visual magnitude estimates of circle size.

Source of Variance	SS	df	MS	F	F for alpha=.05	alpha for F obs.
Linear trend	18.23	1	18.23	1302	2.174*	0.0
Deviation from linear trend	1.654	119	.014			

*From F distribution table (Winer, 1971, pp. 864-869).

Table 12. Results of the Newman-Keuls specific comparison test on pairs of mean log geometric mean visual magnitude estimates of seven circle sizes (inches-squared). Critical values are given for all possible ranges of means spanned. A difference between any two means is significant when it exceeds the appropriate critical value (CV) for alpha=0.05. The number of means spanned is equal k.

	Stimuli							
Means	G (1.37)	F (1.25)	E (1.17)	D (1.07)	C (0.95)	B (0.70)	A (0.33)	CVk
G		0.12*	0.20*	0.30*	0.42*	0.67*	1.04*	CV7=0.081
F			0.08*	0.18*	0.30*	0.55*	0.92*	CV6=0.078
E				0.10*	0.22*	0.47*	0.84*	CV5=0.074
D					0.12*	0.37*	0.74*	CV4=0.070
C						0.25*	0.62*	CV3=0.064
B							0.37*	CV2=0.053

* Denotes a significant difference between a pair of means.

Table 13. Within subject correlation coefficients (Pearson r) between fourteen Trial 1 and Trial 2 REMEs for each of 20 subjects in Session I. "Average" coefficients were determined for each accent mode.

	Accent Mode				
Subject	Freq	Amp	Dura	Comb	$\overline{X}r$*
1	0.63	0.61	0.84	0.56	
2	0.81	0.85	0.91	0.90	
3	0.81	0.58	0.94	0.76	
4	0.87	0.85	0.88	0.91	
5	0.89	0.83	0.84	0.62	
6	0.97	0.96	0.96	0.995***	
7	0.88	0.98	0.71	0.62	
8	0.94	0.84	0.71	0.71	
9	0.78	0.80	0.74	0.93	
10	0.99	0.98	0.995***	0.99	
11	0.84	1.00**	0.84	0.96	
12	0.94	0.92	0.81	0.95	
13	0.38	0.56	0.60	0.89	
14	0.80	0.69	0.73	0.38	
15	0.86	0.96	0.53	0.81	
16	0.57	0.97	0.51	0.67	
17	0.66	0.79	0.55	0.44	
18	0.73	0.87	0.81	0.78	
19	0.91	0.67	0.84	0.85	
20	0.68	0.67	0.45	0.87	
$\overline{X}r$*	0.85	0.89	0.82	0.86	0.86

* "Average" correlations are Fisher's Z to r transformations interpolated from mean Fisher's r to Z transformations (Hays, 1963, pp. 680-681).

** Changed to r=0.998 for conservative transformation of r to Z since there is no transformation for r=1.00.

*** Interpolated from three decimal place coefficient for conservative transformation of r to Z since there is no transformation for r rounded to 1.00.

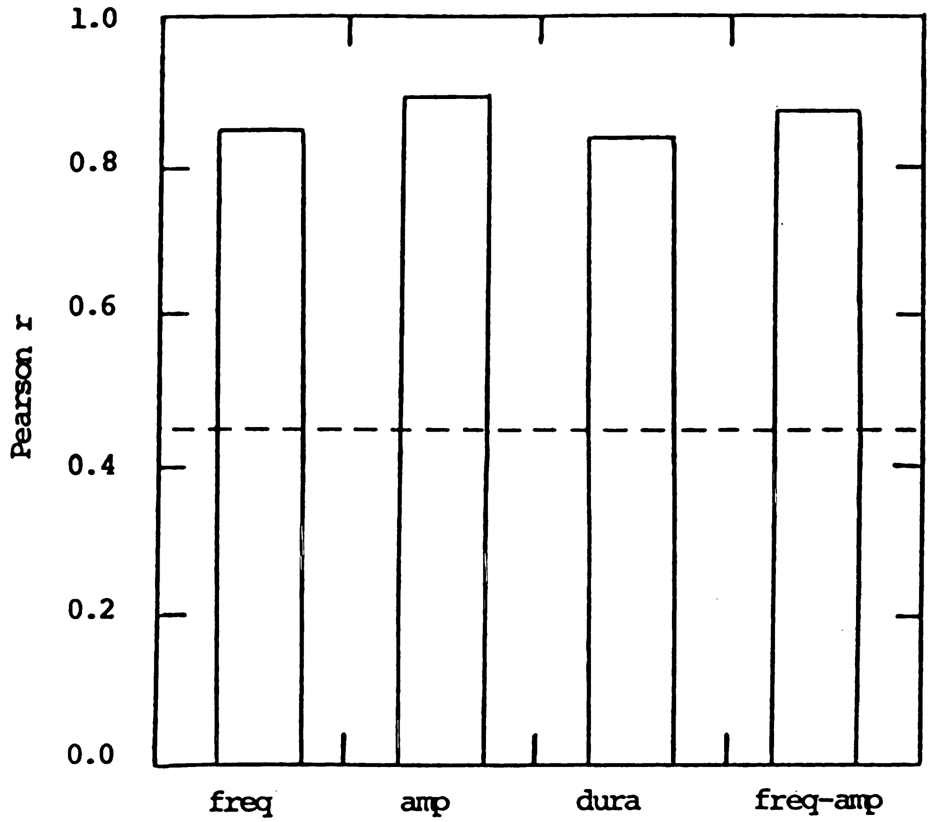


Figure 16. "Average" within-subject test-retest correlation coefficients between fourteen trial 1 and trial 2 REMEs for 20 subjects under four accent modes in Session I. "Average" correlations are Fisher's Z to r transformations (Hays, 1963, pp. 680-681). The dashed horizontal line denotes the significance criterion (r = 0.444).

modes in Session I.

<u>Session II reliability.</u> Table 14 lists individual subject and group (n = 12) "average" correlation coefficients between REMEs for the first and second trials in Session II. Group "average" correlations (Figure 17) were those which equalled or exceeded 0.576. Only two subjects exhibited correlations below significance criterion. One of these subjects' coefficients was nonsignificant for only one accent mode; the other subject's coefficients were nonsignificant for two modes of accent. Again, "average" group coefficients suggested a high degree of reliability for raw REME responses within Session II.

<u>Log Geometric Mean REME Data</u>

<u>Description.</u> Session I mean log geometric mean REMEs, standard deviations, and ranges for all accent mode stimuli are summarized in Table 15. Mean log geometric mean REMEs are also shown graphically as a function of IRR level in Figure 18 for frequency, amplitude, duration, and combination accent mode stimuli. The data appear to follow a similar general pattern in each accent mode: mean log geometric mean REMEs do not appear to be monotonically related to stimulus magnitudes. On the contrary, graphic depiction of data in Figure 18 suggests a curvilinear, perhaps even quadratic relationship between log IRR and log

Table 14. Within subject correlation coefficients (Pearson r) between fourteen Trial 1 and Trial 2 REMEs for each of 12 subjects tested in Session II. "Average" coefficients were determined for each accent mode.

	Accent Mode				
Subject	Freq	Amp	Dura	Comb	$\bar{X}r$*
1	0.78	0.85	0.38	0.94	
2	0.86	0.95	0.87	0.92	
4	0.88	0.90	0.86	0.93	
5	0.85	0.80	0.81	0.91	
6	0.86	0.91	0.81	0.73	
7	0.44	0.54	0.69	0.75	
9	0.93	0.86	0.81	0.83	
10	0.99	0.99	0.995**	0.995**	
15	0.92	0.90	0.96	0.997**	
16	0.86	0.55	0.79	0.83	
17	0.97	0.92	0.77	0.90	
19	0.71	0.87	0.87	0.95	
$\bar{X}r$*	0.89	0.88	0.86	0.94	0.89

* "Average" correlations are Fisher's Z to r transformations interpolated from mean Fisher's r to Z transformations (Hays, 1963, pp. 680-681).

** Interpolated from three decimal place coefficient for conservative transformation of r to Z since there is no transformation for r rounded to 1.00.

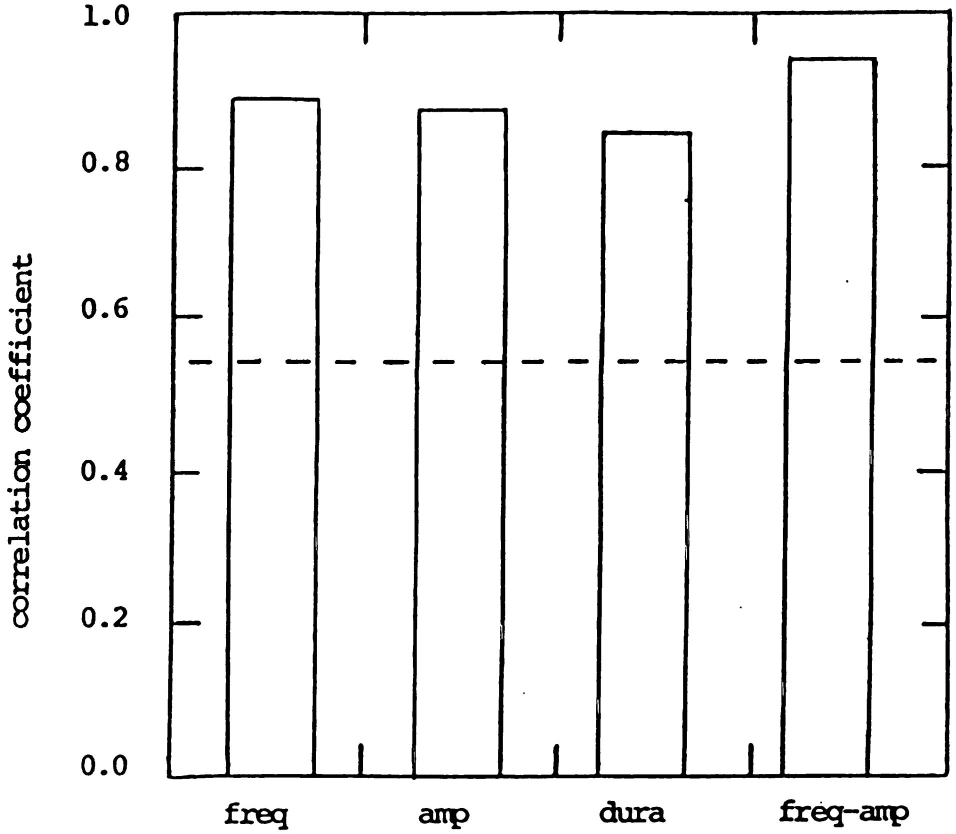


Figure 17. "Average" within-subject test-retest correlation coefficients between fourteen trial 1 and trial 2 REMEs for 12 subjects under four accent modes in Session II. "Average" correlations are Fisher's Z to r transformations interpolated from mean Fisher's r to Z transformations (Hays, 1963, pp. 680-681). The dashed horizontal line denotes significance criterion (r = 0.576).

Table 15. Session I mean log geometric mean REMEs, standard deviations, and ranges for twenty subjects at each of seven levels of IRR as a function of four accent mode types.

		IRR LEVELS 1	2	3	4	5	6	7	ALL LEVELS
FRE	$\bar{X}$	1.52	1.26	1.15	1.12	1.20	1.09	1.60	1.28
	SD	0.29	0.33	0.27	0.27	0.27	0.28	0.31	0.34
	R	1.12	1.44	1.21	1.05	1.21	0.98	1.15	1.84
AMP	$\bar{X}$	1.40	1.18	1.12	1.10	1.18	1.11	1.60	1.24
	SD	0.24	0.31	0.25	0.23	0.28	0.23	0.30	0.34
	R	0.94	1.27	1.01	1.00	1.02	0.99	1.19	1.70
DUR	$\bar{X}$	1.38	1.19	1.11	1.13	1.14	1.08	1.57	1.23
	SD	0.24	0.29	0.29	0.25	0.27	0.25	0.27	0.33
	R	0.91	1.26	1.13	1.00	1.03	0.95	1.07	1.58
COM	$\bar{X}$	1.46	1.25	1.15	1.13	1.19	1.11	1.59	1.27
	SD	0.28	0.28	0.30	0.25	0.28	0.27	0.26	0.34
	R	1.02	1.18	1.08	1.02	1.14	1.04	1.04	1.61
ALL MODES	$\bar{X}$	1.44	1.22	1.13	1.12	1.18	1.10	1.59	1.25
	SD	0.26	0.31	0.30	0.27	0.29	0.26	0.35	0.36
	R	1.34	1.44	1.21	1.05	1.21	1.07	1.18	1.84

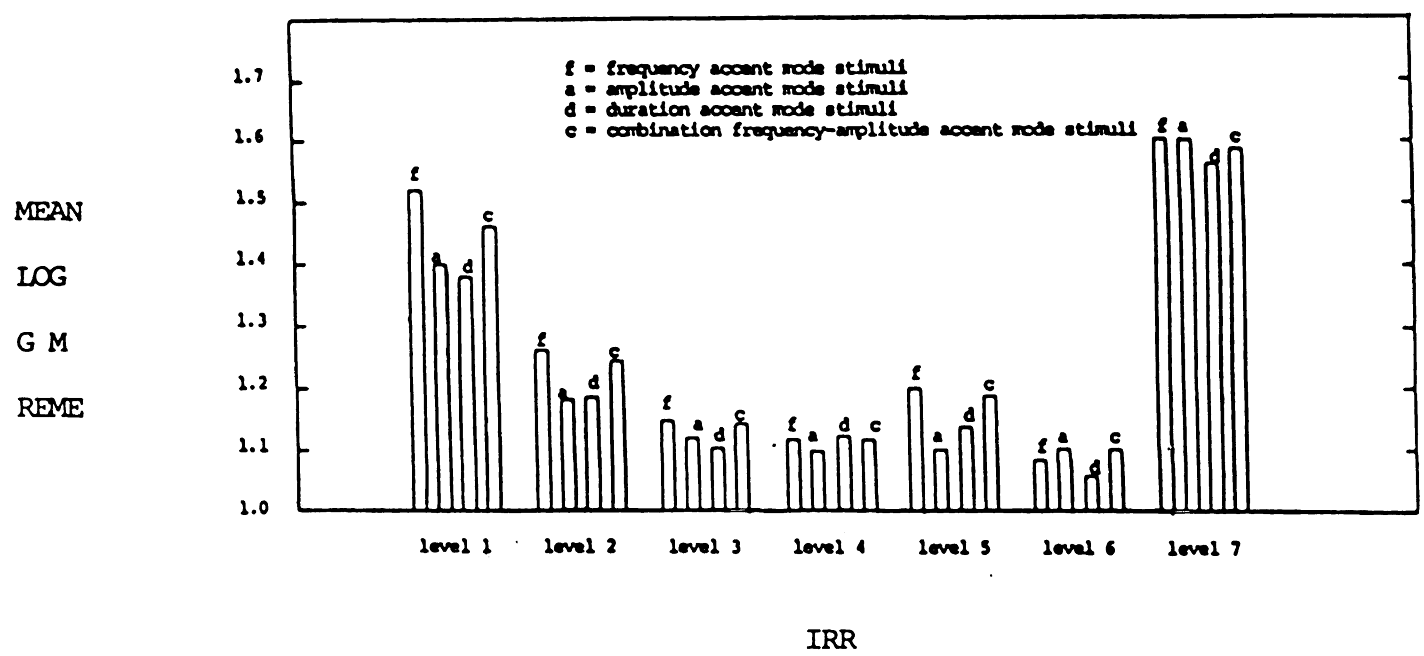


Figure 18. Session I mean log geometric mean REMEs plotted as a function of IRR level for frequency (f), amplitude (a), duration (d), and combination (c) frequency-amplitude accent mode stimuli.

REME for each accent mode.

Reliability. Table 16 lists individual subject and group (n = 12) "average" correlation coefficients between Session I and II log geometric mean REMEs. Average coefficients are also depicted graphically in Figure 19. Significant correlations were those which equalled or exceeded 0.576. All individual correlations were statistically significant. Average coefficients ranged from 0.92 for amplitude accent mode stimuli to 0.95 for combination accent mode stimuli. The grand mean was 0.94, suggesting very high between-session reliability of log geometric mean REMEs.

Analysis. Mean log geometric mean REMEs were examined as a function of IRR for each accent mode to determine the effect of IRR on the perceptual magnitude of perceived pattern regularity. Statistically significant differences were noted among mean log geometric mean REMEs in all modes. Results of specific comparison tests and the cursory observation of similarities among data point configurations for all modes (Figure 18), however, prompted the following additional analyses:

1. examination of the effect of accent mode on the log geometric mean REMEs at each level of IRR across modes,

Table 16. Within subject correlation coefficients (Pearson r) between each of 12 subject's seven log geometric mean REMEs for Session I and II in each of four accent modes.

	Accent Mode				
subject	Freq	Amp	Dura	Comb	$\bar{X}r$*
1	0.72	0.66	0.77	0.78	
2	0.91	0.72	0.94	0.78	
4	0.94	0.90	0.87	0.91	
5	0.96	0.99	0.98	0.97	
6	0.97	0.78	0.94	0.99	
7	0.88	0.78	0.89	0.92	
9	0.97	0.92	0.95	0.96	
10	0.98	0.99	0.99	0.995**	
15	0.99	0.96	0.88	0.99	
16	0.91	0.89	0.97	0.97	
17	0.80	0.92	0.90	0.79	
19	0.92	0.93	0.93	0.81	
$\bar{X}r$*	0.94	0.92	0.94	0.95	0.94

* "Average" correlations are Fisher's Z to r transformations interpolated from mean Fisher's r to Z transformations (Hays, 1963, pp. 680-681).

** Interpolated from three decimal place coefficient for conservative transformation of r to Z since there is no transformation for r rounded to 1.00.

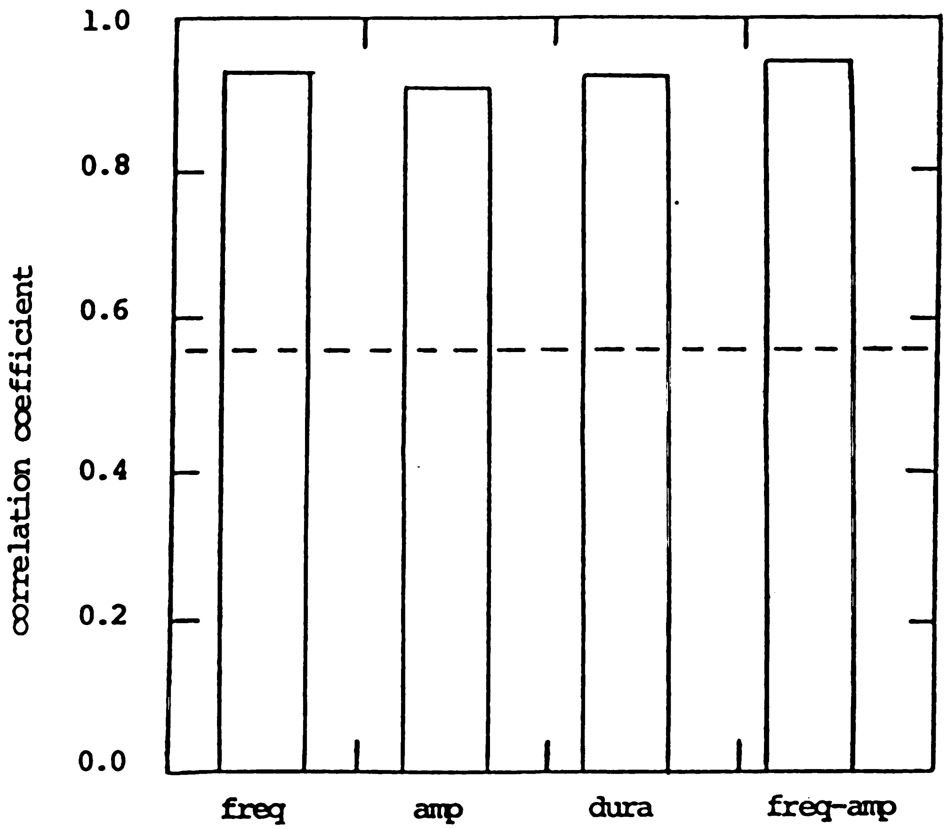


Figure 19. "Average" within-subject test-retest correlation coefficients between seven log geometric mean REMEs for Sessions I and II in each of four accent modes. Twelve subjects were tested in both sessions (n = 12). The dashed horizontal line denotes significance criterion (r = 0.576).

2. examination of any significant interaction effect between accent mode and IRR, and

3. examination of mean log geometric mean REMEs at each level of IRR collapsed across accent modes.

Tables 17-20 summarize four one-way analyses of variance in Session I log geometric mean REMEs across trials as a function of seven levels of log IRR for frequency, amplitude, duration, and combination accent mode stimuli, respectively. Significant F's were observed for each ANOVA, suggesting that mean log geometric mean REMEs differ significantly as a function of IRR levels. Strength of association measures of 0.303, 0.306, 0.283, and 0.284 were computed for the four accent modes, respectively. These measures suggest only a mild to moderate relationship between log IRR and log REME for each accent mode.

Tables 21-24 summarize results of specific comparison tests on all possible pairs of seven mean log geometric mean REMEs for frequency, amplitude, duration, and combination accent mode stimuli, respectively. These results suggest an insufficient number of statistically significantly different data points in each accent mode for meaningful slope determinations. Furthermore, results of specific comparison tests suggest slightly different reorderings (from least to greatest) of mean log geometric mean REMEs among various accent mode stimuli.

Because these group (n=20) results suggested that

Table 17. Summary of analysis of variance in Session I log geometric mean REMEs across trials as a function of log IRR for the frequency accent mode.

Source	SS	df	MS	F	F for alpha=.05	alpha for F obs.
Blocks/ Subjects	9.517	19				
IRR levels	4.999	6	.833	48.094	2.174*	<.001
Error	1.975	114	.017			
Total	16.492	139				

* From F distribution table (Winer, 1971, pp. 864-869).

Table 18. Summary of analysis of variance in Session I log geometric mean REMES across trials as a function of log IRR for the amplitude accent mode.

Source	SS	df	MS	F	F for alpha=.05	alpha for F obs.
Blocks/ Subjects	7.65	19				
IRR levels	4.268	6	.711	39.7	2.174*	<.001
Error	2.043	114	.017			
Total	13.962	139				

* From F distribution table (Winer, 1971, pp. 864-869).

Table 19. Summary of analysis of variance in Session I log geometric mean REMEs across trials as a function of log IRR for the duration accent mode.

Source	SS	df	MS	F	F for alpha=.05	alpha for F obs.
Blocks/ Subjects	7.926	19				
IRR levels	3.864	6	.644	39.757	2.174*	<.001
Error	1.846	114	.016			
Total	13.637	139				

* From F distribution table (Winer, 1971, pp. 864-869).

Table 20. Summary of analysis of variance in Session I log geometric mean REMEs across trials as a function of log IRR for the combination frequency-amplitude accent mode.

Source	SS	df	MS	F	F for alpha=.05	alpha for F obs.
Blocks/ Subjects	8.975	19	.693			
IRR levels	4.158	6	.013	52.969	2.174*	<.001
Error	1.491	114				
Total	14.625	139				

* From F distribution table (Winer, 1971, pp. 864-869).

Table 21. Results of the Newman-Keuls specific comparison test on pairs of mean log geometric mean REMES for each of seven IRR levels in the frequency accent mode. Critical values are given for all possible ranges spanning from two to seven means. A difference between any two means is significant when it exceeds the appropriate critical value (CV) for alpha=0.05. The number of means is equal to k.

IRR Level Means	7 (1.61)	1 (1.52)	2 (1.26)	5 (1.2)	3 (1.15)	4 (1.12)	6 (1.09)	CVk
IRR Level 7		0.09	0.35*	0.41*	0.46*	0.49*	0.52*	CV7=0.1238
Level 1			0.26*	0.32*	0.37*	0.40*	0.43*	CV6=0.1197
Level 2				0.06	0.11	0.14*	0.17*	CV5=0.1145
Level5					0.05	0.08	0.11*	CV4=0.1107
Level 3						0.03	0.06	CV3=0.098
Level 6								

* Denotes a significant difference between a pair of means.

Table 22. Results of the Newman-Keuls specific comparison test on pairs of mean log geometric mean REMEs for each of seven IRR levels for the amplitude accent mode. Critical values are given for all possible ranges spanning from two to seven means. A difference between any two means is significant when it exceeds the appropriate critical value (CV) for alpha=0.05. The number of means is equal to k.

IRR Level Means	7 (1.60)	1 (1.40)	2 (1.18)	5 (1.18)	3 (1.12)	6 (1.11)	4 (1.10)	CVk
IRR Level 7		0.2*	0.42*	0.42*	0.48*	0.49*	0.5*	CV7=0.1238
Level 1			0.22*	0.22*	0.28*	0.29*	0.3*	CV6=0.1197
Level 2				0.00	0.06	0.07	0.08	CV5=0.1145
Level 5					0.06	0.07	0.08	CV4=0.1077
Level 3						0.01	0.02	CV3=0.098
Level 6							0.01	CV2=0.0818
Level 4								

* Denotes a significant difference between a pair of means.

