PERCEPTUAL AND RESPONSE ORGANIZATION

OF RHYTHMIC PATTERNS

by

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39

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ABSTRACT

Four studies were undertaken to investigate the advance
planning and perception of simple rhythmic patterns.
Subjects listened to patterns of identical, computer-
generated tones and then reproduced them as accurately as
possible by tapping on a single response key. Section One
focussed on the advance planning of isochronous rhythmic
patterns in which subjects performed the additional task of
initiating pattern reproduction as quickly as possible. In
Experiment 1, subjects listened to patterns of one to six
tones with interstimulus intervals (ISIs) of 300 ms. The
reproduction phase involved no stimulus uncertainty.
Reaction time (RT) was found to increase linearly with number
of response events. Advance planning thus occurs for
patterns reproduced as slow as 300 ms per response event.
Stimulus uncertainty is not a necessary condition for RT to
increase with response complexity. In Experiment 2, subjects
reproduced patterns of one to eight tones with ISIs of 200,
400, 600, and 800 ms. A linear RT trend was found only at
the 200-ms rate. Patterns slower than this rate did not
display "response coherence". Patterns at the 200-ms and
400-ms rates showed evidence of grouping through the
accenting of first and last intervals. These patterns
displayed "perceptual coherence". Section Two focussed on
the perceptual organization of patterns in which pattern
structures could suggest the grouping of events as two equal-
duration intervals. In Experiment 3, subjects reproduced two

series of patterns, one series in which the suggested grouping-intervals were initiated by external-world events, and one in which they were not. Pattern structures in the latter series were not suggestive enough to induce grouping of events as two equal-duration intervals. Patterns were instead grouped as two intervals of unequal duration showing that the relative temporal positions of external-world events dominates in simple perceptual grouping. Experiment 4 investigated the upper temporal limit of perceptual grouping-intervals and the influence of number of group constituents. Results showed that perceptual grouping of events that span more than 1800 ms is seldom accomplished and that grouping occurs when intervals contain up to seven constituents.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GENERAL INTRODUCTION

Rhythm is a fundamental aspect of existence. It is inherent in the activity of living organisms and non-living matter. Rhythm is apparent, at a macro level, in the revolutions of planetary bodies, and at a micro level, in the vibratory motions of atoms and molecules. Biological systems are replete with rhythmic activity and patterns of behavior. These may be as common as the migratory patterns of animals or as unique as the brief but regular appearance of the 17-year cicada.

Some rhythms are fundamental to human existence. Circadian rhythms, for example, are manifest in alternate periods of rest and activity; cardiac and respiratory rhythms reflect the energetic demands of activity. And electrical activity in the brain is characterized by rhythmic patterns of various frequencies.

We can intentionally create rhythms in such forms as poetry, music and dance. We can create symbolic representations of rhythmic patterns, we can produce rhythms through a variety of modes and we perceptually organize rhythmic patterns when exposed to them.

How is it that we perceptually organize rhythmic patterns? Does perceptual organization reveal itself in the reproduction of such patterns? What processes underlie the preparation of rhythmic pattern production? The present work is concerned with these general questions. The work is comprised of two sections. The focus of the first section is

on the advance planning and response timing of isochronous rhythmic patterns that vary in tempo (rate) and complexity (number of events). The second section is concerned with the perceptual organization of rhythmic patterns that vary in duration, tempo and event frequency. The basic method employed is to have subjects reproduce patterns of identical, computer-generated auditory tones by tapping with a single finger on a response key. Each section of studies is preceded by an introduction and development of the underlying theoretical issues.

The remainder of this General Introduction is devoted to the explanation of central concepts, and outlining the purpose and limitations of the reported studies.

What is Rhythm? Perceived Rhythm?

It would, at first thought, appear rather self-evident what rhythm is. Rhythm entails periodicity. A period implies contrast between/among states/events within a single periodic cycle. The simplest rhythmic pattern is thus the alternation of stress and release (Cooper, 1973). Yet, if matters were so simple, Ruckmich (1913, 1915, 1918) could hardly have compiled a general bibliography of rhythm containing over 500 entries!

What about perceived rhythm? Rhythm can be perceived before a periodic cycle is completed. We begin to perceptually organize a stimulus pattern as soon as it is initiated (Garner, 1974). Perceived rhythm suggests

continuity, and connectivity among events. Thackray (1969) reported evidence that a fundamental factor in rhythm perception is the ability to perceive and memorize a rhythmic structure as a whole. In a classic early work on the psychology of music, Seashore (1938) wrote, "There are two fundamental factors in the perception of rhythm: an instinctive tendency to group impressions in hearing and a capacity for doing this with precision in time and stress." (Seashore, 1938, p.138). Grouping of events (in time) thus seems crucial to the notion of perceived rhythm. The relative timing of events, however, while essential to most Western music, is not essential to "free" rhythm which appears in some Indian songs and ancient European folk music (Apel, 1972). In free rhythm, measure is by groups of notes, but the relative lengths of the notes themselves are not measured.

Grouping is seldom discussed without reference to "accenting" (Berry, 1976; Lerdahl & Jackendoff, 1983). Accenting is that process by which an event is made distinct from, and more salient than, surrounding events. It results in contrast among events in a pattern. For auditory patterns, an event may be produced and/or perceived as accented in at least three ways. First, an event may be louder than surrounding events (dynamic accent). It may be higher in pitch than other events (tonic accent). Thirdly, it may be longer in duration than surrounding events (agogic accent) (Cooper, 1973). In their landmark book, "The

Rhythmic Structure of Music", Cooper and Meyer (1960) suggested that rhythm is the way in which one or more unaccented beats are grouped in time in relation to an accented beat. They noted, however, that accenting alone does not determine rhythmic grouping.

As is characteristic of perception in general, the subjective experience of rhythm results from an interaction of stimulus structure and internal structure (e.g. memory, expectations). We might think of objective rhythm as rhythmic structure inherent in the stimulus pattern and subjective rhythm as the rhythmic structure imposed by the perceiver.

The perception of rhythm, if similar to the perception of time, should not be treated too much like a "sensory" process. Ornstein (1969) has provided evidence that the perception of time depends greatly on the quantitative and qualitative aspects of the information that are (or are not) present in the defined interval. In fact, even in the late-19th century it was thought that the experience of time depends on stimulus intensities, stimulus frequencies, differences among stimuli, attention paid to the stimuli and stimuli-generated associations and expectations (Guyau, 1890, cited in Ornstein, 1969). If this is the case, and in consideration of Frankenhaeuser's (1959) finding that temporal experience is also influenced by emotions and attitudes, then it is not surprising that the experience of

perceiving rhythm can be so rich and diverse ... and so

personal.

Rhythm, Tempo and Meter

In the terminology of music, rhythm is distinguished

from tempo and meter. Interestingly, there is not universal

agreement on the meaning of the terms or the relation among

them. "Tempo" refers to the rate of a composition (Apel,

1972). More specifically, it is the rate of the underlying

"beat" of a pattern. Many notes can be spaced closely

together in time but the underlying beat (as determined by

contextual factors) may indicate a slow tempo. Conversely,

similar factors may indicate a fast tempo when notes are not

spaced closely together. Occurrence of a beat may be

external or internal to the subject (Apel, 1972).

Some have suggested that rhythmic organization does not

depend on tempo (Cooper & Meyer, 1960). In fact, it is not

uncommon to find that current models of rhythm perception

(for example, Povel & Essens, 1985) overlook the possible

role of tempo. Yet, others have argued that this position is

in error and that the perception of rhythm is integrally tied

to the tempo of a pattern (Clarke, 1982,1985; Handel &

Oshinsky, 1981; Michon, 1974). Fraisse (1963) has suggested

that rhythm is lost when sounds are separated by around two

seconds. While this may seem unduly brief when one considers

the powerful influence of context on rhythm perception, it

does draw focus to the issue of the influence of tempo on rhythm.

"Meter" refers to a higher-order temporal unit - the grouping of beats to form a structure the very nature of which influences accenting within the unit. In music, meter is indicated by a time signature, such as "4/4", in which the second number signifies the type of note receiving a beat (i.e. a quarter note) and the first number signifies the number of such notes that are grouped in a measure. The subjective experience of metric organization and beats, however, is not necessarily determined by the symbolic representation of musical structure. Radocy and Boyle explain:

> Meter signatures specify which unit of notation receives a beat; in practice, however, the unit designated by a meter signature as receiving the beat is not always the same as the beat which is felt in response to the music ... When the tempo of the music is quick, the effect on the listener often is to make the notated measure, rather than the metrical beat, the unit of the beat. (Radocy & Boyle, 1979, pp. 70-71.)

There is little dispute that rhythmic organization is influenced by meter. Clarke (1985) presented subjects with a notated rhythmic pattern set in 10 different metrical contexts. Interresponse intervals in the production of this standard pattern were found to vary as a function of the metrical context in which it was presented. Gabrielsson, Bengtsson, and Gabrielsson (1983) reported the lengthening of notes that completed musical groups at various levels of

structure. Essens and Povel (1985) showed that patterns conceivable in a metrical framework are represented and reproduced more accurately than patterns that are not.

Finally, consider the complex interaction of rhythm, tempo and meter. Shaffer, Clarke, and Todd (1985) have studied the skilled performance of a complex rhythmic piece and concluded that the performer is allowed two degrees of freedom in producing rhythm. One is for mapping meter onto a time scale thus determining tempo, and the other is for the expressive timing of groups of events in relation to the meter.

Programs, Programming, Subprograms and Preprogramming

To understand how we plan and control the execution of rhythmic movement patterns (or, for that matter, any movement pattern) we should be familiar with relevant concepts in the field of motor control. The current notion of a "motor program" is that of a generalized, centrally-stored, abstract representation of a plan of action that, once initiated, assumes control of movement (Schmidt, 1987). It is thought to be a generalized action plan in that certain parameters must be input to the program (e.g. overall movement duration, overall force, muscle selection) to satisfy the specific requirements of the task at hand. It assumes control of movement in that it determines the original pattern of action. That pattern of action, however, can be modified following the period of one reaction time (RT) in response to

feedback or non feedback-related voluntary reprogramming of the response. In the absence of contraindicatory feedback or a voluntary change of plan, the motor program runs through its entirety.

This conception owes much to the theoretical insights of Keele (1968), who integrated findings from a number of fields in support of the programmed control of skilled motor performance. Citing the temporal limitations in processing feedback, the reduced attentional demands associated with increasing skill, and the role of memory in anticipating and skillfully producing and reproducing movement, Keele proposed that muscle commands are structured prior to the initiation of a movement sequence, and that the entire sequence is then executed uninfluenced by peripheral feedback. While this is no longer believed to be strictly true (see above), the ideas, as a whole, were instrumental in creating a shift in the theoretical emphasis in the field of motor behavior.

"Programming" refers to the preparation and initiation of a response (Schmidt, 1987). The processes involved in response-programming have been a source of much research and controversy in recent years. Ivry (1986) has argued for separating the processes of program construction from those of program implementation. Program construction involves those processes that can take place prior to the decision to initiate a response, if the relevant parameters are known. In the case of a simple RT task, all of the relevant response parameters are known in advance so the entire program can be

constructed. For a choice RT task, only those parameters known in advance of the signal to respond can be prepared - thus, the motor program is partially constructed (Rosenbaum, Inhoff, & Gordon, 1984). In fact, it is currently acknowledged that programming (construction) of latter/uncertain parts of a movement sequence may co-occur with the execution of earlier/known parts (Rosenbaum, Hindorff, & Munro, 1987; Semjen & Garcia-Colera, 1986). The program (or program parts), once constructed, is presumably stored into some type of short-term memory buffer (Sternberg, Monsell, Knoll, & Wright, 1978).

Program implementation involves those processes that take place after a decision to initiate a response. It has been suggested that these processes involve the translation of abstract codes into sets of motor commands (Semjen & Garcia-Colera, 1984), or the retrieval of specific parts of the program from a buffer (Sternberg et al., 1978). The constructed program is not implemented earlier since, presumably, implementation is in some way tied to response execution. This notion will be dealt with in more detail in Experiment 1.

For the purpose of the studies reported here, it will be interesting to note that both construction and implementation processes are thought to involve largely independent force and timing components and, indeed, there is even evidence that separate functional units of brain organization underlie these components (Keele & Ivry, 1987).

One of the most elaborate and most researched frameworks outlining the processes of program implementation was developed by Sternberg et al. (1978). They postulated that a motor program is comprised of one or more "subprograms". A subprogram represents a single unit of execution in the motor program - a functional response unit. For example, the program for a response pattern of "n" tapping movements would consist of "n" subprograms - one for each movement. Sternberg and his colleagues presented data to support the theoretical position that program implementation first involves the self-terminating, serial search/retrieval of the first subprogram from a non-shrinking buffer. The retrieved subprogram is then "unpacked" (broken down into its constituents - e.g. a stress group in speech can be made up of one or more syllables), the motor commands for the constituents are specified and, finally, response execution is initiated. Along with stimulus processing, this implementation procedure takes place during the RT period. The procedure then repeats itself for each additional subprogram.

The Sternberg et al. model relies heavily on a corresponding linear increase of RTs and quadratic increase of interresponse intervals (IRIs). However, recent findings, for example in the handwriting studies of Hulstijn and van Galen (1983), and Teulings, Mullins and Stelmach.(1986), and the hand manipulation studies of Harrington and Haaland (1987) have failed to replicate this correspondence and, as a

result, have cast doubt on some aspects of this conceptual scheme. Even so, it has proved, and continues to prove, useful as a theoretical framework from which many interesting hypotheses are generated.

"Preprogramming" is not referred to unequivocally in the literature. Perhaps it has been most frequently taken as synonymous with response-programming that occurs prior to response initiation (Schmidt, 1987). Presumably, the initiation of all movements or movement parts that are less than one RT in duration is accomplished through preprogramming. What is not clear is how this notion ties in with the programming of movement during continuous activity - and not just the later programming of a previously known movement part. It doesn't appear to make sense to speak of preprogramming as occurring only in the absence of any movement, yet if preprogramming occurs during ongoing activity, then how are distinct movement parts identified?

Preprogramming will be used here to refer to only those processes that take place prior to the decision to initiate a response. That is, preprogramming is defined as the programming operations that occur in advance of the signal to respond - the processes of program construction in a simple RT paradigm.

Purpose of the Studies

The studies in Section One are designed to provide a better understanding of the interrelation among response

programming, response timing and response articulation.
Previous studies have typically investigated the programming
of response patterns of varying levels of complexity that are
executed as quickly as possible. But what happens with
slower, _isochronous_ response patterns? To what extent is
programming required prior to response initiation? Does this
vary with the rate of response? One focal theoretical
question in the first section is: why do subjects not
completely preprogram all aspects of a known response pattern
(or at least the first response unit) in advance of the
signal to respond? What processes underlie the delay in
initiating a complex response pattern? The research to date
has largely ignored this question. An attempt is made to
answer it in the present work by testing one of two competing
hypotheses.

The studies in Section Two continue the recent research
thrust devoted to uncovering the principles of perceptual
organization for rhythmic patterns. A primary assumption
here is that perceptual organization or grouping is reflected
in the accenting of reproduced patterns; the output form of
the patterns in these studies can reflect only agogic
(duration) accenting. Yet, as Keele, Ivry and Pokorny (1987)
have shown, accenting of this type can be influenced by force
variations in response production.

In the literature, much reference is made to
organization with respect to a fundamental temporal interval
or referent - a "beat-interval". What factors contribute to

the determination of a beat-interval? It has generally been assumed that a beat-interval must be initiated by an external-world event. But is this necessary if other cues suggest the same perceptual organization? Also of interest is how the number of events in a pattern and event frequency (rate) influence the selection of a beat-interval. If there is a duration range that the beat-interval must fall within, as there surely must be (the pertinent literature with respect to this issue will be discussed in Section Two), then manipulating the above variables should allow us to expose it.

Limitations

There are several limitations to the studies presented here. These relate to various aspects of validity. First, with respect to internal validity and method, the method of reproducing auditory stimulus patterns is being used, in part, to make inferences regarding perception. Yet, there is evidence to suggest that the mechanisms involved in reproducing an auditory rhythmic pattern, producing the same pattern from notation, and judging temporal relations in that pattern, are not identical (Allan, 1979; Keele & Ivry, 1987; Sternberg, Knoll, & Zukofsky, 1982; Summers, Hawkins, & Mayers, 1987; Vroon, 1976). Deviation of the response from the criterion may be a result of perceptual or response biases. It is argued here that even though each method has limitations, the method of reproduction is the most direct

since the stimulus and response are both in the form of a rhythmic pattern. Joint use of these methods is not appropriate for the studies outlined since the investigation of programming precludes an "estimation" response, and the perception of specific time-intervals precludes the presentation of a transcribed stimulus.

The second limitation concerns validity and the methods of analysis. Most of the experimental results presented here are analyzed according to some type of Analysis of Variance (ANOVA) procedure. ANOVA makes certain assumptions regarding the distributions of the data being analyzed. These assumptions are typically not met with RT data. RT data are thought to be almost always non-normally distributed - in particular, they are skewed toward higher values of RT (Ratcliff, 1979). In addition, the assumption of independent means and variances is rarely met (Pieters, 1983). However, ANOVA tends to be, for the most part, a robust test even when the underlying assumptions are not completely met (Glass & Hopkins, 1984).

From a theoretical point of view, inferential statistical tests applied to group data do not necessarily uncover what is happening at the level of the individual. The use of a similar response strategy across subjects may yield variable results while the use of dissimilar strategies may yield equivalent results. Individual differences and their causes are difficult to identify and interpret.

The third limitation is with respect to external validity. At the level of stimulus presentation, there is evidence that variability in rhythmic performance depends on the modality of presentation - visual stimuli result in the greatest performance variability while auditory stimuli result in the least (Kolers & Brewster, 1985). Therefore, the present results - Section Two, in particular - may not be generalizable to other stimulus modalities. However, by utilizing the modality that results in least variability we are more likely to uncover differences that could be missed if the visual modality were used for stimulus presentation.

The subjects in the reported studies are primarily North-American, university students. The rhythmic backgrounds of these subjects are specific not only to their personal histories but also to their culture. Davies (1978) has suggested that Western music, while tonally very complex, is rhythmically quite simple. Other forms of music, most notably Indian and African music, are rhythmically very complex (Dowling & Harwood, 1986).[1] In addition, a strong relationship has been found between pulse forms of ethnic music and the rhythms of the corresponding language (Clynes & Walker, 1982). Thus, past rhythmic experience is likely very different among cultural populations and these differences may be evident in the types of tasks performed in the present studies.

A final limitation is one of ecological validity with respect to music. While it is generally recognized that,

"without rhythm, there would be no music" (Radocy & Boyle, 1979), it is true that without music there is much rhythm. And rhythm external to music may be different from rhythm internal to music. The studies reported here involve stimulus and response patterns that vary only in the time intervals between event-onsets. Pitch, loudness and timbre are all controlled and kept constant (though the constant values for these dimensions are different in Experiment 2 of Section One). Also, event durations are kept constant in the stimulus patterns. The perception of these controlled, computer-generated rhythms may be very different from the perception of rhythm in a rich context such as music.

SECTION   ONE:

The Advance Planning and Timing of

Isochronous Response Patterns

What processes underlie the preparation of response patterns? Specifically, are there differences in the preparation of response patterns that vary in complexity? The measure commonly used when investigating these questions is the RT to initiate a response. For response patterns of various types, RT has been found to increase with increasing response complexity.

Freeman (1907) was likely the first to investigate this relationship. He found that simple RT was greater when subjects had to draw a geometric figure or move to a specified point than when they had to draw around a circular track or merely make a vertical movement. In a classic paper, Henry and Rogers (1960) showed that increasing the complexity of a simple hand movement by specifying target locations and directional changes resulted in greater simple RTs. In more recent years, similar RT analyses have been applied to a number of tasks, including handwriting (Hulstijn & van Galen, 1983; Stelmach & Teulings, 1983; Teulings et al., 1986; Teulings, Thomassen & van Galen, 1983), speech (Eriksen, Pollack & Montague, 1970; Klapp, 1974; Klapp, Anderson & Berrian, 1973; Sternberg et al., 1978) and keystrokes and tapping (Fischman, 1984; Klapp & Rodriguez, 1982; Klapp, Wyatt & Lingo, 1974; Rosenbaum et al., 1987; Semjen & Garcia-Colera, 1986; Semjen, Garcia-Colera & Requin,

1984). The underlying assumption has been that differential RTs can help to uncover and explain, among other things, the processes involved in what has variously been referred to as the "advance planning", "programming", or "preparation" of a motor response.

While there is evidence supporting the effect of response complexity on RT, the research findings have not been unequivocal. Eriksen et al. (1970) and Klapp et al. (1973) have found that choice RT increases as a function of the number of syllables to be spoken but not simple RT. Klapp et al. (1974) observed lengthened choice RTs for long as opposed to short key presses but, again, no simple RT effects. Kerr (1979) attempted to replicate the Klapp et al. (1974) findings but instead found no simple RT or choice RT effects. Teulings et al. (1986) reported conflicting results with respect to simple RT and the number of handwritten strokes. Chamberlin and Magill (1987) failed to find increases in simple or choice RT as a function of number of tapping movements. Results such as these have led some researchers to question the reliability and interpretation of simple RT effects (Klapp, 1981). What these results do indicate is that methodology, the defined parameter of response complexity, and task selection may be important considerations in the design of experiments concerned with response preparation and motor programming. Each of these are considered in turn.

Methodology

Both simple RT and choice RT methods are necessary to
reveal a full understanding of the preparation of response
patterns. These methods highlight different response
processes. It is thought that the response processes that
choice RT index are those involved in both motor program
construction and implementation; simple RT indexes only those
response processes involved in program implementation
(Sternberg et al., 1978; Ivry, 1986). Does this imply that
the choice RT method is more revealing and the simple RT
method is merely redundant? Likely not. Simple RT allows a
finer probing of the processes involved in response
implementation. The confounds present in choice RT paradigms
(i.e. stimulus discrimination, stimulus-response, response-
response, and stimulus-response ensemble compatibilities, and
response selection) are avoided in simple RT paradigms.
Still, some have endorsed the choice RT method to the
exclusion of the simple RT method.

Klapp (1981) has been perhaps the most vocal critic of
using simple RT effects to infer motor programming. His
position has been that a response known in advance can be
completely preprogrammed. While not denying the existence of
simple RT effects, these effects are interpreted as having a
basis other than motor programming. One argument (Klapp,
cited in Henry, 1980) is that simple RT effects may reflect
peripheral factors (such as variable limb-segment inertias
and differential digit RTs) as opposed to central processes

(see also Anson, 1982). Fischman (1984) tested this hypothesis by measuring both premotor and motor simple RT components for a serial target-tapping task. The resulting increase in simple RT as a function of the number of taps was attributed almost exclusively to the premotor component. This, in light of the fact that the initial movement segment was standardized across response patterns, provides good evidence against the peripheral factors interpretation.