Table 23. Results of the Newman-Keuls specific comparison test on pairs of mean log geometric mean REMEs for each of seven IRR levels in the duration accent mode. Critical values are given for all possible ranges spanning from two to seven means. A difference between any two means is significant when it exceeds the appropriate critical value (CV) for alpha=0.05. The number of means is equal to K.

IRR Level Means	7 (1.57)	1 (1.38)	2 (1.19)	5 (1.14)	4 (1.13)	3 (1.11)	6 (1.08)	CVK
IRR Level 7		0.19	0.38*	0.43*	0.44*	0.46*	0.49*	CV7=0.1199
Level 1			0.19*	0.24*	0.25*	0.27*	0.30*	CV6=0.1159
Level 2				0.05	0.06	0.08	0.11	CV5=0.1109
Level 5					0.01	0.03	0.06	CV4=0.1040
Level 4						0.02	0.05	CV3=0.0950
Level 6							0.03	CV2=0.0792

Table 24. Results of the Newman-Keuls specific comparison test on pairs of mean log geometric mean REMES for each of seven IRR levels in the combination frequency-amplitude accent mode. Critical values are given for all possible ranges spanning from two to seven means. A difference between any two means is significant when it exceeds the appropriate critical value (CV) for alpha=0.05. The number of means is equal to k.

IRR Level Means	7 (1.59)	1 (1.46)	2 (1.25)	5 (1.19)	3 (1.15)	4 (1.13)	6 (1.11)	CVk
IRR Level 7		0.13*	0.34*	0.40*	0.44*	0.46*	0.48*	CV7=0.1080
Level 1			0.21*	0.27*	0.31*	0.33*	0.35*	CV6=0.1046
Level 2				0.06	0.10	0.12*	0.14*	CV5=0.1000
Level 5					0.04	0.06	0.08	CV4=0.0941
Level 3						0.02	0.04	CV3=0.0860
Level 4							0.02	CV2=0.0700
Level 6								

* Denotes a significant difference between a pair of means.

slope analysis be abandoned, it was decided, as an alternative analysis strategy, to examine mean log geometric mean REMEs as a function of accent modes (1) for each level (1-7) of IRR, and (2) for any significant interaction of mode and IRR. This plan called for a two-way (4 x 7) fixed effects ANOVA with repeated measures on the four accent modes and seven IRR levels (Winer, 1971, pp. 518-526).

Table 25 summarizes results of a two-way analysis of variance in Session I log geometric mean REMEs as a function of accent modes (4) and IRR levels (7). The main effect for accent modes was not significant. The main effect for IRR levels, however, was significant, as was the mode-by-IRR interaction. The strength of association measure (eta-squared) computed for the IRR main effect was 0.290. This measure agrees quite well with eta's computed from the four mode ANOVAs (Tables 17-20), and suggests that mean log geometric mean REMEs are moderately influenced by changes in IRR level. The computed eta-squared for a significant mode-by-IRR interaction was 0.0036. This suggests that approximately 0% of the variance in log geometric mean REMEs could be explained by a mode-by-IRR interaction.

Because the effect of accent mode on IRR was not significant and the mode-by-IRR interaction was almost nil, it seemed feasible to collapse the data across accent modes so as to characterize the log IRR-log REME relationship

Table 25. Results of a two-way analysis of variance in Session I log geometric mean REMEs as a function of four accent modes and seven levels of IRR.

Source	SS	df	MS	F	F for alpha=0.05	alpha for F obs.
Blocks/ Subjects	32.336	19				
Accent mode	0.223	3	.074	2.453	2.768*	.071
Error	1.733	57	.030			
IRR Levels	17.075	6	2.845	62.329	2.174*	<.001
Error	5.204	114	.045			
Mode X IRR	.216	18	.012	1.912	1.645*	.014
Error	2.151	342	.006			
Total	58.941	513				

* Interpolated from F distribution table (Winer, 1971, pp. 864-869).

with one set of data points.

Table 26 summarizes results of the Newman-Keuls specific comparison test on pairs of mean log geometric mean REMEs collapsed across accent modes. These results suggest that mean log geometric mean REMEs associated with IRR levels 1 and 2 are significantly greater than all other levels of IRR, but not significantly different from each other. Furthermore, mean log geometric mean REMEs associated with IRR levels 2-6 are not significantly different from each other. Mean log geometric mean REMEs collapsed across accent modes are plotted graphically in Figure 20 as a function of log IRR. Data points falling within the same circle (dashed line) are not significantly different from one another.

Slope Data

Although too few significantly different data points exist in the log-log plots to warrant the determination of slopes for accent mode comparison purposes, the above alternative analyses demonstrated that different accent types had a nonsignificant effect on the perception of pattern regularity when the relative temporal placement of physical accents in a sequence was held constant across different accent types.

Stevens (1975) would characterize the percept of pattern regularity by the slopes of log stimulus-log response functions, which in the present study corresponded

Table 26. Results of the Newman-Keuls specific comparison test on pairs of mean log geometric mean REMEs for each of seven IRR levels collapsed across accent modes. Critical values are given for all possible ranges spanning from two to seven means. A difference between any two means is significant when it exceeds the appropriate critical value (CV) for alpha=0.05. The number of means is equal to k.

IRR Level Means	7 (1.59)	1 (1.44)	2 (1.22)	5 (1.18)	3 (1.13)	4 (1.12)	6 (1.10)	CVk
IRR Level 7		0.15	0.37*	0.41*	0.45*	0.47*	0.49*	CV7=0.2010
Level 1			0.22*	0.26*	0.31*	0.32*	0.34*	CV6=0.1943
Level 2				0.04	0.09	0.10	0.12	CV5=0.1858
Level 5					0.05	0.06	0.08	CV4=0.1749
Level 3						0.01	0.03	CV3=0.1593
Level 4							0.02	CV2=0.1327

* Denotes a significant difference between a pair of means.

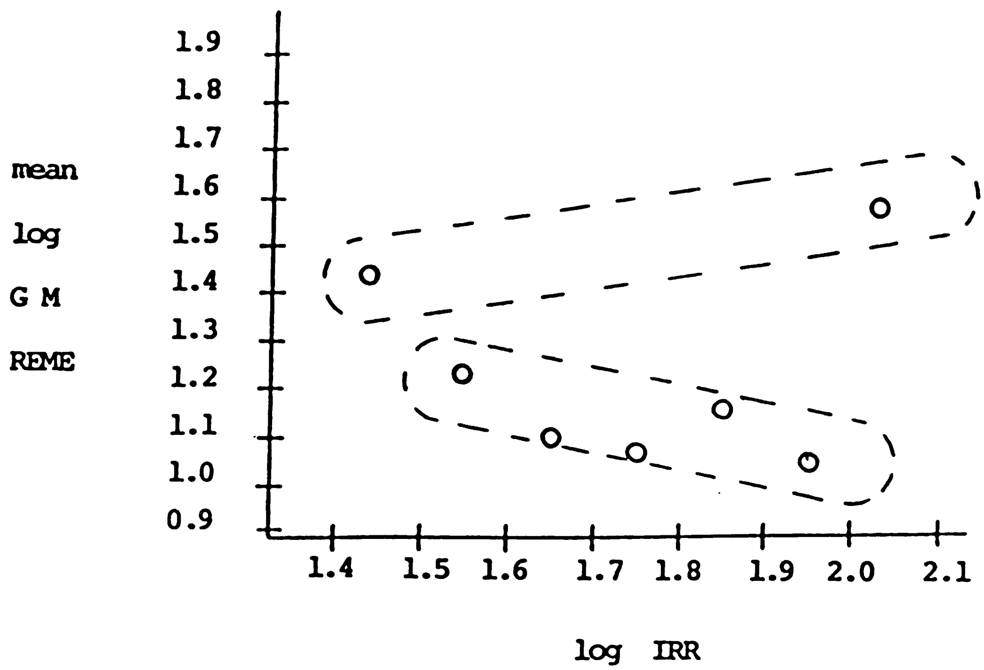


Figure 20. Session I mean log geometric mean REMEs collapsed across accent modes plotted as a function of log IRR. Data points falling within the same circle (dashed lines) are not statistically significantly different from one another.

to slopes of the log IRR-log REME functions. It was decided to procede with slope analysis in order to assess the relative merit of these derived dependent variables as descriptors of the percept (i.e., "pattern regularity" in tonal sequences) and also to compare results of Stevensonian analysis to results of the alternative analysis strategies described above.

Description. Table 27 summarizes Session I mean slope terms, standard deviations, and ranges for quadratic equations describing log IRR-log REME relationships for each of the four accent modes. Summary statistics were computed for the first and second degree slope terms of the quadratic (i.e., 2nd degree polynomial) functions. Mean slope terms are also depicted graphically in Figure 21.

Reliability. Table 28 lists test-retest correlation coefficients between Session I and Session II slope terms describing least squares, quadratic lines of best fit for the log-log data. Coefficients of correlation were determined for 0th, 1st, and 2nd degree slope terms (the 0th degree term actually refers to the Y intercept of the quadratic function, while the 1st and 2nd terms are actual slopes). "Average" correlations for each mode are also depicted graphically in Figure 22. The group averaged correlations range from 0.67 for duration accent mode stimuli to 0.94 for combination accent mode stimuli. The

Table 27. Mean slope terms, standard deviations, and ranges for twenty subjects tested in Session I for each of four accent modes. First and second degree slope terms were obtained from least squares solutions for the quadratic functions describing log IRR-log REME relationships.

	Degree of Slope Term					
	1			2		
	$\bar{X}$	SD	Range	$\bar{X}$	SD	Range
Freq	-16.09	7.54	24.6	4.62	2.18	7.3
Amp	-15.31	6.76	22.7	4.43	1.94	6.4
Dura	-14.38	7.41	31.4	4.16	2.14	9.1
Comb	-15.46	7.07	28.6	4.43	2.01	8.2
All modes	-15.31	6.4	32.6	4.41	4.3	9.3

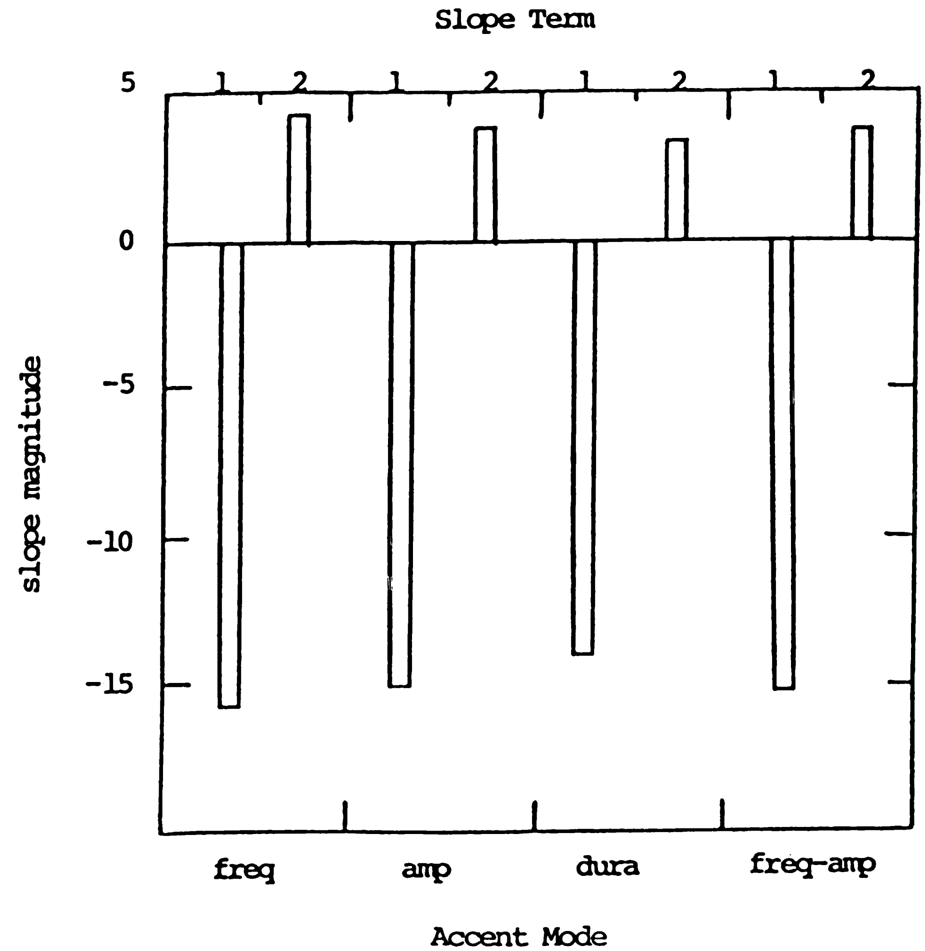


Figure 21. Mean slope terms for twenty subjects tested in Session I for each of four accent modes. First and second degree slope terms were obtained from least squares solutions describing quadratic stimulus-response relationships in each accent mode.

Table 28. Test-retest correlation coefficients (Pearson r) and "average" coeffecients between Session I and Session II slope terms describing quadratic lines of best fit for log IRR-log geometric mean REME functions. Coefficients of correlation were determined for 0, 1, and 2 degree slope terms.

	Accent Mode				
Degree of Slope term	Freq	Amp	Dura	Comb	$\overline{X}r$*
0	0.78	0.79	0.69	0.94	
1 (N=12)	0.80	0.81	0.67	0.94	
2	0.80	0.82	0.67	0.95	
$\overline{X}r$*	0.79	0.81	0.67	0.94	0.83

* "Average" correlations are Fisher's Zto r transformations interpolated from mean Fisher's r yo Z transformations (Hays, 1963, pp. 680-681).

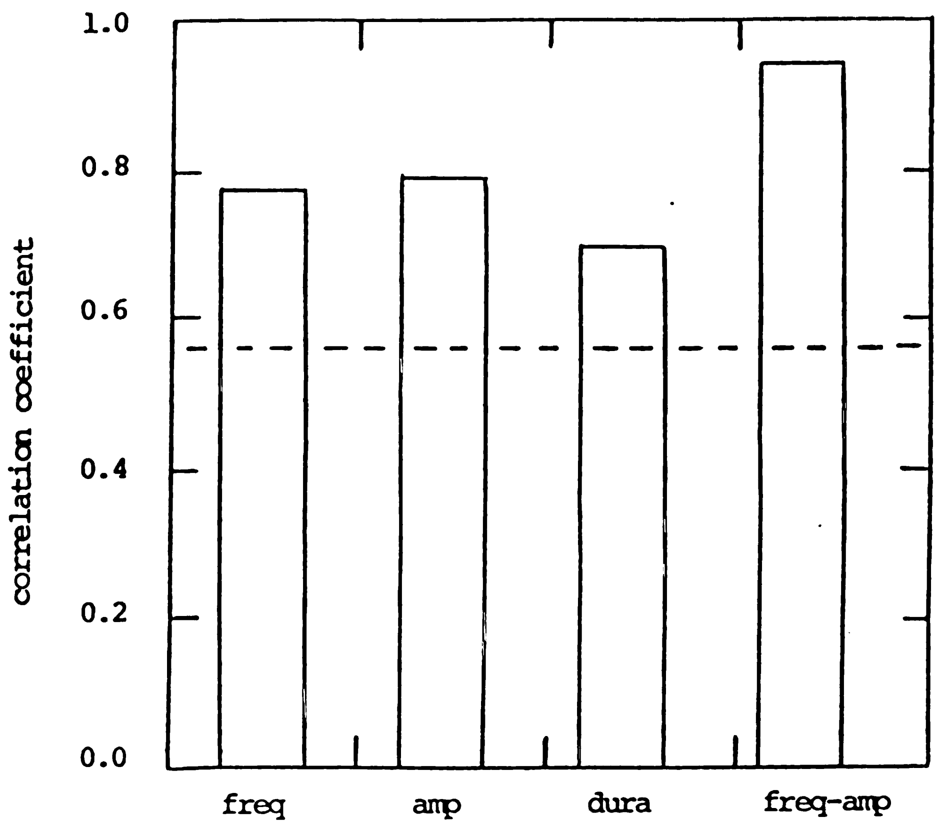


Figure 22. Test-retest correlation coefficients (Pearson r) between Session I and Session II slope terms for 12 subjects. These "average" correlations were determined across slope terms (0, 1, and 2) describing a quadratic fit to the log IRR-log REME relationship in each accent mode. The dashed horizontal line denotes significance criterion (r = 0.576).

grand mean of the averaged correlations was 0.83, suggesting satisfactory between-session reliability of slope terms.

Analysis. Alternative tests for linear, quadratic, and cubic trend (Winer, 1971, pp. 296-300) were performed on the log-log data for each accent mode. Tables 29-32 summarize results of these analyses for frequency, amplitude, duration, and combination accent mode stimuli, respectively. Table 33 summarizes the approximate percentage of variance in log geometric mean REMEs "explained" by linear, quadratic, and cubic trends for each accent mode. Significant results were obtained only for quadratic equations across all accent mode stimuli. Furthermore, only quadratic "fits" (see Table 33) accounted for more than 50% of REME variance, suggesting that quadratic functions are the lowest order equations providing a satisfactory explanation of the log-log data for all accent mode stimuli.

Figures 23-26 graphically represent quadratic functions of best fit (determined by least squares solutions) for log-log frequency, amplitude, duration, and combination accent mode data, respectively. Figure 27 depicts all four functions in the same log-log space. Mean coefficients of determination for the four functions were 0.72, 0.69, 0.68, and 0.74, respectively (refer to Table 34 and Figure 28). These values were taken as measures of the

Table 29. Summary of alternative tests for trend in Session I log geometric mean REMEs as a function of log IRR for frequency accent mode stimuli.

Source	SS	df	MS	F	F for alpha=0.05	alpha for F obs.
Linear trend	.00075	1	.00075	.0078	3.92*	1.128
Dev/lin	11.49	119	.0966			
Quad trend	4.004	1	4.004	63.1	3.92*	0.0
Dev/quad	7.49	118	0.0635			
Cubic trend	0.144	1	.144	1.48	3.92*	0.229
Dev/cubic	11.35	117	.097			

* Interpolated from F distribution table (Winer, pp. 864-869).

Table 30. Summary of alternative tests for trend in Session I log geometric mean REMEs as a function of log IRR for amplitude accent mode stimuli.

Source	SS	df	MS	F	F for alpha=0.05	alpha for F obs.
Linear trend	0.193	1	0.193	2.4	3.92*	0.093
Dev/lin	9.5	119	0.08			
Quad trend	3.26	1	3.26	60.37	3.92*	0.00
Dev/quad	6.43	118	0.054			
Cubic trend	0.147	1	0.147	1.79	3.92*	0.169
Dev/cubic	9.55	117	0.082			

* Interpolated from F distribution table (Winer, 1971, pp. 864-869).

Table 31. Summary of alternative tests for trend in Session I log geometric mean REMEs as a function of log IRR for duration accent mode stimuli.

Source	SS	df	MS	F	F for alpha=0.05	alpha for F obs.
Linear trend	0.103	1	0.103	1.29	3.92*	0.276
Dev/lin	9.67	119	0.08			
Quad trend	2.88	1	2.88	49.66	3.92*	0.00
Dev/quad	6.89	118	0.058			
Cubic trend	0.243	1	0.243	3.03	3.92*	0.51
Dev/cubic	9.53	117	0.08			

* Interpolated from F distribution table (Winer, 1971, pp. 864-869).

Table 32. Summary of alternative tests for trend in Session I log geometric mean REMEs as a function of log IRR for combination accent mode stimuli.

Source	SS	df	MS	F	F for alpha=0.05	alpha for F obs.
Linear trend	0.016	1	0.016	0.18	3.92*	0.837
Dev/lin	10.43	119	.088			
Quad trend	3.28	1	3.28	53.77	3.92*	0.00
Dev/quad	7.16	118	.061			
Cubic trend	0.176	1	0.176	2.00	3.92*	0.137
Dev/cubic	10.27	117	.088			

* Interpolated from F distribution table (Winer, 1971, pp. 864-869).

Table 33. Percentage of variance in Session I log geometric mean REMEs accounted for by linear, quadratic, and cubic trends.*

		Accent Mode			
		Freq	Amp	Dura	Comb
	Linear	0**	5	3	0
Trend	Quadratic	80	76	75	79
	Cubic	3	3	6	4

* Percentage of shared variance estimated by the equation 100 (SS trend-type/SS IRR levels).

** All percentages rounded off to nearest whole percent.

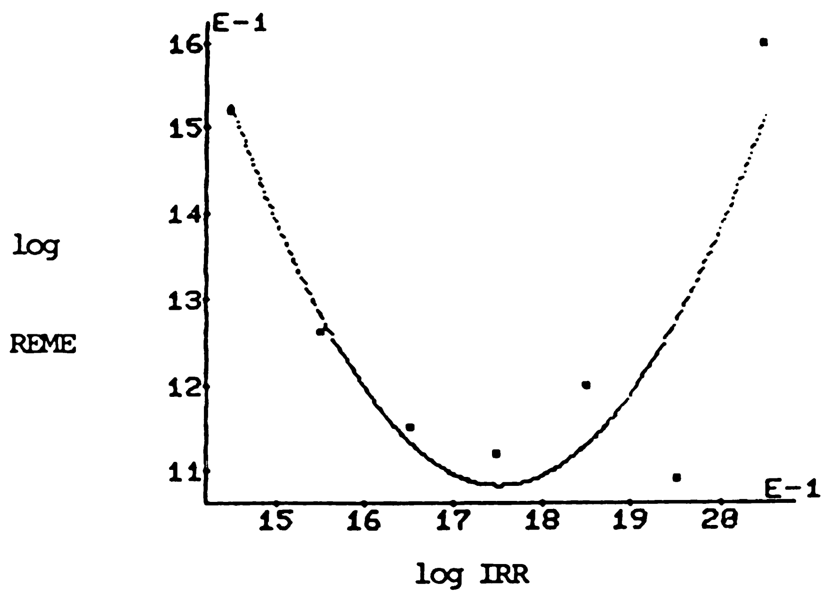


Figure 23. Least squares, quadratic function of best fit describing log IRR-log REME data for frequency accent mode stimuli.

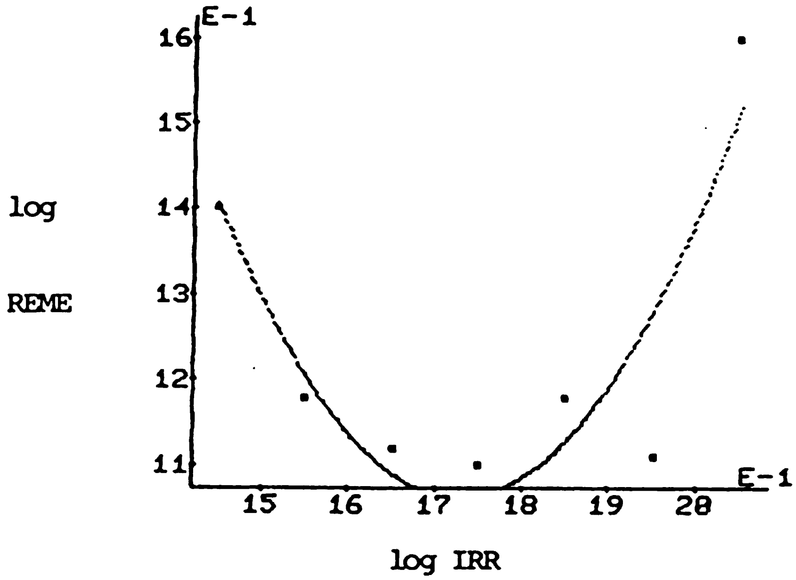


Figure 24. Least squares, quadratic function of best fit describing log IRR-log REME data for amplitude accent mode stimuli.

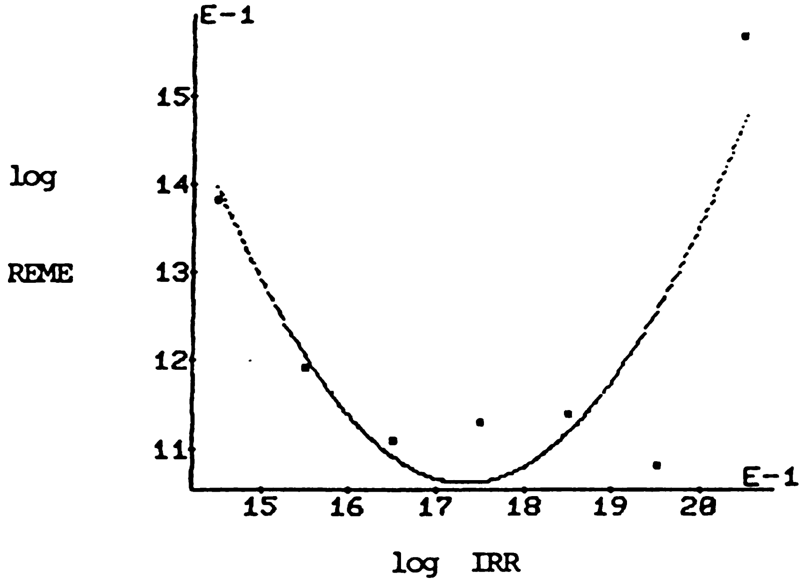


Figure 25. Least squares, quadratic function of best fit describing log IRR-log REME data for duration accent mode stimuli.

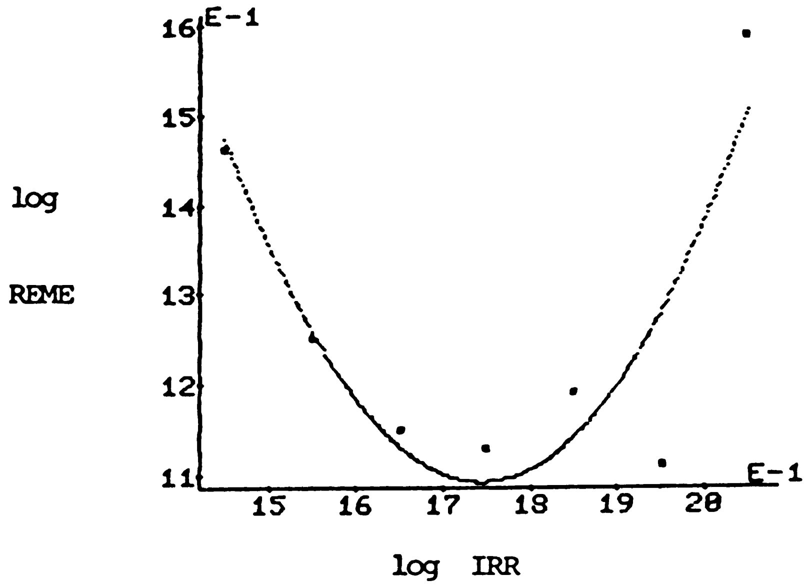


Figure 26. Least squares, quadratic function of best fit describing log IRR-log REME data for combination frequency-amplitude accent mode stimuli.

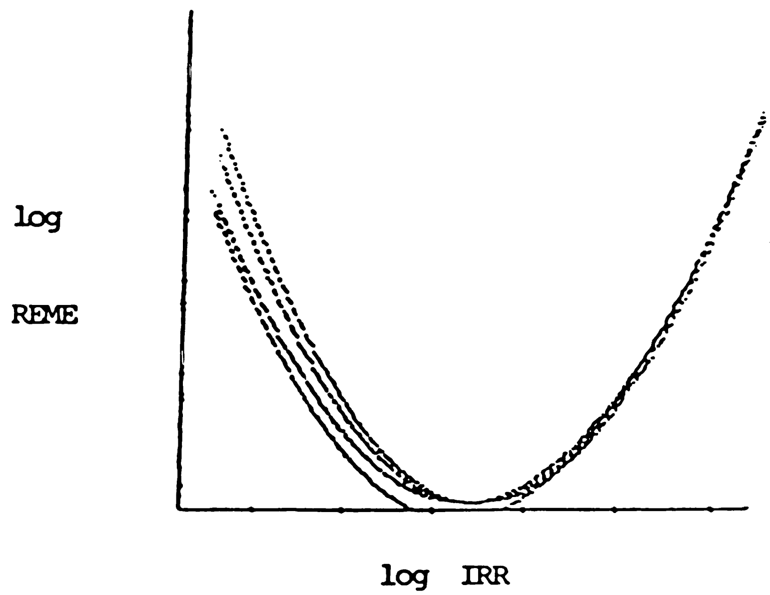


Figure 27. Least squares, quadratic functions of best fit describing log IRR-log REME data for all accent mode stimuli. For comparison purposes, all four functions are depicted graphically in the same log-log space.

Table 34. Mean coefficients of determination, standard deviations, and ranges for twenty subjects tested in Session I. Mean coefficients assess the relative potency of least squares, quadratic functions describing log IRR-log REME relationships.

	$\bar{X}$	SD	Range
Freq	0.72	0.09	0.34
Amp	0.69	0.13	0.47
Dura	0.68	0.15	0.51
Comb	0.74	0.09	0.38
All modes	0.71	0.11	0.51

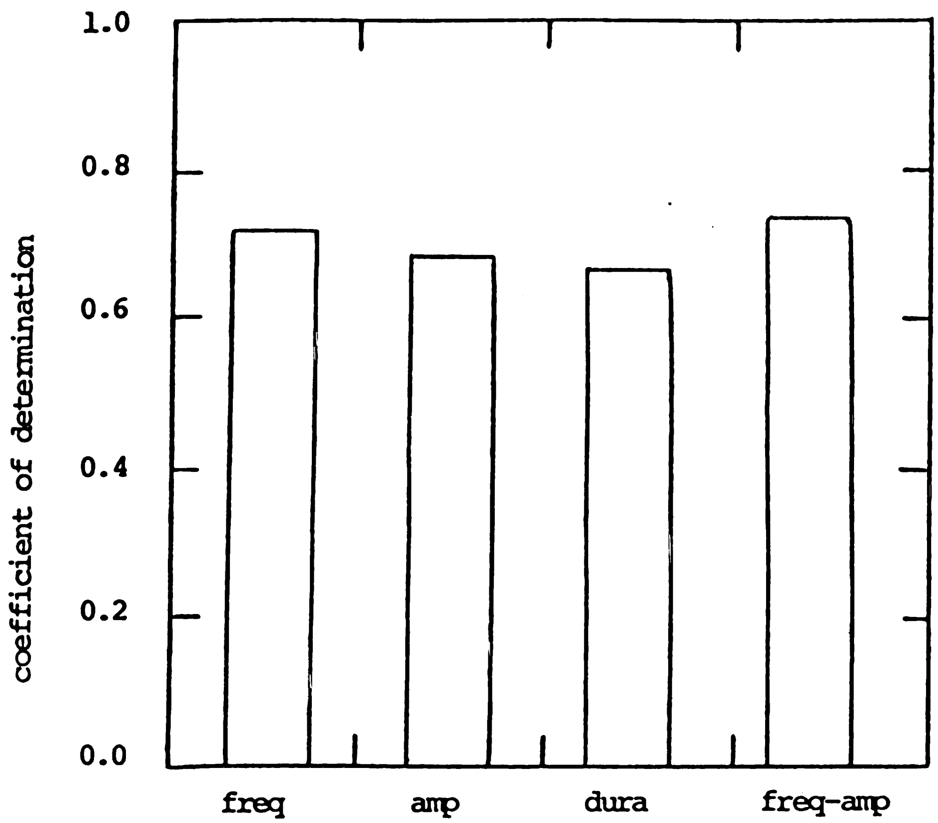


Figure 28. Mean coefficients of determination assessing the relative potency of least squares, quadratic functions describing log IRR-log REME relationships. Mean coefficients were computed for twenty subjects tested in Session I in each of four accent modes.

relative potency (i.e., strength of association) for stimulus-response functions in each accent mode. Subsequent analyses involved coefficients of determination and slope terms describing the log-log functions.

Relative potency of the stimulus-response functions was examined by performing two analyses of variance on individual coefficients of determination. Session I coefficients (n = 20) were examined as a function of accent modes by a one-way ANOVA with repeated measures on the four accent modes (Winer, 1971, pp. 261-268). Individual coefficients of subjects tested in both sessions (n = 12) were examined as a function of session, mode, and session-by-mode interaction by a two-way (2 x 4) ANOVA with repeated measures on the two sessions and four modes (Winer, 1971, pp. 518-526).

Tables 35 and 36 summarize the results of these analyses. No significant differences were noted. Session I coefficients of determination did not differ significantly as a function of accent modes, and coefficients from both sessions did not differ significantly as a function of session, mode, or session-by-mode interaction. These results suggest (in Stevensonian terms) that the strength of the percept (i.e., "pattern regularity") is (1) quite potent, (2) stable across experimental sessions, and (3) not effected by accent mode or session-by-mode interactions.

Questions involving slope comparisons were addressed

Table 35. Summary of analysis of variance in coefficients of determination for individual quadratic functions describing log IRR-log REME relationships as a function of accent modes for twenty subjects tested in Session I.

Source	SS	df	MS	F	F for alpha=0.05	alpha for F obs.
Blocks/ Subjects	0.517	19				
Accent Modes	0.040	3	0.013	1.329	2.768*	0.273
Error	0.580	57	0.010			
Total	1.139	79				

* Interpolated from F distribution table (Winer, 1971, pp. 864-869).

Table 36. Summary of a two-way analysis of variance in coefficients of determination for individual quadratic functions describing log IRR-log REME relationships as a function of four accent modes and two sessions.

Source	SS	df	MS	F	F for alpha=0.05	alpha for F obs.
Blocks/ Subjects	0.301	11				
Sessions	0.000	1	0.000	0.014	4.84*	1.058
Error	0.248	11	0.022			
Accent Modes	0.019	3	0.006	0.499	2.89*	0.685
Error	0.429	33	0.013			
Sessions X Accent mode	0.014	3	0.004	.370	2.89*	0.775
Error	0.438*	33	0.013			
Total	1.452	95				
Residual	1.117	77				

* Interpolated from F distribution table (Winer, 1971, pp. 864-869).

by a series of ANOVAs. Because the lines of best fit describing log-log data in each accent mode were quadratic, two slope terms (i.e., 1st and 2nd degree) were examined for each mode. Session I slope terms (n = 20) were examined as a function of accent mode. Individual slope terms obtained from both sessions (n = 12) were examined as a function of session, mode, and session-by-mode interaction.

Tables 37-40 summarize the results of these ANOVAs. No significant differences among mean slope terms were observed. These results suggest (in Stevensonian terms) that the perception of pattern regularity in tonal sequences is not significantly affected by accent mode, experimental session, or mode-by-session interaction. Furthermore, these results suggest that the actual percept of pattern regularity in tonal sequences is relatively stable over time.

Summary

Pattern discrimination data

Reliability of correct discrimination judgments was very high, suggesting that the twenty subjects included in this study were relatively homogenous in listening ability. Subject retention rates for the experiment tended to

Table 37. Summary of analysis of variance in Session I 1st degree slope terms as a function of four accent modes. Slope terms were obtained from least squares, quadratic functions describing log IRR-log REME relationships.

Source	SS	df	MS	F	F for alpha=0.05	alpha for F obs.
Blocks/ Subjects	3467.606	19				
Accent Modes	29.816	3	9.938	1.18	2.768*	0.325
Error	479.749	57	8.416			
Total	3977.173	79				

* Interpolated from F distribution table (Winer, 1971, pp. 864-869).

Table 38. Summary of analysis of variance in Session I 2nd degree slope terms as a function of four accent modes. Slope terms were obtained from least squares, quadratic functions describing log IRR-log REME relationships.

Source	SS	df	MS	F	F for alpha=0.05	alpha for F obs.
Blocks/ Subjects	288.408	19				
Accent Modes	2.153	3	0.717	1.058	2.768*	0.374
Error	38.638	57	0.677			
Total	329.199	79				

* Interpolated from F distribution table (Winer, 1971, pp. 864-869).

Table 39. Results of a two-way analysis of variance in 1st degree slope terms as a function of four accent modes and two sessions. Slope terms were obtained from least squares, quadratic functions describing log IRR-log REME relationships.

Source	SS	df	MS	F	F for alpha=0.05	alpha for F obs.
Blocks/ Subjects	5678.316	11				
Sessions	6.411	1	6.411	0.177	4.84*	0.842
Error	397.554	11	36.141			
Accent Modes	30.843	3	10.281	1.196	2.89*	0.326
Error	283.622	33	8.594			
Sessions X Accent mode	12.814	3	4.271	0.548	2.89*	0.652
Error	256.898	33	4.271	0.548		
Total	6666.460	95				
Residual	938.075	77				

* Interpolated from F distribution table (Winer, 1971, pp 864-869).

Table 40. Results of a two-way analysis of variance in 2nd degree slope terms as a function of four accent modes and two sessions. Slope terms were obtained from least squares, quadratic functions describing log IRR-log REME relationships.

Source	SS	df	MS	F	F for alpha=0.05	alpha for F obs.
Blocks/ Subjects	467.810	11				
Sessions	0.655	1	0.655	0.226	4.84*	0.802
Error	31.861	11	2.896			
Accent Modes	2.179	3	0.726	1.060	2.89*	0.380
Error	22.611	33	0.685			
Session X Accent mode	1.322	3	0.440	0.742	2.89*	0.534
Error	19.596	33	0.593			
Total	546.036	95				
Residual	74.069	77				

* Interpolated from F distribution table (Winer, 1971, pp. 864-869).

confirm pilot study (Appendix B) results. That is, approximately 4 out of 5 of those screened met criterion (90% correct) performance levels. Analyses of both pilot and experimental data, however, suggest that same-different discrimination judgments are more difficult when elements of tonal sequences are accented by differences in duration than for either frequency or amplitude accents.

Visual magnitude estimation data

Reliability of visual magnitude estimates of circle size across trials suggests that experimental subjects understood the concept of magnitude estimation. Comparison of the log stimulus-log response function with previous results (Lawson, 1980) lends credibility to the task as a valid screening device. Subsequent analyses of (1) log geometric mean visual estimates of perceived size as a function of circle area, (2) differences between pairs of mean log geometric mean visual magnitude estimates, and (3) linear trends in the log-log data, suggest that slope determination was a valid procedure for the visual task.

Auditory magnitude estimation data

High reliability of both the raw and log-transformed REME data suggests the legitimacy of the percept under investigation (i.e., "pattern regularity" in tonal sequences). Reliability of slope terms describing the log stimulus-log response functions corroborates this in

Stevensonian terms. Analyses of the log geometric mean REME data suggest that physical accent type has little effect on the perception of pattern regularity in tonal sequences exhibiting the same relative temporal placement of accents. Stevensonian analyses of slope terms confirm this notion. Slope analyses further indicate that IRR is flawed as an *a priori* predictor of pattern regularity, as quadratic functions best describe the log-log data for all accent modes.

CHAPTER IV

DISCUSSION

Introduction

Chapter III described the results produced by 20 normal hearing subjects on (1) a same-different pattern discrimination task, (2) a visual magnitude estimation task, and (3) a pattern regularity magnitude estimation task. On the pattern discrimination task, percent-correct judgments were obtained as a function of three accent types, or modes (frequency, amplitude, and duration). On the visual task, fixed-modulus magnitude estimates were obtained as a function of square and circle size. In the REME experiment, modulus-free REMEs were obtained as a function of seven degrees of pattern regularity (as defined by seven levels of IRR) for each of four accent modes (frequency, amplitude, duration, and combination frequency-amplitude).

Percent-correct judgments generated by the pattern discrimination task were used to determine the listening ability of experimental subjects. Only subjects who achieved scores of 90% or better were retained for the study. Qualitative comparisons between pilot (Appendix B) and experimental subjects' performance levels in pattern discriminartion were used to establish generalizability of experimental results. Correct raw scores were analyzed for significant differences as a function of accent mode.

Two dependent variables were derived from the visual magnitude estimates: (1) log geometric mean visual magnitude estimates, and (2) slopes of the functions relating log visual estimates to log circle size. Log data were examined as a function of circle size for both significant differences and significant trends. Slope data were qualitatively compared to that of Lawson (1980) to establish validity of the task as a screening device.

Two dependent variables were also derived from the individual REMEs: (1) log geometric mean REMEs and (2) slopes of the lines relating log geometric mean REME to log stimulus values (log IRR). The log geometric mean REMEs were examined for significant differences as a function of IRR levels for each accent mode. When differences were found, specific comparison tests were employed to determine significant differences among pairs of mean log geometric mean REMEs for each accent mode. Results of specific comparison tests suggested an insufficient number of data points in the log-log plots of each accent mode for meaningful slope determination. Therefore, log geometric mean REMEs were examined as a function of accent mode, IRR, and mode-by-IRR interaction.

Alternative tests for trend were performed on the log geometric mean REMEs, however, to identify the lowest order equation providing a statistically significant fit to the data. Slope terms were obtained and analyzed to find significant differences as a function of accent mode, experimental session, and mode-by-session interaction.

The findings and their implications are discussed below.

Pattern discrimination data

Findings

A statistically significant, strong-positive reliability coefficient (0.93) was computed for discrimination scores. Also, a very high percentage (98%) of control items were correctly judged as being the "same". Mean raw correct judgments for frequency and amplitude stimuli were not significantly different from each other, but both were significantly higher than scores for duration stimuli.

<u>Implications for the REME experiment</u>

The high reliability coefficient suggests consistent performance by experimental subjects (n = 20) on the pattern discrimination task. Reliability of the pilot group (n = 38, r = 0.543) was significantly lower. These data suggest that consistency of performance improves as discrimination ability improves, further suggesting that the experimental group was relatively homogeneous in listening ability.

The relationship between discrimination ability and consistency of performance has further implications for the REME experiment. Pattern discrimination scores were significantly lower for duration accent mode stimuli than for either frequency or amplitude accent mode stimuli. This suggests that REME performance for duration stimuli should be less consistent than for other accent modes.

Approximately 4 out of 5 people screened for pattern discrimination ability met performance criteria (90% or better correct). This confirms pilot study results and suggests good generalizability of experimental results to a population of normal hearing, young adults.

Visual magnitude estimation data

Findings

Only one potential subject was rejected for failing to achieve reliability criterion (r equal to or exceeding 0.90) on the visual task. This confirms the notion that subjects can easily be trained to understand the concept of magnitude estimation (Stevens, 1975). Also, the mean slope for twenty experimental subjects agrees well with slopes reported by others (Stevens, 1975; Lawson, 1980) for the same, or similar, visual task. Significant differences between all pairs of mean log visual estimates as a function of circle size suggest high resolvability (i.e., discriminability) among visual stimulus magnitudes and thus yielded a sufficient number of data points (7) for meaningful slope determination.

Implications for the REME experiment

High reliability on the visual task suggests that inconsistency of performance in the REME experiment should not be attributed to confusion regarding the psychophysical task. Furthermore, a comparison of the number of significantly different data points yielded by both magnitude estimation tasks (visual and auditory) suggests a greater degree of perceptual resolvability for the visual stimuli than for the auditory stimuli.

REME experiment

Reliability

The first experimental question asked how consistently subjects scaled perceived pattern regularity within and between experimental sessions. In general, response consistency was judged as being good to excellent.

Within sessions . Pearson product-moment correlation coefficients (r) were used to assess the reliability of the raw data (REMEs). Individual coefficients were determined for 20 subjects from Session I and 12 subjects in Session II, and "average" coefficients were consistently high, ranging from 0.82 to 0.89. Session II coefficients ranged from 0.86 to 0.94. Coefficients "averaged" across accent modes were 0.86 and 0.89 for Session I and II, respectively.

The "average" within-session reliability of REMEs is sufficiently high to suggest that subjects were very consistent in their ability to assign numbers to auditory sequences describing the pattern regularity exhibited by those sequences. This consistency of "raw" responses is of primary importance, because the dependent variables of interest for this study (i.e., the log geometric mean REMEs and slopes) were derived from the REMEs.

Between sessions. Between-session agreement of log geometric mean REMEs and slopes was examined for 12 subjects who participated in both experimental sessions. "Average" individual subject correlations between log geometric mean REMEs for Session I and Session II were extremely high, ranging from 0.92 to 0.95. Slope correlations were moderately high, ranging from 0.67 to 0.94. Reliability of both the log data and slopes suggests that experimental subjects' behavior in the perceptual scaling of pattern regularity was very consistent over time.

That between-session correlations of the log geometric mean data were slightly higher than within-session correlations of the raw data is worthy of mention. Taking the geometric mean of the raw REMEs is intended to reduce the effects of extreme scores. Therefore, assuming that individual subjects' "internal scales" for perceived regularity were relatively stable over time, log-transformed geometric mean scores could quite conceivably be more consistent than raw responses.

Measures of between-session accent mode slope reliability may be linked to the relative resolvability (i.e., discriminability) of the different accent mode stimuli. Pattern discrimination data from both the pilot study (Appendix B) and the screening task suggest that same-different discrimination judgments for duration stimuli are significantly more difficult than for either amplitude or frequency stimuli. Between-session correlation coefficients for frequency and amplitude slopes were very similar (0.79, and 0.81, respectively), while between-session slope reliability for duration accent mode stimuli was only 0.67. It seems reasonable to assume that discriminability of the actual sequences must in some way relate to discriminability of "attributes" (i.e., such as "pattern regularity") of those sequenes. Therefore, it might also be reasonable to assume that slope reliability for duration accent mode stimuli would be less than that for either frequency or amplitude accent mode stimuli.

If there is indeed a relationship between the discriminability of the actual sequences and the discriminability of "attributes" of the sequences, such as "pattern regularity", some reasonable explanation might be given regarding the extremely high between-session slope reliability of the combination frequency-amplitude accent mode stimuli. Neither the pilot study nor pattern discrimination screening investigated the discriminability of combination accent mode stimuli. This was due to the fact that subjects were tested or screened under widely varying conditions--several different earphones were used, and many pilot subjects were tested in a sound-field. It was therefore unrealistic to control for environmental and transducer effects. Signal levels of experimental stimuli, however, were carefully controlled such that the perceptual magnitudes (i.e., pitch and loudness) of the combination accent mode stimuli reflected a clear and consistent summation of sensory magnitudes of single accent mode stimuli (i.e., frequency and amplitude). Additivity of perceptual magnitudes was addressed by experimental question number 7. It was predicted that pattern regularity would be more obvious (i.e., more resolvable) for tonal sequences accented by both frequency and amplitude than for tonal sequences exhibiting only one type of accent (either frequency or amplitude). Analysis of log geometric mean REMEs and slopes, however, did not support this notion. The between-session slope coefficient of reliability (0.94) for combination accent mode stimuli, however, might suggest greater discriminability for tonal sequences accented by a combinaton of physical parameters. Some degree of additivity, then, may exist in terms of perceptual scaling of tonal sequences exhibiting physical accents in more than one accent mode which auditory magnitude estimation could not detect.

Log geometric mean REMEs

Experimental questions 2-4 deal with (a) the effect of IRR on perceived regularity, (b) trend analysis of the log IRR-log REME relationships in each accent mode, and (c) characterization of these relationships for the four accent modes in terms of trend-type. These questions were dealt with directly by analyses of the log geometric mean REMEs. Additional analyses were performed on the log data, however, in an effort to address experimental questions 5-7, which deal with the effects of accent mode on the perception of pattern regularity.

Effects of IRR . The second experimental question asked whether stimuli with different IRRs produced significantly different perceptions of pattern regularity as indexed by magnitude estimates. On the basis of the results obtained, the answer to this question would be a qualified yes. Statistically significant differences were found in the log geometric means in each accent mode as a function of log IRR; however, specific comparisons of all possible pairs of seven mean log geometric mean REMEs in each accent mode suggested an insufficient number of data points in the log-log plots for meaningful trend analysis and subsequent slope determination. Stevens (1975) suggests that at least 5 data points are necessary for adequate characterization of the slope of a function, but only about 3 significantly different points were found in each accent mode for log IRR-ordered stimulus magnitudes. Sequences exhibiting IRR levels 1 and 7 were consistently judged as being more regular than all others (IRR levels 2 - 6) but were typically not judged as being significantly different from each other, in terms of pattern regularity. Thus configuration of log-log data points for each accent mode tended to form a trough-like, or U-shaped function, with IRR levels at the extremes (i.e., levels 1 and 7) judged as being very regular, and IRR 2 - 6 clustered at the bottom of the trough, judged as exhibiting low (and not significantly different) levels of pattern regularity.

A reasonable explanation for these results is that only small differences of "pattern regularity" were exhibited by these particular sequential auditory stimuli. Within-session REME responses were very reliable, as were between-session log geometric mean REMEs. Futhermore, collapsing the ranges of magnitude estimates by log transforming the geometric mean responses had no effect on visual magnitude estimates (all seven visual mean log geometric mean estimates were significantly different). The logical conclusion to be drawn here, then, is that tonal sequences with IRR levels 2 - 6 exhibited very small perceptual differences in terms of their pattern regularity.

Trend analysis suggested, however, that a statistically significant equation could be fit to the log-log data in each accent mode. Quadratic functions (i.e., second degree polynomials) provided statistically siginificant "fits" and also accounted for a large percentage of variance in log geometric mean REMEs as a function of log IRR for each accent mode. These results provided positive answers to experimental questions 3 and 4.

The implications of these results, however, impugn IRR as an a priori predictor of pattern regularity. Wood (1980) found a monotonic relationship between IRR and percent-correct discrimination judgments for a limited range of IRR magnitudes. This study examined eight-element sequences exhibiting the entire range of IRR magnitudes and found that a nonlinear, nonmonotonic function best describes log IRR- log REME relationships in each accent mode.

Effects of accent mode . Additional analyses performed on the log geometric mean REMEs suggest that accent mode (i.e., type of physical accent) has little effect on the perception of pattern regularity in tonal sequences. Log geometric mean REMEs did not differ signifigantly as a function of accent mode. Futhermore, acent mode-by-IRR level interaction was judged to be nil.

Slopes

Analysis of slope terms allows for the discussion of the percept of pattern regularity in Stevensonian terms.

The results of slope analysis tended to confirm the results of alternative analyses performed on the log geometric mean REMEs.