It has been suggested that simple RT effects may only be evident for large-scale movements as opposed to small finger movements (Klapp, 1980). However, this seems unlikely since simple RT is thought to reflect processes that underlie parameters other than movement extent (Hayes & Marteniuk, 1976). Sternberg et al. (1978) reported an increase in simple RT as a function of number of typed letters but the letters (and thus response locations) were not identical.

There is also concern that an increase in simple RT may be due to a variable speed/accuracy trade-off across levels of complexity (Klapp, 1981). There is presently insufficient evidence to comment on this issue.

Other arguments are that simple RT effects may result from insufficiently motivating the subject to respond as quickly as possible (Klapp et al., 1979), and that simple RT effects can be eliminated with practice (Klapp et al., 1974). Of course, even with explicit instructions, feedback, and appropriate reinforcers it may be that motivation is insufficient. The best we can do is to emphasize these

motivational strategies and assume that the subject is being induced to respond as instructed. These strategies have been employed in past studies. The argument with respect to practice seems unlikely in light of the Sternberg et al. (1978) results which showed a significant increasing trend in simple RT even after high levels of practice. However, practice did result in an overall decrease in mean RT and the RT regression coefficient. This decrease was asymptotic over sessions. Yet, even if no increasing trend were found after much practice, it could simply mean that the "units" of programming change as one becomes more skilled.

A final argument is derived from a study in which a linear relationship between simple RT and number of spoken words was found but different task conditions produced different regression coefficients (Klapp et al., 1979). The "repeat" condition, in which subjects had to repeat the number "one" (from one to five times), yielded a significantly larger coefficient than the "count" condition, in which subjects had to count ascending integers starting with "one" (up to five integers). This difference prompted the conclusion, "...we can reject the motor-programming interpretation for results of this type" (p.99). However, rather than attributing differential RT regression coefficients to processes other than motor programming, it would be more useful to explain these differences within a motor programming framework. For example, counting numbers may simply be a more familiar and well-learned task than

repeating them in which case, as noted earlier, a smaller coefficient would result.[2] Alternatively, programming, in the case of the repeat condition, may involve additional processes, the durations of which depend on the number of units to be spoken. The additional processes could reflect a set of instructions - one for each time the number of (identical) response units executed is to be compared with the total required. Analogously, Sternberg et al. (1978) found that, for typed keystrokes, the simple RT regression coefficient was greater for alternating hands than for a single hand. It may be that programming for alternate hand typing also involves additional processes - one for each time a change of hands must be made.

Although some concerns still remain, there appears to be no decisive evidence opposed to a programming interpretation for simple RT effects. What, then, are the benefits of using the simple RT method? As previously stated, in addition to avoiding choice RT confounds, the simple RT method allows a finer probing of the processes involved in the implementation of a motor program. Indeed, only the simple RT method can address the question, "Why must some processes be delayed until the signal to respond, even though the subject knows in advance exactly what he/she is to do?"

The choice RT method alone cannot unambiguously separate the processes of program construction from those of program implementation. This is evident when we examine programming models. Simple RT data led to the Sternberg et al. (1978)

model which postulates distinct stages to account for processing that follows the construction of a motor program. On the other hand, the Hierarchical Editor Model of Rosenbaum et al. (1984; see also Rosenbaum et al., 1987), while very impressive in explaining how choice RT varies as a function of the number of response elements prior to and following an uncertain response element, explains simple RT effects simply by means of a "tree-traversal process". Simple RT increases for longer patterns because the distance along a "node path" from the top of a pattern "tree" to its first terminal node increases. While providing a metaphor, this does little to suggest or explain the processes that underlie simple RT effects. The goal of research into response programming is a unified model - one that explains both simple and choice RT processes. It appears that both simple and choice RT methods are necessary for the ultimate development of such a model.

Parameters of Response Complexity

There are many candidate parameters of response complexity (see Hayes & Marteniuk, 1976, and Kerr, 1978, for reviews). Contrasting simple and choice RT methods can tell us which parameters are and are not programmed prior to a stimulus signal. For instance, Ivry (1986) has found that choice RT varies with the need for instructions to deactivate force output, while simple RT does not. Thus, for a known response, force deactivation can be programmed in advance of the response signal. Choice RT studies typically investigate

the effects of uncertainty along one or more response parameters. In movement precuing studies, for example, these have included the limb, direction and extent of a movement (Goodman & Kelso, 1980; Larish & Frekany, 1985; Rosenbaum, 1980) as well as digit and movement duration (Zelaznik & Hahn, 1985). In force-timing studies, it has been the serial position of a stressed tap in a series of otherwise identical taps (Semjen & Garcia-Colera, 1986; Semjen et al., 1984). Experimental design can allow various uncertain parameters and thus choice RT can index many (contrived) parameters of response complexity. Yet, as Kerr (1978) has cautioned, "...task-defined parameters...that we identify as important may be very different from the internal values that truly affect the motor control system" (p.66). It is suggested here that contrived parameters of response complexity should not automatically be assumed to reflect the "natural" parameters intrinsic to the motor control system.

The parameters that most reliably lend themselves to investigation by the simple RT method are: 1) <u>number</u> of response units (subprograms), and 2) response duration. The response unit may be identical with an individual response element or may represent a group of elements - much as an IRI is comprised of response onset and offset times. What determines this functional grouping is not always clear. For the clear interpretation of results, a stated requirement has been that response patterns be comprised of elements thought to be fundamentally identical (i.e. the "element-invariance"

requirement, Sternberg et al., 1978). An increase in RT as number of response units increases (each comprised of one or more elements) would reflect processes sensitive to this parameter of complexity. The increase, when observed, is typically a linear one.

Separating "number" from "duration" as response parameters is difficult since patterns with more response units normally take longer to execute. If number of response units is held constant and response duration varied, then there is the risk of allowing complete "on-line" control for the later events of slower patterns.

While there is some evidence that choice RT increases as a function of response duration (Klapp, 1977; Klapp et al., 1974), recent studies have measured RT trends for both total response duration and movement velocity, and found that RT increases in inverse proportion only to the latter variable (Falkenberg & Newell, 1980; see also, Carlton, Robertson, Carlton & Newell, 1985).

Task Selection

The selection of an appropriate task is important to ensure that the defined parameter of complexity is not confounded with other variables (see, for example, Fischman, 1984). Consider handwriting and speech. In the case of handwriting, researchers have tried with limited success to show an increase in simple RT as a function of the number of response units - the response unit being, presumably, either

a letter or a stroke. Teulings et al. (1986) have noted that the continuous nature of handwriting may well underlie its resistance to decomposition into distinct units and thus the inconsistent results. In addition, the fact that stroke lengths and durations are variable and that movement in handwriting occurs along the horizontal as well as the vertical axis indicates that the elements of handwriting fail to meet the element-invariance requirement (see above).

The variability among stroke durations, in particular, presents a problem. The amount of processing required prior to response initiation can be influenced by the (variable) rate of unit execution. In the case of slower rates, processing requirements prior to execution may be reduced due to time allowance for on-line processing during execution. As a result, simple RT could fail to increase as number of strokes increase. In fact, Hulstijn and van Galen (1983) have suggested that the failure to show reliable latency effects with handwriting may be due to the relatively low maximum output rate that is observed. They argue that a low output rate might mean there is no need to program an entire sequence, indeed, no need to program more than one letter in advance of the signal to respond. Thus, the method of investigation (choice or simple RT) and chosen parameter of complexity (number of response units) can fail to reveal RT effects if the selected task is not appropriate.

The response unit in speech appears to be the stress-group (a segment of speech associated with primary stress).

Simple RT has been found to increase linearly as number of stress-groups increase (Sternberg et al., 1978). Yet, as with handwriting, the response unit durations have not been controlled. Although maximum output rates are high for speech, thus increasing the necessity for processing prior to the signal to respond, the lack of control for unit duration restricts our ability to explain the processes that underlie latency effects and response execution. Other problems arise when studying RT effects of speech production (see Sternberg et al., 1978). Most importantly, measurement of latencies (and IRIs) typically depend on identifying a vocal response that exceeds a specified level of intensity. Vocal intensity, however, varies considerably with the length of a sequence, the volume of air in the lungs at any given time and the nature and context of the specific stresses to be vocalized.

Contrast the task of producing keystrokes. When performed with a single finger on a single key, keystrokes are simple and relatively invariant movements. Significant movement occurs only in one plane, the maximum output rate is high (up to 12 taps per second, cited in Seashore, 1938), requirements of spatial accuracy encourage response consistency, response units are relatively discrete, and stroke-onset times can be precisely defined and measured. If time is not controlled and measured then subjects might impose unknown rhythmic structures upon response sequences thus clouding the interpretation of RT effects. This task

seems ideally suited to the investigation of response complexity (defined as the number of response units) and simple RT effects. Yet, only Garcia-Colera and Semjen(1987; also Semjen & Garcia-Colera, 1986, and Semjen et al., 1984) have regularly employed this task to these ends.

Synthesis

The studies reported here are specifically concerned with response programming after the signal to respond (i.e. program implementation). The simple RT paradigm is thus employed. In this paradigm the response pattern is typically produced as fast as possible. This is to maximize programming requirements and minimize "on-line" movement control. Subjects, here, reproduce series of isochronous auditory tones - rhythmic patterns - by tapping a single response key. Placing temporal constraints on the response pattern allows examination of how various response rates (i.e. tempi) affect the amount of required programming. It also allows measurement of the accuracy and consistency of response timing.

RT effects of response complexity are investigated - complexity being defined as the number of response units. Why isn't the first response unit completely programmed (constructed and implemented) and simply "triggered" given the signal to respond? In this paradigm, is stimulus "uncertainty" the root cause of programming delay? What can

response timing tell us about perceptual and response

organization? These questions are the focus of Section One.

Experiment 1

The purpose of this study is to examine a fundamental issue regarding the nature of response processing that has, for the most part, gone unattended. Namely, in a simple RT paradigm, why do we not program all aspects of a known response, or at least the first response unit, and simply "trigger" it in response to a stimulus? Why are the operations that follow the construction of a motor program not initiated until <u>after</u> the signal to respond? Two possible explanations have been put forth (Sternberg et al., 1978). Consider again that "programming" is thought to involve program construction processes (which in the case of a known response can take place before the signal to respond) and program implementation processes. It may be that the initiation of implementation processes <u>automatically</u> leads to response execution. Initiating these processes prior to the stimulus would then cause the subject to erroneously respond on catch trials. Alternatively, the implemented program stored in a motor buffer might be subject to rapid decay or interference in the event of stimulus processing. This would delay the initiation of at least some programming operations until after the signal to respond.

In this study, the first of the above hypotheses is tested - namely, that only the threat and experience of catch trials prevents program implementation prior to the signal to respond. If this is the case, then removing catch trials, and thus the threat, should result in no simple RT

differences across levels of complexity. The programmed response can be triggered. In fact, it has previously been assumed that in the absence of temporal, spatial or event uncertainty subjects are able to overtly initiate a response just after the signal to respond (Quesada & Schmidt, 1970).

Other questions are also of interest here. Does the timing of an isochronous response pattern have implications for the preparation of that pattern? How accurately and consistently do subjects reproduce isochronous patterns in an RT paradigm? How many response units can be programmed in advance of response initiation? Speech, typing and tapping studies have found a linear increase in RT through five response units (Fischman, 1984, Sternberg et al., 1978). The patterns in the present study contain up to six response units.

Method

Subjects. Twelve male and female students from the University of British Columbia participated in the study as part of a course requirement. Subjects ranged in age from 21 to 24 years. A $20.00 prize was offered to the subject who best performed the joint task of rapidly initiating and accurately reproducing the response patterns.

Apparatus. Stimulus events were produced as tones through an Apple IIe microcomputer and heard through headphones. Stimulus tone durations and toneless interval durations were also controlled through the Apple IIe.

Reproduction of individual tone durations and subsequent intervals was realized by subjects pressing and lifting from a specified key on the computer keyboard with the preferred finger of the dominant hand. A minimum force of 1.2 Newtons (N) was required to depress a key. The resting force generated by the weight of a finger was found to range from 0.5-0.6 N. This meant that an additional force of 0.6- 0.7 N was required to produce key depression. The same finger and key were to be used for the duration of the experiment. Reproduced tones were of an intensity and frequency identical to those of the stimulus tones. The reproduced tone durations, toneless intervals, and the latency to initiate the first event in each trial were all recorded by the computer.

Stimulus Patterns. Subjects were instructed to reproduce six different stimulus patterns. The patterns consisted of one to six 100 ms tones (events). All tones were of an identical intensity and produced at a frequency of 1420 Hz. Adjacent tones in multi-tone patterns were separated by toneless intervals of 200 ms resulting in interstimulus intervals (i.e. the time from tone-onset to tone-onset) of 300 ms.

Procedure. Subjects were seated at a table and instructed as to the nature of the study. A demonstration of the procedure was viewed. Then, wearing headphones and resting the fingertips of the preferred hand on the computer keyboard, subjects listened to a stimulus pattern consisting

of one to six tones. Presentation of the stimulus pattern
was preceded by a one second Ready tone (of equal intensity
to the stimulus tones but produced at a frequency of 400 Hz)
and a Pre-Presentation interval also one second in duration.
The final stimulus tone in the pattern was followed by a
Post-Presentation interval of 1200 ms. The offset of a
Warning tone (identical in all aspects to the Ready tone) was
the signal for subjects to initiate reproduction of the
stimulus pattern (see Figure 1). Following reproduction of
the final tone the experimenter pressed a key on the keyboard
thus ending the trial and preparing the computer for the
subsequent trial. A 6 X 10 factorial repeated-measures
design was employed. Subjects performed 10 consecutive
trials for each stimulus pattern. The order of pattern
presentation across subjects was determined by a balanced
Latin Square design. Reproduction of all six stimulus
patterns concluded the study.

The twofold task was: 1) to initiate reproduction of the
stimulus pattern as quickly as possible following the offset
of the warning tone, and 2) to reproduce the timing of each
stimulus pattern as accurately as possible. Equal emphasis
was placed on the two aspects of the task.

Analysis. Mean RT was the primary measure of interest.
RTs greater than 1000 ms were omitted from the analyses. In
light of the results from previous studies, RTs this slow
would clearly be errors and reveal nothing about response
programming (the slowest, mean simple RTs found in the

Figure 1.   Time line of a typical trial for a 3-tone pattern.

READY TONE

STIMULUS
TONES

WARNING
TONE

INTERRESPONSE
INTERVALS

1.0

.1 .1 .1

1.0

1.0

.2 .2

1.2

PRE-
PRESENTATION
INTERVAL

INTERTONE
INTERVALS

POST-
PRESENTATION
INTERVAL

RT
INTERVAL

TERMINAL
EVENT
INTERVAL

SECONDS
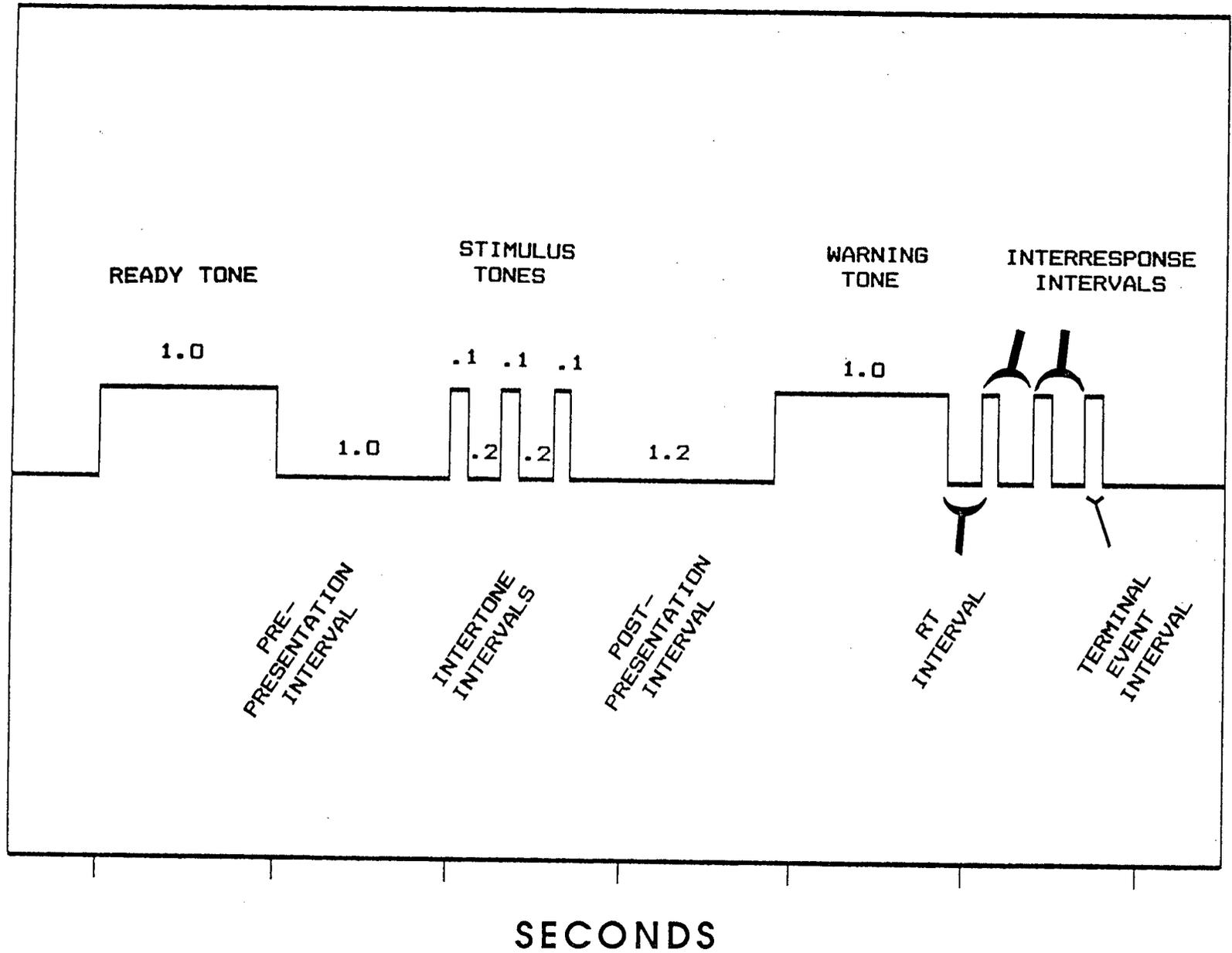
literature for studies of this sort are in the range of 345 ms to 380 ms - Semjen & Garcia-Colera, 1984, Expt. 1). Omitted RT data were replaced with single subject means for the same condition. This correction procedure was utilized only in cases where the total number of missing data points was two or less per cell.

The interresponse interval (IRI) was the primary measure used in the analysis of duration data. The IRI is the combined duration of a reproduced tone and the subsequent toneless interval - in other words, the duration from tone-onset to tone-onset (see Figure 1). Since individual onset and offset durations are thought to generally reflect response articulation rather than timing processes (Clarke, 1985; Sternberg, Knoll, & Zukofsky, 1982), the IRI is commonly used as the functional measure for temporal pattern reproduction (Povel, 1981; Semjen & Garcia-Colera, 1986; Vorberg & Hambuch, 1984).

For each subject five dependent variables were calculated. These included: mean intratrial IRIs and intratrial standard deviations (for multi-IRI patterns), the mean and standard deviation of mean intratrial IRIs, and the mean intratrial standard deviation. These variables represent, respectively: the mean and variability of IRI scores within each trial, the mean and variability of trial means, and the mean within-trial variability. Comparisons made across conditions allowed for inferences regarding the accuracy and consistency of pattern reproduction.

An intratrial standard deviation was calculated for all
IRIs within each pattern, and for just the first two IRIs
common to each multi-IRI pattern. The latter measure gives a
more accurate comparison when intratrial variability is
concentrated at the beginning of the response pattern.

The duration of the final response or "terminal event
interval" was also measured and analyzed since, by design, it
was not followed by a measurable interval.

IRIs of less than 100 ms or greater than 500 ms were
considered to be errors since they represent more than a two-
thirds deviation from the criterion intervals. These data
were omitted from the analyses. Non-usable trial data
resulting from the subject pressing more than one key, using
more than one finger, or incorrectly reproducing the number
of response elements were similarly omitted. The omitted IRI
data were replaced with single subject means for the same
condition and serial position. Omitted terminal event data
were replaced with single subject means for the same
condition. These correction procedures were utilized only in
cases where the total number of missing data points was two
or less per cell. In fact, corrected IRI and terminal event
data accounted for 1.4% and 1.9% of the data used in the
analyses, respectively.

Results

Latency Data. Preliminary analysis of the data revealed

that mean RTs were typical for studies of this sort (cf. Sternberg et al., 1978). As a result, RTs of less than 100 ms were considered errors of anticipation - and not a normal mode of response given the absence of catch trials. Corrected latency data (both fast and slow) accounted for 3.9% of the data analyzed.

Analysis of variance (ANOVA) uncovered a significant trials effect, $F(9,99)=4.05$, Greenhouse-Geisser $p=.012$.[3] Tukey post hoc analysis revealed that only the first trial was significantly different from the others (see Figure 2). Differences were significant at $p<.01$ for all but the second and final trials ($p<.05$). To exclude the effects of learning and/or familiarization with the task, first trials were omitted from all subsequent analyses.

Mean reaction time data are shown in Figure 3a. Trend analysis revealed only a significant linear orthogonal component, $F(1,11)=5.66$, $p=.037$. Visual inspection of the raw data, however, revealed that the mean performance of one particular subject, while not deviant enough to be excluded from the analysis based on a priori criteria, was both very slow across respective conditions (mean RTs: 289, 369, 442, 537, 358, 198 ms) and highly variable (mean standard deviations: 127, 82, 160, 131, 81, 24 ms). Indeed, and perhaps as a result, group standard deviations (58, 69, 79, 114, 71, 86 ms) were unusually high. This subject's data appear, in particular, to have contributed to the unusually high mean and standard deviation in the four taps condition.