Effects of IRR. Functions obtained across modes and sessions were all quadratic, and the slope terms of these functions were found not to differ significantly as a function of mode, session, or mode-by-session interaction. The reliability, stability and nonmonotonic nature of these slopes suggests that IRR is flawed as an *a priori* predictor of pattern regularity.

It is quite possible, however, that examination of other binary-accented sequences would yield different log-log slopes. This study examined only 7 of 256 available sequences for each accent mode. It is quite possible, then, that "actual" slopes (and indeed, the actual functions) might be very different than those obtained here.

Effects of accent mode. The fifth experimental question was concerned with the relative potency (i.e., strength of association) of the log-log functions across accent modes. Coefficients of determination for each function were examined in response to this question. All mode coefficients were fairly high, ranging from 0.68 to 0.74, and the "average" coefficient across modes was 0.71. Session I coefficients (n=20) did not differ as a function of accent mode, and coefficients obtained from both sessions (n=12) did not differ as a function of mode, session, or mode-by-session interaction. These results suggest (in Stevensonian terms) that the strength of the percept (1) was fairly high, (2) was relatively stable over time, and (3) did not differ as a function of accent mode. Again, statements regarding the relative potency of the log-log functions across accent mode must be guarded by the fact that only a small number of available stimuli from what Garner (1974) would call the "stimulus set" were examined in this study.

Experimental questions 6 and 7 dealt with the issues of equivalency and additivity, respectively. Session I slope terms (n=20) describing the least squares, quadratic functions of best fit were found not to differ significantly as a function of accent mode. Slope terms obtained from both sessions (n=12) were not significantly different as a function of mode, session, or mode-by-session interaction. These results suggest that the percept of pattern regularity (as characterized, in Stevensonian terms, by slope-terms) is (1) relatively stable over time, and (2) not effected by accent mode, or type, when accent patterns are held constant. Also, because no significant differences were noted among slope terms, the function describing log-log data for combination mode stimuli did not exhibit any degree of "perceptual additivity".

As mentioned earlier, however, statements about these results must be guarded due to such a small sampling of available stimulus patterns. Some "perceptual additivity" might exist in combination accent mode stimuli that was not effectively measured by magnitude estimation, and some additivity might be inferred by comparing "average" between-session reliability of slope terms across accent modes. Average test-retest coefficients for frequency and ampltitude stimuli slope terms were 0.79 and 0.81, respectively. The average test-retest correlation for the combination frequency-amplitude mode was noticeably higher (0.94). If we can assume that response consistency improves as the task becomes easier, then some "perceptual assistance" appears to have taken place in combination accent mode stimuli due to the summation of sensory magnitudes from physical accents in unimodal (i.e., frequency mode and amplitude mode) stimuli.

Implications for the IRR metric

A priori computations of IRR were thought to quantify the amount of transmissive redundancy exhibited by stimulus sequences. Thus, ascending levels of IRR (1-7) were thought to reflect ascending "magnitudes" of pattern regularity. In this sense, IRR levels can be regarded as measures of predicted stimulus magnitudes.

The amount of percieved pattern regularity was determined by REME responses. Therefore, mean log geometric mean REMEs collapsed across accent modes can be taken as measures of perceived stimulus magnitudes.

Linear functions for the log IRR log REME data would have suggested a clear and direct relationship between predicted and perceived stimululus magnitudes. The determination of quadratic functions, however, suggests that closer examination of IRR and REME stimulus magnitudes is necessary for an adequate discussion of IRR's a priori computational validity.

The relationship between predicted (IRR) and perceived (REME) stimulus magnitudes is characterized in Table (41). Tonal elements of sequential stimuli are depicted by the digits 1 and 0 (recall that all stimuli consisted of eight tonal elements), where "1" elements received a greater degree of physical accent (frequency, amplitude, duration, and combination frequency-amplitude) than "0" elements. Predicted stimulus magnitudes (i.e., IRR-ordered) are shown to the left; perceived magnitudes (i.e., REME-ordered) are on the right. The order of IRR and REME stimulus magnitudes (from "most regular" to "least regular") procedes from top to bottom. Thus IRR-ordered magnitudes procede from level 7 to level 1, and REME-ordered stimuli procede from greatest to least in "pattern regularity" as determined by descending values of mean log geometric mean REMEs collapsed acrross accent modes (column, far right). Appropriate IRR levels precede each REME-ordered stimulus in parenthesis.

Only IRR levels 7 and 3 show agreement between

Table 41. Comparison of IRR-ordered and REME-ordered stimulus "magnitudes", from least to greatest. The eight-element tonal sequences are represented by 1's and 0's, where the digit 1 suggests a high level of physical accent, and the digit 0 suggests a low level of physical accent. One REME-ordering was acomplished by collapsing Session I mean log geometric mean REMEs across accent modes for each level of IRR.

IRR Level	IRR-ordered (predicted)		(IRR) (Level)	REME-ordered (perceived)	$\overline{X}$ log GM REME
		(most)			
7	1 1 1 1 1 1 1 1	↑	(7)	1 1 1 1 1 1 1 1	1.59
6	1 1 1 0 1 0 0 1		(1)	0 1 0 1 0 1 0 1	1.44
5	1 0 0 1 0 0 1 1		(2)	0 1 0 1 0 1 1 1	1.22
4	0 1 0 0 1 1 1 0	pattern regularity	(5)	1 0 0 1 0 0 1 1	1.18
3	0 0 0 1 0 1 1 1		(3)	0 0 0 1 0 1 1 1	1.13
2	0 1 0 1 0 1 1 1		(4)	0 1 0 0 1 1 1 0	1.12
1	0 1 0 1 0 1 0 1	↓	(6)	1 1 1 0 1 0 0 1	1.10
		(least)			

predicted and perceived magnitudes of pattern regularity. The other five IRR levels (1, 2, 4, 5, and 6) appear to be almost inverted for the REME-ordered stimuli. In fact, a spearman rho coefficient computed between IRR levels associated with predicted and perceived stimulus magnitudes suggests a weak, negative relationship between IRR and REME-ordered stimuli (rho = -0.14).

The nature of this apparent weak link between IRR and REME stimulus values can be determined by a closer examination of the pattern characteristics of the seven stimulus sequences. These pattern characteristics (i.e., temporal arrangements of accents) were held constant across four different types (or modes) of accent, and the values given to each pattern characteristic were determined by a specific IRR computation (refer to Appendix A). Ascending IRR values were taken as measures of ascending amounts transmissive redundancy (refer to "definitions", Chapter I) exhibited by each stimulus sequence.

Evidence that IRR is an inappropriate descriptor of transmissive redundancy (i.e., pattern regularity) for the seven stimulus sequences is suggested by (1) the nonmonotonic functions describing log IRR-log REME relationships, and (2) the weak, negative correlation between IRR-REME values. A closer examination of the pattern characteristics of REME-ordered stimuli, however, suggests that the computational underpinnings of IRR relating to the concept of relative accent level appear to be flawed, while the computational characteristics relating to the notion of relative timing appear to be sound.

In general, the concept of relative accent refers to temporal placement of specific accent magnitudes in a sequence; the notion of relative timing refers to the overall pattern created by a specific ordering of accent magnitudes (Martin, 1972). Wood's (1980) subsequent concept of relative accent level suggested that relative accent interacts with relative timing to impose a degree of transmissive redundancy in tonal sequences (p.46).

The IRR metric reflects this interaction between relative accent magnitudes and the relative timing of these accent magnitudes in tonal sequences. The failure of IRR to predict transmissive redundancy, however appears to be linked to lack of sufficient information regarding the effects of relative accent magnitudes on perceptual processes involving the resolution of temporal auditory sequences.

Relative accent level . The fundamental computational flaw in IRR seems to relate to Martin's (1972) original notion of relative accent, which suggests that pattern regularity increases when the first element of a two-element sequence receives the greatest degree of physical accent. Martin would suggest that:

1	2		1	2	sequence element
1	0	>	0	1	physical accent

in regularity.

Sequences with more than two elements, Martin would suggest, tend to exhibit pattern regularity when odd numbered sequence elements receive greater degrees of physical accent. Thus the sequence

1	2	3	4	5	6	7	8	sequence element
1	0	0	0	1	0	0	0	physical accent

is very regular, because the eight elements (tones) of the sequence are subdivided into two "perceptually equal" four-element subunits by a greater physical accent falling on odd-numbered sequence elements 1 and 5, respectively. Furthermore, the sequence

1	2	3	4	5	6	7	8	sequence element
1	0	1	0	1	0	1	0	physical accent

is highly regular, because greater degrees of physical accent fall on all odd-numbered sequence elements, thus dividing the eight tones into four equal subpatterns.

As a consequence of these regularity criteria of Martin, the stimulus

1 2 3 4 5 6 7 8	sequence element
0 1 0 1 0 1 0 1	physical accent

received the lowest level of IRR (i.e., level 1), because greater degrees of physical accent fall on all even numbered sequence elements. Moreover, the stimulus

1 2 3 4 5 6 7 8	sequence element
0 1 0 1 0 1 1 1	physical accent

received the second lowest IRR (level 2) because high degrees of physical accent fall on even-numbered sequence elements 2, 4, 6, and 8, respectively.

As can be seen in Table 41, however, these sequences received very high ratings (REMEs), suggesting that the perceived regularity of these tonal stimuli was very high. This seems to suggest that IRR computations relating to the concept of relative accent level are flawed.

Further evidence of the inability of relative accent level to explain perceived pattern regularity (at least, in regard to the tonal stimuli employed in this study) can be seen in sequences exhibiting IRR level 6. That is, the sequences,

1	2	3	4	5	6	7	8	sequence element
1	1	1	0	1	0	0	1	physical accent

where greater degrees of physical accent fell on odd numbered sequence elements 1,3, and 5, respectively. The concept of relative accent level would suggest these sequences to be highly regular (hence, the second, highest IRR level); however, these sequences received the lowest REME ratings, regardless of type (or mode) of physical accent.

The work of Watson et al., (1975) offers indirect corroboration that the concept of relative accent level is insufficient as a predictor of pattern regularity. He found a recency effect for the discriminability of target elements in ten-tone sequences. That is, pitch differences for higher frequency tones tended to be more resolvable when these tones occurred in later serial positions in the sequence. Although his psychophysical task relates more to jnd studies than pattern perception studies, his results do suggest that greater degrees of physical accent (i.e., higher frequencies) falling on later-occurring sequence elements may provide more structural information (i.e., temporal regularity information) than when these elements tend to occur earlier in the sequence, as he found no primacy effect for target sequence elements.

Perhaps more importantly, when the work of Watson _et al._, (1975) and the concept of relative accent level (Martin, 1972) are considered in parallel terms, the notion emerges that very little is known about the effect of relative degrees of physical accent on the perception of auditory sequence patterns. Ptacek and Pinhiero (1971) determined that a 10 dB difference between "soft" and "loud" bursts of white noise was necessary before a 50% correct judgment criterion was reached regarding the temporal order of bursts. Some researchers have noted that frequency differences among sequence elements which exceed a critical band tend to enhance temporal pattern resolution (Thomas and Fitzgibbons, 1971), while others have suggested that frequency differences exceeding critical band limits tend to distort perceptual judgments (Peters, 1964, 1967). The results of this study seem to indicate that neither accent type nor degree of physical accent have as much to do with the perception of temporal regularity in tonal sequences as does the temporal _pattern_ of accents, regardless of degree or type. Thus the relevant parameters for determining appropriate stimuli for studies of auditory pattern perception may be those outlined simplistically, yet elegantly, by Royer and Garner (1966):

> The simplest way to generate auditory temporal patterns is to use dichotomous elements, qualitatively different, in sequences of specified length which repeat themselves exactly (p. 41).

The results of this study further demonstrate that the perceptual dominance of accent pattern over accent type and degree lends credibility to Martin's (1972) and Wood's (1980) notion of relative timing, the next topic of discussion.

<u>Relative timing.</u> Relative timing defines the temporal relations between and among elements of auditory sequences (Martin, 1972). Wood (1980) states that relative timing is "...the essential underlying principle which governs the temporal arrangement of elements in a rythmic pattern" (p. 39). Auditory sequences exhibiting high degrees of relative timing tend to be more easily resolved (i.e., discriminated, recalled) than do sequences exhibiting low degrees of relative timing. That is to say, high degrees of relative timing suggest sequence "goodness" (Royer and Garner, 1966; Garner 1974), sequence "regularity" (Martin, 1972; Sturges and Martin, 1974), and "transmissive redundancy" (Wood, 1980).

For the sake of clarity, the REME-ordered stimuli are again listed in Table 42. Each stimulus has been renamed, from A (least regular) to G (most regular). It is presumed, because serial positioning of relative accent magnitudes has failed to explain REME responses, that ascending stimulus "values" (i.e., A-G) now reflect differences in relative timing.

For discussion purposes, it will be useful to apply

Table 42. "Renamed" REME-ordered sequences. The eight sequence elements are represented by 1's and 0's, denoting physical accent magnitudes. Sequences from A-G were judged as exhibiting least-to-most pattern regularity as determined by REME ratings.

Stimulus	sequence elements	Mean log Geometric Mean REME Ratings
G	1 1 1 1 1 1 1 1	1.59
F	0 1 0 1 0 1 0 1	1.44
E	0 1 0 1 0 1 1 1	1.22
D	1 0 0 1 0 0 1 1	1.18
C	0 0 0 1 0 1 1 1	1.13
B	0 1 0 0 1 1 1 0	1.12
A	1 1 1 0 1 0 0 1	1.10

the nomenclature of Garner (1974) to the seven sequential stimuli. Garner would suggest that "pattern goodness" is mediated by the subset sample size in relation to the size of the total stimulus set (population). Since only 7 of 256 possible stimuli were employed in this experiment (i.e., a sample of less than 3% of the population), it will be difficult to generalize to the population of eight-element sequences exhibiting binary levels of accent. Nevertheless, some general, qualitative conclusions can be drawn if the term "subpattern" is substituted for Garner's usage of "subset" (1974, p.5).

For present purposes of discussion, a subpattern is loosely defined as any identifiable portion of a sequence that repeats itself. Repeating subpatterns tend to give auditory stimuli "internal structure", or "intrinsic redundancy" (Garner, 1974, pp. 1-6). The "population" of possible subpatterns for eight-element sequences is 4. That is, a subpattern is defined by its number of elements; therefore, the largest repeatable subpattern for eight-element sequences consists of four elements occurring twice, (having one repetition).

The four determinants of transmissive (i.e., intrinsic) redundancy exhibited by the REME-ordered (Table 42) stimuli, then, seem to be:

1. the number of identical subpatterns in a sequence,
2. the number of tonal elements in the subpattern

3. the primacy of subpattern occurrence, and

4. the adjacency of subpattern occurrence.

The first determinant of transmissive redundancy effectively explains the ordering of stimuli receiving the four highest REME ratings. Stimulus G has 8 repetitions of the subpattern "1"; stimulus F, 4 repetitions of the subpattern "01"; stimulus E, 3 repetitions of the subpattern "01", and; stimulus D, 2 repetitions of the subpattern "100".

The second determinant of transmissive redundancy also effectively explains the ordering of the four highest REME-rated stimuli. All subpatterns in stimulus G consist of single tonal elements; all subpatterns in sequences F and E consist of two (duple) elements; while the subpatterns in stimulus D contain 3 (triplet) elements.

The third determinant of transmissive redundancy also explains the first four REME stimuli. Subpattern structure is apparent in stimulus G after the occurrence of only 1 tonal element; subpattern structure becomes apparent in sequences F and E after the occurrence of 2 tonal elements; while subpattern structure in stimulus D is established at the occurrence of tonal element 3.

The ability of the 4 determinants of transmissive redundancy to "explain" stimuli A-C is less direct, but still apparent. Two adjacent repetitions of the subpattern "01" occur in stimulus C; as do two "10" subpatterns in stimulus A. These repetitions are embedded, however (hence, no primacy effect). Two repetitions of the subpattern "01" also occur in stimulus B, but not only is one subpattern embedded, the two repetitions are nonadjacent as well.

Several other pattern characteristics of the REME stimuli are worthy of mention, as the rather loose definition of subpattern suggests other interpretations of REME stimuli A-C. Stimulus A for example, received the lowest REME rating, yet 3 repetitions of the subpattern "1" occur at the beginning of the stimulus. Thus stimulus A seems to fulfill many criteria for transmissive redundancy in terms of (1) having 5 identical subpatterns or occurrences of "1", (2) exhibiting single element subpatterns, (3) exhibiting a primacy effect, and (4) an adjacency effect of "1" subpatterns. Furthermore, two adjacent repetitions of the subpattern "10" are embedded in stimulus A, as are two nonadjacent repetitions of the subpattern "01". It could be argued that a host of redundancy criteria are fulfilled by stimulus A.

Garner (1974) offers a possible explanation for the low REME rating for stimulus A. Highly redundant stimuli, he suggests, demonstrate correlational structure, which is in turn dependent upon dimensional structure (pp. 2-10). Dimensional structure is ultimately mediated by the perceptual parameters describing the total set from which the stimulus sample or subset is taken. The perceptual parameters of REME stimuli included all possible permutations and combinations of two levels of accent (high and low) for eight serial sequence positions. Although many potential indices of transmissive redundancy exist in stimulus A, few are correlated, as is the more apparent case in sequences D-G.

A more elaborate explanation of the low REME ratings for sequence A-C might be possible by an alternate interpretation of subpattern size. The largest repeatable subpattern for 8 element sequences is 4, hence

1	2	3	4	sequence element
2 x	2 x	2 x	2	possible levels of accent

$2^4 = 16$ possible four-element subpatterns could occur in stimuli A-C; however, a cursory examination of these stimuli reveals no repetitions of four-element subpatterns. Likewise, 2^3 , or 8 possibilities exist for three-element subpatterns; again, however, no repetitions of three-element subpatterns exist in stimuli A-C. The number of possible two element subpatterns is $2^2 = 4$. Two repetitions of duple subpatterns exist in each of the A-C stimuli; however, these repetitions are either imbedded and/or nonadjacent. A cursory observation of the stimuli in Table 42 will confirm that (1) defining the largest repeating subpattern, (2) determining the number of adjacent repetitions of that subpattern, and (3) establishing a primacy effect, will also "explain" the ascending REME ratings for sequences D-G.

To summarize, the major implications for the IRR metric resulting from this study are:

1. that accent pattern (i.e., relative timing) may dominate accent magnitude (i.e., relative accent level) in the determination of relative amounts of transmissive redundancy exhibited by tonal sequences, and

2. future attempts to quantify transmissive redundancy should investigate such potential redundancy determinants as subpattern size, subpattern primacy, and subpattern adjacency.

<u>Implications for the perceptual model</u>

The results of this study suggest that relative differences in accent type and degree have a negligible impact on the perceptual processes involved in the resolution of transmissive redundancy in tonal sequences. That is, differences in the perceived pitch, loudness, and protensity of sequence elements did not significantly affect the estimation of pattern regularity when the relative timing (i.e., pattern) of sequential stimuli was held constant. Also, qualitative examination of stimulus sequences suggests that potential determinants of transmissive redundancy may relate to the identification of (1) significant subpatterns in tonal sequential stimuli, (2) subpattern primacy effects, and (3) subpattern adjacency effects. These findings suggest several implications for the Wood-Chial (1980) temporal perceptual model:

1. That encoding functions thought to be precognitive operations may be mediated at higher cortical levels, and

2. That perceptual processes associated with redundancy reduction may reflect structural rather than spectral signal characteristics.

Tonal sequences were systematically given higher REME ratings, regardless of accent type or degree, when significant subpatterns emerged quickly (primacy effect) and repetitively (adjacency effect). This suggests that feature differentiation (in terms of temporal auditory pattern perception) may relate more to stimulus "structure" than stimulus "energy" (Garner, 1974). Stimulus structure relates to the information-carrying portion of a stimulus, while stimulus energy relates to that portion of the stimulus which "activates the senses" (Garner, 1974, p.2). Spectral features of sequential stimuli had no measurable effect on REMEs, and because spectral signal characteristics are generally conceded to be peripherally mediated, some higher-order neural processes seem to be implicated in feature detection of relevant "structural" information in the sequential stimuli. If such potential determinants of transmissive redundancy as subpattern size, primacy, and adjacency effects can be identified, the parallel processing features of the model (i.e., the interaction of search mechanisms with short-long term memory for subsequent decoding and inhibition) will be substantiated. Furthermore, the analogy between redundancy reduction and data processing will be strengthened, since temporal "looping" characteristics associated with parallel processing and subsequent signal inhibition tend to reflect potentially relevant structural signal characteristics. Inhibition of certain spectral characteristics may indeed be a primary feature of certain "dedicated" expectancy mechanisms.

Implications for future research

Reliability of subject performance on the REME task suggests that the verbal label (i.e., "pattern regularity") assigned to the percept under investigation was (1) appropriate and (2) comprehensible to normal hearing, young adults. Comparison of visual and auditory magnitude estimation data, coupled with acceptable REME reliability, suggests that the percept, though subtle in magnitude, was indeed stable over time.

This study demonstrated that certain spectral characteristics of sequential tonal stimuli did not affect the perceived redundancy in these stimuli to nearly the same degree that temporal pattern characteristics did. These findings have implications for additional research relating to both (1) the *a priori* selection of stimulus patterns, and (2) the possibility of future application of temporal auditory perceptual tasks in the clinical assessment of central auditory processing problems.

A priori stimulus classification. Stimulus magnitudes in this study were _a priori_ measures of relative redundancy as determined by an Index of Relative Redundancy (Wood, 1980). Computational features of the IRR metric reflect Martin's (1972) notions of relative accent and relative timing. Furthermore, IRR tends to order binary stimuli in ways that reflect notions of associative chain theorists who have employed extensive _a posteriori_ techniques (Garner, 1974).

The fundamental flaw in IRR, however, appears to be the "weighting" factor associated with Wood's (1980) concept of Relative Accent Level (p. 48), which assigns specific values to sequence elements according to each element's (1) accent magnitude, and (2) serial position. Results of this study suggest that relative serial position of sequence elements is a far more important determinant of pattern regularity than accent magnitude. Moreover, results of this study suggest that notions relating to the concept of relative timing of sequence elements are a key determinant of pattern regularity.

Future efforts to revise the IRR metric should probably emphasize the importance of correlational and structural redundancy (Garner, 1974). Structural redundancy refers to stimulus characteristics which impart information to the observer. Structurally redundant stimuli are said to exhibit "pattern goodness" (Royer and Garner, 1966), and pattern "regularity" (Martin, 1972).

Correlational redundancy is a type of structural redundancy. Stimulus sets exhibiting correlational redundancy tend to "share" similar redundant characteristics. In the present study, several general observations were made regarding "shared" characteristics of redundancy. Tonal sequences tended to be judged as exhibiting more pattern regularity when (1) significant subpatterns could be identified, (2) subpatterns emerged quickly (primacy effect), and (3) subpatterns tended to concatenate (adjacency effect). Future efforts to revise the IRR metric should look for quantification procedures that tend to reflect primacy and adjacency effects of significant subpatterns in tonal sequences. Moreover, quantification of relative redundancy should accomodate definitional features for subpatterns which allow for redundancy "enhancement" to be caused by repetition of like-accent subpatterns as well as multiple-accent subpatterns.

Other future efforts to quantify transmissive redundancy should, in the interest of parsimony, encorporate computational characteristics which would allow for generalizability to more tonal stimuli, exhibiting a wider variety of structural stimulus parameters. Certain structural characteristics of tonal stimuli which are known to enhance perceptual resolvability could be encorporated as computational variables - describing such things as subpattern size and subpattern repetition. Other variables could be encorporated which might allow for comparisons among tonal sequences of different length exhibiting different numbers (and/or types) of accent levels.

One very important issue remains unresolved - the relative structural redundancy of binary subpatterns over nonbinary subpatterns. That is, the amount of structural information in a tonal sequence tends to be increased more when subpattern elements are grouped in twos or multiples of two than for triplet subpatterns. Sturges and Martin (1974) demonstrated that eight-element tonal sequences were more easily resolved than seven-element sequences. A similar effect of binary subpattern structure was observed in the results of this study. Subpattern repetitions "explained" an equal number of sequence elements (6) in stimuli D and E, and both stimuli exhibited a subpattern primacy effect. Stimulus E contained three "01" subpatterns, while stimulus D contained two "100" subpatterns. Stimulus E, however, was consistently rated as exhibiting more pattern regularity than stimulus D.

Martin (1972) suggests that binary accent structure is a "natural" phenomenon -- that the simplest auditory pattern will consist of one accented element and one unaccented element (p. 488). This explanation seems too simplistic. Jones (1978a) suggests (though indirectly) that amounts of structural information imparted by subpattern size may relate to the overall size of the stimulus. That is, three repetitions of the subpattern "01" in stimulus E might contribute more structural information than two repetitions of the subpattern "100" simply because both subpatterns occur in sequences consisting of eight total elements. In other words, some structural "distortion" may have occurred in stimulus D that did not occur in stimulus E, because, in terms of number of subpattern elements, the "size" of subpatterns in stimulus E bore a more direct relationship than those in stimulus D to the "size" of the total stimulus.