Figure 2. Mean reaction time (RT) across trials - 72
    observations per point.
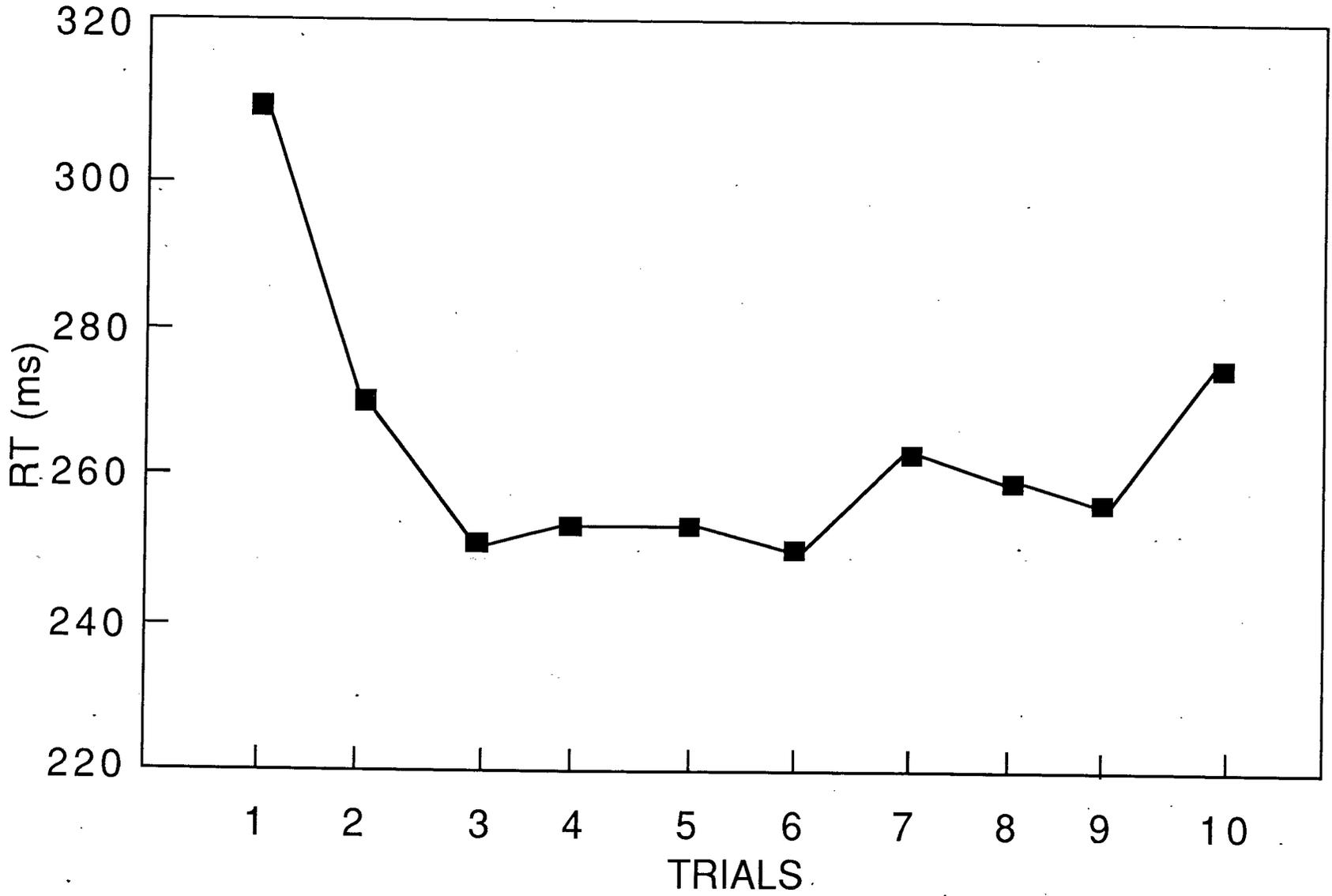
Figure 3. Mean reaction time (RT) as a function of number of taps. a. Results for 12 subjects - 108 observations per point. b. Results for 11 subjects - 99 observations per point.
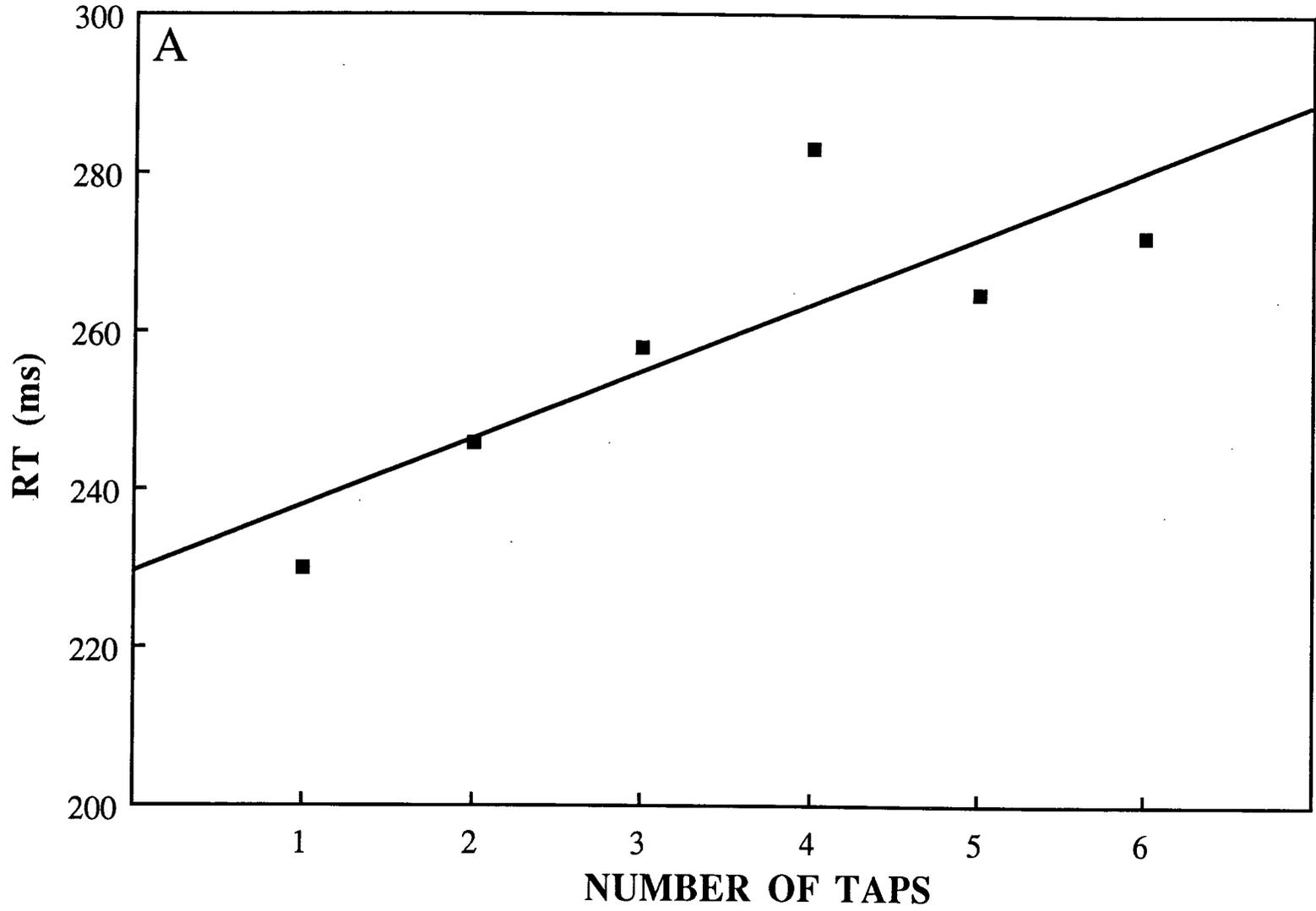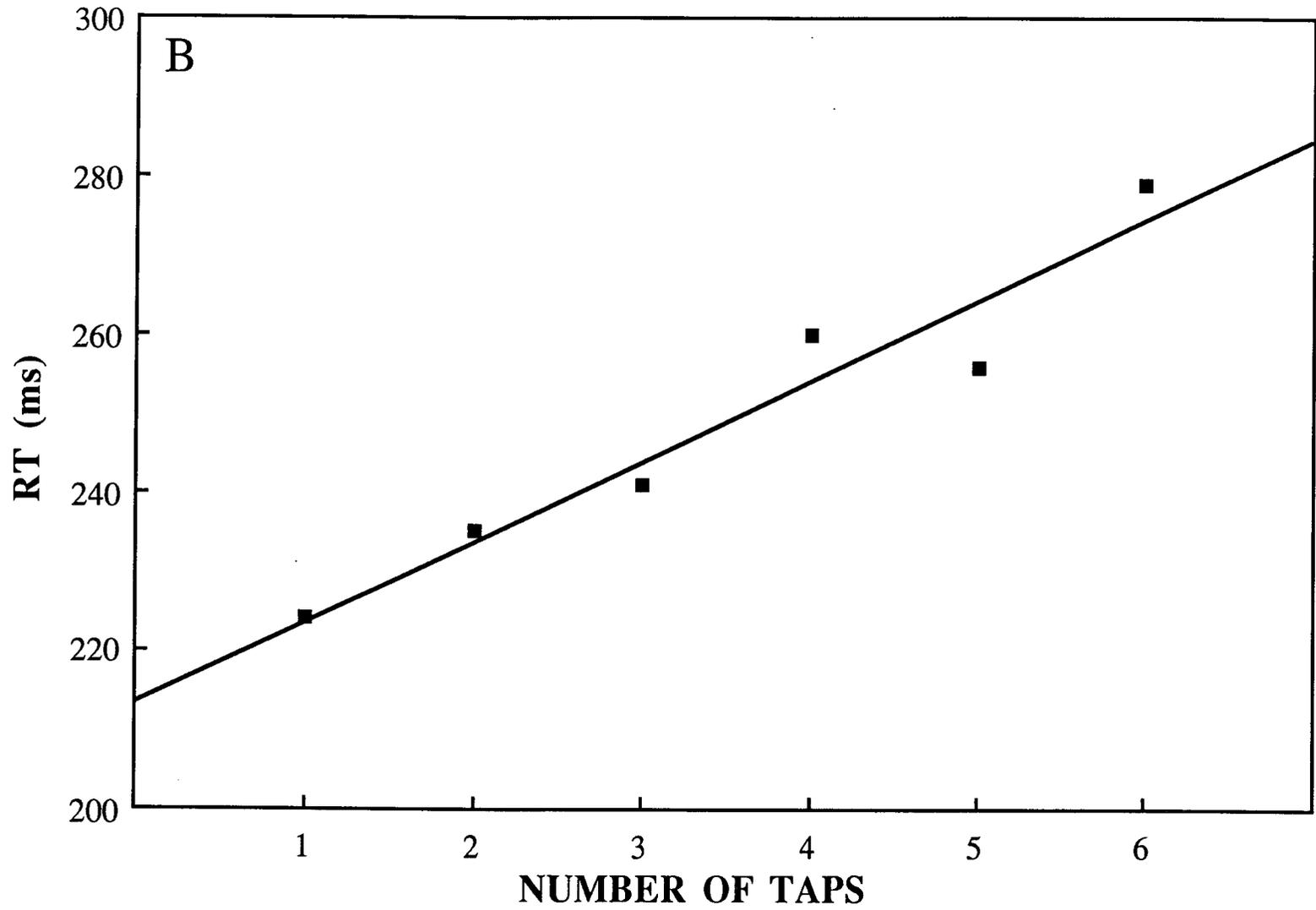
Despite the relatively good fit of the regression line, it is
not beyond question that an increasing linear relationship
that plateaus after four taps is the best representation of
the data here. A subsequent analysis was therefore conducted
in which all latency data from the subject in question were
eliminated. The resulting mean data are shown in Figure 3b.

Indeed, the new data were found to be slightly less
variable overall, most noticably in the four taps condition
(58, 60, 57, 86, 68, 87 ms). As well, RT for the four taps
condition fell more into line with the predicted effect. In
addition to the reliable linear effect, $\underline{F}(1,10)=9.38$, $\underline{p}=.012$
(the only significant trend), the overall conditions effect
was found to be significant, $\underline{F}(5,50)=4.06$, Huynh-Feldt
$\underline{p}=.005$. The calculated regression coefficient indicated that
latency increased at a rate of 10.2 ms/tap (RT (ms) = 10.2 X
Number of Taps + 213). Linear regression accounted for 93%
of the variance among mean latencies.

Interval Data. Mean condition IRIs are presented in
Table 1. Reproduced serial position and condition means were
close approximations of the criterion intervals of 300 ms.
ANOVA revealed no significant differences either within or
between conditions. Overall accuracy did not systematically
vary across conditions. Mean intertrial standard deviations
are presented in Table 2. Subjects' response timing across
trials was clearly less variable as pattern length increased.
Intratrial standard deviations for all IRIs and for the first
two IRIs common to each multi-IRI pattern are also displayed

Table 1
Mean IRI and Terminal Event (TE) Durations (ms) and
Corresponding SD's as a Function of Serial Position and
Pattern Length

			Mean Duration					
		IRI Serial Position						TE
Number of Taps		1	2	3	4	5	M	
1								
	M							113
	SD							24
2								
	M	289					289	131
	SD	18					18	18
3								
	M	292	303				298	123
	SD	18	33				24	17
4								
	M	301	306	308			305	127
	SD	16	20	22			17	14
5								
	M	302	307	298	307		303	124
	SD	19	16	20	21		17	13
6								
	M	299	304	298	307	310	304	127
	SD	19	18	15	19	17	13	13

Table 2
Mean and SD of Intratrial and Intertrial IRI SD's (ms) as a
Function of Pattern Length

	Number of IRI's				
	1	2	3	4	5
Intratrial SD's					
All serial positions					
M	-	17.92	17.63	18.96	18.44
SD	-	12.36	4.90	5.43	8.54
1st 2 serial positions					
M	-	17.92	13.65	16.90	17.04
SD	-	12.36	3.10	8.62	11.12
Intertrial SD's					
M	26.85	17.67	12.28	8.45	8.15
SD	12.10	7.33	8.54	3.90	2.51

in Table 2. Shown are the mean intratrial standard deviations (collapsed across trials and subjects), and the mean within-subject standard deviations of intratrial standard deviations. Mean intratrial variability did not systematically vary as pattern length increased. However, the consistency of variability (within-subjects) for the 3-IRI pattern was clearly greater than for the other patterns. This was the only pattern in which the consistency of intratrial variability was greatest for just the first two IRIs indicating that, for the other patterns, within-subjects variability was concentrated at the beginning of the pattern.

Terminal Event Data. Terminal event data are shown in Table 1. ANOVA uncovered no significant differences among terminal event intervals. However, the alternating long and short durations suggested the performance of a post hoc trend analysis in order to determine if this particular higher-order trend was significant. Not surprisingly, the analysis did reveal a significant quintic effect, $F(1,10)=6.07$, $p=.033$. This effect, in addition to the observation that the reproduced intervals were substantially longer than the criterion interval of 100 ms, underscore the idea that response onset times reflect articulative and not necessarily timing processes.

Discussion

The claim that simple RT increases as a linear function of the number of response units - single finger taps - is

supported in this study. The primary intent of this study was to determine if such a finding would occur in the absence of catch trials, and thus speak to the hypothesis that the processes of program implementation automatically lead to response execution and, therefore, are delayed until after the stimulus only when the paradigm involves catch trials. These results do not support this hypothesis. In a simple RT paradigm, stimulus uncertainty is not a necessary condition for programming delay. Why, then, should a subject wait until the signal to respond to implement a programmed response if he/she knows what is to be done, when it is to be done and that it always must be done? The present findings are consistent with the Sternberg et al. (1978) suggestion that program implementation is delayed because placing the implemented but yet-to-be-triggered program in a motor buffer would subject it to rapid decay, or interference in the event of stimulus processing.

Typically, subjects are to respond as quickly as possible in studies of this sort. Yet, the linear increase in RT reported here for the reproduction of response tones separated by around 300 ms indicates that, even at this relatively slow rate, the entire pattern was treated in some way as a coherent response. In terms of the Sternberg et al. model, RT increased because the search/retrieval process was faced with an increasing pool of subprograms.

The linear increase in RT is consistent with the model of Sternberg and his colleagues. However, their model also

predicts that movement duration per response unit should
increase as the length of the response pattern increases.
That was not the case here. Pattern length did not affect
the mean reproduction of IRIs. Recall, though, that the
patterns in the present study were reproduced at a specified
rate. The Sternberg et al. model was based on response
patterns that are produced as fast as possible. The
additional time-per-unit predicted by their model might well
be "absorbed" in the longer IRIs of the patterns in this
study. Therefore, we are unable to comment on the duration
aspect of the Sternberg et al. model.

With respect to the reproduction of IRIs, mean
intratrial variability was similar across conditions although
within-subject consistency of intratrial variability was
greatest in the 3-IRI pattern. We might speculate that with
the majority of popular Western musical rhythm being in the
structure of 4/4 time, the 3-IRI (i.e. 4-tap) pattern induced
subjects to access a learned structure; therefore,
intrapattern variability was consistent.

The intertrial variability findings are the most
interesting of the IRI data. For the longer patterns,
subjects were more consistent in their mean rate of response
across trials. It may be that the feedback from reproducing
longer patterns and/or the exposure to longer stimulus
patterns more thoroughly embeds the temporal or rhythmic
qualities of the pattern. The perception of only two
sequential events does not suggest the phenomenon of a

"pattern" so much as it does temporal distinctiveness. As pattern length increases so does the expansion of temporal structure for relations between adjacent and non-adjacent intervals.

The general finding of a linear RT function for increasing response complexity is extended to the reproduction of up to six response units. In the next study, programming requirements for various response rates and a broader range of response complexity (i.e. number of events) are investigated. The effects of response rate on response timing and articulation (i.e. tone-onset times) are also studied. Comment on the quintic effect observed for terminal event durations in this first Experiment will be reserved until the general discussion for Section One.

Experiment 2

How does the required rate of response execution influence programming requirements prior to response initiation? Rapid movement patterns are treated as coherent responses and this is reflected in differential RTs such as those found in Experiment 1. We would not expect this same effect for slower patterns if they are not treated as coherent responses. Hulstijn and van Galen (1983) have suggested that for handwriting (a relatively slow output form) either part of a handwritten sequence is fully programmed or the entire sequence is partially programmed in advance of response initiation (see also Stelmach & Teulings, 1983). The remaining programming is done "on-line". Harrington and Haaland (1987) investigated RT and IRI profiles for series of hand manipulation movements and concluded that the first two response units are completely programmed prior to response initiation. Although it seems clear that response patterns are controlled in part through on-line programming, the issue of how much programming is done prior to and after response initiation remains uncertain.

Semjen and Garcia-Colera (1986) found that simple and choice RTs to initiate a five finger-tap pattern decreased as response rate decreased from 300 ms to 600 ms per response. No such differences were found when tapping rate varied between 140 ms and 300 ms. Indeed, whereas rapid patterns may truly be prepared as response "patterns", slow patterns

may be produced as series of separable responses or response "chunks".

Programming requirements for response rates of 200, 400, 600, and 800 ms per response unit are investigated. In the case of a simple tapping task, it is predicted that RT will increase as a function of number of response units for the 200-ms condition but not for the 600-ms or 800-ms conditions. There is no precedent in the literature for making a prediction regarding the 400-ms condition.

Previous investigations have yet to discover a reliable "ceiling" to the number of response units that result in an increase in simple RT. Of course, it is hardly plausible that RT increases indefinitely for increasingly long response patterns regardless of how rapidly they are produced. Analogously, choice RT does not continue to increase when the number of stimulus-response alternatives becomes very high (Seibel, 1963, showed this when testing up to 1032 alternatives (!)). What would a limit to the simple RT effect mean (with respect to number of response units)? It could mean, again, that the response pattern is not treated as a coherent whole - that the number of subprograms subject to a search/retrieval process is limited.

A RT limit is thus likely dependent on both response rate and the total number of response units. Both response rate and the number of response units are manipulated in the present study. As a result, total response duration also varies. A significant linear RT trend for more than one

response rate would shed light on whether response duration and/or the number of response units is the critical parameter of response complexity in a simple RT paradigm.

Would different timing profiles be expected among response patterns reproduced at different rates? Povel and Essens (1985) have suggested that temporal patterns are accented in a way that reflects their perceptual organization. Specifically, they have proposed that isolated events, the second in a cluster of two events, and the initial and final events in clusters of more than two events, are psychologically accented regardless of the combination in which such clusters occur in a temporal pattern. However, their model fails to consider pattern tempo. The interaction of rhythm and tempo in pattern perception is considered by many to be crucial and should not be ignored (for example, Clarke, 1985). If slow stimulus patterns are perceived more as a pattern of stimuli than as a unitary stimulus pattern, then such patterns should not display evidence of the psychological accenting suggested by Povel and Essens. One way in which the accenting of an interval is realized is to lengthen the duration of that interval (i.e. an agogic accent). The accenting of isochronous patterns that vary in tempo is investigated here by determining the relationships among IRIs (durations) within each condition. Measurable accenting of these patterns may help to reveal how they are perceptually organized.

Finally, the articulative properties (i.e. tone-onset times) of response patterns are examined. Although a somewhat neglected measure of performance (recent exceptions being Garcia-Colera & Semjen, 1987; Keele et al., 1987), response articulation, as an emergent feature of performance, may provide insight to the control of response patterns produced at different rates.

Method

Subjects. Eleven male and female students from the University of British Columbia participated in the study as an optional course requirement. (Different subjects participated in each of the four studies reported here). Subjects ranged in age from 20 to 39 years. All but two of the subjects had at least the equivalent of one high school course in typing.

Apparatus. The experiment was controlled through an IBM "XT" microcomputer. A circuit board was designed to interface a "Tecmar Labmaster" data acquisition, multi-function board that was resident in the computer with an apparatus comprised of 11 LEDs, miniature speakers and push button response switches (see Figure 4). For this study, only two speakers (one for the ready and warning tones, one for the stimulus tones) and one response key were functional. All LEDs were covered with black tape. The designated circular response key was 1.2 cm in diameter. On its black surface was a red, 0.9 cm tape square. Stimulus events were

Figure 4. Response apparatus and computer interface systems
for Experiment 2.