It is quite possible, then, that three-element subpatterns contribute more structural information in 9-element stimuli that do two-element subpatterns. It is also quite possible that two "100" and three "01" subpatterns impart equal amounts of structural information to 6-element stimuli. Therefore, future attempts to quantify structural redundancy should allow for measures of subpattern "size" relative to the "size" of the total stimulus.

If we can discuss transmissive redundancy in terms of "structural information", several general models exist which may offer conceptual as well as computational parallels for revisions in IRR.

Shannon and Weaver (1949, 1963) suggest that:

$$I \text{ (amount of information)} = 2tw \log (S+N/N),$$

where t stands for signal duration, w for width of the usable frequency range, S for maximum amplitude of the signal, and N for minimum discernable intensity differences. This model (and metric) has been used to evaluate speech communication systems. Although computational variables in the associated metric involve only spectral signal characteristics, it would not be difficult, however, to conceive variables for parallel structural characteristics as well, which could be used in metric revisions of IRR.

It is difficult to conceive, however, that substituting structural for spectral variables in the above equation would yield a "better" IRR metric. Lassman (1964), however, proposed a "noise interference" model to describe the transmission and reception of information. According to this model,

$$I = \frac{S/N \text{ environment}}{N \text{ hearing aid} + N \text{ peripheral auditory system} + N \text{ central auditory system}},$$

where I is intelligibility, S is signal magnitude, and N is noise that interferes with signal transmission. This "metric" is more conceptual than computational in nature, and its general form might provide a basis for developing a metric to describe structural information in tonal sequences:

$$I = \frac{E}{D},$$

where I = structural information, E = "enhancers" of structural information, and D = "distorters" of structural information.

As discussed previously, some structural distortion seems to occur when stimulus "size" is not an exact multiple of subpattern "size". Also, and more importantly, structural redundancy seems to be maximized when adjacent subpatterns "explain" the entire stimulus. Thus, a logical quantification of maximinal structural redundancy would be:

$$I = \frac{S}{T},$$

where I is structural information, S is the total number of elements in adjacent subpatterns, and T is the total number of elements in the stimulus.

A logical extension of this formula might include other pattern characteristics: structural enhancers in the numerator, and structural distorters in the denominator. A slightly more well-developed equation might be:

$$I = \frac{SR}{T + n},$$

where S is the number of subpattern elements, R is the number of subpattern repetitions, and n is the number of elapsed stimulus elements before the first repeating subpattern emerges.

An additional, and indeed desirable, component in any new proposed IRR metric should address the issue of accent levels. That is, what role does the number of accent levels play in determining the amount of structural redundancy in a tonal sequence? And how does the number of accent levels present in a stimulus interact with other determinants of structural redundancy, such as (1) the number of elements in repetitive subpatterns, (2) the adjacency of these subpatterns, and, (3) the total number of stimulus elements? An additional computational variable which addresses these issues might be added in this way,

$$I = \frac{SRL}{T + n} ,$$

where I = structural information, S = number of elements in largest subpattern, R = number of subpattern repetitions, L = number of accent levels, T = number of stimulus elements, and n = number of elapsed stimulus elements before the first repeated subpattern emerges.

This equation suggests some interesting and potentially useful applications for the a priori construction of sequential tonal stimuli. It would, for example, allow the experimenter to hold any value constant while systematically varying others; or, hold all variables constant to examine the effects of change in only one. It would also allow for comparisons between sequential stimuli exhibiting different numbers of tonal elements and/or accent levels.

For eight-element sequences exhibiting 2 levels of accent, this equation seems to solve some of the problems of IRR associated with the concept of Relative Accent Level. For example, in terms of structural information, this solution would equate the following stimuli:

11111111 = 00000000 ;

01010101 = 10101010 ;

10001000 = 00010001 ;

00110011 = 11001100 .

When applied to the seven REME stimuli, "I" values correlate very highly with REME ratings (Pearson r = 0.97). This suggests (1) immediate utility for the a priori generation of other eight-element sequences exhibiting two levels of accent and (2) potential utility for a priori generation of sequences which differ in length and/or number of accent levels.

To summarize, future research involving a priori stimulus-generation should (1) indentify potential determinants of stimulus structure, and (2) encorporate these potential determinants parsimoniously into some metric which would seem to apply to as large a "stimulus set" as possible.

Clinical application. Efforts to refine the quantification of transmissive redundancy in auditory sequences may lead to the clinical application of tonal sequential stimuli in the diagnosis and assessment of central auditory processing problems.

Peters (1973) and Watson et al. , (1975) suggest that systematic examination of "temporally complex" tonal stimuli may be successful in abstracting and identifying significant nonlinguistic structural features which contribute redundancy to the speech signal. Quantification of these structural features might allow for further research to determine the relative contributions of linguistic and nonlinguistic redundancy to the perception of speech and language.

Differences in hemispheric loci for perceptual resolution of speech and nonspeech stimuli have been recognized for quite some time. Milner (1962) reported that patients with right temporal lobe lesions performed poorly on the tonal memory subtests of the Seashore Test of musical abilities. This finding was later confirmed by Berlin et al. , (1965), who examined the performance of 37 patients with temporal lobectomies (20 postoperative right; 17 postoperative left) on a variety of tasks thought to assess lateralility effects. He found significant differences in performance on both the tonal memory and rhythm subtests of the Seashore battery as a function of which temporal lobe had been ablated. Subjects with left-temporal lobectomies performed significantly better than subjects with right-temporal lobectomies, suggesting that nonspeech information is processed in the nondominant, right side of the brain. This relation between hemispheric dominance and the processing of sequential nonspeech stimuli has been confirmed by other investigators (Kimura, 1964; Levy-Aresti and Sperry, 1968).

Pinheiro (1977) reported that children with learning disabilities could repeat short tonal sequences by humming, but not by manually tapping response buttons. She suggested that signal encoding and decoding for the hummed response were probably mediated by the right hemisphere, whereas decoding of the signal for a manual response probably required hemispheric interaction (pp.242-244).

The Pitch Pattern Sequence (PPS) Test has been reported to provide useful diagnostic information in brain-damaged children and adults (Pinheiro, 1979). Stimuli for the PPS are a series of tone bursts, each consisting of three tones. Pitches are either high (1430 Hz) or low (880 Hz), and each test sequence exhibits two tones of one pitch and one tone of the other pitch. Tone bursts are 200 msec in duration, and interburst-intervals are 150 msec. A seven second response interval follows each test pattern. The test is administered under earphones at 50 dB SL (re; threshold at 1000 Hz), and subjects are asked to repeat the correct order of the three-tone sequences within hummed, verbal, or manual response.

Scoring is accomplished by summing percent-correct responses and the percent correct reversals (i.e., where the response "HLH" was given to the sequence "LHL", etc.). The following norms have been reported:

	Adults	Age 9-10
Means for correct response	90%	91%
Means for final total scores	96%	96%
Ranges	88-100%	85-100%

(Pinheiro, 1979, p.3)

Interpretation of PPS is accomplished by comparing nonverbal (egs. humming, whistling, singing) and verbal (either spoken or manual) scores. Diagnostic implications suggest that subjects with certain brain stem lesions or learning disabilities may hum the correct response quite easily, but respond very poorly in the manual or verbal response mode. Subjects with brain lesions in temporo-parietal areas of either hemishpere usually exhibit poor scores bilaterally; right-hemisphere lesions may result in chance-level scores for the left (contralateral) ear (p. 3).

The apparent clinical utility of PPS suggests several implications for future research. The normative data for PPS suggests that normal subjects perform quite well. It appears that potential clinical applications may result from laboratory examination of more difficult listening tasks. Results of the present study suggest the following stimulus parameters and experimental paradigms as potentially fruitful avenues of investigation:

1. presentation rate
2. sequence length
3. accent levels
4. reversals
5. magnitude estimation
6. discrimination
7. accent modes

The PPS purports to be a test of pattern perception and temporal sequencing. The presentation rate of PPS test items is 3.3 elements-per-second. Garner and Gottwald, 1966) suggest that presentation rates greater than two elements-per-second facilitate "perceptual" rather than "learning" response behaviors (p. 2); however, they also report a range of presentation rates from 0.8 to 8 elements-per-second as not significantly affecting perceptual performance for some listening tasks. Future research should investigate potential diagnostic applications of pattern perception tasks by examining impaired versus normal performance as a function of increasing presentation rates.

More knowledge is needed regarding perception of auditory sequential stimuli as a function of sequence length. Typically, 7, 8, 9, or 10 element sequences have served as stimuli. The PPS uses 3-element sequences. Future laboratory studies should examine longer sequences in an effort to establish normative data as a function of sequence length, and perhaps more importantly, as a function of structural or correlational redundancy exhibited by these longer sequences.

Laboratory studies need to be conducted to determine the effects on performance of varying numbers of accent levels in a sequence. As sequence length increases, the structural components of tonal stimuli should be examined as a function of increased numbers of accent levels.

Pattern reversals may provide useful clinical information. The PPS scores pattern reversals as correct. More laboratory data must be gathered using complex tonal stimuli, however, before any clinical significance can be established for the phenomena of pattern reversals.

Results of this study indicate that normal young adults can, with proper training, perform reliably in the estimation of rather "subtle" stimulus attributes. The continued laboratory use of magnitude estimation is therefore recommended. Clinical application of magnitude estimation, however, is not recommended at this time.

It is quite possible, however, that once structurally redundant characteristics of tonal sequences are quantified--that is, once a valid "x-axis" is determined for tonal stimuli, that reliable performance-"intensity" functions can be established for normals. If this proved to be the case, analysis of slope differences might prove to be a useful clinical tool.

Results of this study indicate that accent type may not play a major role in determining pattern structure. It is therefore recommended that future attempts to discover clinical utility for pattern discrimination tasks investigate pattern type rather than accent type. Furthermore, if accent magnitudes have an insignificant effect on pattern perception, stimulus frequencies below 500 Hz would optimize opportunities to apply central auditory tests of this nature on a hearing impaired population. This approach should minimize the confounding effects of peripheral hearing loss associated with most central speech test batteries (Pinheiro, 1977).

To summarize, it appears that tasks involving the perceptual processing of tonal sequential stimuli may be of clinical utility. More information is needed, however, to define the range of normal performance on tasks of this nature.

CHAPTER V

SUMMARY AND CONCLUSIONS

Introduction

Background

The concept of temporal redundancy has been applied to nonspeech auditory stimuli by several investigators (Martin, 1972; Garner, 1974). Easily resolved (i.e., recalled, discriminated) nonspeech stimuli, such as tonal patterns, are thought to exhibit temporal or "structural" redundancy much like speech signals exhibit semantic and syntactic redundancy. Tonal patterns which have been identified as being temporally or structurally redundant have been qualitatively described as exhibiting pattern "goodness" (Royer and Garner, 1966) and pattern "regularity" (Sturges and Martin, 1974). Few attempts have been made, however, to quantify temporal or structural redundancy. A metric of this nature might prove to be a useful tool for evaluating structural and linguistic redundancy in speech (Peters, 1973; Watson, et al., 1975).

Ultimately, the quantification of structurally redundant features in tonal patterns might lead to the development of stimuli for the clinical diagnosis and assessment of central auditory processing problems (Berlin *et al.*, 1965; Pinheiro, 1979).

Wood (1980) developed a metric for the quantification of transmissive redundancy in eight-element tonal sequences exhibiting binary levels of accent. This index of relative redundancy (IRR) described a monotonic relationship between stimulus (IRR) "magnitudes" and percent-correct discrimination judgments for a limited range of IRR values.

In general, insufficient knowledge regarding IRR exists to allow for statements to be made regarding the relationship between this metric and those temporal sequence attributes it purports to measure. More information is needed to evaluate IRR's ability to quantify those structurally redundant characteristics of tonal sequential stimuli which up to now have received only qualitative description.

Purpose

This study was designed to obtain pattern regularity magnitude estimates (REMEs) from trained, normal-hearing young adults who exhibited similar listening ability. The REMES were obtained as a function of seven stimulus "magnitudes" (i.e., levels of structural redundancy as measured by IRR) and four types of accents (frequency, amplitude, duration, and combination frequency-amplitude). The log geometric mean REMEs and least-squares lines of best fit describing log IRR-log REME relationships were analyzed:

1. to determine how consistently subjects scaled perceived pattern regularity within and between experimental sessions;

2. to determine if stimuli exhibiting different IRR "magnitudes" produced significantly different perceptions of pattern regularity to be influenced by changes in IRR;

3. to determine if there were significant trends for estimated pattern regularity to be influenced by changes in IRR;

4. to identify the lowest order equation that provided a satisfactory fit to the log-log functions;

5. to determine if the stimulus-response (slopes) differed in strength of association as a function of accent modes;

6. to determine if slopes of the functions differed as a function of accent modes, experimental sessions, or combinations of the two; and

7. to determine if the slope of the combination frequency-amplitude function was greater than that for the frequency function, the amplitude function, or the sum of the two.

Experimental design

Subjects

Twenty young adults served as subjects in this experiment. Mean age was 24.7 years. Mean, right ear threshold at 1000 Hz was 0.75 dB; mean left-ear threshold was 1.00 dB. Speech discrimination scores averaged 99.7 percent for right and left ears. All impedance measurements were within normal limits. No subjects reported a history of noise exposure, tinnitus, or use of pharmacological agents.

Stimuli

Discrimination stimuli. Discrimination stimuli consisted of 30 sequence pairs (all possible combinations of IRR levels 1, 3, 5, and 7 for frequency, amplitude, and duration accents). Subjects responded to these sequence pairs with same-different discrimination judgments.

Visual stimuli. The visual stimuli consisted of three sets of seven pairs of geometric forms. The left member of each pair was always the standard stimulus, whose size did not change; the right member of each pair was always one of the seven comparison stimuli which differed in size. The first set of seven pairs consisted of squares, while the last two sets of seven pairs consisted of circles. Each set represented a trial.

REME stimuli. The REME stimuli were audio recordings of seven tonal patterns. Two levels (high and low) of accents were exhibited in each stimulus sequence, and stimulus patterns were held constant across four accent modes (frequency, amplitude, duration, and combination frequency-amplitude). Each pattern type represented one of seven stimulus "magnitudes" as defined by IRR. Thus each pattern exhibited different ammounts of transmissive redundancy, from least (IRR level=1) to greatest (IRR level=7). Final test tapes consisted of pattern types recorded in pairs. Each pair consisted of a standard stimulus followed by one of seven comparison stimuli. Each comparison stimulus represented one of the seven pattern types, while the standard stimulus always represented the middle (fourth) level of IRR. The seven levels of IRR represented equilog intervals, from minimum to maximum ammounts of transmissive redundancy, for eight-element sequences exhibiting two levels of accent (Wood, 1980).

Procedures

All subjects underwent: (1) a hearing screening, (2) pattern discrimination training and screening, (3) visual magnitude estimation training and screening, (4) REME training, and (5) the REME experiment, in that chronological order. Twelve subjects returned to repeat the REME training and the REME experiment at a later date.

Hearing screening. The hearing screening consisted of a brief history, pure tone air conduction testing, reflex decay testing, and impedance testing.

Discrimination screening. Only subjects who correctly discriminated (same-different) 90% of test items were retained for visual magnitude estimation screening.

Visual screening. Each subject assigned numerical estimates to a standard shape, and then assigned numbers to comparison shapes, which varied in size. The visual task served as a procedural model for the REME tasks. Only subjects whose reliability of visual estimates equalled or exceeded 0.9 were retained for the REME experiment.

REME training. Subjects were first instructed in the meaning of "pattern regularity" by listening to two, twenty-element sequences; a "regular" pattern consisting of 5 alternating groups of 4 high and low accents, and; an "irregular" sequence, where the two levels of accent occurred randomly. Subsequently, twenty-eight tape-recorded practice items (seven levels of IRR for each of four accent modes) preceded the REME experiment. Accent modes for REME practice items and REME test items were counter-balanced for each session. Levels of IRR were randomized within accent modes. Listeners assigned REMEs to the auditory standard and comparison stimuli in the same manner used to make visual magnitude estimates in the visual task.

REME experiment. REMEs were obtained on 28 experimental items (seven levels of IRR for each of four accent modes) following the same procedure used in the visual and REME training tasks. Four presentations of each level of IRR were given in each session. Hence, a total of 112 REMEs were gathered (7 levels of IRR x 4 presentations, for each of 4 accent modes) for each subject in each session.

Dependent variables

Two dependent variables were derived from the REMEs. Geometric means across presentations were computed for REME responses. All REMEs were then log-transformed for y-axis placement in log IRR-log REME data plots. Thus REMEs provided the basis for the derived dependent variables of interest: log geometric mean REMEs within subjects across trials, and ; slope terms of the lines of best fit relating log REMEs to log levels of IRR.

Findings

Findings of this study include the following.

1. Same-different discrimination judgments were more consistent for experimental than pilot subjects on the pattern discrimination task.

2. Approximately 82% of all those who were screened on the pattern discrimination task met criterion levels of performance.

3. Mean raw scores for the pattern discrimination task were significantly higher for frequency and amplitude stimuli than for duration stimuli.

4. Over 98% of those screened on the visual task met criterion levels of performance.

5. Mean log geometric mean visual magnitude estimates (a) were all significantly different from one another and (b) formed a linear function (Stevens, 1975) with log stimulus size.

6. Only one subject did not grasp the concept of "pattern regularity"; hence, 95% of those who participated in REME training met criterion levels of performance.

7. Reliability of raw REME responses was judged to be good to excellent, as was the reliability of the derived dependent variables (i.e., log geometric mean REMEs and slopes).

8. Comparison of slope reliability across modes indicated (a) slopes were least consistent for duration mode stimuli (b) slopes were equally consistent for frequency and amplitude stimuli (c) slopes were most consistent for combination frequency-amplitude stimuli.

9. The percentage of shared variance between log IRR and log REME values was judged to be moderate.

10. Mean log geometric mean REMEs differed significantly as a function of IRR, but many did not differ significantly from one another.

11. Mean log geometric mean REMEs did not differ significantly as a function of accent mode, and mode-by-IRR interaction for mean log geometric mean REMEs was judged to be nil.

12. Statistically significant quadratic functions were fit to the log-log data for each accent mode.

13. Coefficients of determination describing these quadratic functions did not differ as a function of accent mode, experimental session, or mode-by-session interaction.

14. Quadratic slope terms did not differ as a function of accent mode, experimental session, or mode-by-session interaction.

Conclusions

The results of this study provide the basis for the following general conclusions:

1. High reliability of pattern discrimination judgments suggests that (a) the twenty experimental subjects were relatively homogenous in listening ability

(b) response consistency improves as discrimination ability improves, and (c) discrimination judgments are significantly more difficult for duration stimuli than for frequency or amplitude stimuli.

2. The visual magnitude estimation task is a useful training tool for Stevensonian scaling techniques.

3. Subject retention rates for both pattern discrimination and visual magnitude estimation suggests that the tasks are easily managed by normal young adults.

4. Significant differences between all possible pairs of mean visual estimates suggests a high degree of perceptual resolvability for the visual stimuli.

5. High REME reliability suggests that (a) the verbal label (i.e., "pattern regularity") was appropriate, and (b) differences in the "attribute" of pattern regularity exhibited by experimental stimuli, though subtle, were consistently recognized.

6. The index of relative redundancy (IRR) appears to be flawed as an _a priori_ descriptor of pattern regularity in tonal sequences.

7. Judgments of pattern regularity are not effected by accent type or degree, but by relative temporal accent placement.

8. Relative differences in slope consistency across accent modes suggests that possible differences in the perceptual resolvability of REME stimuli due to accent type and degree were not effectively measured by magnitude estimates.

9. The findings of this study were sufficiently encouraging to warrant additional research concerning the development of (a) a quantification procedure for the description of structurally redundant features exhibited by tonal sequential stimuli, and (b) normative data for the eventual use of these types of stimuli in the clinical assessment of central auditory processing problems.

APPENDIX A

INDEX OF RELATIVE REDUNDANCY (IRR): BACKGROUND, RELEVANT CONCEPTS, AND COMPUTATION

Background

Martin (1972) developed a generative-type grammar based upon observed stress patterns in spoken english. Central to Martin's grammar are the concepts of relative accent and relative timing. Relative accent refers to different magnitudes of physical accent exhibited by adjacent sequence elements. Relative timing refers to the relative temporal placement of these physical accents in an auditory sequence.

Martin's grammar described relationships among physical accent placements as either "regular" or "irregular" according to the "rules" of relative accent and relative timing. In the smallest possible auditory sequence (i.e., a sequence with two elements, one following the other in real time) regularity, according to the rule of relative accent, would be exhibited by the greater magnitude of physical accent falling on the first sequence element. Irregularity would be exhibited when the greater magnitude accent fell on the second (last) element of the sequence.

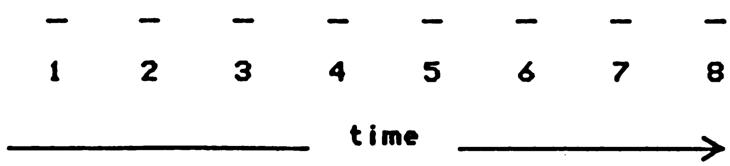
Regularity and irregularity in regards to relative timing refers to the overall temporal pattern of physical accent magnitudes in longer sequences. Regular relative timing divides longer auditory sequences into shorter, temporally meaningful subunits. An eight-element auditory sequence with high magnitude accents on serial elements 1 and 5 is "regular" because the relative timing of these physical accents divides the eight-element series into two, four-element subunits.

Martin (1972) also developed the concept of hierarchical "trees" (to be discussed below) which allowed for the gross assessment of relative timing for auditory sequences containing any number of elements. Sturges and Martin (1974) found that same-different discrimination judgments and written recall were enhanced when tonal sequences exhibited "regularity" according to the "rule" of relative timing.

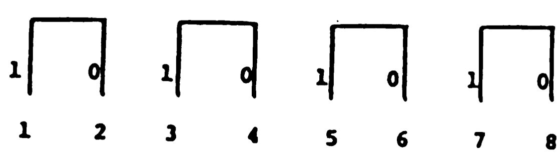
CONCEPT OF RELATIVE ACCENT LEVEL: RAL

Wood and Chial (1980) developed an extension to Martin's original grammar in an attempt to quantify degrees of rhythmic redundancy in auditory sequences. Central to their quantification procedure is the concept of relative accent level (RAL), which refers to the relative magnitudes of physical accents in a sequence.

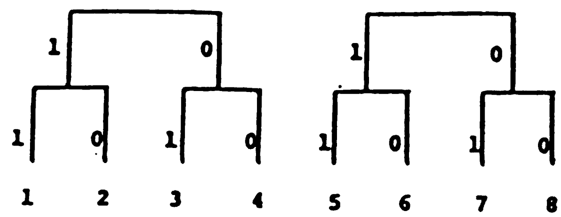
Relative accent magnitude of a particular element in a sequence is determined by its sequence position, which in turn is governed by the generative hierarchical tree. Our example sequence consists of 8 successive elements.



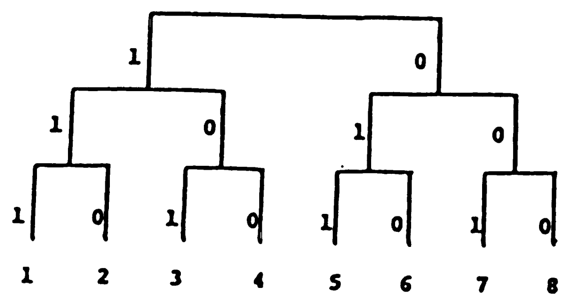
Recall that Martin's original grammar determines regularity or irregularity on the basis of physical accent placement for each pair of elements. That is, a pair of elements is considered regular if the greatest physical accent falls on the first element of the pair. If "1" or "0" characterize physical accents of different magnitude, the following sequence of 8 elements would be considered redundant:



Note in the above sequence that the first element in each pair is given the greatest physical accent. If we progress up the hierarchical tree, each second order pair will now also exhibit maximal regularity if its first element receives greater accent:

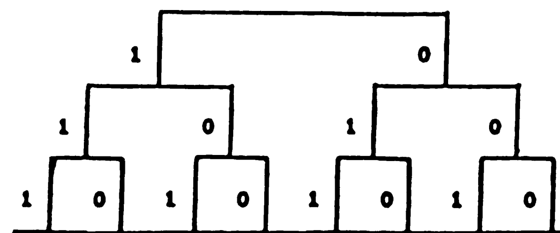


The entire tree describing maximum regularity for a sequence of 8 elements would look like this:



We can now determine the RAL of any sequence element by binary addition of accent magnitudes, starting at the bottom (Figure A-1) from each original element and progressing upward through its path to the summit of the tree. Resultant binary numbers are converted to their decimal equivalents, and 1 is added to represent the presence of an element at every sequence position.

We now have a sequence of 8 elements exhibiting a high hierarchical tree



STEP								
1. binary digits fall from tree	111	011	101	001	110	010	100	000
2. convert to decimal equivalent	7	3	5	1	6	2	4	0
3. add 1 if element is stressed	1	1	1	1	1	1	1	1
4. sum = RAL for each element	8	4	6	2	7	3	5	1
(element sequence)	1	2	3	4	5	6	7	8

Figure A-1. Relative Accent Level (RAL) computation for an eight-element sequence.

degree of regularity. Note that relative accents of greatest magnitude are placed on first and fifth sequence elements, dividing the original 8 element sequence into two perceptually similar 4 element sequences; furthermore, relative accents of next greatest magnitude fall on sequence elements 3 and 7, so each four element unit is further subdivided into perceptually similar sequences consisting of two elements each. Finally, note that the first sequence element of each serial pair receives greater relative accent than the second element of the pair.

REDUNDANCY PRECEPTS

The computed RALs reflect maximum redundancy for sequences of various lengths. It is important to note, however, that the hierarchical tree is the sole determiner of serial orderings of RALs. Operative rules for the generation of indices of relative redundancy (IRR) are used to compare the redundancy of different sequences, and IRRs are derived from the RALs of a particular sequence. Again, the exact RAL position is pattern specific. A tree should be used to verify exact RAL position when other than 8 elements are used.

There are, however, several underlying precepts governing RAL sequence for all pattern lengths. These precepts reflect ideal conditions conducive to maximum redundancy. Actual sequences are compared to the ideal tree structures to determine relative redundancy. A precise statement of redundancy precepts has not yet been formalized, but, generally, the precepts state:

1. The first element of a sequence receives the highest RAL.

2. The last element in a sequence receives the lowest RAL.

3. Individual RALs alternate in magnitude.

4. Furthermore, RALs alternate in magnitude at successive 2 to the nth power sequence positions.

The above precepts allow us to generate indices of relative redundancy by formalizing a set of operative rules that are pattern specific.

COMPUTATION OF IRRmax

The five operative rules for determining relative redundancy are listed on tote sheet A (Figure A-2). These rules adapt the application of general redundancy precepts to sequences of specific length. Before we discuss the application of these rules, it will be useful to see how maximum redundancy is calculated for sequences of specific length.

Again, our example will consist of 8 elements. Observe Figure A-2 again. We use this tote sheet to

IRR COMPUTATION: TOTE SHEET A

RAL sequence	1	2	3	4	5	6	7	8	
RAL	8	4	6	2	7	3	5	1	
physical accent	+	+	+	+	+	+	+	+	
element sequence	1	2	3	4	5	6	7	8	
RULE									
1. RALx ≥ RALx-1	1	1	1	1	1	1	1	1	
2. RALx ≤ RALx+1	1	1	1	1	1	1	1	1	
(for odd elements)									
3. PAesn ≥ PAesn+1	1		1		1		1		
4. PAesn ≥ PAesn-1	1		1		1		1		
(for even elements)									
3. PAesn ≤ PAesn+1		1		1		1		1	
4. PAesn ≤ PAesn-1		1		1		1		1	
5. accent rule	1	1	1	1	1	1	1	1	(COMPUTATIONS)
	5	5	5	5	5	5	5	5	sum columns
	40	20	30	10	35	15	25	5	multiply by RAL (sum row of products)
								180	Rtot
									Rtot/Rmax*
								1.0	IRR

*(recall: Rmax = 180)

Figure A-2. Computation of IRR max.

calculate IRRs for specific patterns. The first row displays RAL sequence from 1-8 in real time progressing from left to right. Row two shows ideal RAL magnitude for a maximally redundant sequence of 8 elements, and row three describes the actual sequence for which IRR is being computed. The bottom row shows element sequence in real time.

Application of specific redundancy rules involves asking a series of binary questions about each element in the actual sequence. If a rule is satisfied, a "1" is entered in the appropriate place. If a rule is not satisfied, a "0" is entered. If all 5 rules are satisfied, the total possible column sum for any sequence element is 5. Since the actual sequence under scrutiny here is maximally redundant, all columns total 5.

Each column total is further weighted by multiplying it by its associated RAL, and the resulting products are again summed to reflect total redundancy. Total redundancy is then divided by maximum redundancy to compute the IRR for this sequence. Since the sequence we have chosen is maximally redundant, Rtot = Rmax, and therefore, IRR = 1. Maximum redundancy for sequences of 8 elements remains constant (180); Rmax8 becomes the ideal standard to which Rtots of actual 8 element sequences are compared. Tote sheet B (Figure A-3) shows an actual 8 element sequence exhibiting less than maximum redundancy. Note that its Rtot = 99, and its IRR = 0.55. Continue to refer to Figure

IRR COMPUTATION: TOTE SHEET B

RAL Sequence	1	2	3	4	5	6	7	8	
RAL	8	4	6	2	7	3	5	1	
physical accent	+	0	+	+	0	+	0	+	
element sequence	1	2	3	4	5	6	7	8	
RULE									
1. RALx ≥ RALx-1	1	0	1	1	0	1	1	1	
2. RALx ≤ RALx+1	1	1	0	1	1	0	1	1	
(for odd elements) 3. PAesn ≥ PAesn+1	1		1		0		0		
4. PAesn ≥ PAesn-1	1		1		0		0		
(for even elements) 3. PAesn ≤ PAesn+1		1		0		0		1	
4. PAesn ≤ PAesn-1		1		1		0		0	
5. accent rule	1	0	0	0	0	0	0	0	(COMPUTATIONS)
	5	3	3	3	1	1	2	3	sum columns
	40	12	18	6	7	3	10	3	multiply by RAL (sum row of products
								99	Rtot
									Rtot/Rmax*
								0.55	IRR

*(recall: Rmax = 180)

Figure A-3. Index of Relative Redundancy (IRR) computation.

A-3 as we discuss application of the 5 redundancy rules.

APPLICATION OF THE 5 REDUNDANCY RULES

Actual sequence regularity is determined by the extent to which the physical accents of elements in that sequence correspond serially to the sequence positions of RALs prescribed by a particular tree. Figure A-3 shows a sequence of 8 elements exhibiting two levels of physical accent. Each element in this sequence is stressed: a "+" indicates physical accent of greater magnitude than a "0". As you can see, sequential elements 1, 3, 4, 6, and 8 receive equal accent, and so do elements 2, 5, and 7. Elements 1, 3, 4, 6, and 8, however, receive physical accent of greater magnitude than do elements 2, 5, and 7.

Above each physical accent is the ideal RAL magnitude associated with sequences of 8 elements. Rules 1 and 2 will determine the degree of correspondence between the actual physical accents of our sequence to the sequence placement of the ideal RALs above them.

Let's look at element 1 of our sequence. Its ideal associated RAL is 8. That is, if our sequence is to be considered maximally redundant, element 1 should receive the greatest physical accent. And furthermore, the physical accents of elements 2-8 in our sequence should reflect RALs directly above them to exhibit maximum redundancy.

Rule 1 states:

$$RALx \geq RALx-1 .$$

In words, this means we must proceed down the RAL continuum from RALs of greatest to least magnitude to examine the physical accents in our sequence. The greatest RAL here is 8. This becomes RALx if we are examining the physical accent of element 1 in our sequence. Notice that element 1 in our sequence has a physical accent of "+".

To invoke rule 1, we must now look at RAL 7 (i.e., Ralx-1). RAL 7 corresponds to element 5 in our sequence, which has a physical accent of "0". Now, RAL 8 is by definition greater in magnitude than RAL 7. The relationship between RAL 8 and RAL 7 is therefore regular. Likewise, the physical accent of element 1 in our sequence must be greater than or equal to the physical accent of element 5 to be considered regular. Since "+" is greater than "0", we would consider this relationship regular. Rule 1 has been satisfied for element 1 in our sequence, so we enter a "1" under it in the tote sheet.

For practice, let us now invoke rule 1 for element 2 in our sequence. RAL 4 is associated with element 2, so RAL 4 now becomes the RALx of interest. We must now look for RALx-1. If RAL 4 = RALx, then RALx-1 must be RAL 3. We can see that RAL 3 is associated with element 6 in our sequence, so the relationship between the physical accents of element 2 and 6 is now under scrutiny. To be considered regular, the physical accent of element 2 must be greater than or equal to the physical accent of element 6. Since "0" is less than "+", the relationship is considered irregular, rule 1 is not satisfied, and element 2 gets a zero in the tote sheet for rule 1.

Rule 2 states:

$$RALx \leq RALx+1 .$$

Again, RALx becomes the RAL associated with the element of our sequence under scrutiny. Let us now invoke rule 2 on element 4 of our sequence.

We are interested in determining the regularity of sequence element 4, so we look at its associated RAL, which in this case is RAL 2. Rule 2 states that we must now compare RAL 2 with RALx+1, which is RAL 3. Now, RAL 3 is associated with element 6 of our sequence; therefore, the relationship under scrutiny now is that of the physical accent of element 4 to the physical accent of element 6. Again, RAL 2 is by definition less than or equal to RAL 3 and is therefore considered regular. Likewise, the physical accent of sequence element 4 must also be less than or equal to the physical accent of sequence element 6 to be considered regular. Since "+" = "+", the relationship is indeed regular, rule 2 is satisfied, and sequence element 4 gets a "1" in the tote sheet for rule 2.

Application of rules 3 and 4 is governed by serial order position of the elements in the sequence under scrutiny. Pattern regularity occurs when physical accents alternate sequentially in magnitude, and, as we saw in rules 1 and 2, the alternation of physical accents is again determined by RAL configuration. Examination of the RAL sequence in our example tells us that sequentially odd-numbered RALs are flanked on either side (preceding and succeeding in real time) by RALs of lesser magnitude. Conversely, sequentially even-numbered RALs are flanked by RALs of greater magnitude. Note further that RAL sequence is identical to element sequence, so we can satisfy rules 3 and 4 by examining element sequence numbers and their respective physical accents, keeping in mind that pattern regularity is ultimately governed by RAL fluctuation as determined by the hierarchical tree.

For convenience, we have divided rules 3 and 4 into two distinct sets: one for odd-numbered sequence elements, and one for even-numbered sequence elements. Rule 3 for odd-numbered sequence elements states:

$$PAesn \geq PAesn+1 .$$

That is, if odd sequence element n is under scrutiny, its physical accent must be greater than or equal to the physical accent of the sequence element following it in time. For example, odd sequential element 1 has a physical accent of "+"; the physical accent of element 2 is "0". Since "+" is greater than "0", rule 3 is satisfied, and a "1" is entered under element 1 for rule 3 governing odd-numbered sequential elements.

Rule 4 for odd-numbered element sequences describes the relationship between the element under scrutiny and the sequence element preceding it in real time. Rule 4 states:

$$PAesn \geq PAesn-1 .$$

That is, the physical accent of any odd element sequence n is greater than or equal to the physical accent of the preceding element if it is to be considered regular. Let's examine odd sequence element 5; it has "0" corresponding physical accent. Preceding element sequence 4, however, has a physical accent of "+", and "0" is not greater than or equal to "+". Therefore, the relationship is not regular, rule 4 is not satisfied, and a "0" is entered in the tote sheet for odd element sequence 5 at rule 4.

RULES 3 & 4 FOR EVEN-NUMBERED ELEMENT SEQUENCES

The same principles apply here. Note, however, that the signs are reversed for the even numbers (refer to Figure A-3).

RULE 5: THE ACCENT RULE

If a sequence element receives a physical accent, and all preceding rules (operatives 1-4) have been satisfied, the element gets an additional "1". Otherwise, it gets an additional "0".

IRR COMPUTATION: (refer to Figure A-3, bottom)

1. Sum the columns for each element sequence.
2. Multiply each column sum by its associated RAL.
3. Sum all resulting products; this sum = Rtot.
4. Divide: Rtot/Rmax = IRR. (recall, Rmax = 180)

The particular IRR for a sequence compares its relative redundancy with maximum redundancy. Maximum redundancy for any sequence is always 1.00. Minimum redundancy is a function of sequence length (i.e., number of elements per sequence). Minimum IRR for eight-element sequences is 0.30 (Wood, 1982, personal communication).

APPENDIX B

PILOT STUDY OF A PATTERN DISCRIMINATION TASK

A 12-minute, taped, pattern discrimination task was developed to assess the "listening ability" of potential subjects. It was desirable to develop a test that avoided the sorts of bias associated with most tests of musical ability (i.e., the use of a highly specialized vocabulary which correlates with formal training, but not other musical experience, musical ability, or related auditory skills). It was also hoped that the discrimination task would yield a distribution of scores amenable to the adoption of a decision rule for subject retention in (or rejection from) the REME experiment. Finally, and perhaps most importantly, it was desirable to develop a screening task for the REME experiment which provided a behavioral measure of perceptual skills correlating with those needed to make REME judgments.

To those ends, thirty auditory discrimination items were prepared. Each item consisted of two, eight-element tonal sequences. Spectral and temporal parameters of tonal sequence elements conformed to those described for frequency, amplitude, and duration accent modes (refer to Chapter II). Four pattern "types" (i.e., 4 different temporal arrangements of binary accents) were included in each accent mode, and pattern type was defined by IRR

(Wood, 1980). Thus IRR levels 1, 3, 5, and 7 described pattern types in each of the three modes of accent. Discrimination items (pairs of pattern types) included all possible combinations of the four IRR levels, including "control" items consisting of two sequences exhibiting the same level of IRR. The 10 possible pairs of sequences in each of the 3 modes therefore comprised the 30 item discrimination task.

Purpose

This study was designed to obtain pilot data on the newly developed discrimination materials. The data were examined statistically to answer the following questions:

1. How consistently do subjects perform same-different discrimination judgments for the thirty-item test?
2. Is there a statistically significant difference in discrimination scores as a function of accent mode?

In addition, the data were examined qualitatively to answer the following informal questions:

3. What type of distribution of scores is yielded by the 30 item discrimination task?
4. Is the distribution amenable to the adoption of a decision rule by which subjects exhibiting "homogenous listening ability" (based upon discrimination scores) can

be included in the REME experiment?

<u>Method</u>

The pattern discrimination task was administered to 38 college students who reported normal hearing. Discrimination testing wass accomplished in an acoustically-treated classroom with a seating capacity of up to twenty students, and test items were presented in the sound field at a comfortable listening level. Verbal labels (i.e., "item one") preceded each test item, and subjects were asked to circle the correct word ("same-different") on response sheets with corresponding item numbers. The discrimination task was preceded by taped instructions (found in this appendix).

<u>Quantitative and Qualitative results</u>

Consistency of discrimination response was evaluated by computing an ANOVA-based reliability coefficient for a test of k=30 dichotomous items (Winer, 1971, p. 294). The coefficient obtained was 0.543, suggesting that pilot subjects were only moderately consistent in their response behavior.

Mean raw discrimination scores, standard deviations, and ranges are summarized in Table B-1. Table B-2 summarizes results of a one-way analysis of variance in raw discrimination scores as a function of accent mode. Results of this analysis indicated significant differences

Table B-1. Mean raw scores, standard deviations, and ranges for 38 subjects who participated in the pattern discrimination pilot study.

Subscale											
Freq			Amp			Dura			Total		
$\overline{X}$	SD	Range	$\overline{X}$	SD	Range	$\overline{X}$	SD	Range	$\overline{X}$	SD	Range
9.31	0.7	2	9.76	0.71	4	8.6	1.0	4	27.68	1.57	7

Table B-2. Summary of analysis of variance of raw scores for the pattern discrimination pilot as a function of accent mode.

Source	SS	df	MS	F	F for alpha=0.05	alpha for F obs.
Blocks/ Subjects	28.070	37				
Accent Modes	25.912	2	12.956	20.802	3.15*	<.001
Error	46.087	74	0.622			
Total	100.070					

* From F distribution table (Winer, 1971, pp. 864-869).

among mean scores, and results of the Neuman Keuls specific comparison test (Table B-3) indicated all three mean scores to be significantly different form one another. This suggested that (1) the amplitude stimuli were most resolvable, (2) frequency stimuli were next-most resolvable, and (3) the duration stimuli were least resolvable.

The distribution of scores could be described as negatively skewed and leptokurtic (Glass and Stanley, pp. 88-92). Most pilot subjects (n=38) found the discrimination task to be quite easy. Although only 8% of those tested received perfect scores, 82% of the pilot subjects received scores of 90% or better. In addition, 61% demonstrated discrimination scores equal to or exceeding 95% correct, while 32% of the pilot subjects exhibited scores equal to or exceeding 97% correct.

Discussion

The consistency of discrimination responses was judged to be only moderate. This may have been due to temporary lapses in attention caused by a less than ideal testing environment. Nevertheless, the reliability of the task was thought to be adequate for the purposes of screening for the REME experiment.

Analysis of mean differences in raw discrimination scores as a function of accent mode suggested significant differences in the discriminibility of sequences exhibiting

Table B-3. Results of the Newman-Keuls specific comparison test on pairs of mean correct raw scores for each accent mode in the pattern discrimination pilot task. Critical values are given for all possible ranges spanning from two to three means. A difference between any two means is significant when it exceeds the appropriate critical value (CV) for alpha=0.05. The number of means is equal to k.

Accent Mode (Means)	Amp (9.76)	Freq (9.31)	Dura (8.60)	CVk
Amp		0.45*	1.16*	CV3=0.4389
Freq			0.71*	CV2=0.3670

* Denotes a significant difference between a pair of means.

the three accent types. These results should be interpreted with caution, however, for although presentation orders for the 10 test items in each accent mode were randomized, accent mode presentations were not counterbalanced. Consequently, mean discrimination scores may have been influenced by order effects. Accent mode presentation order was (1) frequency, (2) amplitude, and (3) duration. Factors relating to response uncertainty may have depressed frequency accent mode scores, while fatigue factors may have significantly lowered duration accent mode scores.

Because the distribution of discrimination scores was negatively skewed and leptokurtic, decision rules commonly applied to normally distributed functions could not be applied (i.e., "retain subjects whose discrimination scores fall within one standard deviation of the mean"). Therefore, it was decided to adopt a decision rule based on percent-correct judgments. Because 82% of pilot subjects demonstrated scores equal to or exceeding 90% correct (i.e., correct same-different judgments on 27 of 30 possible test items), it was decided to retain all subjects for the REME experiment who exhibited pattern discrimination scores of 90% or better. This seemed to be a reasonable strategy because (1) it successfully eliminated subjects who performed very poorly in the pattern discrimination task, and (2) it allowed for rather broad generalizations to be made regarding the ability of normal young adults to yield reliable magnitude estimates of pattern regularity (REMEs).

INSTRUCTIONS

PATTERN DISCRIMINATION

This is a test of your ability to tell the difference between two sound sequences. Each test item will consist of two, eight-tone sequences. Sometimes the pattern of tones in each sequence will be the same, and sometimes the pattern of tones in each sequence will be different.

Observe your response sheet. Your task will be to circle the correct word for each test item. If the pair of tonal sequences sounds the same, circle the word "same". If the pair of sequences sounds different, circle the word "different".

Observe your response sheet again while you listen to some examples. For test items 1-10, tonal sequences will receive pitch accents. Here is an example of two tonal sequences receiving pitch accents where the pattern of accents in each sequence is the same . Now listen to an example of two sequences receiving pitch accents where the pattern of accents in each sequence is different .

The sequences in test items 11-20 will receive loudness accents. Here is an example of two tonal sequences receiving loudness accents where the pattern of accents in each sequence is the same . Now listen to an example of two sequences receiving loudness accents where the pattern of accents in each sequence is different .

Test items 21-30 will contain pairs of tonal sequences receiving duration accents. Here is an example of two tonal sequences receiving duration accents where the pattern of accents in each sequence is the same . Now listen to an example of two tonal sequences receiving duration accents where the pattern of accents in each sequence is different .

You will have about 7 seconds to respond to each test item. Again, your task will be to circle the correct word corresponding to each item.

ARE THERE ANY QUESTIONS?

RESPONSE FORM

PATTERN DISCRIMINATION

Subject Name ____________ Subject Number __________

Date _____

1. same different
2. same different
3. same different
4. same different
5. same different
6. same different
7. same different
8. same different
9. same different
10. same different
11. same different
12. same different
13. same different
14. same different
15. same different
16. same different
17. same different
18. same different
19. same different
20. same different
21. same different
22. same different
23. same different
24. same different
25. same different
26. same different
27. same different
28. same different
29. same different
30. same different

APPENDIX C

TABULAR SUMMARY OF AGE AND AUDIOMETRIC DATA FOR EXPERIMENTAL SUBJECTS

Table C-1 summarizes the age and audiometric data for twenty adult females who served in the REME experiment. REME stimuli were tonal sequences consisting of 1024 and 3001 Hz tones. Presentation levels of these tonal sequences ranged from 40 to 60 dB SL (re: threshold for 1000 Hz). Individual data are listed for each subject, and means, standard deviations, and ranges are reported for (1) age, (2) right and left ear threshold at 1000 Hz, and (3) right and left ear speech discrimination scores.

Table C-1. A summary of ages, thresholds at 1000 Hz, and speech discrimination scores for all experimental subjects,

Subject	Age (yrs.)	Threshold at 1000 Hz R dB	Threshold at 1000 Hz L dB	% Discrimination Score R	% Discrimination Score L
1	22	0	0	100	96
2	23	0	0	100	100
3	22	0	0	100	96
4	33	5	5	100	100
5	23	0	0	96	100
6	24	0	0	100	100
7	26	0	0	100	100
8	28	0	0	100	100
9	27	0	0	100	96
10	23	0	0	100	100
11	21	0	0	100	100
12	27	0	0	100	100
13	32	0	5	96	100
14	24	0	0	100	100
15	25	5	5	100	100
16	22	0	0	96	100
17	29	0	0	100	100
18	21	0	0	100	100
19	22	5	5	100	96
20	20	0	0	100	100
Mean	24.70	0.75	1.00	99.40	99.20
SD	3.55	1.79	2.00	1.43	1.60
Range	13.00	5.00	5.00	4.00	4.00

APPENDIX D

VISUAL MAGNITUDE ESTIMATION TRAINING

Although it has been shown that relatively unsophisticated subjects can perform reliably in ratio scaling procedures, S. S. Stevens (1975) suggested that a simple training task might be useful to introduce subjects to the magnitude estimation paradigm. In regards to the present study, it was useful to eliminate subjects who could not perform simple magnitude estimates reliably.

A visual magnitude estimation training task was developed by Chial and Lawson (in Lawson, pp. 179-185). Subjects were required to estimate the apparent magnitude of squares and circles projected on a rear screen slide viewer with synchronized, taped instructions. Three trials were given. The first trial (practice) involved squares as visual stimuli. Trials 2 and 3 (experimental) used circles as stimuli.

Reliability coefficients (Pearson r) were computed between trial 1 and trial 2 visual magnitude estimates for 12 subjects. The 12 coefficients ranged from 0.93 to 1.00 and were all significant. Furthermore, 100% agreement among standard stimulus values was noted across subjects and trials (Lawson, p. 190). A one-way analysis of variance yielded statistically significant differences in log geometric means (for visual magnitude estimates) as a function of log circle size, and tests for linear trend suggested a significant power law fit (Stevens, 1975) to the log circle size-log visual magnitude estimate functions (Lawson, p. 196).

Since reliability issues relating to perceived temporal regularity in tonal sequences was unsettled, it proved useful to eliminate subjects whose reliability of performance on a simple magnitude estimation task was questionable. Therefore, subjects retained for the present study must exhibited reliability coefficients greater than or equal to 0.90 and also 100% correct agreement in standard stimulus values for trials 2 and 3 of the visual magnitude estimation task (Lawson, 1980).

INSTRUCTIONS AND RESPONSE SHEET FOR VISUAL TASKS

Please read these instructions as you listen to them. You are going to see some pictures of squares and circles. We want you to assign numbers to these shapes in a special way. Before we explain the numbers, let's look at a sample of what you'll be seeing.

Slide of Two Squares . Notice the square on the left. This shape is labeled "S" for standard. This "S" will always be on the left. The other shape is labeled "C" for comparison. This shape will always be on the right. However, we will be changing the size of the shape labeled "C".

Slide of One Square . Here we have only one shape, a standard. When you see a slide like this, you are to assign a number to the shape. The number you pick should represent your impression of the size of the shape. You can pick any number you want, but it will be easier if you pick a whole number. (slide off).

In a moment, we'll show you some more pairs of shapes. One will be a standard; the other will be a comparison. Your job will be to refer to the number you initially gave the shape "S" and then pick a number for shape "C". The number for shape "C" should represent the size of shape "C" relative to the size of the standard. In other words, the number you pick for "C" should relate to the number for "S" in the same way that the size of "C" relates to the size of "S".

Let's try an example. We show you a slide with a single shape on it. That shape is labeled "S" for standard. Following the instructions given at the time, you assign that standard some number, let's say 20. Then we show a slide sith the same shape "S", plus a shape "C". If "C" looks twice as big as "S", then "C" gets the number 40. If "C" looks half as big as "S", then "C" gets the number 10. Each time you see a new slide, you give the "C" shape a number that represents its size compared to the size of "S". Or, let's assume that you called shape "S" 5. If the comparison shape "C" looks three times bigger than "S", you'd call the "C" shape 15. If "C" looks one-fifth as big as the standard, you'd call it 1.