IBM PC/XT

TECMAR LABMASTER

CPU

MOTHER BOARD

DAUGHTER BOARD

DIGITAL I/O

PORT C

PORT A

SOSMP CIRCUIT BOARD

EXPERIMENTER

SOSMP APPARATUS

WARNING SPEAKER ⎯⎯⎯⎯⎯ ○
WARNING LED ⎯⎯⎯⎯⎯ ■

STIMULUS SPEAKERS ⎯⎯ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○
RESPONSE SWITCHES ⎯⎯ ● ● ● ● ● ● ● ● ● ●
STIMULUS LEDs ⎯⎯ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■

SUBJECT
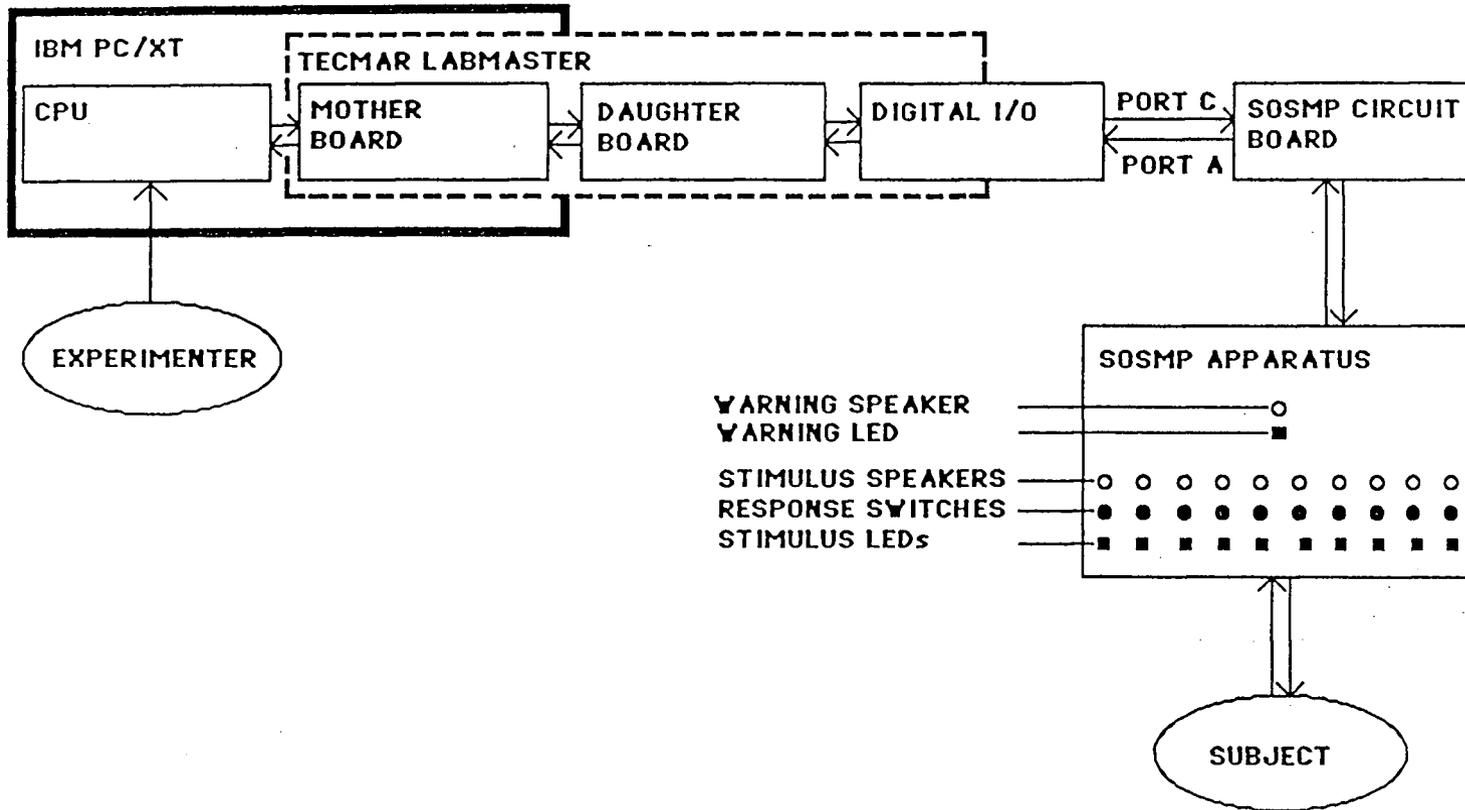
produced as tones through the stimulus speaker. The ready
and warning tones were produced through the second speaker.
Tone durations and toneless interval durations were
controlled through the computer. Reproduction of the
stimulus patterns was realized by pressing and lifting from
the response key with the index finger of the dominant hand.
Reproduced tones were identical to the stimulus tones in
intensity and frequency. Response durations, toneless
intervals and the latency to initiate the first event in each
trial were all recorded by the computer.

Stimulus Patterns. Subjects reproduced 29 different
stimulus patterns. The patterns consisted of one to eight
100 ms tones. Multi-tone patterns were presented with
interstimulus intervals (ISIs) of 200, 400, 600, and 800 ms
(resulting in 28 different patterns). The single tone
pattern was not associated with an ISI. All tones were equal
in intensity and frequency.

Procedure. Subjects were seated at a table directly in
front of the apparatus and instructed as to the nature and
procedure of the experiment. They rested their dominant hand
on or near the apparatus so that their index finger was
resting on the response key. Subjects were instructed to
maintain contact with the response key at least through
completion of the first response tone. Subjects listened to
one of 29 stimulus patterns. Presentation of the stimulus
pattern was preceded by a one second Ready tone (lower in
frequency than the stimulus tones) and a Pre-Presentation

interval also one second in duration. The final stimulus tone in the pattern was followed by a Post-Presentation interval ranging between 2100 and 2700 ms. The offset of a Warning tone (identical in all aspects to the Ready tone) was the signal for subjects to initiate reproduction of the stimulus pattern (see Figure 5). Following reproduction of the final tone the experimenter pressed a key on the computer keyboard thus initiating the subsequent trial. Subjects consecutively performed 12 practice trials and 24 performance trials for each pattern. Of these, 16.7% were catch trials. High between-subjects variability for RT in Experiment 1 (see the Results section) may have been a result of some subjects anticipating the signal to respond. Catch trials were included in the present study in order to control for any anticipation that might have otherwise occurred. The Warning tone continued for four seconds in the event of a catch trial. Practice trials were included in order to reduce variability. Testing covered three days for each subject. Each day involved two one-hour sessions separated by a rest period of five minutes.

The twofold task was: 1) to initiate reproduction of the stimulus pattern as quickly as possible following the offset of the warning tone, and 2) to reproduce the timing of each stimulus pattern as accurately as possible. Equal emphasis was placed on the two aspects of the task.

Analysis. Mean RT was again the primary measure of interest. For each subject the condition mean RTs and

Figure 5. Time line of a typical trial for a 3-tone pattern.

(4.0 s
for catch trials)

READY TONE   STIMULUS   WARNING   INTERRESPONSE
                     TONES   TONE   INTERVALS

1.0   .1 .1 .1   1.0

                 1.0   .3   .3   2.1 (to 2.7)

PRE-
PRESENTATION   INTERTONE   POST-   RT   DOWN
INTERVAL   INTERVALS   PRESENTATION   INTERVAL   TIMES
                                         INTERVAL

SECONDS
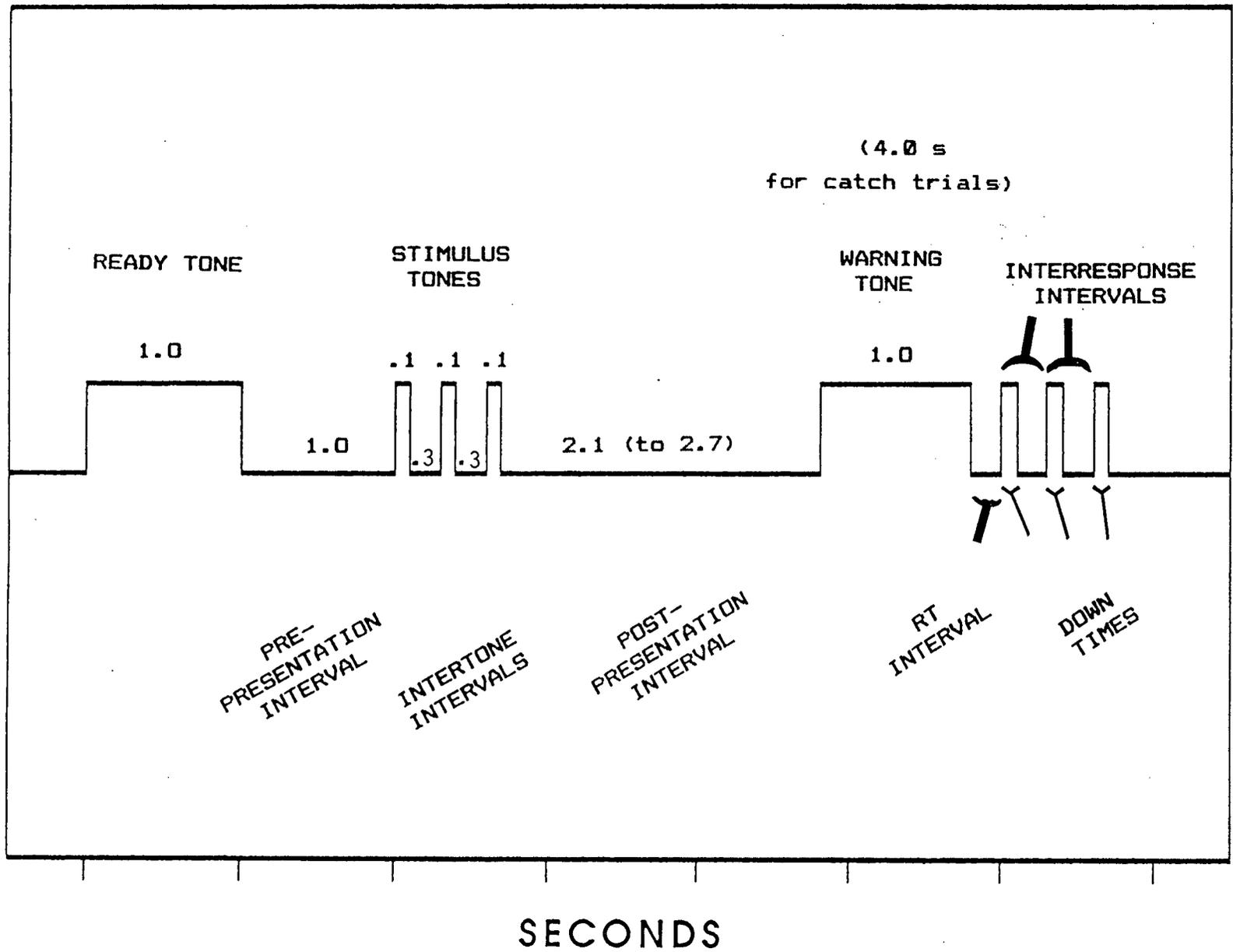
standard deviations were calculated. Individual trial RTs that exceeded two standard deviations from the condition mean were considered errors as were mean RTs greater than 500 ms. Errorful data were not included in the analyses.

For IRIs, errors were defined as those scores falling outside of an allowed tolerance range. For the 200-ms rate a tolerance range of ±50% was allowed. For the 400-, 600-, and 800-ms rates a tolerance of ±25% was allowed. The shorter response durations of the 200-ms patterns are more sensitive to mechanical and physiological variability, thus the greater tolerance range was allowed. Given the accuracy and consistency of subjects RTs and IRIs in Experiment 1, the criteria for acceptable RT and IRI performance were reduced in the present study.

Tone-onset times or "down-times" (DTs) were not subject to tolerance ranges for acceptable performance. Since they are thought to reflect articulative and not timing features of a response pattern (recall that the combined IRI reflects pattern timing), performance criteria were not deemed to be appropriate.

Results

One subject experienced great difficulty in concentrating on both aspects of the task and this was reflected in his performance. As a result, the subject's data were omitted from all analyses.

Latency Data. As predicted, trend analysis uncovered a significant linear orthogonal component for the 200-ms response rate, $\underline{F}(1,9)=11.25$, $\underline{p}=.009$, along with a significant overall effect, $\underline{F}(7,63)=3.01$, Huynh-Feldt $\underline{p}=.009$ (see Figure 6). No other higher-order trends were significant. The regression coefficient was calculated to be 4.9 ms/tap (RT (ms) = 4.9 X Number of Taps + 211). However, the single-tap RT is clearly distinct from the multi-tap RTs. This finding is not uncommon and will be discussed later. Taking into account just the multi-tap patterns, the regression coefficient was 3.0 ms/tap (RT (ms) = 3.0 X Number of Taps + 222). Similar trend analyses revealed no effects for the other rates. Surprisingly, however, RTs across conditions for the other rates were not consistently low (see Table 3). Still, as can be seen in the right hand column of the table, the overall mean RT was greatest for the 200-ms response rate.

Interval Data. The time profiles for the reproduction of IRIs are shown in Figure 7. For patterns at the 200-ms and 400-ms rates, the first and last intervals were reproduced longer than the interior intervals. There was no apparent trend in the patterns produced at slower rates with the exception of the elongated first interval at the 800-ms rate. Means of the first and last intervals for each rate are contrasted with the means of the interior intervals in Table 4. Subsequent analyses of these data revealed significant differences for the 200-ms rate, $\underline{F}(1,9)=52.87$,

Figure 6. Mean reaction time (RT) as a function of number of

taps for the 200 ms response rate. A: Regression line

calculated over all but the first task conditions.

B: Regression line calculated over all task conditions.

Table 3
Mean RT and Corresponding SD's (ms) as a Function of Response
Rate and Pattern Length