We're just about ready to start. You'll be seeing three sets of shapes. The first set is for practice and consists of squares. The next two sets are test items and use circles. Remember, this is not an intelligence test or a "trick" test. Even though there are no wrong answers, we want you to pay careful attention to what you see and hear. Remember, your job is to recall the number you gave "S" and to assign a number to "C" that represents the size of "C" compared to the size of "S".

If you want to reread these instructions or ask the experimenter a question, press the button marked "STOP".

When you are ready to begin, press the button marked "PLAY" and go to the next page.

Once you start, do not press the "STOP" button until you are told to do so.

RESPONSE SHEET

Subject No.________ Date_______ Session_____ Trial_____

TRIAL 1		TRIAL 2		TRIAL 3	
S		S		S	
1		1		1	
2		2		2	
3		3		3	
4		4		4	
5		5		5	
6		6		6	
7		7		7	

APPENDIX E

INFORMED CONSENT RELEASE FORM

1. I, ______________________, freely and voluntarily consent to serve as a subject in a scientific study of pattern perception conducted by Dr. Michael R. Chial, Mr. Thomas H. Simpson and other student assistants.

2. I understand that the purpose of this study is to determine the reliability and validity of a particular method of measurement of pattern perception which may be of future clinical usefulness.

3. I understand that I will not be exposed to any experimental conditions which constitute a threat to my hearing, nor to my physical or psychological well-being.

4. I understand that data gathered from me for this experiment are confidential, that no information uniquely identified with me will be made available to other persons or agencies, and that any publication of the results of this study will maintain anonymity.

5. I engage in this study freely, without payment to me or from me, and without implication of personal benefit. I understand that I may cease participation in the study at any time.

6. I have had the opportunity to ask questions about the nature and purpose of the study, and I have been provided with a copy of this written informed consent form. I understand that upon completion of the study, and at my request, I can obtain additional explanation about the study.

Date: ____________________ Signed: ____________________

PRO. NO. ____________________ SEQ. NO. ____________________

GRP. NO. ____________________

APPENDIX F

RUN PROTOCOL

Project name: ____________________

Experimenter: ____________________

<u>Subject Identification</u>

Name: ________________________ Number: _________

Release form signed? yes ___ no ___

<u>Audiologic Screening Results</u>

History clear? yes ___ no ___

Criteria met? yes ___ no ___

Right ear: yes ___ no ___

Left ear: yes ___ no ___

<u>Pattern Discrimination Screening</u>

Raw Score _____ Criteria met? yes ___ no ___

Continue? yes ___ no ___

<u>Visual Screening</u>

Training and screening completed? yes ___ no ___

Criteria met? yes ___ no ___

Continue? yes ___ no ___

<u>Experimental Session I</u>

Date: _____ Time: _____

Criterion calibration voltage? yes ___ no ___

Presentation level criteria met? yes ___ no ___

REME training completed? yes ___ no ___

Experimental condition order

Tape for S ________

1st _____ 2nd _____ 3rd _____ 4th _____

CONTINUE? yes ___ no ___

<u>Experimental Session II</u>

Date: _____ Time: _____

Criterion calibration voltage? yes ___ no ___

Presentation level criteria met? yes ___ no ___

REME training completed? yes ___ no ___

Experimental condition order

Tape for S ________

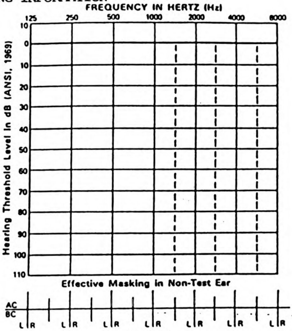
1st _____ 2nd _____ 3rd _____ 4th _____

CONTINUE? YES ___ NO ___

APPENDIX G

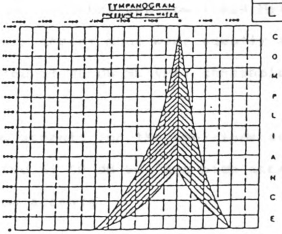
AUDIOMETRIC SCREENING INFORMATION

HISTORY:
- otologic surgery?
- familial loss?
- recent URI?
- vertigo?
- tinnitus?
- noise exposure?
- pharmacologic agents?



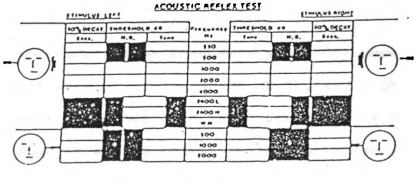
LEGEND

EAR	AIR	MASK	BONE	MASK	No. Resp.
R	O	Δ	<	[	
L	X	□	>	]	



SPEECH AUDIOMETRY

	SRT	PTA	DISCRIMINATION					UCL
			%	HTL	Mask	S/N	List	
R								
L								
SF								
AID								



APPENDIX H

FREQUENCY RESPONSE MEASUREMENTS USED IN EARPHONE SELECTION AND SYSTEM CALIBRATION

Maintaining equal-loudness for sequence elements as a function of frequency was critical to this study. The following criteria were adopted:

1. High (3001 Hz) and low (1024 Hz) accents for the frequency accent mode were equally loud, and they were presented at 40 dB SL (re: threshold at 1000 Hz).

2. Low accents for the amplitude accent mode were presented at 40 dB SL, and high accents were 20 dB greater than low accents.

3. High (100 msec) and low (50 msec) duration accents were presented at 40 dB SL, and were equally loud.

4. For the combination frequency-amplitude mode, low (1024 Hz) accents were presented at 40 dB SL, and high (3001 Hz) accents were presented at a level perceived as being equally loud to a high accent in the amplitude accent mode

(i.e., equally loud to a 1000 Hz tone presented at 60 dB SL).

5. Equal-loudness was maintained between right and left earphones for diotic stimulus presentation.

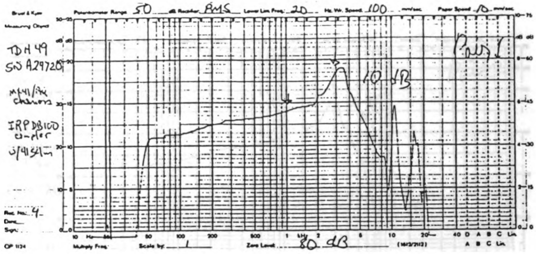
Maintaining criterion presentation levels was accomplished by matching subject earphones and generating stimulus master tapes separately for each accent mode, with high and low levels of accent on discrete tracks of magnetic tape.

Earphone Selection Procedures

Frequency response curves were generated for several earphones. Four phones were matched (re: output differences between 1 and 3 kHz). Figures H-1 and H-2 depict these differences for right and left phones of the two pair selected for the REME experiment.

The average difference between 1 and 3 kHz was computed across the four phones to represent an "average" transducer effect. Also, equal loudness contours (Robinson and Dadson, 1956) were consulted to determine the effect of presentation level on the relative loudness of 1 and 3 kHz tones.

The presentation level effect (in dB) was combined with the average transducer effect to determine target



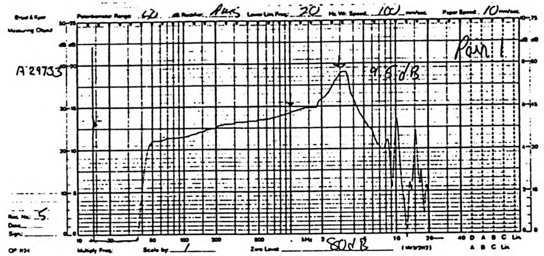
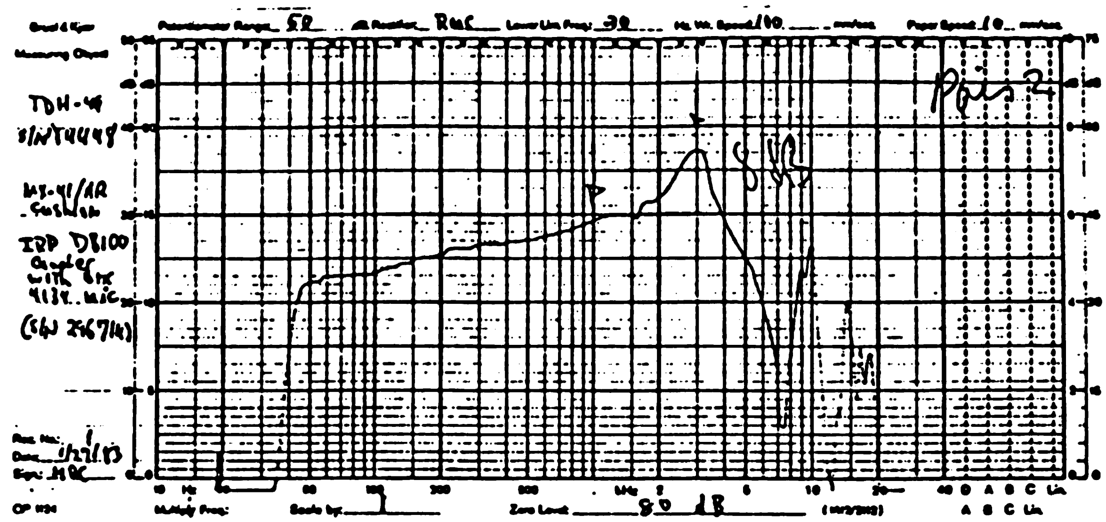


Figure H-1. Frequency response curves for right and left earphones selected for pair 1 of the REME experiment. Differences in sensitivity at 1 and 3 kHz were accounted for in determining criterion presentation levels for REME stimuli.



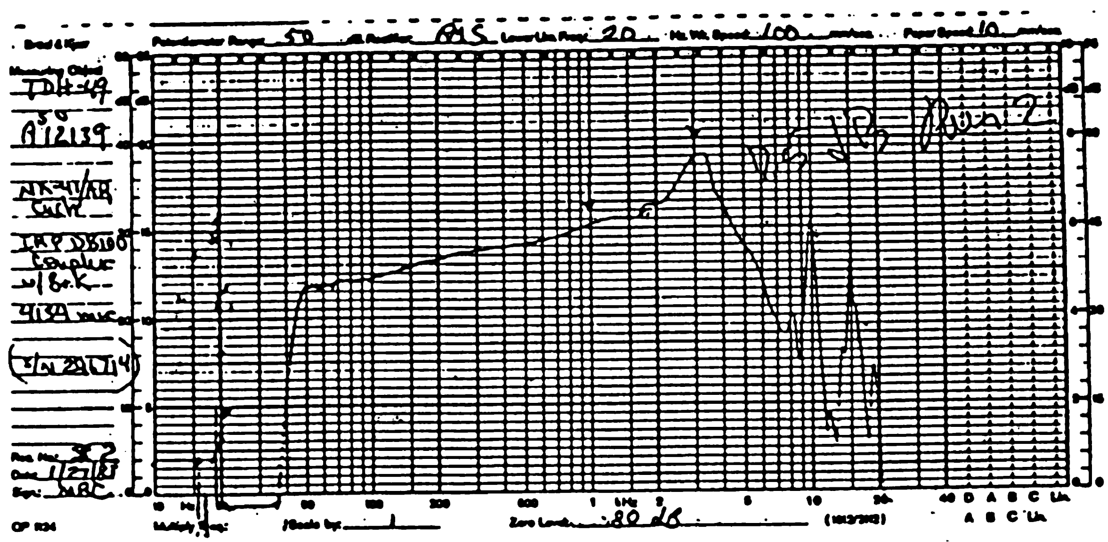


Figure H-2. Frequency response curves for right and left ear-phones of pair 2 of the REME experiment. Differences in sensitivity at 1 and 3 kHz were accounted for in determining criterion presentation levels for REME stimuli.

peak-to-peak voltages for sequence elements for the submaster recordings. These target voltages were obtained during the generation of submaster recordings from the master tapes, where high and low levels of accent had previously been recorded at equal peak-to-peak levels on tracks 1 and 3, respectively. Calibration tones corresponding in peak-to-peak voltage to each accent level were also on each master tape on the appropriate track. Target voltages were obtained during the dubbing process (refer to Figure 10, Chapter II) and verified with a dual trace, storage oscilloscope. After level verification, high and low levels of accent were mixed and re-recorded on the same track of magnetic tape to produce a submaster recording for each accent mode. Table H-1 lists target voltages for high and low levels of accent in each of the four accent modes. Voltages were obtained relative to high levels of accent in the amplitude accent mode, which corresponded to zero V U on the stimulus presentation apparatus (Figure 11, Chapter II). Thus all criterion stimulus levels were "locked" to the 800 mv peak-to-peak level of a calibration tone (1000 Hz) at zero VU.

System Calibration Procedures

Figure H-3 depicts a block diagram of system calibration apparatus. A sine-random generator (B & K Type 1024) was substituted for the reel-to-reel tape recorder

Table H-1. Target voltages (mv) for high and low accents in each accent mode necessary to achieve criterion presentation levels (in parenthesis). Voltages were obtained at zero VU for high levels of amplitude accent.

RELATIVE ACCENT MAGNITUDE	ACCENT MODE Freq	Amp	Dura	Comb
High	36 (41.75dB*)	800** (60dB)	80 (40dB)	360 (61.75dB)
Low	80 (40dB)	80 (40dB)	80 (40dB)	80 (40dB)

* dB SL re: each subject's threshold at 1000 Hz.

** Target voltage for high level, amplitude accents corresponded to voltage of calibration tones on each final run tape at zero VU.

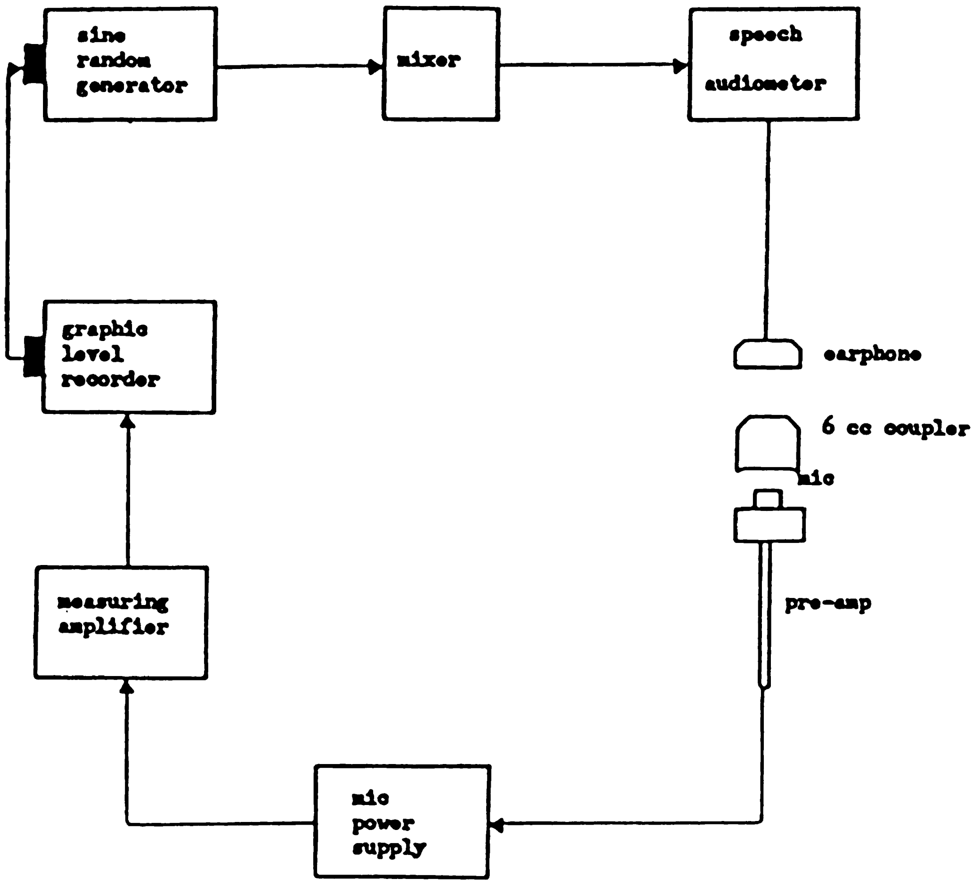


Figure H-3. Block diagram for system calibration apparatus.

used for stimulus presentation. Calibration signals were passed through the mixer (Teac, Model 2) and the speech audiometer (Grason Stadler GS 162) to each experimental earphone. Earphones were placed on an ANSI standard, 6 cc acoustic coupler (NBS 9A), which housed a laboratory standard pressure microphone (B & K Type 4144, serial number 406548). Signals received by the microphone were routed to a preamplifier (UA 0196), power supply (B & K Type 2804), and measuring amplifier (B & K Type 2607). Ultimately, system frequency response characteristics were plotted on a graphic level recorder (B & K Type 2305), which communicated to the sine-random generator by way of a mechanical linkage.

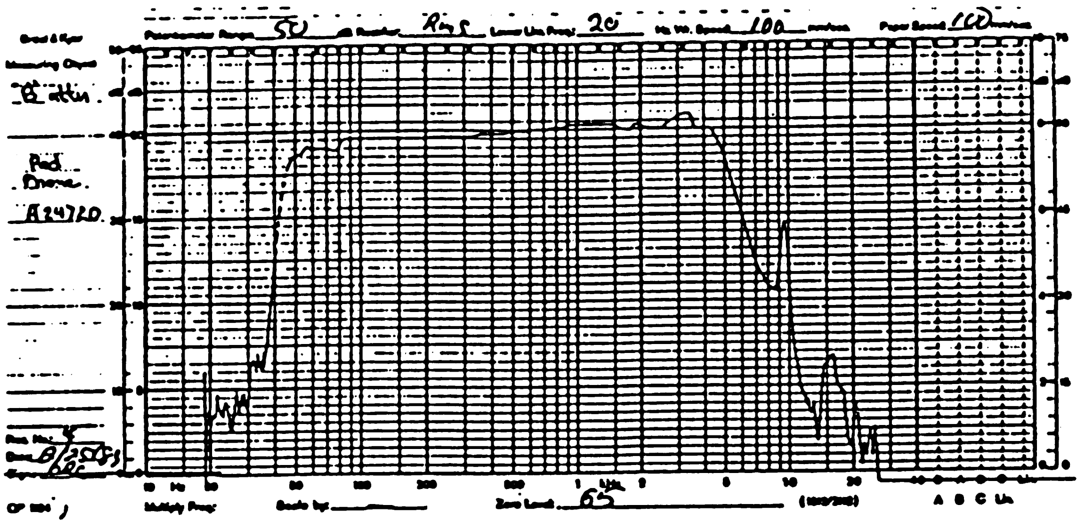
Earphone pairs 1 and 2 were examined for right and left channels of the speech audiometer, respectively. Absolute sensitivity was determined by adjusting the calibrated attenuator corresponding to the channel (right or left) of interest to 90 dB HTL, with the attenuator for the nontest channel remaining at zero. Voltages measured at the earphone terminals for right and left channels were 86 and 91 mv, respectively, for a 1000 Hz tone of unknown but constant level delivered at zero VU to the system. These voltages became reference voltages for running calibration, which took place before each REME testing session.

Amplitude linearity was examined by decrementing the calibrated attenuator of right and left channels of the speech audiometer (nontest attenuator at zero) from 90 to 60 dB HTL in 10 dB steps. The test signal was 1000 Hz, and all system VU meters were adjusted to zero. Table H-2 summarizes results of this calibration procedure. Nominal attenuator settings corresponding to coupler outputs were used to determine presentation levels for the REME experiment. The nominal setting of 0 dB HTL on a calibrated speech audiometer, for a 1000 Hz stimulus, typically outputs 19 dB in a standard acoustic coupler (ANSI S3.6-1969). Output SPLs measured during the amplitude linearity check were approximately 3 dB less, which was attributed to loading the system with two sets of earphones.

System frequency response characteristics were obtained for each earphone in its appropriate test channel. Test attenuators were adjusted to 90 dB HTL, while nontest attenuators remained at zero. The calibration stimulus for frequency response measurements was a sine wave swept from 20 Hz to 20 kHz. Figures H-4 and H-5 summarize results of system frequency response calibration for each test earphone.

Table H-2. Summary of amplitude linearity calibration of stimulus presentation apparatus.

Channel				
Right Earphone			Left Earphone	
Right	Left		Right	Left
coupler dB SPL		Nominal dB HTL	coupler dB SPL	
107.0	107.0	90.0	106.0	106.5
97.0	97.0	80.0	96.5	96.5
87.5	88.0	70.0	87.0	87.0
78.5	CNT	60.0	DNT	DNT



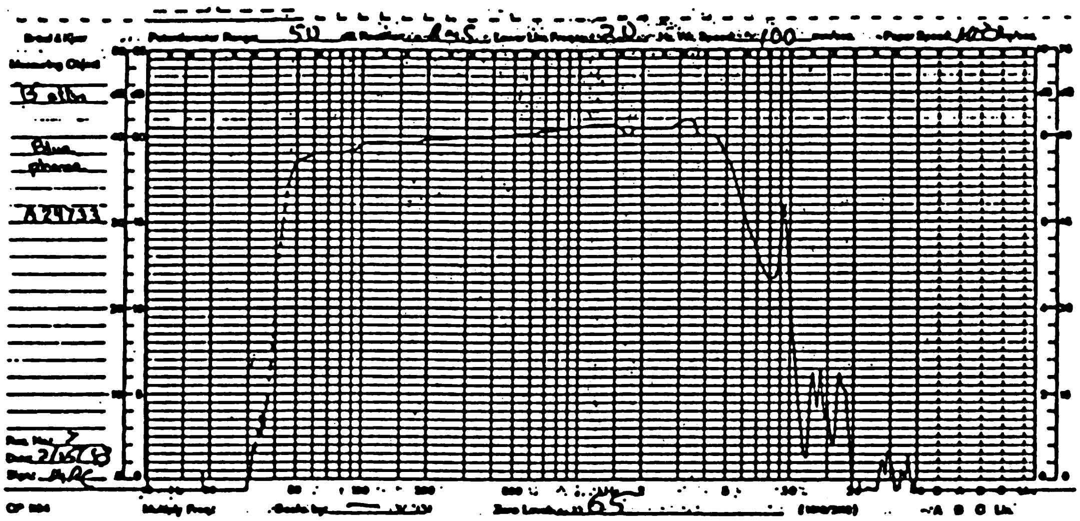
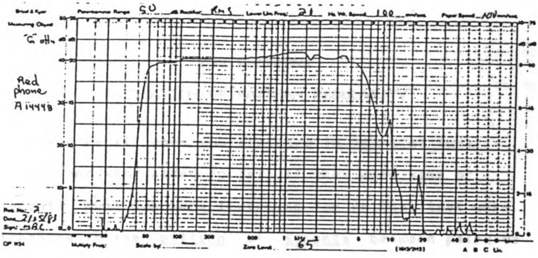


Figure H-4. Frequency response characteristics of stimulus presentation apparatus in the right and left earphones of pair 1. The attenuator setting on the appropriate channel of the speech audiometer was adjusted to 90 dB HTL. The nontest attenuator was adjusted to 0 dB HTL.



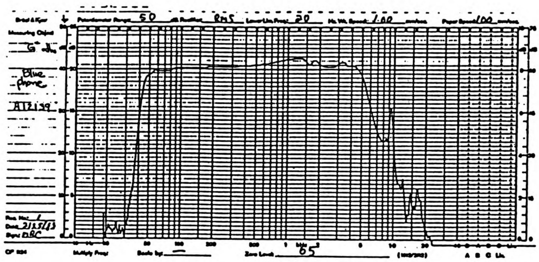


Figure H-5. Frequency response characteristics of stimulus presentation apparatus in the right and left earphones of pair 2. The attenuator setting on the appropriate channel of the speech audiometer was adjusted to 90 dB HTL. The nontest attenuator was adjusted to 0 dB HTL.

APPENDIX I

INSTRUCTIONS

ESTIMATION OF PATTERN REGULARITY

Do you recall when you listened to pairs of tonal sequences and were asked to tell if they were same or different? What you were listening for in that task were differences in the pattern of accents between pairs of tonal sequences.

It seems that the pattern of accents in an auditory sequence has something to do with how we respond to that sequence. For example, we remember our favorite songs because a certain pattern of tonal pitches appeals to us, or we learn a new dance step by learning to move to a specific pattern of rhythmic accents.