Response Rate	Number of Taps							
	2	3	4	5	6	7	8	M
400 ms								
M	242	221	227	233	229	226	220	228
SD	49	42	36	39	33	29	28	29
600 ms								
M	242	239	214	235	216	238	225	230
SD	57	43	38	36	36	36	28	29
800 ms								
M	241	224	216	248	237	239	227	233
SD	53	33	35	57	40	36	44	31
200 ms								
M								237
SD								24
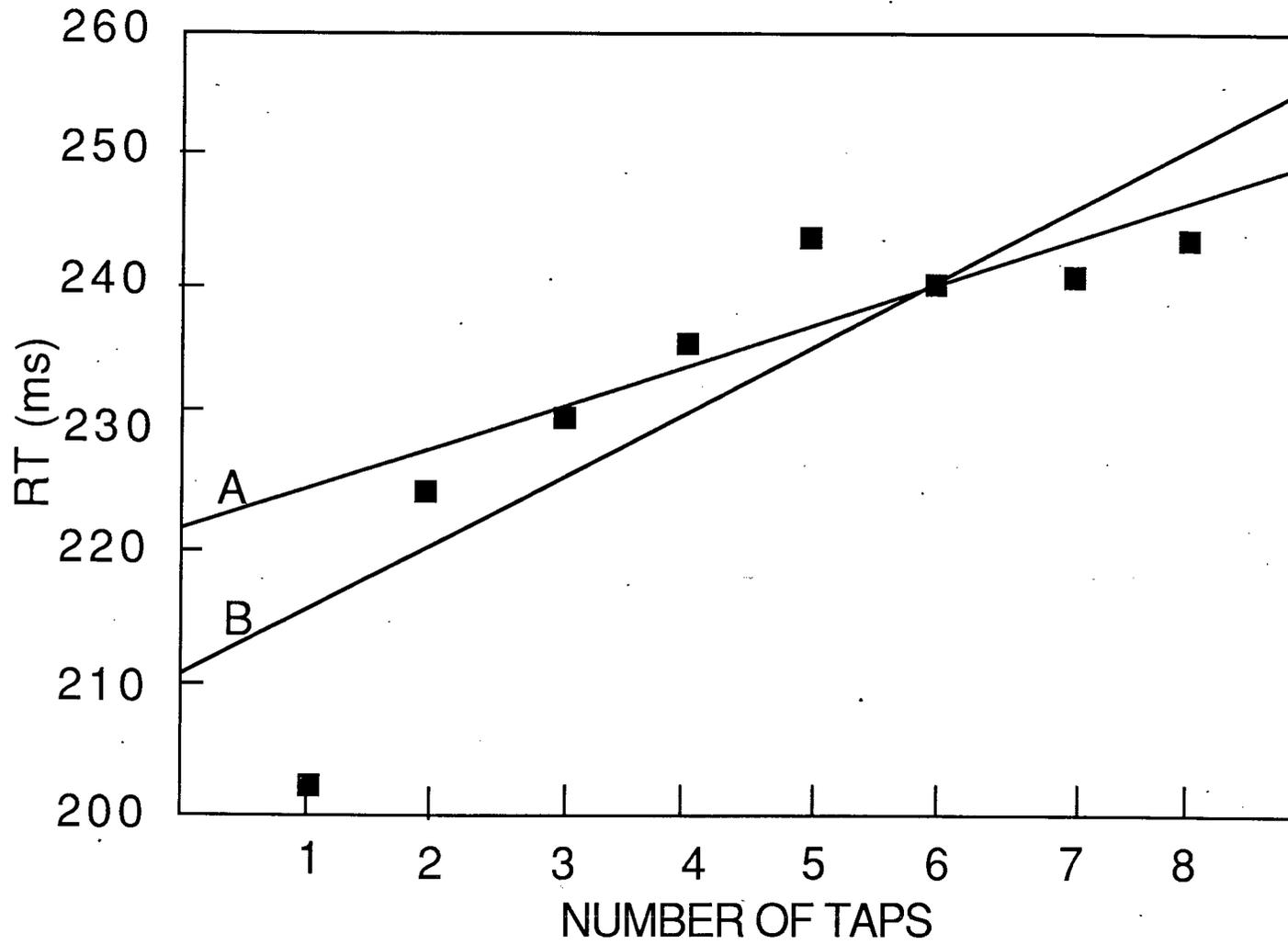
Figure 7. Mean interresponse interval (IRI) durations as a
function of pattern length. a. 200-ms rate,
b. 400-ms rate, c. 600-ms rate, d. 800-ms rate.
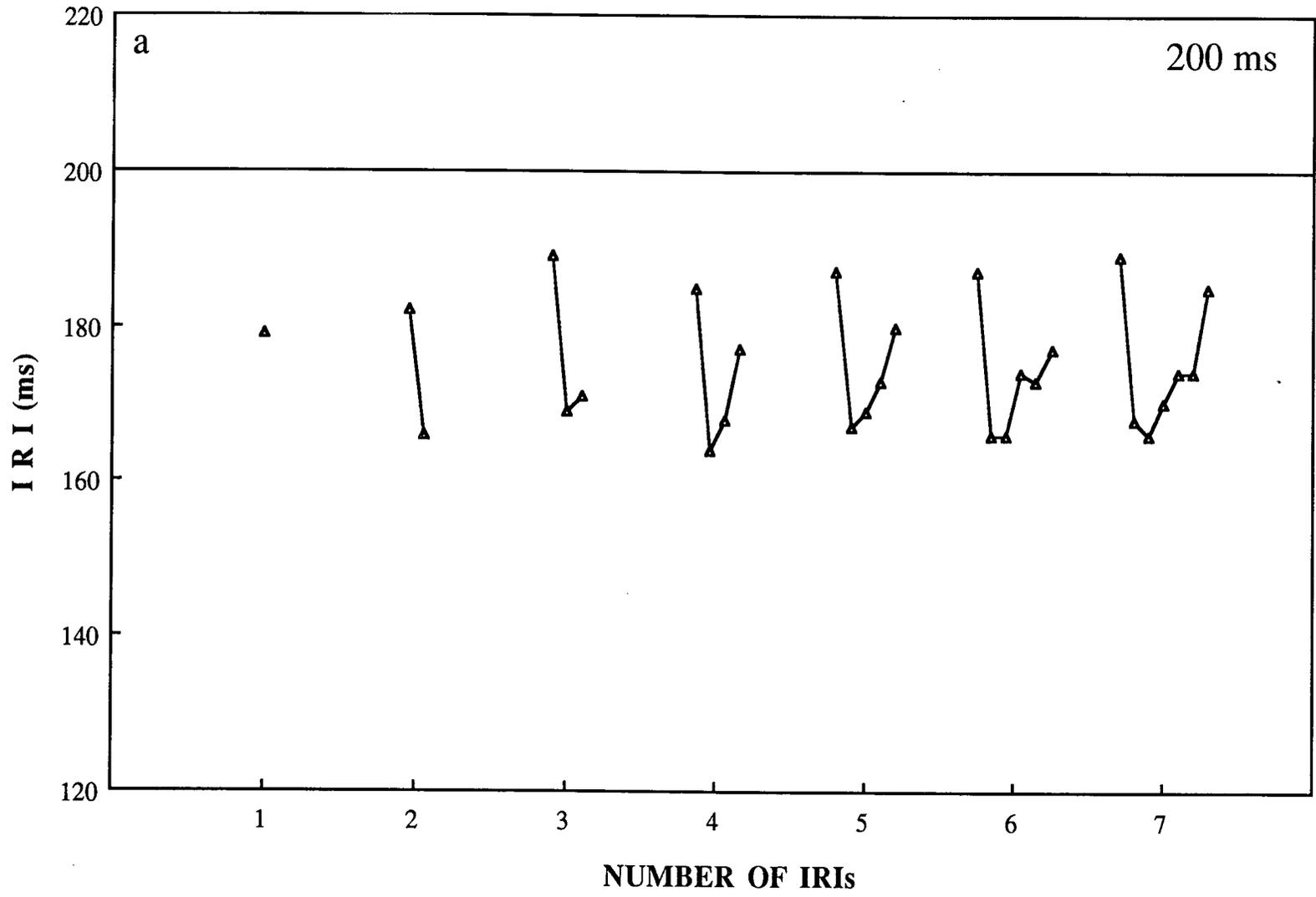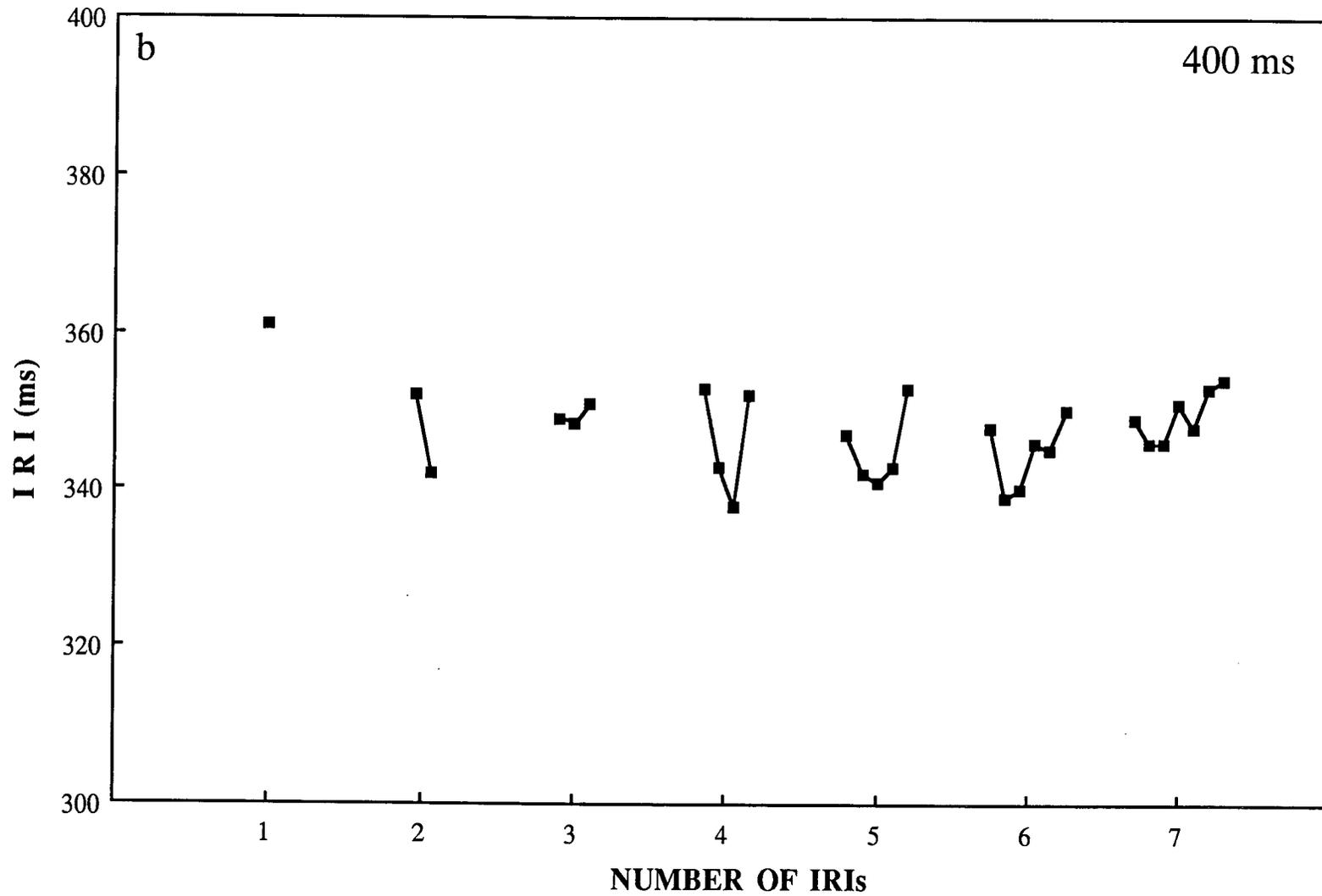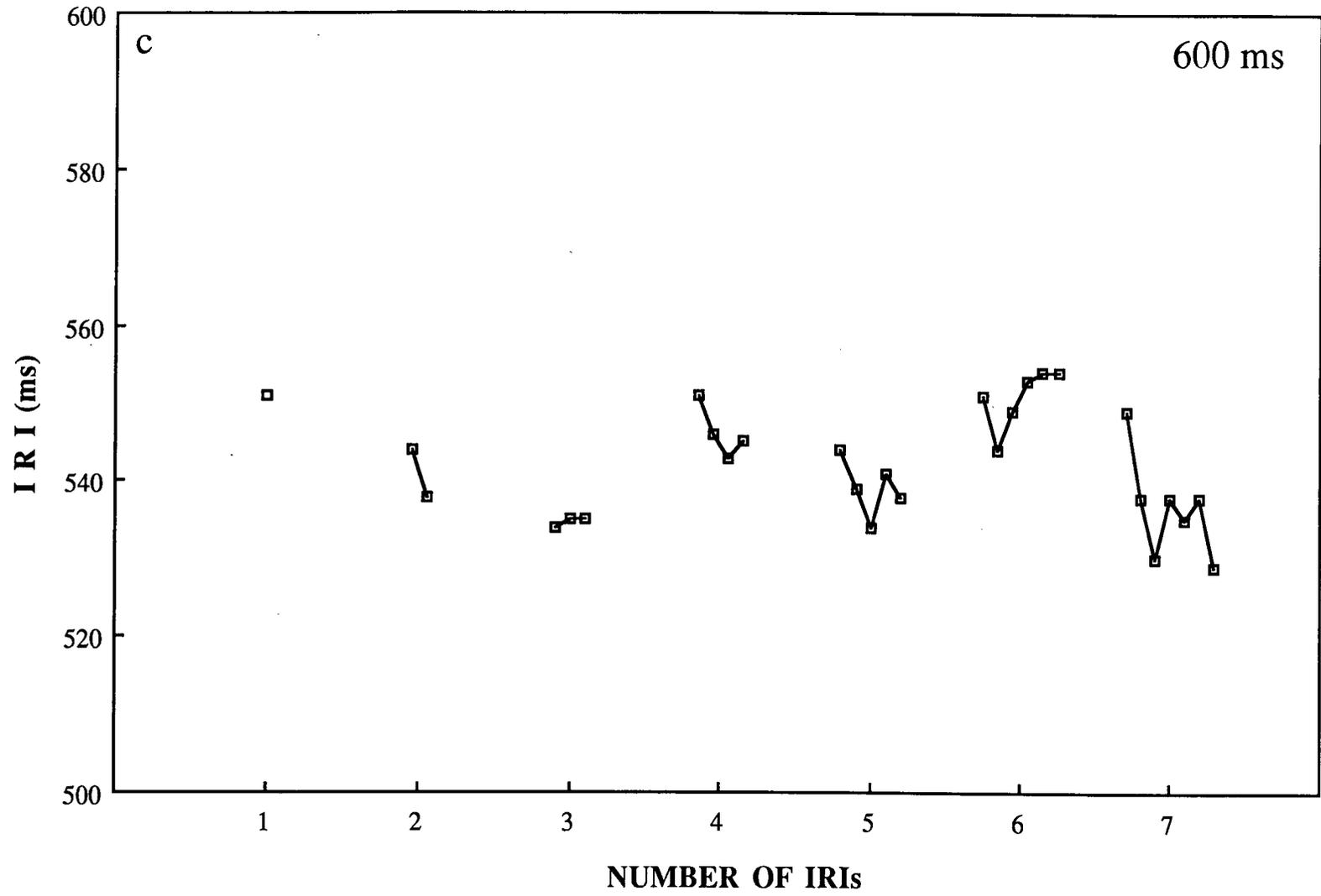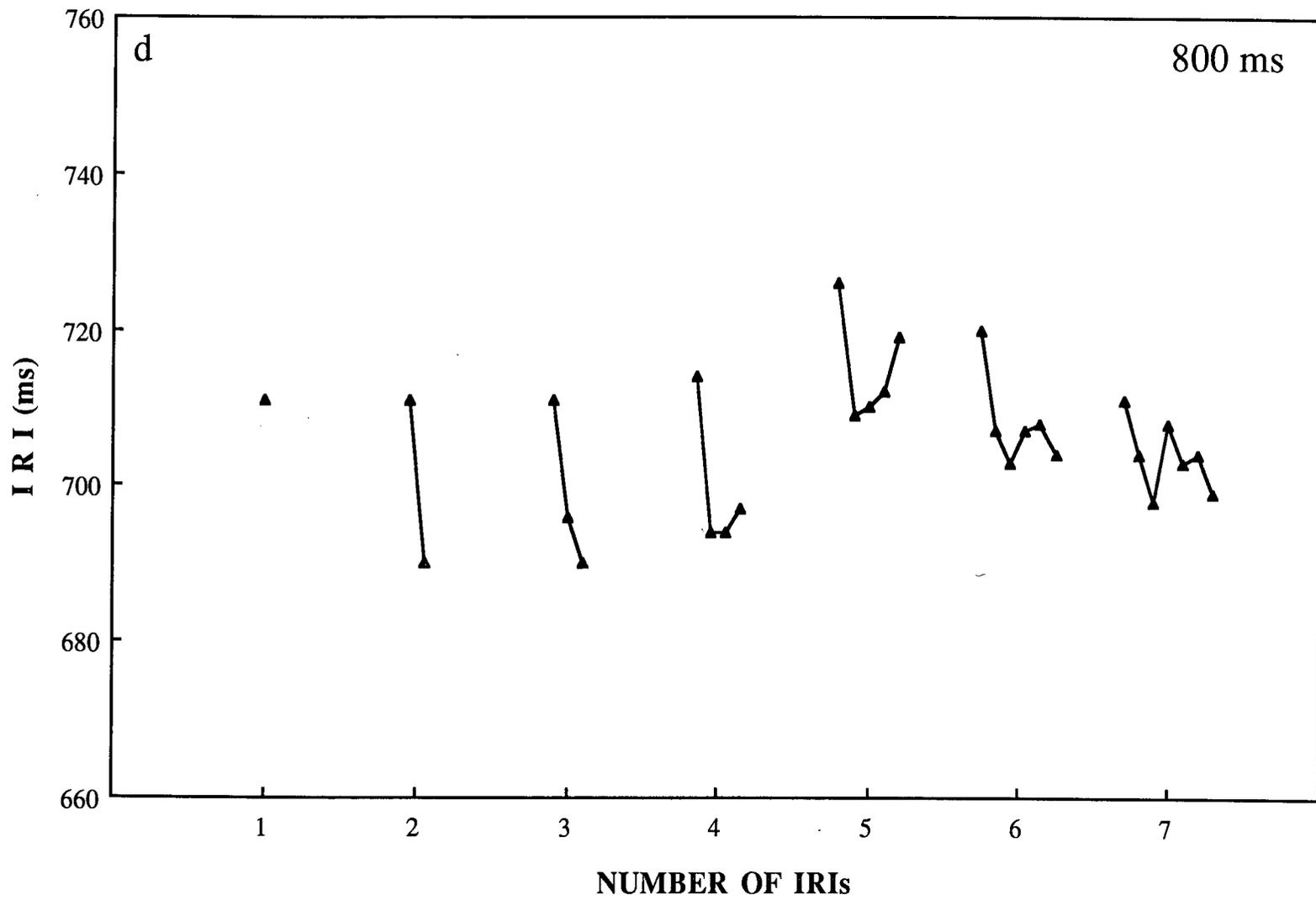
Table 4

Mean IRI Durations and Corresponding SD's (ms) as a Function
of Response Rate and Serial Position

Response Rate	Serial Position	
	First & Last Elements	Interior Elements
200 ms		
M	183	169
SD	17	14
400 ms		
M	351	345
SD	16	13
600 ms		
M	543	541
SD	19	20
800 ms		
M	709	704
SD	33	29

p<.001, and 400-ms rate, $F(1,9)= 10.11$, p=.011. Reliable differences were not found for the other response rates.

Down Time Data. The time profiles for DTs are shown in Figure 8. For patterns at the 200-ms rate, first and last DTs were longer than interior DTs. For all other response rates the first DT was the shortest in the pattern. In Table 5, the mean of the first and last DTs for patterns reproduced at the 200-ms rate is contrasted with the mean of the interior DTs. Subsequent analysis revealed a significant difference between these means, $F(1,9)=31.92$, p<.001. For the other response rates, the means of the first DT are contrasted with the means of all other DTs. Reliable differences were found at the 400-ms rate, $F(1,9)=7.62$, p=.022, the 600-ms rate, $F(1,9)=16.94$, p=.003, and the 800-ms rate, $F(1,9)=30.66$, p<.001. Visual analysis of the data made clear that the quintic (alternating) effect observed for final DTs across levels of complexity in the first experiment was not replicated for any of the response rates in the present study.

Errors. General and relevant specific error data are presented in Table 6. Total performance errors were quite high - 14.4%. That no "short" IRIs were found for the 200-ms patterns is not surprising. That the majority of short IRIs occurred in the 400-ms patterns is puzzling. Perhaps most interesting is the fact that 77% of the "long" IRIs were found for the 200-ms patterns and that, of these, 66% occurred in the last serial position (whereas 22% would be

Figure 8. Mean down-time (DT) durations as a function of
response rate and pattern length.
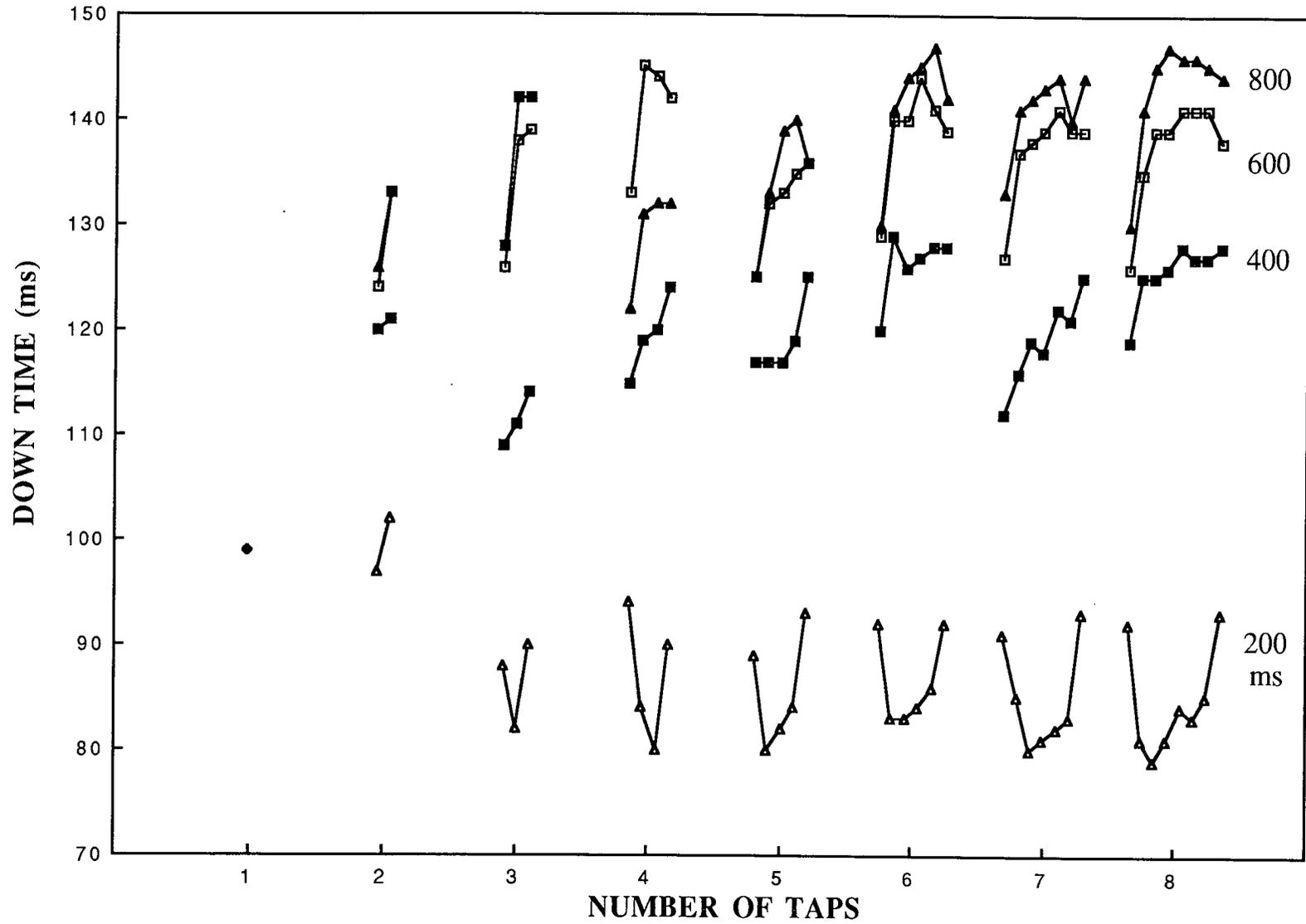
Table 5
Mean DT Durations and Corresponding SD's (ms) as a Function
of Response Rate and Serial Position

	Serial Position		
Response Rate	First & Last Elements	Interior Elements	M
200 ms			
M	91	82	85
SD	12	9	10

	Serial Position		
Response Rate	First Element	All Other Elements	M
400 ms			
M	116	122	121
SD	31	31	31
600 ms			
M	127	139	137
SD	40	42	42
800 ms			
M	128	141	138
SD	44	48	47

Table 6
<u>Classification and Frequency of Error Trials in Relation</u>
<u>to the Total Number of Trials and the Next Superordinate</u>
<u>Error Category</u>

Errors and Pattern Type		Errors		
		Number	% of Total Trials	% of Next Superordinate Error Category
Total Performance Errors		835	14.4%	
Non-RT Errors		442	7.6%	
Short IRI's		298	5.1%	
200 ms		0		0%
400 ms		161		54%
Long IRI's		94	1.6%	
200 ms		72		77%
Last ser. pos.				66% *
6-tap pattern				18%
7-tap pattern				29%
8-tap pattern				24%
400, 600, 800 ms		22		23%
Last ser. pos.				38% *
Extra tap(s)		50	0.9%	
200 ms		42		84%
6-tap pattern				14%
7-tap pattern				29%
8-tap pattern				50%
RT Errors		393	6.8%	
Catch Trial Errors		22		1.9% **

*   These percentages were calculated from the total <u>multi-</u>
<u>IRI</u> patterns. A single-IRI that was lengthened could not
be classified as a "last" serial position. Four of 72
long IRI's in the 200 ms patterns, and one of the 22 long
IRI's in the other patterns fell into the single-IRI
category. By chance, long IRI errors should have
occurred in the last serial position 22% of the time.[4]
**   This error score was calculated as a percentage of the
total catch trials.

predicted by chance for multi-IRI patterns). This is likely explained by the fact that at times subjects stopped tapping exactly one tap before the end of the pattern. The experimenter had to remind them to reproduce one additional tap. Conversely, subjects also made errors of reproducing too many taps. Again, these errors were concentrated in the 200-ms patterns and, specifically, in the longest patterns at this rate. It is clear that subjects experienced relative difficulty in reproducing the correct number of taps for longer patterns at the fastest rate.

RT errors revealed no systematic tendencies across response rate or response length. This was to be expected, however, since RTs were eliminated on the basis of exceeding twice the subject's standard deviation for each condition. For one condition performed by a single subject the mean condition RT exceeded 500 ms and was thus eliminated.

Discussion

RT, programming, response rate and response length. Execution rate determines how much processing must be done in advance of response initiation. Patterns at the 200-ms response rate display response coherence. In terms of the Sternberg et al. (1978) model, RT increases with the number of pooled subprograms that must be searched. Similar increases are not observed for the slower rates which indicates that the number of subprograms searched does not increase with increasing pattern length - the patterns do not

display response coherence. The predictions regarding programming requirements for isochronous patterns reproduced at various rates are confirmed. The 400-ms response rate, for which no prediction was made, failed to display coherence in response programming.

Three interesting aspects of the RT data require elaboration: 1) the distinctly low RT for the single-tap condition, 2) the pattern of RT means across conditions for each of the 400-ms, 600-ms and 800-ms response rates, and 3) the high mean RT for the five-tap condition at the 200-ms rate. We might account for the deviant single-tap RT by referring again to the element-invariance requirement introduced by Sternberg and his colleagues (1978). Specifically, they argued that the production of a single element may be fundamentally different from the production of multi-element patterns which have a beginning element, a terminating element, and vary only in the number of interior elements they possess. Their one-handed typing data, and the data presented here, show a greatly reduced single-element RT in relation to the trend of multi-element RTs.

However, the general evidence in this regard has been conflicting. With respect to handwriting, Hulstijn and van Galen (1983, expt. 1) found that simple RT increased linearly from two to four letters after a significant decrease from one to two letters. However, a second experiment revealed an increasing trend from one to four letters. Teulings et al. (1986, expts. 1,2) found that in patterns of one to six

continuous curved-strokes, and one to five continuous straight-strokes, RT was greatest in the single stroke condition. Yet, a third experiment showed that with the horizontal progression of successive written strokes eliminated, the deviant single stroke RT fell into line and a small nonsignificant increase resulted. Sternberg et al. (1978) found no deviations from an increasing linear trend for the single response unit in speech or two-handed typing. In our first experiment, the single-tap RT did not deviate from the trend of multi-tap RTs. Unfortunately, evidence regarding the element-invariance requirement is clouded and no conclusions can be drawn in this regard.

Perhaps more importantly, in consideration of the present design, is the fact that a single tap requires no timing component, whereas for multi-tap patterns an IRI must be programmed. This additional operation would add a constant time to multi-tap RTs. Yet, this explanation is not supported in the results of Experiment 1.

The inconsistent pattern of RT means across conditions for each of the three slower response rates is a surprising finding. We might speculate, and indeed it was observed, that reproduction of the slower patterns does not require as much attention or "effort" as for the 200-ms patterns. If subjects are not consistently attentive for the slower patterns, then they may perceive them as more or less coherent, and may employ different response strategies in

executing them. We would then expect an inconsistent pattern of RT means to result.

For the 200-ms condition, RT continued to increase through eight taps although the small increment of the slope and the relatively high five-tap RT make this interpretation somewhat tenuous. It may be that RT "plateaus" at this number of response units (or total response duration). In general, interpretation is likely to be difficult for designs that involve practice trials - as this one did - since the regression coefficient for RT decreases with learning and, as it does, becomes more difficult to distinguish from a horizontal relationship or plateau effect.

Response timing and rhythmic organization. IRI profiles show that, relative to interior pattern intervals, the first and last intervals in a pattern are lengthened for the 200-ms and 400-ms rates but not for the slower rates. Similar results have been found by Semjen and Garcia-Colera, (1986 - for pattern rates up to 300-ms but not for a rate of 600-ms), Povel (1981), and, for piano performance, by Povel (1977), Shaffer (1980) and Shaffer et al. (1985). Recall that the clustering of stimuli within a pattern is thought to result in psychological "accenting" of certain pattern elements. For clusters of more than two elements, Povel and Essens (1985) have argued that the first and last elements are accented. Shaffer et al. (1985) have suggested that this is how "coherent sequences" are organized.

If this is the case, then it appears that only those patterns presented at the 200-ms and 400-ms rates display perceptual coherence. The hierarchical structuring of temporal patterns as evidenced by accenting is what Michon (1974), among others, considers as characteristic of rhythmic patterns. The conclusion here is that, in the context presented, patterns of isochronous elements separated by more than 400-ms are not perceived as "rhythmic" patterns. Within more elaborate contexts, of course, such as those in music, pauses between elements may be greater in duration yet rhythm is still maintained.

Response articulation and system dynamics. DT profiles reveal the nature of pattern-articulation as opposed to pattern-timing. In patterns reproduced at the fastest rate, the first and last DTs are lengthened. Why? Since it takes time to overcome inertia and accelerate the response segment to a velocity that will correspond with the desired frequency of response, the first DT contact is lengthened. In terms of the Kay, Kelso, Saltzman, and Schoner (1987) Limit-Cycle Oscillator model, the "stiffness" required for the generation of a rapid rhythmic pattern is not yet achieved (stiffness is argued to be the control parameter that underlies peak velocity/frequency and amplitude/frequency relationships). The explanation with respect to the final DT is similar. Presumably, as subjects approach the end of a rapidly reproduced pattern they slow their movement (i.e. decrease the stiffness component of the system) so as not to reproduce

an extra response. Indeed, for high-frequency, low-amplitude movement patterns, this decrease is likely anticipated in advance. As a result, slowing should occur before the last element is produced - precisely what was found for the 200-ms patterns.

If there is ample time to modulate stiffness in the reproduction of patterns at slower response rates then why are the DTs not equivalent across serial positions? Why are they consistently shorter for the first tap? Simply, the task employed here was also a RT task. It was imperative to accelerate the response segment maximally to produce the initial tap as quickly as possible before achieving the stiffness required to generate responses at the desired frequency.

This interpretation of DT results, while speculative, addresses an important question with respect to response control. Specifically, to what extent do response programming, feedback, and response system dynamics interact and account for the features of response production? A specific and interesting question that results from the present study is: Are errorful patterns where an extra tap is produced due to improperly programming too many responses (a programming interpretation), inadequately processing feedback in time to terminate the response (a feedback interpretation), or a failure to modulate stiffness appropriately (a dynamical interpretation)? Of course, these alternatives are not necessarily exclusive to one-another.

One final observation is of interest here. It was visually apparent that to produce patterns at the three slower response rates subjects could quite comfortably move only their index finger. To achieve the faster 200-ms rate, however, they typically vibrated either about their wrist or their elbow. Of course, the linear velocity of a distal point along a radial arm vibrating at a fixed frequency increases as the length of the arm increases. Thus, a different and larger coordinative structure may have been employed in order to realize the high velocities required at the distal limb segment (see Kugler, Kelso, & Turvey, 1980; Kelso, Holt, Kugler, & Turvey, 1980). One outcome of this would be the necessity to overcome a greater inertia when stopping a movement and thus a greater likelihood of producing an extra tap. However, empirical research is required to shed more light on this issue.

GENERAL DISCUSSION

The major findings and implications of Section One are summarized in four parts.

The Design of "Programming" Experiments

At the outset, attention was drawn to three areas of concern in the design of experiments that investigate programming operations: methodology, the parameters of response complexity, and task selection. The simple RT method was adopted here in order to examine the processes of response implementation and the conditions under which such processes would be executed prior to response initiation. The resultant findings for various response rates, levels of complexity, and varying stimulus uncertainty, lend support to the use of this method.

Based on the linear, increasing RT trends found for the 300-ms rate in Experiment 1, the 200-ms rate in Experiment 2, and the results of previous studies (e.g. Garcia-Colera & Semjen, 1987), "number of response units" is a strong candidate for a parameter of response complexity. Unfortunately, since no similar trend was found for the 400-ms rate, this parameter cannot be separated from "total response duration". Because of different designs, equipment and procedures, RT trends cannot be compared across Experiments 1 and 2. What is needed to resolve this issue is a study in which, again, response rate and number of response units is covaried, but the response rates are kept within a

range known to result in an increasing, linear RT trend (i.e. at or below 300-ms).

In terms of the results, single key tapping proved to be a reliable task. Producing these simple and relatively invariant movements also allowed for the accurate measurement of DTs and IRIs, and their subsequent analyses.

Programming Requirements and Response Rate

Isochronous patterns were used as stimuli as opposed to "as-fast-as-possible" patterns, in order to control for and determine the influence of response rate on programming prior to response initiation. Findings from the two studies indicate that only those patterns executed at a rate at or below 300-ms display coherence and are programmed accordingly (although, Franks and van Donkelaar, 1987, have uncovered some evidence for an increase between two and three taps at a 400-ms rate). Patterns executed at slower rates are not treated as coherent as evidenced by the non-significant RT trends. The greater RT slope for the 300-ms rate in Experiment 1 compared to the 200-ms rate in Experiment 2 (10.2 ms/tap vs. 3.0 ms/tap) is likely due to the absence of practice trials in the former study - recall that Sternberg et al. (1978) found that the magnitude of the regression coefficient decreases with learning.

The RT results reported here are consistent with the theoretical distinction between program construction and program implementation (Ivry, 1986). Specifically, the program for a known response pattern is constructed in

advance of the signal to respond. But the implementation of the program is delayed until after the signal to respond. The duration of program implementation for the first response unit (RT) is directly related to the number of response units in the pattern.

Stimulus Uncertainty

Experiment 1 is the first study to show that RT increases linearly with response complexity even in the absence of externally-induced stimulus uncertainty. If the initiation of program implementation automatically led to response execution then removing catch trials should allow for implementing the program prior to the signal to respond, and thus no simple RT effects would result. Yet, this was not the case. An alternative explanation that remains is that placing an implemented but yet-to-be-triggered program in a motor buffer would subject it to rapid decay or interference in the event of stimulus processing (Sternberg et al., 1978).

Response Timing and Response Articulation

The reproduction of isochronous stimulus patterns revealed several interesting findings. First, in Experiment 1, intertrial variability decreased with increasing pattern length. The development of a well-defined temporal structure may be directly related to the number of temporal intervals in a pattern. Longer patterns allow for an expanded network of relations among adjacent and non-adjacent intervals.

Second, in Experiment 2, IRI profiles showed that the 200-ms and 400-ms patterns were organized as accented clusters of tones (i.e. rhythmic patterns). The first and last IRIs in these patterns were consistently lengthened in relation to interior IRIs. Curiously, similar accenting was not observed for reproduction of the 300-ms patterns in Experiment 1, although, with fewer trials, a rhythmic organization may not yet have developed.

Finally, the results of Experiment 2 give a preliminary indication that measuring response articulation may be useful in reflecting the dynamic features of movement production. It would appear to take time both to accelerate a response segment to a velocity that corresponds with a rapid response rate, and to decelerate that segment in order to avoid making more responses than desired. (However, this does not presume a specific cause for the error data discussed earlier). RT studies demand maximal acceleration in the production of a first response unit which explains why DTs are not equivalent for response patterns reproduced at slower rates.

SECTION   TWO:

The Perceptual Organization of

Rhythmic Patterns

What are the principles that govern the perceptual

organization and representation of rhythmic patterns? Since

the mid-1800's this question has been investigated - with

especial vigor over the last 20 years. Although the focus

here is not necessarily rhythm in a musical context, much has

been learned from studying rhythm in such a context. In this

section, the major efforts in the study of rhythm perception

will be reviewed.

The principles that govern rhythm perception must

ultimately account for a number of subjective phenomena.

These include: the groupings of events in a pattern, the

accenting of events, the ordinal and ratio relations among

events, the absolute durations of events, and the limits in

perceiving each of these. In addition, account must be made

of the fact that recognition of patterns that vary in

"expressive" timing still occurs (Clarke, 1985). How far

such expression can be "stretched" before recognition is

lost, and how that depends on the nature of the specific

pattern is presently unknown.

Is it meaningful to talk of the experience of rhythm as

just "perceptual"? Likely not. Since global aspects of a

rhythmic pattern are extended in time, memory becomes

inextricably linked with rhythm perception (Dowling &

Harwood, 1986). Memory demands have been used to explain why

low scores are observed for longer items in tests of rhythm perception, performance and movement (Thackray, 1969). The development of a rhythmic organization allows us to anticipate and predict what will follow (Fraisse, 1982). The perception of rhythm is also sensitive to learning. Sloboda (1985) recounts the powerful experience of suddenly realizing a new relationship among events in a long-familiar piece of music - an experience well-known by serious music listeners.

Finally, by way of introduction, the perception emerging from concurrent, conflicting rhythmic patterns (polyrhythms) is a whole other, and challenging, area of investigation (see Deutsch, 1983; Handel & Oshinsky, 1981; Handel & Lawson, 1983; Yeston, 1976). Because of the seemingly boundless diversity of polyrhythms, some have suggested that, " ... it is unclear whether there is a level or levels at which generalizations about rhythm can emerge." (Handel & Lawson, 1983, p.120). The perception of rhythm as emergent from the presentation of polyrhythms will be not be discussed in this section.

Subjective Rhythmization

A pattern of identical sounds separated by equal time-intervals is spontaneously perceived in groupings of two, three, or four events (Bolton, 1894). This holds for ISI durations of 115 ms to 1500-2000 ms (Bolton, 1894; MacDougall, 1903; Fraisse, 1956). Bolton (1894) found that the size of the grouping increases with the rate of

presentation. MacDougall (1903) showed that if subjects produce groups of two, four or six intervals, the rate of production increases with the size of the group. In performances of Erik Satie's piano piece "Vexations", Clarke (1982) observed that the music was segmented into fewer groups when played at faster tempi. These early studies demonstrated that optimal group size interacts with tempo.

Gestalt Principles of Grouping

A number of Gestalt grouping principles are applicable to the perceptual organization of rhythmic patterns. The law of Pragnanz states that the psychological organization of a perceptual field will be as "good" as the prevailing conditions allow. Garner and his colleagues were the first to invoke this notion with respect to temporal patterns (Garner, 1962; Garner & Clement, 1963; Royer & Garner, 1966). It was shown that patterns of dichotomous elements which have few alternative modes of organization are considered simple, easy to organize, and thus good (Royer & Garner, 1966). Such patterns have a higher psychological redundancy and are less uncertain than more complex patterns.

This notion of goodness was later shown to have temporal limits, reiterating the notion that grouping interacts with tempo. On the basis of experimental evidence, Garner and Gottwald (1968) defined pattern perception as occurring when (constant) stimulus presentation rates are greater than two elements per second, and pattern learning as occurring at

lower rates. They argued that the perception of a pattern is
integrated and phenomenally immediate while the learning of a
pattern is an active, intellectualized, extended process.
This distinction, while useful at the time, can be regarded
as too limited in light of the fact that most rhythmic
patterns are not isochronous and that, even in the case of
isochronous patterns, rapid patterns extended over a very
long period are neither integrated nor immediate.

A number of researchers (Preusser, Garner & Gottwald,
1970; Restle, 1967; Restle, 1970; Restle and Brown, 1970;
Royer and Garner, 1970), extended the principles of serial
pattern organization to include the Gestalt laws of
similarity and good continuation. With respect to
similarity, these researchers showed that a "run" - a series
of consecutive elements of one type in a larger pattern of
mixed elements - is a psychologically meaningful unit.
Preferred grouping places the longest run at either the
beginning or the end of a pattern depending on whether the
element-type is regarded as figure or ground (Preusser,
Garner & Gottwald, 1970). With respect to good continuation,
patterns that have a "directional simplicity" of either
increasing or decreasing run-lengths are also preferred
(Royer & Garner, 1970).

The description of rhythmic pattern perception based on
Gestalt grouping principles was found to be inadequate for
several reasons. One main reason was that there was no
account of higher-order groupings or relationships between

Gestalt-determined groups - in short, there was no hierarchical organization. In a paper of considerable foresight, Lashley (1951) discussed rhythmic action, and hierarchical conceptions of behavior as possible solutions to the problem of serial order in behavior. The emerging research in rhythm perception in the 1970's, and beyond, followed his lead, and theorization in the area experienced a quantum leap.

Tenney and Polansky (1980) proposed a temporal gestalt model of perception that outlines the hierarchical organization of patterns of time-spans in monophonic music. They suggested that elements in a musical piece are grouped according to the Gestalt laws of similarity, good continuation and proximity. With respect to proximity, it was stated that, all else being equal, listeners tend to place group boundaries at intervals that are longer than the immediately preceding and succeeding intervals - proximal elements are grouped together. Higher levels of organization result by applying the laws to lower-level groups. This process continues until no higher-level group can be organized.

The model, which integrates the parameters of time, pitch and intensity, was applied to musical pieces composed by Varese, Webern and Debussy. The predicted segmentations were compared with the segmentations made by experts in the music analysis literature. Results showed that the predicted organizations compared well with those suggested in the

literature. These researchers attributed deviations from the
model to the fact that it does not account for: timbre as a
parameter, harmonic factors, motivic factors, and further,
does not allow for single-event perceptual groups.

We can question the model on several counts. First,
because of the model's high degree of hierarchical
organization, substantial "recognition-delays" (i.e. the time
from the physical initiation of an organizational unit until
the time that the unit is recognized as completed) are
implicit at higher levels since group boundaries are
determined in comparison to preceding _and_ succeeding time
intervals. Given such recognition-delays and the need for
memory and anticipation, does it make sense to speak of
"perceptual processing"? This problem is acknowledged by the
authors. Second, the reality of unlimited higher-order
grouping can be questioned. Is this _really_ a subjective
phenomenon; what purpose would it serve? Third, while
proposing an organization based on the _ordinal_ relations
between time-spans, the model does not consider their _ratio_
relations and how these might influence perceptual
organization. With the exception of the Garner and Gottwald
(1968) study on perception, learning and the _interval_
relations of ISIs, most Gestalt descriptions of rhythmic
pattern perception are restricted to the ordinal
relationships between intervals.

In developing a generative theory of tonal music,
Lerdahl and Jackendoff (1983; also Jackendoff & Lerdahl,

1981) have proposed a series of Grouping (and Metrical) "Well-Formedness" and "Preference" rules. The former establish the formal structure of grouping patterns and their relationship to the series of musical events that form a piece, and the latter determine which of the formally possible structures correspond to the listener's actual intuitions. This theory marked a significant advance in that some consideration was given to relative timing among Gestalt-determined groups. For example, one Grouping Preference Rule states a preference for group subdivision into two parts of equal length. While unquestionably a step in the right direction, the treatment of relative timing in rhythm perception requires a much more comprehensive analysis.

Perception of Temporal Ratios

It is a fairly robust finding that subjects' reproductions of unequal temporal intervals are biased towards a ratio of either 2:1 or 1:1. Fraisse (1946) demonstrated this finding for patterns with a long interval less than twice the duration of a shorter interval. Povel (1981) replicated this finding and extended it for patterns with a long/short ratio of more than 2:1. Summers, Sargent and Hawkins (1984) observed this trend for three-event patterns. Sternberg et al. (1982) extensively researched the judgement, production and reproduction of temporal ratios. The reproduction research yielded general support for the

above findings. Presented patterns that deviated the most from a 2:1 ratio (i.e. 8:1, 6:1 and 8:7, 6:5) were clearly reproduced with a tendency towards 2:1. This effect was not as clear, however, for patterns with long/short ratios closer to 2:1 (i.e. 4:1 and 4:3). These results, in general, support the notion that temporal ratios are reproduced in accordance with preferred rhythmic structures - 2:1 or 1:1. This is not surprising, considering Fraisse's (1956) report that an average of 86% of tone durations in a representative sample of Western music stood in the relation of 2:1.

As with the earlier Gestalt descriptions of rhythm perception, the above generalization says nothing about possible hierarchical organizations of more complex rhythmic patterns. Martin (1972) developed a model to answer this criticism. He suggested that rhythmic patterns are organized in the form of binary trees and proposed rules for determining the relative timing and relative accent for each event within a pattern. Events may be external-world events, or internal-world events which do not occupy a space in the external physical pattern but do have a psychological reality. While providing a good account for simple examples of speech and music, Martin's model is limited in several respects. First, it applies only to sequences that contain a total of 2^n events. Clearly, we often group and accent rhythmic patterns by threes rather than twos (dancing a waltz would be rather difficult, otherwise!). Second, given a long sequence of events, the model necessitates a multi-level

hierarchy (e.g 4 levels for 16 events, 5 levels for 32 events, etc.) that would predict distinct accent levels for each event.

Povel (1981) investigated the perception of various temporal ratios within the context of rhythmic patterns. He outlined and tested a "beat-based" model for rhythmic pattern perception in which the initial step is the segmentation of a pattern into equal intervals bordered by psychologically accented, external-world events called "beats". Shorter temporal intervals within the pattern are represented as subdivisions of the beat-interval. For example, the pattern "250/250/250/250/1000" (all units in ms) is organized as two-1000 ms beat-intervals, the first subdivided into four equal interval units. On the other hand, the pattern "250/250/250/250/800" would not conform to a beat-based model since it cannot be segmented into equal beat-intervals. Note that beat-intervals are consistent with the Gestalt laws of similarity, and regularity - the tendency to group things into regular bundles rather than irregular ones. Povel found, in general, that the reproduction of patterns that conformed to a beat-based model was more accurate than for patterns that did not.

Povel's model and findings were inconclusive for several reasons. First, although it was stated that beat-intervals typically range between 250 and 1500 ms, no account was given for how to select among candidate beat-intervals within this range. More complex rhythmic patterns are likely to have

more than one interval that could serve as the beat-interval.
Second, only external-world events are allowed to initiate a
beat-interval. In music, however, it is common to have rest
notations lasting the duration of one beat, one measure or
longer. In Povel's scheme, any pattern lacking a recurring,
external-world event would be poorly organized and
reproduced. Third, rules for beat subdivision were not
determined, with the exception that the first level of
subdivision below the beat-interval can only be of one type.

Povel and Essens (1985; also Essens & Povel, 1985;
Essens, 1986) developed a model for rhythmic pattern
perception based on the accenting of local events and the
fitting of a "best" internal clock to these accents. In
patterns of identical tones differing only in their ISIs, we
psychologically accent isolated tones, the second in a
cluster of two tones, and the initial and final tones in a
cluster of more than two tones. Consider a sample pattern:

/ / / / / . . / / . / . / / / .

where "/" indicates an external-world event and the
subsequent interval (i.e. an ISI), and "." indicates a silent
pause of equal duration to the ISI. According to the accent
rules, the following representation would result:

```
    '          '        '    '    '    '
    / / / / / . . / / . / . / / / .
```

where " ' " represents a local accent. A competition between
possible clocks then takes place. Clocks can vary according
to their unit size (i.e. the number of ISIs or duration

between "ticks") and their location (i.e. their starting location). The clock unit must be an integer divisor of the total pattern duration that is greater than two. Clock units of only one interval do not contribute to a higher order organization and thus are not considered. Clock induction strength is based on the calculation of how many clock ticks coincide with locally accented, unaccented, or silent events. Clock selection is determined by the amount of counter-evidence a clock meets in a pattern. If the possible clocks for the above pattern are considered (see Table 7), then clock (3) is selected as the preferred clock for pattern perception. Every clock tick coincides with the accenting of a local feature.

Following the generation of the best clock, any unaccented or silent intervals that coincide with clock ticks are accented as "beats". In cases where a best clock cannot be determined from counter-evidence, it is determined by the ease of pattern coding. For example, equally spaced subintervals (up to three) or empty unit intervals are more easily represented than complex integer relations among unit subintervals.

Several concerns arise from this model. First, there is no explanation of why clock units must be less than (as opposed to less than or equal to) 1/2 the total pattern duration. Indeed, this requirement results in a failure to explain the Povel (1981) findings that the patterns "250/250/250/750", and "250/250/250/250/1000" were well

Table 7
<u>All Possible 2-unit and 4-unit Clocks for a Rhythmic Pattern</u>

```
              '        '        '   '   '    '

              / / / / / . . / / . / . / / / .

2-unit    -   -   -   -   -   -   -   -           (1)

  "           -   -   -   -   -   -   -   -       (2)

4-unit    -       -       -       -               (3)

  "           -       -       -       -           (4)

  "               -       -       -       -       (5)

  "                   -       -       -       -   (6)
```

(" - " represents tick location)

reproduced - each presumably as two equal beat-intervals
varying in subdivision frequency.

Second, what if a pattern is interspersed with a few
rapid elements? Let us consider again the sample pattern:

```
  '         '        '    '    '     '
 / / / / / . . / / . / . / / / .
 -         -        -        -
                ^
```
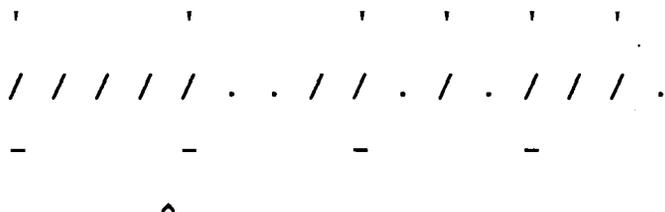
and subdivide the fourth event into three subintervals. This
means that silent intervals must be inserted throughout the
rest of the pattern to match the shortest fundamental
subinterval. The entire accenting pattern would change as a
result (the previous pattern of clock ticks is displayed).

```
 '  '  '  '  '  '  '  '  '      '      '  '  '
/../../../////.........../../...../...../../../.....
 -        -        -        -
```
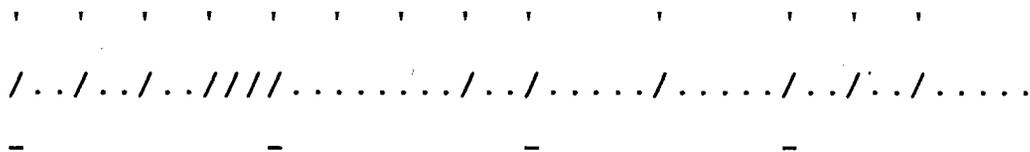
Recall that clock units can not be easily subdivided into
more than three equal units. This new representation results
in many complex subdivisions and necessitates the search for
a new clock. This does not seem correct. In music, a
constant beat and meter can be maintained even in the event
of a brief period of very rapid notes.

Finally, there is no regard in the model for the
absolute durations of intervals and, thus, pattern tempo.
And it may be that this oversight underlies the second
problem with the model noted above. Specifically, if
fundamental intervals and clock units were required to be

within an absolute range of durations then the modelling
problems created by the intrusion of a few, rapid events
might be avoided.

Processes in Rhythm Perception

The Povel and Essens (1985) model is presented by the
authors as a descriptive, not a process, model. Longuet-
Higgins and Lee (1982, 1984) have developed a process model
of rhythm perception that emphasizes the identification of
metrical units. On the basis of the first ISI, the listener
forms a hypothesis and predicts the occurrence of the next
beat. Confirmation of this hypothesis leads to a new
hypothesis regarding recurrence of the combined, higher-level
interval. If successful, this process continues up to a
maximum metrical-unit duration of around two to three
seconds. Disconfirmation of a hypothesis causes the listener
either to update the hypothesis by using the second ISI as
the reference interval or to stretch the first ISI to include
the duration from the second to third beats.

Results of the model's predictions were encouraging but
a failure to account for organization in the event of
changing tempos, changing meters, expressive variations in
timing, and the influence of Gestalt grouping principles
either in support of or counter to the predictions based on
relative note lengths, all constitute limitations. In
addition, Lee (1985) has argued that the inability to explain
how metrical evidence earlier in a pattern is weighted more

than later evidence, as well as what determines whether contrary evidence is regarded as a counter-example or merely as an exception to the hypothesis, presents difficulties for the model.