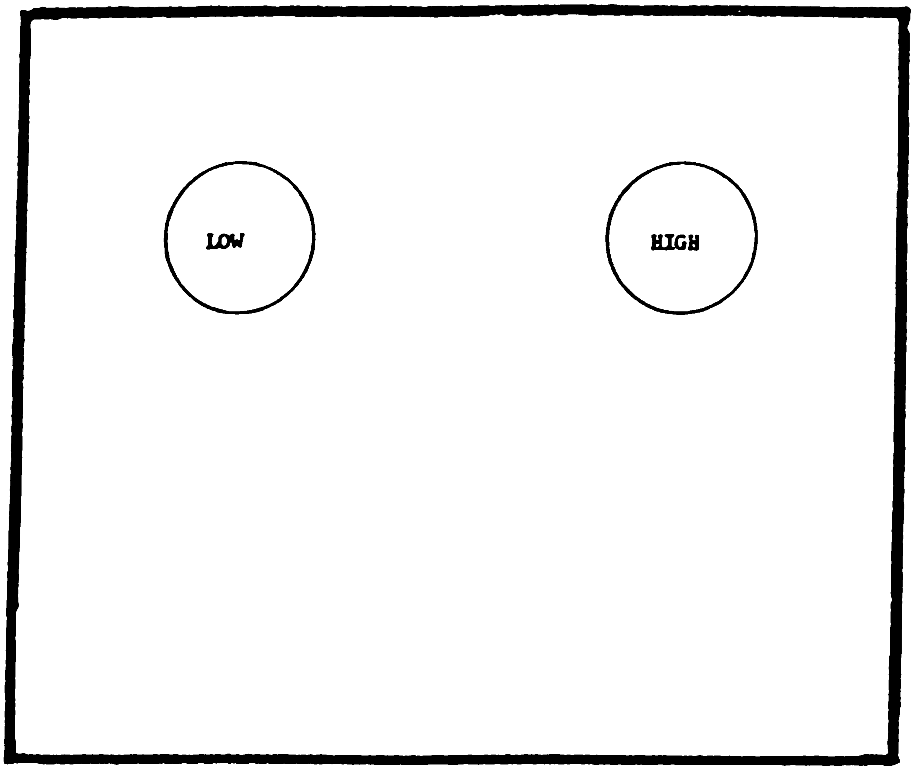
Have you ever played an electronic game called "Simon"? For those of you who haven't, the "Simon" game operates on the same principle as the children's game "Simon Says". When activated, the game produces a series of tones accented by pitch. Your job, as a player, is to repeat the series of tones by pressing the appropriate buttons. If you produce the same pattern of pitch accents that Simon played, you win. If you make a mistake, you lose. Everytime you win, however, the Simon game increases the difficulty of the pattern. If you have ever played this game, you know how difficult some of the patterns can get!

In the present experiment, we are interested in learning about what makes some auditory sequences easier to remember than others. We think that it has something to do with the arrangement or pattern of accents in the sequence. Sequences that are easy to remember seem to exhibit a regular pattern of accents, while sequences that are difficult to remember seem to exhibit an irregular pattern of accents. In other words, auditory sequences that are easy to remember seem to exhibit what we are going to call "pattern regularity".

To help you understand what we mean by "pattern regularity", we are going to simulate our own "Simon" game. Notice the extra sheet of paper in front of you (refer to Figure I-1). A "box" has been drawn on this sheet of paper. On the box are two "buttons". One is marked "low", and the other is marked "high". Have you located this sheet of paper?

You will be hearing some tonal sequences exhibiting pitch accents. Some tones in the sequences will be high-pitched, and some tones will be low-pitched. Your task will be to repeat the pattern of accents that you hear by pressing the appropriate "button" on the box before you.

For example, if you hear a sequence that sounds like this...



TRY TO REMEMBER THE <u>PATTERN</u> OF HIGH AND LOW PITCHED TONES BY PRESSING THE APPROPRIATE "BUTTONS" IN THE CORRECT ORDER.

Figure I-1. Simulator used for REME training.

> EXAMPLE SEQUENCE , consisting of two low-pitched tones (1000 Hz), a high-pitched tone (3000 Hz), and another low-pitched tone. Refer to Figure I-2 for descriptions of REME training sequences.

you would respond by first pressing the "low" button twice, then the "high" button once, and finally, the "low" button once again. Having done this you would have correctly remembered the pattern of accents in the sequence.

Do you understand this task? If so, let's continue with our example.

You will hear two tonal sequences with pitch accents. After you hear each sequence, try to "play" that sequence by pressing the appropriate buttons on the box pictured before you. Don't worry if you have trouble with this task. The patterns you will be hearing will be quite long, and they may be very difficult to remember. So just give it a try and do the best you can. Our purpose here is merely to illustrate what we mean by "pattern regularity".

First you will hear a SEQUENCE A, followed by a 10 second silent interval. After you hear the sequence, try to remember it by pressing the appropriate "buttons" in the correct order...

SEQUENCE A (refer to Figure I-2)

Now we will repeat the task for SEQUENCE B...

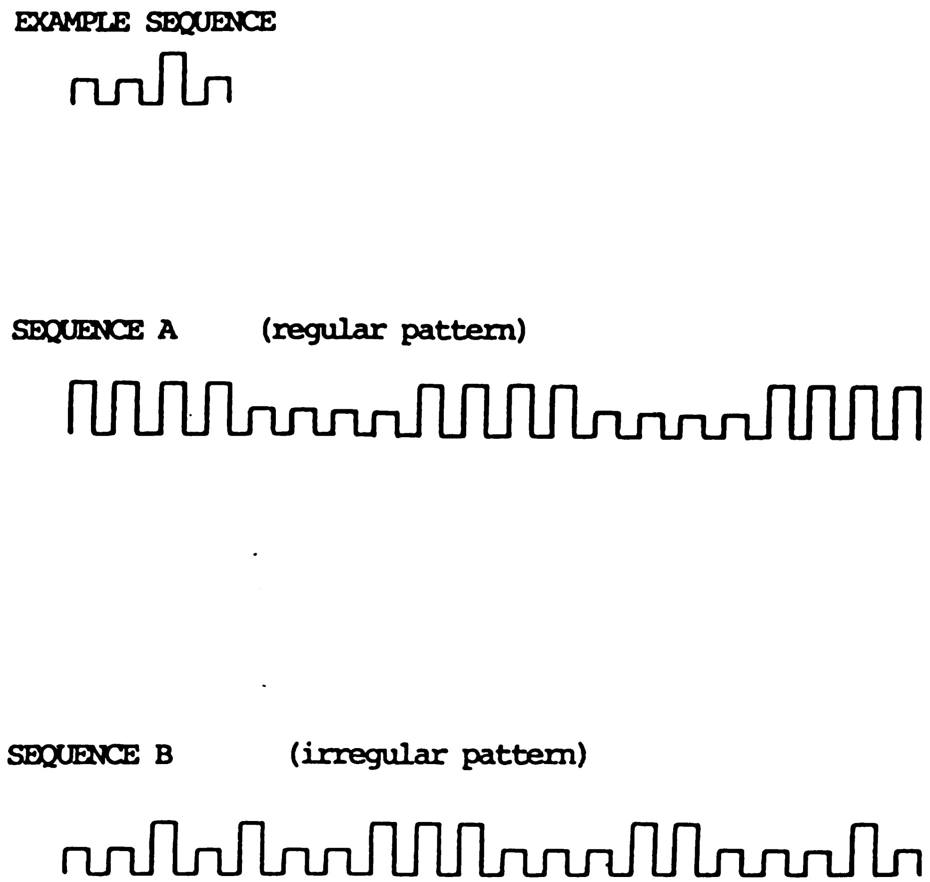


Figure I-2. Time domain depiction of REME training stimuli. Binary frequency accents were 1 and 3 kHz tones with on-off times of 90 msec.

<u>SEQUENCE B</u> (refer to Figure I-2)

Was one of the sequences easier to remember than the other? Listen to both sequences again, and decide which one is easier to remember. Is SEQUENCE A or SEQUENCE B easier to remember?

<u>SEQUENCE A</u> ... <u>SEQUENCE B</u> (refer to figure I-2)

Yes, SEQUENCE A is probably easier to remember than SEQUENCE B. We think this is because the <u>pattern</u> of accents in SEQUENCE A is more <u>regular</u> than the <u>pattern</u> of accents in SEQUENCE B. That is, SEQUENCE A exhibits a great deal of <u>pattern regularity</u>, while SEQUENCE B does not.

Do you understand what we mean by "pattern regularity"? Do you wish to have any of the above examples repeated? If not, then we will continue.

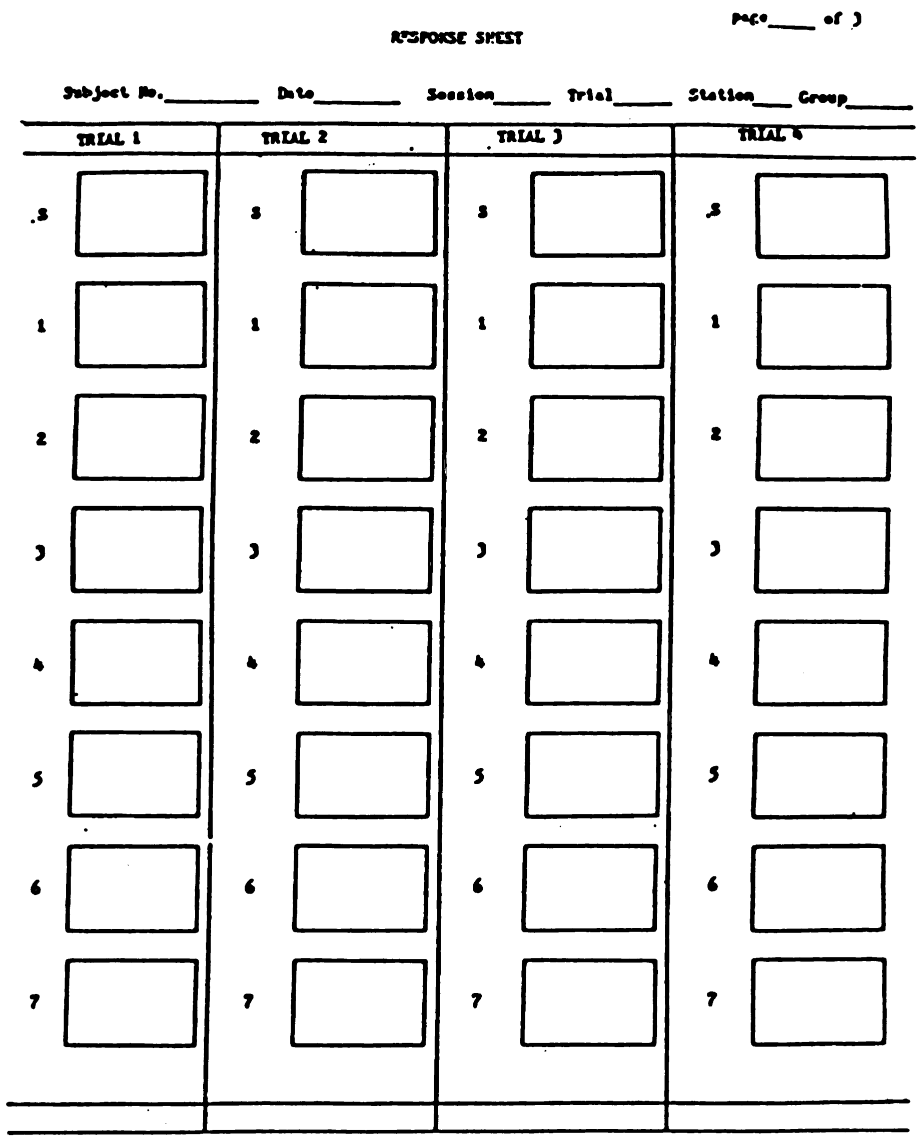
Now that you have some notion of what we mean by <u>pattern regularity</u>, we would like you to listen to some tonal sequences and evaluate or "rate" them for pattern regularity. You will do this in the same manner you rated the relative size of circles and squares. In other words, you will be assigning numbers to tonal sequences which describe how <u>regular</u> you think the <u>pattern</u> of accents are in these sequences. The higher the number you assign to a particular sequence, the more regular you think the pattern of accents is in that sequence. You will write these numbers on a response sheet similar to the one you used before.

Instead of seeing pairs of shapes, you will be hearing pairs of tonal sequences. The first sequence in each pair will be the standard sequence, and the second sequence will always be the comparison sequence. The pattern of sounds in the comparison sequence will change from time to time.

Do you recall when you listened to pairs of sequences and were asked to tell if they were the same or different? The sequences you are about to listen to now are very similar to the ones you heard before. Some comparison sequences will have a very "regular" pattern of tones; other sequences will have an "irregular" pattern of tones. The pattern of tones in the standard sequence will always be the same.

First, you will hear the word "standard" followed by a single tonal sequence. The number you pick should represent your impression of the overall regularity of the pattern of tones in that sequence. You may pick any number you want. Write the number you pick in the block labeled "S" on your response sheet (refer to Figure I-3).

Next, you will hear pairs of tonal sequences. Each pair or item will be preceded by a spoken item number which corresponds to a block number on your response sheet. Your job will be to refer to the number you initially gave to



Page____ of 3

RESPONSE SHEET

Subject No._______ Date_______ Session_____ Trial_____ Station___ Group_____

TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4
S	S	S	S
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7

Figure I-3. Response form for the REME experiment.

the standard and then pick a number for the comparison. The number for the comparison sequence should represent the overall regularity of the pattern of tones in the sequence relative to the pattern regularity of the standard. In other words, the number you pick for the comparison should relate to the number for the standard in the same way that the pattern regularity of the comparison relates to the pattern regularity of the standard.

Let's take an example. Say you hear the word "standard" followed by a tonal sequence. You assign that sequence some number, say 16. Then you hear an item number followed by the same standard sequence and then a comparison sequence in that order. If the pattern of tones in the comparison sequence sounds twice as regular as the pattern of tones in the standard, the comparison gets the number 32. If the pattern of tones in the comparison sounds one-fourth as regular , you'd call it a 4.

After hearing a trial of seven pairs of sequences, you will hear a new trial beginning with a new standard sequence. Just follow the same procedure used before. We're almost ready to start. Remember, this is not an intelligence test or "trick" test. Even though there are no wrong answers, we want you to pay careful attention to what you hear. Remember, your job is to recall the number you gave the stndard sequence and to assign a number to the comparison sequence that represents the _pattern regularity_ of the comparison relative to the _pattern regularity_ of the standard sequence.

Look at your response sheets (Figure I-3). After each item you will have about 5 seconds to write a number in the appropriate box. Start with the blocks for Trial 1 in the left-hand column and work from top to bottom as you did before. You should have three response sheets. The first sheet is for practice items. The last two sheets are for test items.

If you want to reread these instructions or ask a question, inform the experimenter. Also, inform the experimenter when you are ready to begin the practice test.

REFERENCES

REFERENCES

AMERICAN NATIONAL STANDARDS INSTITUTE, Criteria for Permissible Ambient Noise during Audiometric Testing. ANSI S3.1-1977. New York: American National Standards Institute (1977).

AMERICAN NATIONAL STANDARDS INSTITUTE, Methods for the Calculation of the Articulation Index. ANSI S3.5-1969. New York: American National Standards Institute (1973).

AMERICAN NATIONAL STANDARDS INSTITUTE, Specifications for Audiometers. ANSI S3.6-1969. New York: American National Standards Institute (1970).

AMERICAN NATIONAL STANDARDS INSTITUTE, Methods for Coupler Calibration of Earphones. ANSI S3.7-1973. New York: American National Standards Institute (1973).

AMERICAN NATIONAL STANDARDS INSTITUTE, Methods for Manual Pure-Tone Threshold Audiometry. ANSI S3.21-1978. New York: American National Standards Institute (1978).

AMERICAN NATIONAL STANDARDS INSTITUTE, American National Standard for an Occluded Ear Simulator. ANSI S3.25-1979. New York: American National Standards Institute (1980).

ANDERSON, H., BARR, B., and WEDENBERG, E. Early diagnosis of eighth-nerve tumors by acoustic reflex tests. ACTA Otolaryngologica Supplement , 263 , 232-237 (1970).

BERLIN, C. I., CHASE, R. A., DILL, A. and HAGEPANOS, T. Auditory findings in patients with temporal lobectomies. ASHA , 7 , 386 (1965).

BROADBENT, D. E. and LADEFOGED, P. Auditory perception of temporal order. Journal of the Acoustical Society of America , 31 , 1539 (1959).

BRUNING, J. L., and KINTZ, B. L. Computational Handbook of Statistics. Glenview, Illinois. Scott, Foresman and Company (1968).

CAMPBELL, D. T., and STANLEY, J. C. Experimental and Quasi-experimental Designs for Research. Chicago: Rand McNally (1963).

CHIH-AN, L. and CHISTOVICH, L. A. Frequency-difference limens as a function of tonal duration. Soviet Physical Acoustics , 6 , 75-80 (1960).

CUTTINGS, J. A. Perception of Speech and Nonspeech With and Without Transitions , Status Report 33 , Haskins Laboratories, New Haven, Conn., 39-46 (1973).

DEUTSCH, D. Musical illusions. Scientific American , 233 , 92-104 (1975).

DIVENYI, P. L. and HIRSH, I. J. The effect of blanking on the identification of temporal order in three-tone sequences. Perception and Psychophysics , 17 , 246-252 (1975).

FLETCHER, H. A method of calculating hearing loss for speech from an audiogram. Journal of the Acoustical Society of America , 22 , 1-5 (1950).

GARNER, W. R. The processing of Information and Structure. Hillsdale, N. J.: Lawrence Erlbaum Associates (1974).

GARNER, W. R. and GOTTWALD, R. L. The perception and learning of temporal patterns. The Quarterly Journal of Experimental Psychology , 20 , 97-109 (1968).

GJAEVENES, K. and RIMSTAD, E. R. The influence of rise time on loudness. Journal of the Acoustical Society of America , 51 , 1233-1239 (1972).

GLASS, G. V., and STANLEY, J. C. Statistical Methods in Education and Psychology. Englewood Cliffs, New Jersey: Prentice-Hall, Inc. (1970).

HAYS, W. Statistics for Psychologists. New York: Holt Rinehart and Winston (1963).

HIRSH I.J. Auditory perception of temporal order. Journal of the Acoustical Society of America , 31 , 759-767 (1959).

HIRSH I. J. Information processing in input channels for speech and language: the significance of the serial order of stimuli. In C. H. MILLIKAN and F. L. DARLEY (eds.), Brain Mechanisms Underlying Speech and Language. New York: Grune & Stratton (1967).

HIRSH, I. J. and SHERRICK, C. E. Perceived order in different sense modalities. Journal of Experimental Psychology , 62 , 423-432 (1961).

JERGER, J. Clinical experience with impedance audiometry. Archives of Otolarynogology , 92 , 311-324 (1970).

JERGER, J. and JERGER, S. Critical off-time in VIIIth nerve disorders. Journal of Speech and Hearing Research , 9 , 573-583 (1966).

JESTEADT, W., WIER, C. G. and GREEN, D. M. Intensity discrimination as a function of frequency and sensation level. Journal of the Acoustical Society of America , 61 , 169-177 (1977).

JONES, M. R. Auditory patterns: studies in the perception of structure. Unpublished manuscript, The Ohio State University (1978).

KIMURA, D. Left-right differences in the perception of melodies. Quarterly Journal of Experimental Psychology , 16 , 355-358 (1964).

LASHLEY, K. S. The problem of serial order in behavior. In L. A. JEFFRESS (ed.), Cerebral Mechanisms in Behavior. New York: John Wiley and Sons (1951).

LASSMAN, F. A noise-interaction theory of intelligibility and its relation to hearing-aid amplification. Auditory Rehabilitation in Adults , Seminar Proceeding, Cleveland, June 8-12 (1964).

LAWSON G. D. Quality magnitude estimation functions for degraded speech by listeners with normal hearing and listeners with sensorineural hearing loss. Unpublished doctoral dissertation, Michigan State University, East Lansing, Michigan (1980).

LEVY-AGRESTI, J. and SPERRY, R. W. Differential perceptual capacities in major and minor hemispheres. Procedures of the National Academy of Science , 61 , 1151 (1968).

LIBERMAN, A., COOPER, F. S., SHANKWEILER, D. P. and STUDDERT-KENNEDY, M. Perception of the speech code. Psychological Review , 74 , 431-461 (1967).

LIBERMAN A., DELATTRE, P. C., GERSTMAN, L. J. and COOPER, F. F. Tempo of frequency change as a cue for distinguishing classes of speech sounds. Journal of Experimental Psychology , 52 , 127-137 (1956).

LINTON M. and GALLO P. S. The Pratical Statistician: Simplified Handbook of Statistics. Montery, California: Brooks/Cole (1975).

MARTIN J. G. Rhythmic (hierarchical) versus serial structure in speech and other behavior. Psychological Review , 79 , 487-509 (1972).

MEHRENS, W. A. and EBEL, R. L. Principles of Educational and Psychological Measurement: A Book of Selected Readings. Chicago. Rand McNally & Company (1967).

METZ O. Threshold of reflex contractions of muscles of the middle ear and recruitment of loudness. Archives of Otolaryngology , 55 , 536 (1952).

MILNER, B. Laterality effects in audition. In V. B. Mountcastle (ed.), Interhemispheric Relations and Cerebral Dominance. Baltimore: Johns Hopkins Press (1962).

NATIONAL ASSOCIATION OF BROADCASTERS, NAB Standard, Magnetic Tape Recording and Reproducing (Reel-to Reel). Washington, D. C.: National Association of Broadcasters (1965).

NEISSER, U. and HIRST, W. Effect of practice on the identification of auditory sequences. Perception and Psychophysics , 15 , 391-398 (1974).

PATTERSON, J. H. and GREEN, D. M. Discrimination of transient signals having identical energy spectra. Journal of the Acoustical Society of America , 48 , 894-905 (1970).

PETERS, R. Perceived order of tone impulses. Journal of the Acoustical Society of America , 36 , 1042 (1964).

PETERS, R. Perceived order of tone impulses. Journal of the Acoustical Society of America , 42 , 1216 (1967).

PETERS, R. The measurement of temporal factors in auditory perception. In S. SINGH (ed.), Measurement Procedures in Speech, Hearing, and Language , Baltimore: University Park Press (1975).

PINHEIRO, M. L. Tests of central auditory function in children with learning disabilities. In R. W. Keith (ed.), Central Auditory Dysfunction. New York: Grune & Stratton (1977).

PINHEIRO, M. L. The pitch pattern sequence test. Available from Auditec of St. Louis, St. Louis, MO 63119 (1979).

PTACEK, P. H. and PINHEIRO, M. L. pattern reversal in auditory perception. Journal of the Acoustical Society of America , 49 , 493-498 (1971).

RAZ, I. and BRANDT, J. F. Categorical perception of nonspeech stimuli by musicians and nonmusicians. Paper presented at convention of the Acoustical Society of America, Miami Beach (1977).

ROBINSON, D. W. and DADSON, R. S. A re-determination of the equal-loudness relations for pure tones. British Journal of Applied Physics , 7 , 166-181 (1956).

ROEDERER, J. G. Introduction to the Physics and Psychophysics of Music. New York: Springer-Verlag New York Inc. (1975).

ROYER, F. L. and GARNER, W. R. Response uncertainty and and perceptual difficulty of auditory temporal patterns. Perception and Psychophysics , 1 , 41-47 (1966).

ROYER, F. L. and GARNER, W. R. Perceptual organization of nine-element auditory temporal patterns. Perception and Psychophysics , 7 , 115-120 (1970).

SCHARF, B. Critical Band. In J. V. TOBIAS (ed.), Foundations of Modern Auditory Theory, Volume 1 , New York: Academic Press (1970).

SCHARF, B. Loudness. In E. C. CARTERETTE and M. P. FRIEDMAN (eds.), Handbook of Perception, Volume IV: Hearing, New York: Academic Press (1978).

SCOTT, H. L. Time-order errors in the discrimination of short tonal durations. Journal of Experimental Psychology , 18 , 741-766 (1935).

SHANNON, C. E. and WEAVER, W. The Mathematical Theory of Communication. Urbana, Illinois: University of Illinois Press (1949, 1963).

SHOWER, E. G. and BIDDULPH, R. Differential pitch sensitivity of the ear. Journal of the Accoustical Society of America , 3 , 275-287 (1931).

STEVENS, S. S. Psychophysics: Introduction to Its Perceptual, Neural, and Social Prospects. New York: John Wiley & Sons (1975).

STURGES, P. T. and MARTIN, J. G. Rhythmic structure in auditory temporal pattern perception and immediate memory. Journal of Experimental Psychology , 102 , 377-383 (1974).

THOMAS, I. B. and FITZGIBBONS, P. J. Temporal order and perceptual classes. Journal of the Acoustical Society of America , 50 , 86-97 (1971).

THOMAS, I. B., HILL, P. B., CARROLL, F. S., and GARCIA, B. Temporal order in the perception of vowels. Journal of the Acoustical Society of America , 48 , 1010-1013 (1970).

WARME, P. K. CURVE FITTER : Interactive Microware, Inc., P. O. Box 771, State College PA (1980).

WARREN, R. M., OBUSEK, C. J., FARMER, R. M. and WARREN, R. P. Auditory sequence: confusion of patterns other than speech and music. Science , 164 , 586-587 (1969).

WATSON, C. S., WROTON, H. W., KELLY, W. J. and BENBASST, C. A. Factors in the discrimination of tonal patterns: component frequency, temporal position, and silent intervals. Journal of the Acoustical Society of America , 57 , 1175-1185 (1975).

WINER, B. J. Statistical Principles in Experimental Design. New York: McGraw-Hill Book Company (1971).

WOOD, R. W. The perceptual processing of rhythmic auditory pattern temporal order. Unpublished doctoral dissertation, Michigan State University, East Lansing, Michigan (1980).

WOOD, R. W. Analysis of IRR scale in terms of eight-element patterns. Personal communication (1982).