Summary

A comprehensive model of rhythm perception is currently not to be found. At least part of the problem is that theoreticians have often overlooked the role of factors that were introduced at the outset of this section, and demonstrated throughout, to be critical in the perception of rhythm. One fundamental factor is Gestalt organization. Although dealing, for the most part, with ordinal relations between events, the principles of Gestalt grouping are salient in the perceptual organization of temporal events.

The hierarchical organization of temporal structure is another fundamental factor. However, as evidenced in the Martin (1972) and Tenney and Polansky (1980) models, excessively "vertical" hierarchical structure is both inefficient and unlikely given the accumulating durations required for higher levels of structure. Consider also, as Sloboda and Parker (1985) have insightfully noted, that a rhythmic pattern may not be perceived as a fully coordinated structure, especially the first time it is heard. Again, this addresses the role of memory in filling the gaps or exposing new relationships in previously "incomplete" rhythmic structure.

The importance of relative timing in rhythm perception is unquestionable. Much of the work of Povel and his colleagues clearly shows how certain ratio relations and subdivision frequencies are preferred both within and outside of a metrical context.

With the current emphasis on relative timing, the absolute durations of the intervals investigated must not be taken for granted. Fundamental beat-intervals and higher-order metric groupings likely occur within a more-or-less fixed range of durations. Recall that the interaction of grouping and tempo was one of the original areas of investigation in rhythm perception.

Flexibility is necessary in a comprehensive model of rhythm perception. Perceptual organization is maintained in the presence of changing meters (higher-order temporal units), changing tempi (beat rates), and expressive variations within each of these.

Rhythm perception may best be characterized as the dynamic interplay among local, global, and what I will call regional features in a temporal stimulus pattern. A crucial process in rhythm perception is the identification of the beat-interval. If a beat-interval must fall roughly within a range of 250-1800 ms (beat-interval ranges will be discussed more thoroughly in Experiment 4), then, presumably, both higher-order and lower-level units should be organized in terms of that interval. The beat-interval is a regional feature.

Although this is speculative, I would suggest a loose analogy to Kinchla and Wolfe's (1979) "middle-out" processing in which the order of stimulus processing originates from more optimally-sized features and proceeds in directions of both increasing and decreasing size. In terms of accommodating changing meters and expressive timing, decreasing the role of memory processes in perception, and given the flexibility for changing tempi, it makes sense for this stimulus level - the beat-interval - to display processing dominance (i.e. in general, to be perceived more easily, remembered longer and more accurately, and be more resistant to interference - see Ward, 1983) even though it does not necessarily have temporal precedence in extraction from the stimulus pattern. However, as Ward (1983) has noted, temporal precedence is only one possible cause of processing dominance.

Processing by means of a "top-down" hierarchy (once it is constructed) does not allow for the flexibility required of real-world rhythm perception. Although there is currently no evidence in support of the processing dominance of regional features, this may be a direction to consider in the search for a broader understanding of rhythm perception.

The studies in this section investigate the conditions under which perceptual events are organized into coherent groups. Does the grouping of stimulus events require that patterns be divided into intervals of equal duration? Must external-world events initiate the perceived grouping-

intervals in simple rhythmic patterns? Is the perceptual
grouping of auditory stimuli subject to limits of duration or
number of events?

Of central interest here are the regional features of
auditory stimulus patterns. Individual events are the local
features; regional features emerge from the grouping of
these. And with the cyclical presentation of each pattern,
subjects may perceive higher-level global features, although
the investigation of this is beyond the scope of the present
studies.

Consistent with the concerns discussed throughout the
introduction to this section, the data reported here are
analyzed with respect to their absolute timing, relative
timing, and ordinal relationships, in order to provide a more
complete picture of rhythmic pattern perception and
reproduction.

Experiment 3

A common feature among models of rhythm perception is
that the relative timing of external-world events determines
the selection of higher-order (beat or metrical) grouping-
intervals (Longuet-Higgins & Lee, 1982; Povel, 1981; Povel &
Essens, 1985). Typically, the higher-order grouping-interval
must be initiated, if possible, by an external-world event.

As is often the case in music, though, a metrical
context can be preserved even if the measure is not initiated
by an external-world event. Apel (1972) reminds us that a
beat may be external or internal to the subject. Canic and
Franks (1985) found that well-practiced patterns could be
accurately reproduced if the first higher-order interval was
divided into subintervals of equal duration and the second
such interval was empty of external-world events. Sternberg
et al. (1982, expt. 12) showed that for the production of
beat-fractions, subjects were just as accurate when the start
of production coincided with a given "beat" as when it began
just after the given beat - that is, when the beat-interval
was not initiated by a subject-generated event. Yet, in the
latter case, the initiation of the first beat-fraction was
minimally delayed with respect to the given beat.

For simple rhythmic patterns, do subjects perceive
higher-order groupings of equal duration when each higher-
order interval is not initiated by an external-world event?
Do such patterns provide sufficient context for the
perceptual organization of equal duration higher-order

groupings? We might consider, by way of analogy, the importance of context in pitch perception. Lockhead and Byrd (1981) investigated "practically perfect pitch" - the ability to identify any note of the musical scale. They found that musically-trained subjects with this ability performed almost flawlessly in recognizing musical notes as played on a piano; however, performance was significantly poorer for the identification of variable-frequency sine waves generated by a computer controlled oscillator.

We investigate, here, patterns which are divisible into two intervals of equal duration. For all patterns the first interval is divided into subintervals of equal duration. In one group of patterns the second interval is initiated by an external-world event - the only event in the interval. In the other group of patterns the second interval contains no external-world events. An underlying assumption, consistent with all but Povel and Essens (1985), is that the duration of a higher-order grouping does not have to be less than half the duration of the entire pattern.

If the presented patterns are perceptually organized as two higher-order intervals of equal duration then the accuracy of pattern reproduction would not be expected to differ. Opposing principles of organization may be at work, however. The Gestalt principles of similarity, symmetry and regularity would suggest the organization of rhythmic patterns into higher-order intervals of equal duration (see Jackendoff & Lerdahl, 1981; West, Howell, & Cross, 1985).

This tendency may be opposed if there is no external-world event to initiate each interval - the higher-order grouping may not be realized. It may also be opposed by a "Grouping Preference Rule" proposed by Jackendoff and Lerdahl (1981) that strongly discourages single event groups.

If these patterns are not all perceptually organized in the same way then the (agogic) accenting of events is likely to reflect these differences. It is generally accepted that events at the beginning and the end of stimulus groups are psychologically accented (Fraisse, 1978, 1982; Povel & Essens, 1985). Can beats that are internal to the perceiver occupy these positions?

Method

Subjects. Twenty-four male and female students from the University of British Columbia participated in the study as part of a course requirement. Subjects ranged in age from 21 to 33 years. A $20.00 prize was offered to the subject who most accurately reproduced the response patterns.

Apparatus. The apparatus was the same as described in Experiment 1.

Stimulus Patterns. Subjects were instructed to reproduce eight different stimulus patterns. Two pattern-types were presented for each of four different pattern durations (see Table 8). All patterns could be divided into two intervals of equal duration with the first interval further divided into equal duration subintervals. For half

Table 8
Stimulus Patterns for Experiment 3

Pattern-Type	Pattern Representation / Ratio	
X (1200 ms) E	/../.. /..... /../..	1:1:2
X (1800 ms) E	/../../.. /........ /../../..	1:1:1:3
X (2400 ms) E	/../../../.. /........... /../../../..	1:1:1:1:4
X (3000 ms) E	/../../../../.. /.............. /../../../../..	1:1:1:1:1:5

"/"   represents an external-world event (100 ms)

"."   represents a silent interval (100 ms)

"X"   represents patterns in which both intervals are initiated by an external-world event

"E"   represents patterns in which the second interval is empty

*

For the sake of clarity a break has been inserted artificially dividing each pattern into two intervals of equal duration.

of the patterns the second interval was initiated with an external-world event ("X"-type patterns); the other half contained no external-world event ("E"-type patterns). The physical characteristics of the tones and the tone durations (100 ms each) were the same as in Experiment 1.

Procedure. Subjects were seated at a table and instructed as to the nature of the study. A demonstration of the procedure was viewed. The time line for stimulus presentation was the same as in Experiment 1 (see Figure 1) with the following exceptions: Stimulus patterns were those shown in Table 8, subjects listened to 20 cycles of each stimulus pattern, the Post-Presentation interval (prior to the 1000 ms Warning tone) ranged from 1500 to 2700 ms, and subjects reproduced each pattern cyclically until keypressing no longer generated response tones (after 20 cycles).

One trial was performed for each stimulus pattern. The order of presentation across subjects was determined by a balanced Latin Square design. Reproduction of all eight stimulus patterns concluded the study.

The task was to reproduce the timing of each stimulus pattern as accurately as possible. In addition, half of the subjects were instructed to initiate reproduction of the stimulus pattern as quickly as possible following the offset of the warning tone. This condition was added to investigate the effects of response complexity and duration on RT. However, with the cyclical (rather than singular) presentation of each stimulus pattern, the size of the

implemented response program is likely to vary among subjects.

Analysis. The fundamental unit of comparison was the IRI. Relative measures of the shortest temporal intervals (300 ms) to the longest intervals (600-1500 ms) were not possible for the patterns with the empty second interval since there is no external-world event that acts as a marker in time. As a result, patterns of the same type were compared with respect to: 1) total pattern duration, 2) the profiles across the shorter IRI durations common to each pattern, 3) interindividual variability in the reproduction of shorter IRIs and total pattern durations.

Total durations for X-type and E-type patterns were compared by calculating a proportional error score equal to $(x-c)/c$ where "x" is the reproduced pattern duration and "c" is the criterion duration (i.e. 1200, 1800, 2400, 3000 ms).

There is general agreement that filled intervals are estimated as being longer in duration than unfilled intervals (Allan, 1979; Ornstein, 1969; Poppel, 1978). To test this hypothesis, the relative durations of higher-order intervals were compared in the X-type patterns.

RT to initiate the cyclical reproduction of the response pattern was also measured. Comparisons were made across instruction conditions (RT vs. Control), and within the RT group in contrast with response complexity (defined as the number of taps per one cycle of the pattern) and total pattern duration.

Results

Latency data. RT was significantly different across instruction conditions, $F(1,22) = 11.04$, $p=.003$. Mean RT was 1397 ms for the Control group and 351 ms for the RT group. As no visible trends were obvious for the data of the Control group, further analyses were not performed. Visual analyses of the RT group data suggested that RT increases with number of taps per one cycle of the pattern (see Figure 9) and total pattern duration (see Figure 10). However, these observations were not statistically supported by trend analyses ($p=.212$ and $p=.061$, respectively, for the linear orthogonal components - no other components were closer to significance). The failure to reach significance is likely due to the extremely high between-subjects standard deviations which ranged from 120 to 212 ms.

Interval data. No differences were found between instruction conditions for any of the interval data tests so these data were combined. Means and standard deviations for the reproduced interval data are shown in Table 9. ANOVA was performed on the proportional error scores for the total pattern durations (see Analysis section for explanation); this allowed comparisons across patterns of different total durations. A significant difference between X-type and E-type patterns was revealed, $F(1,23) = 6.66$, $p=.017$; the X-type patterns were reproduced more accurately. There were no reliable proportional error differences across total pattern durations, nor were there for the interaction of duration X

Figure 9. Mean reaction time (RT) as a function of number of
taps.
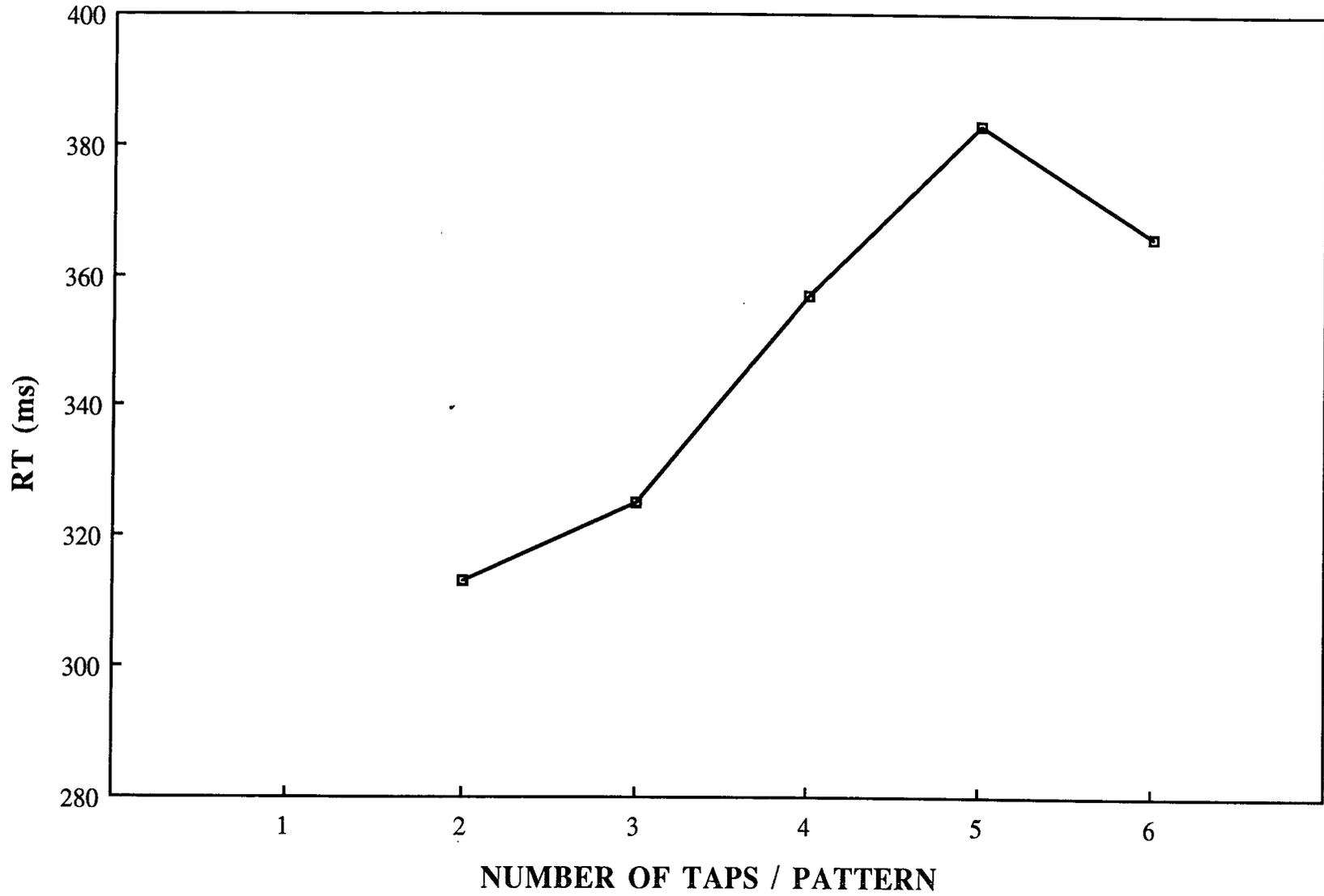
Figure 10. Mean reaction time (RT) as a function of total
pattern duration.
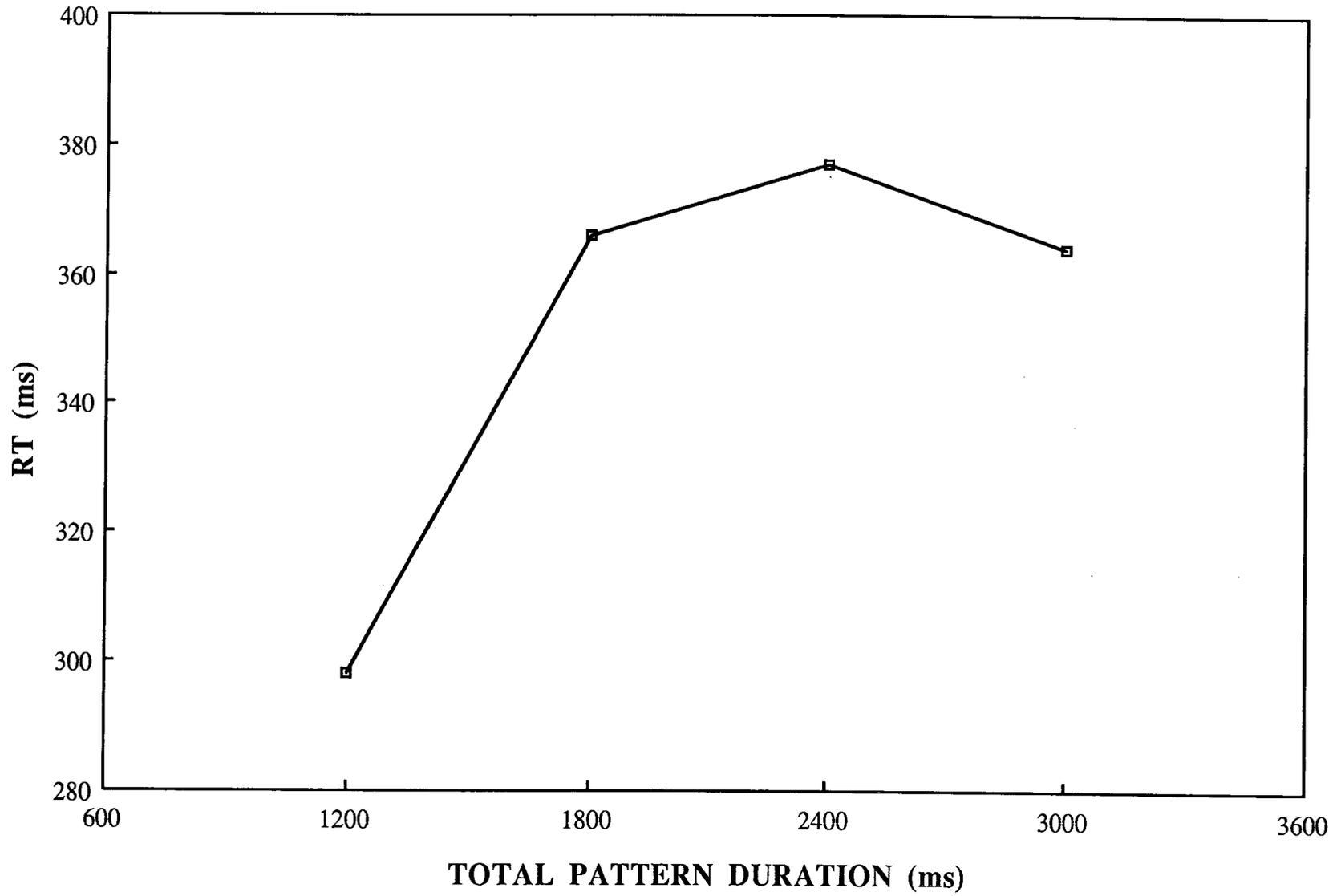
Table 9
Mean IRI and Total Pattern (T) Durations (ms) and
Corresponding SDs as a Function of Serial Position for Each
Pattern

| Pattern-Type | IRI Serial Position | | | | | | T |
	1	2	3	4	5	Last	
X	285	294				608	1187
(1200 ms)	12	14				36	38
E	299					824	1123
	39					91	85
X	292	290	289			849	1720
(1800 ms)	24	18	13			113	119
E	295	305				1125	1725
	38	38				233	161
X	292	294	288	300		1134	2308
(2400 ms)	23	26	21	10		165	174
E	296	293	299			1319	2207
	46	34	43			230	240
X	296	296	291	295	299	1339	2816
(3000 ms)	36	31	27	30	14	263	259
E	299	293	286	307		1605	2790
	49	41	34	41		278	310

"X" represents patterns in which both subintervals are
     initiated by an external-world event

"E" represents patterns in which the second subinterval
     is empty

pattern-type. As can be seen in Table 9, the superior performance of X-type patterns was not consistent for all pattern durations. A subsequent ANOVA was undertaken to see if this inconsistency might be attributed to an additional factor; specifically, patterns with an even number of shorter durations in the first interval generally appear to be better reproduced than those with an odd number of such durations (see Table 10). This insight was supported, $\underline{F}(1,23) = 6.70$, $\underline{p}=.016$.

The duration profiles for the shorter IRIs (i.e. serial position trends) were compared across pattern-types at each duration. A significant interaction effect (serial position X pattern-type) was found for the four shorter intervals common to the 3000-ms patterns, $\underline{F}(3,69) = 13.04$, Greenhouse-Geisser $\underline{p}<.001$, for the three intervals common to the 2400-ms patterns, $\underline{F}(2,46) = 4.54$, Huynh-Feldt $\underline{p}=.023$, and for the two intervals common to the 1800-ms patterns, $\underline{F}(1,23) = 6.28$, $\underline{p}=.020$. A comparison of the single shorter intervals common to the 1200-ms patterns failed to reach statistical significance, $\underline{F}(1,23) = 3.63$, $\underline{p}=.070$. No main effects of pattern-type were uncovered indicating that differences in performance were largely attributable to reproduction of the largest temporal interval. Only one effect of serial position was found - for the 3000-ms patterns, $\underline{F}(3,69) = 14.61$, Greenhouse-Geisser $\underline{p}<.001$.

The relative durations of each shorter interval (common to both pattern-types) to the total pattern duration are

Table 10.
<u>Mean Proportional Reproduction Error as a Function of</u>
<u>Pattern-Type and the Number (Even/Odd) of Shorter Temporal</u>
<u>Intervals</u>

Pattern-Type		Number of Shorter Temporal Intervals				
		1	2	3	4	5
X	(even)	---	.011	---	.039	---
	(odd)	---	---	.045	---	.061
E	(even)	---	.041	---	.070	---
	(odd)	.064	---	.080	---	---

*

The Proportional Reproduction Error (PRE) is equal to
the reproduced pattern duration minus the criterion
pattern duration all divided by the criterion pattern
duration. The Mean PRE is equal to the mean of the
absolute values of the PREs.

shown in Table 11. These data highlight the finding that even when the total duration of the X-type patterns was reduced, the relative timing of intervals within each pattern was well maintained.

Four separate ANOVAs were conducted to contrast the durations of the first and second beat-intervals within the X-type patterns. The second interval duration (shown under the heading "Last") is less than the first interval duration (calculated by subtracting "Last" from "T") in all cases except for the 1200-ms pattern (see Table 9). However, these findings were not statistically significant.

Discussion

Povel (1981; also Povel & Essens, 1985; Essens & Povel, 1985) showed that patterns divisible into equal intervals initiated by external-world events were accurately reproduced. Yet we know from music that a metrical context can be preserved even if each measure is not initiated by an external-world event. The main purpose of this study was to determine if a minimal context would be sufficient for subjects to perceive higher-order groupings of equal duration when each grouping is not initiated by an external-world event. Three pieces of evidence suggest that the context provided here was insufficient for such an organization. First, the overall reproduction of pattern durations was better for the X-type than the E-type patterns. Second, the duration profiles for the shorter IRIs were different across

Table 11
<u>Mean Relative Durations of Shorter Temporal Intervals to</u>
<u>Longer Temporal Intervals as a Function of Pattern-Type</u>

Pattern-Type	Reproduction Ratio				Criterion Ratio
	S1/T	S2/T	S3/T	S4/T	
X	.240				
(1200 ms)					.250
E	.266				
X	.170	.169			
(1800 ms)					.167
E	.171	.177			
X	.127	.127	.125		
(2400 ms)					.125
E	.134	.133	.135		
X	.105	.105	.103	.105	
(3000 ms)					.100
E	.107	.105	.102	.110	

"Sn/T" represents the ratio of the nth shorter temporal
interval (300 ms) to the total pattern duration

the two pattern-types. Third, for each of the 10

corresponding shorter IRIs and each of the 4 total durations,

intersubject variability was greater for the E-type patterns

(see Table 9). This indicates that subjects, as a whole,

were not perceiving and reproducing the E-type patterns in a

consistent way. These patterns proved to be more difficult

to organize than the X-type patterns. Although Canic and

Franks (1985) did find that E-type patterns could be well

reproduced, the patterns in their study were more highly

learned than the patterns reproduced here.

There was no main effect of pattern-type for the

reproduction of shorter IRIs (just the interaction effect

noted above). This indicates that differences were

attributable almost entirely to the reproduction of the

longer IRIs Recall that Sternberg et al. (1982) found that

subjects accurately produced beat-fractions whether or not

production began on the external-world beat.

If the E-type patterns were not organized as two

intervals of equal duration then how were they organized?

The duration profiles of the shorter IRIs may give us a clue

here. For each E-type pattern with multiple shorter IRIs,

the last IRI is longest in duration. If we again apply the

rule that intervals that end perceptual groups are accented -

agogically, in this case - then it appears that all the short

intervals are grouped together and the longer interval is

treated as a distinct unit. The E-type patterns are

organized as two higher-order intervals of <u>differing</u>

durations. The principles that would suggest the organization of two equal duration intervals are overridden by the lack of contextual cues. This explanation is supported by the observation that equivalent longer ISIs (e.g. 900 ms for the X-type 1800-ms patterns and the E-type 1200-ms pattern) were always better reproduced in the X-type patterns. In the presence of a metrical (equal interval) context, reproduction of a longer interval is degraded less than when it occurs in the absence of such a context - when it occurs in isolation.

Why should the error always be in the direction of reducing the longer interval? There is some evidence that an "indifference interval" (that interval of time that is neither overestimated or underestimated) exists around 700 ms (Coren, Porac, & Ward, 1984; but cf. Poppel, 1978; and Woodrow, 1951). Longer intervals are underestimated and shorter intervals are overestimated. In the results presented here, the longer ISIs are underestimated in every case of both pattern-types with the exception of the 600-ms ISI in one X-type pattern. The shorter ISIs are not overestimated, however. But if we consider that they are grouped as a unit, then the unit durations are underestimated as they almost always should be.

Of course, there are alternative explanations. First, Essens and Povel found that non-metrical patterns are reproduced so that the ratio of longer to shorter durations approaches 2:1. The second explanation is found in Helson's

(1964) adaptation-level theory. The central idea adapted to the present study is that stimuli are organized so that their differences along a common dimension are reduced. Consistent with both explanations, for patterns with well-defined (multiple) shorter IRIs, the longer IRI will be reduced.

A comparison of the two higher-order intervals in X-type patterns showed that the mean first interval duration is longer than the second interval for every case but one. This provides weak evidence for the "filled-interval illusion" (Coren, Porac, & Ward, 1984) - the observation that filled intervals are estimated as longer than unfilled intervals (in this case, when their durations exceed that of the indifference interval).

Finally, the mean RT data provide some support for the position that RT increases as a function of number of response units and/or response duration. However, since these patterns were reproduced cyclically, the high between-subjects variability indicates that subjects may not have implemented response programs of the same size. The data, while suggestive, point to the conclusion that this procedure is not optimal for the investigation of RT effects.

Experiment 4

The ability to perceptually organize a brief pattern of identical temporal stimuli into groups of equal duration requires that each group be initiated by an external-world event. What other limits are there to the grouping of intervals? The two limits referred to most frequently in the literature are the duration of the group and the number of subintervals per group.

Much of the focus, with respect to group duration, has been on the interval range which allows for the perception of beat-intervals. The Harvard Dictionary of Music reported that beat-intervals typically range from 429 to 1200 ms (Apel, 1972). Lerdahl and Jackendoff (1983) suggested a broader range of 375 to 1500 ms while Povel (1981) stated that beat-intervals in Western music range from 250 to 1500 ms. Based on his review of the literature, Fraisse (1978, 1982) concluded that grouping occurs for interval durations of up to 1800 ms.

The general position of these investigators is that adjacent or non-adjacent stimuli separated by long intervals are not grouped together and perceived as a coherent pattern of beats since they lose their perceptual continuity. Conversely, stimuli separated by very short intervals are not perceived as beats but as fractions of beats due to their rapidity.

Is there a maximum number of equal subintervals by which a beat can be divided? In music the question is usually

framed at the next higher level of organization: how many

beats are contained in a single metric unit - a measure? As

was noted in Section One, however, the perceptual distinction

between metrical and beat organization is not always an

unambiguous one (Radocy & Boyle, 1979). Most Western rhythm

is confined to meters involving units of 2, 3, or 4 beats

(Davies, 1978). Lerdahl and Jackendoff (1983) have proposed

a number of "Metrical Well-Formedness Rules", one of which

states that " ... at each metrical level, strong beats are

spaced either two or three beats apart".

In a non-musical context, Essens (1986) has determined

that hierarchical levels in the organization of temporal

patterns must relate as integers less than five. Yet,

Deutsch (1983) found that when subjects synchronize with

dichotically presented, isochronous stimulus patterns that

vary in their integer, interval relations, the base rate ISI

(1200 ms) was more consistently performed when the other

(faster) rate stood in a relation of 5:1 than when the

relation was 4:1, 3:1, or 2:1. This finding is consistent

with Getty's (1976) discovery that the variance in

reproducing an interval decreases as the number of

subintervals it is divided into increases.

The purpose of this study is to determine if grouping

occurs when the suggested grouping-intervals: 1) exceed 1800

ms, and 2) are divided into more than 4 subintervals of equal

duration. Agogic accenting is again the dependent measure

used to evidence grouping. It has been applied by Garcia-

Colera and Semjen (1987) who reported that, in general, first and last pattern events were lengthened relative to interior events in patterns of 3 to 8 intervals (although this finding was not supported statistically).

Method

Subjects. Twenty-two male and female students from the University of British Columbia participated in the study as part of a course requirement. Subjects ranged in age from 20 to 27 years. A $20.00 prize was offered to the subject who most accurately reproduced the response patterns.

Apparatus. The apparatus was the same as described in Experiment 1.

Stimulus Patterns. Subjects were instructed to reproduce 12 different stimulus patterns (see Table 12). As in Experiment 3, all patterns can be divided into two intervals of equal duration with the first interval further divided into equal duration subintervals. Patterns varied in the number of subintervals they contained (i.e. 4, 5, 6, 7). All patterns were of the "X-type" described in the previous experiment. That is, each suggested grouping-interval was initiated by an external-world event. The physical characteristics of the tones, and the tone durations were the same as in Experiment 3.

Procedure. The procedure was identical with that of Experiment 3 with the following exceptions: There were 12 stimulus patterns - those shown in Table 12, the Post-

Table 12
Stimulus Patterns for Experiment 4

Pattern-Rate   Pattern Representation / Interval Duration

---

200 ms

/./././. /.......   800 ms

/././././. /.........   1000

/././././././. /...........   1200

/././././././. /.............   1400

300 ms

/../../../.. /...........   1200

/../../../../.. /.............   1500

/../../../../../.. /................. 1800

/../../../../../../.. /.................... 2100

400 ms

/.../.../.../... /..............   1600

/.../.../.../.../... /................. 2000

/.../.../.../.../.../... /................... 2400

/.../.../.../.../.../.../... /.................... 2800

*

For the sake of clarity a break has been inserted
artificially dividing each pattern into two intervals
of equal duration.

Presentation interval ranged from 1700 to 3700 ms, and
subjects were not instructed to initiate reproduction of the
stimulus patterns as quickly as possible although, like
Experiment 3, the offset of a 1000 ms Warning Tone signalled
that pattern reproduction could begin. Subjects were
instructed to reproduce the timing of each stimulus pattern
as accurately as possible.

Analysis. The IRI was the fundamental unit of
comparison. The mean absolute durations of each shorter and
longer interval in all of the stimulus patterns were
calculated as were the mean proportional errors for these
intervals. Agogic accenting of both the first and last
events (in relation to all intervening events) in the first
grouping-interval was taken as evidence of grouping.
Consistent with the literature, the ordinal relationships
among IRI means were subjectively analyzed. Statistical
tests were not performed. Indeed, the differences typically
observed in evidence of accenting are consistent but very
subtle.[5] Proportional error scores for the total pattern
durations were also calculated.

Mean relative durations of each short-to-long interval
were calculated in order to determine the accuracy of
relative timing in pattern reproduction.

Results

Means and standard deviations for each shorter and
longer IRI are shown in Table 13. Lengthening of the first

Table 13
Mean Durations (ms), Corresponding SDs and Proportional Error
(PE) Scores for Shorter and Longer IRIs

Pattern-Rate	IRI Serial Position							
	1	2	3	4	5	6	7	Last

200 ms

	1	2	3	4	5	6	7	Last
X	215	208	209	216				868
SD	13	14	13	14				94
PE	.075	.039	.045	.081				.086
X	221	215	216	213	217			902
SD	15	14	15	13	16			198
PE	..105	.074	.078	.067	.087			-.098
X	215	212	213	213	208	222		1114
SD	13	12	11	12	14	13		234
PE	.073	.061	.066	.064	.040	.108		-.072
X	215	213	214	214	210	212	217	1335
SD	20	18	13	13	16	17	18	257
PE	.074	.066	.072	.072	.052	.059	.087	-.046

300 ms

	1	2	3	4	5	6	7	Last
X	300	292	288	297				1232
SD	20	16	14	18				143
PE	-.001	-.026	-.041	-.009				.027
X	303	297	295	297	303			1511
SD	20	18	14	16	17			288
PE	.010	-.010	-.016	-.009	.011			.008
X	306	299	301	302	298	307		1959
SD	21	17	16	17	17	16		567
PE	.020	-.003	.004	.006	-.005	.024		.088
X	301	298	296	300	297	299	304	2283
SD	20	20	22	22	20	20	24	552
PE	.004	-.006	-.013	.000	-.010	-.004	.013	.087

400 ms

```
X        381   377   371   381                             1660
SD        29    25    26    29                              205
PE     -.048 -.059 -.071 -.048                             .037

X        393   394   386   392   396                       2126
SD        22    25    23    25    25                        498
PE     -.018 -.016 -.036 -.020 -.011                       .063

X        385   387   386   389   387   394                 2618
SD        29    30    26    30    31    30                  852
PE     -.037 -.031 -.034 -.026 -.033 -.015                 .091

X        389   386   386   389   387   392   392           3054
SD        23    27    24    26    24    25    23           1017
PE     -.029 -.036 -.035 -.037 -.033 -.020 -.019           .091
```

and last shorter IRIs relative to interior IRIs was taken as evidence of accenting and, therefore, perceptual grouping. Presented in a condensed form, it can be seen that evidence of grouping systematically changes with increasing interval-duration - the transition point coming above 1800 ms (see Table 14).

Proportional Error (PE) scores for each IRI are also shown in Table 13. PE scores for all 200 ms intervals were positive indicating that these intervals were reproduced longer than the criterion. PE scores for all 400 ms intervals were negative indicating that they were reproduced shorter than the criterion. PE scores for the 300 ms intervals were both positive and negative, and in general were much lower than those for the other durations indicating that these intervals were most accurately reproduced.

PE scores for the longer intervals in each pattern are shown in Figure 11. These data show no apparent trend. But if we consider just the reproduction of patterns with subinterval frequencies of 300 and 400 ms, then a marked increase in error occurs at 1800 ms. This is around the interval duration at which suggested grouping no longer occurs. Yet, for the long interval durations of less than 1800 ms, the 200 ms data do not seem to fit. However, if we plot proportional error versus the total pattern duration, then the patterns in question fall in line with the other patterns below 3600 ms (2 intervals X 1800 ms) with the exception of the 200/200/200/200/800 ms pattern (see Figure

Table 14
First Interval Duration (ms) and Resultant Evidence for
Grouping Based on Agogic Accenting of the First and Last IRIs

Interval-Duration	Evidence of Grouping
800	Positive
1000	"
1200 (200-ms rate)	"
1200 (300-ms rate)	"
1400	"
1500	"
1600	"
1800	"
2000	Negative
2100	Positive
2400	Negative
2800	"

Figure 11. Proportional Error versus Criterion Long Interval
     Duration. ■ = 200 ms subintervals, ◆ = 300 ms
     subintervals, ◘ = 400 ms subintervals.
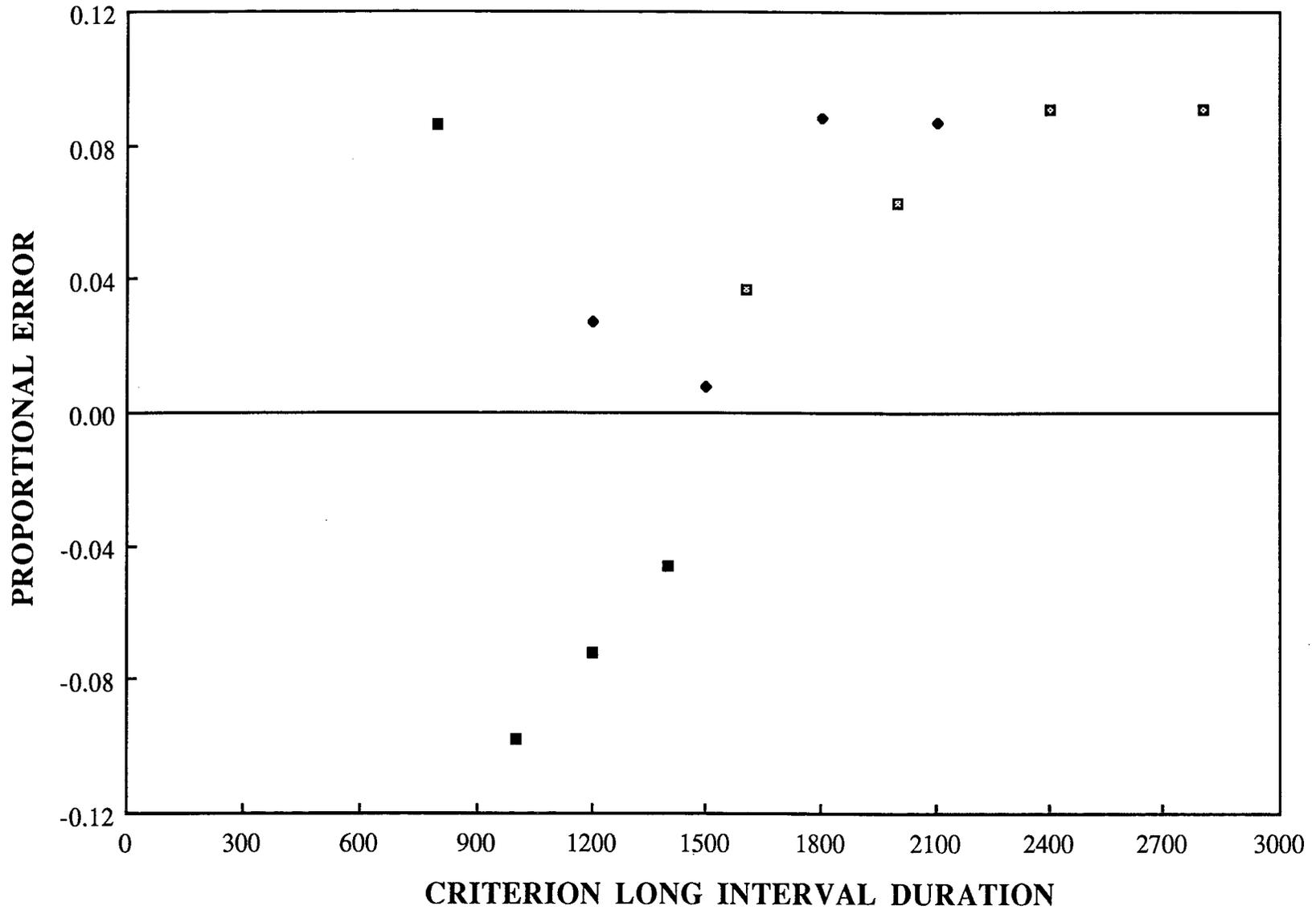
12). For this pattern, the duration of the second interval almost matches that of the first interval.

The relative timing for each pattern was determined by comparing each shorter IRI to the corresponding longer IRI. Results are displayed separately according to number of shorter intervals in Figure 13. When the number of shorter intervals is five, six or seven, the relative timing for patterns at the 300 and 400 ms rates is well maintained while the same is not the case for the 200 ms patterns. When the number of shorter intervals is four, all patterns were quite well reproduced - moreso, from 400 to 300 to 200 ms patterns.

Discussion

The main purpose of this study was to determine if grouping would occur when the suggested grouping-intervals exceed 1800 ms (the largest interval suggested in the literature, Fraisse, 1982) or were divided into more than 4 equal duration subintervals. All patterns with suggested grouping-intervals less than or equal to 1800 ms showed evidence of accenting. All longer patterns, with the exception of the pattern with the suggested 2100 ms intervals failed to display accenting.

Why should the 2100 ms intervals display accenting and not the 2000 ms intervals? One possible explanation is simply that the upper limit for group duration is a fuzzy boundary. Another explanation is that the boundary is influenced by the interaction of subinterval rate and number.

Figure 12. Proportional Error versus Criterion Total Pattern
  Duration. ■ = 200 ms subintervals, ♦ = 300 ms
 subintervals, ▣ = 400 ms subintervals.
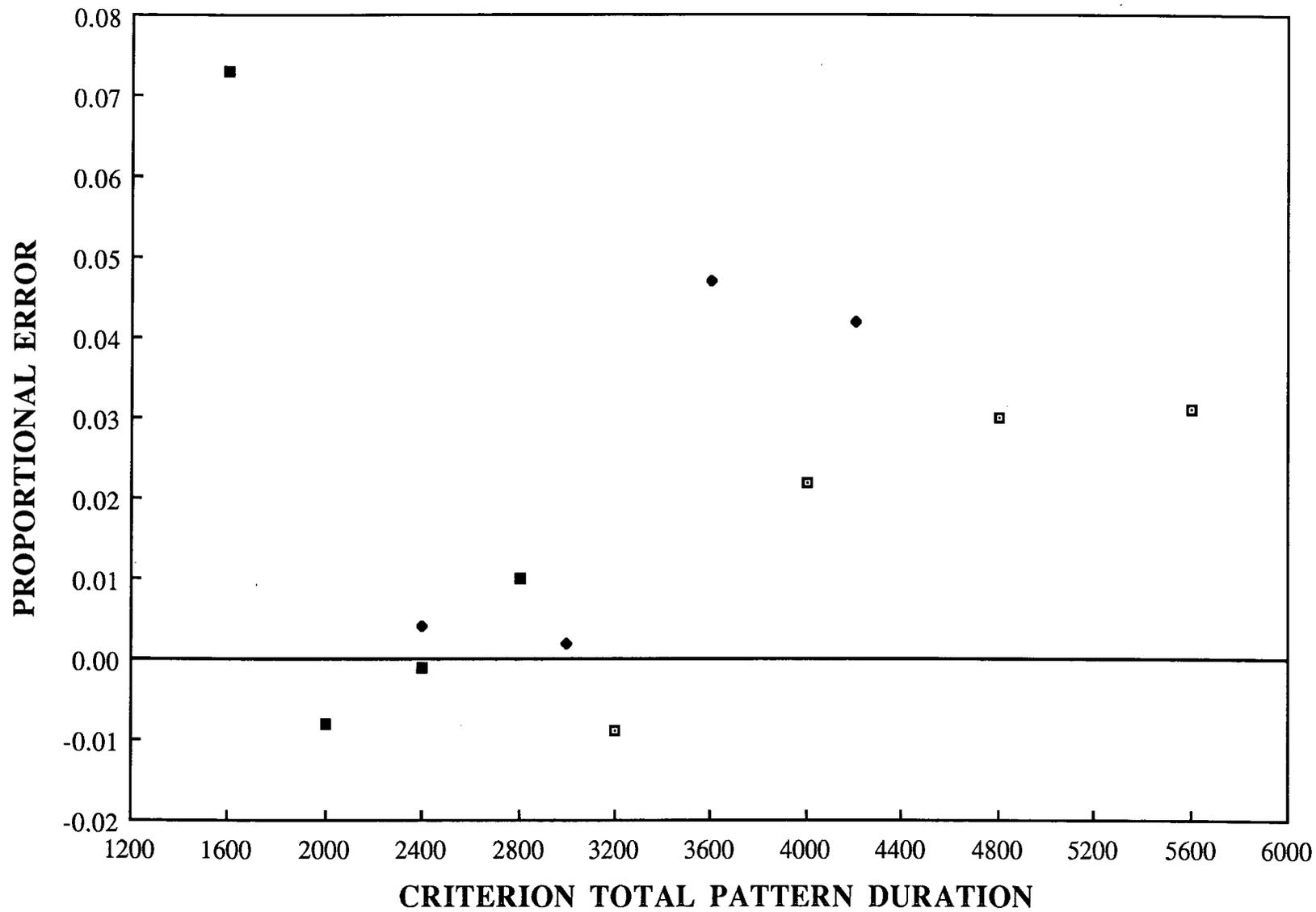
Figure 13. Mean Reproduction Ratio (short-to-long interval) for each Serail Position. a. criterion ratio: 0.25, b. criterion ratio: 0.20, c. criterion ratio: 0.17, d. criterion ratio: 0.14.

■ = 200 ms subintervals, ◆ = 300 ms subintervals, ▣ = 400 ms subintervals.
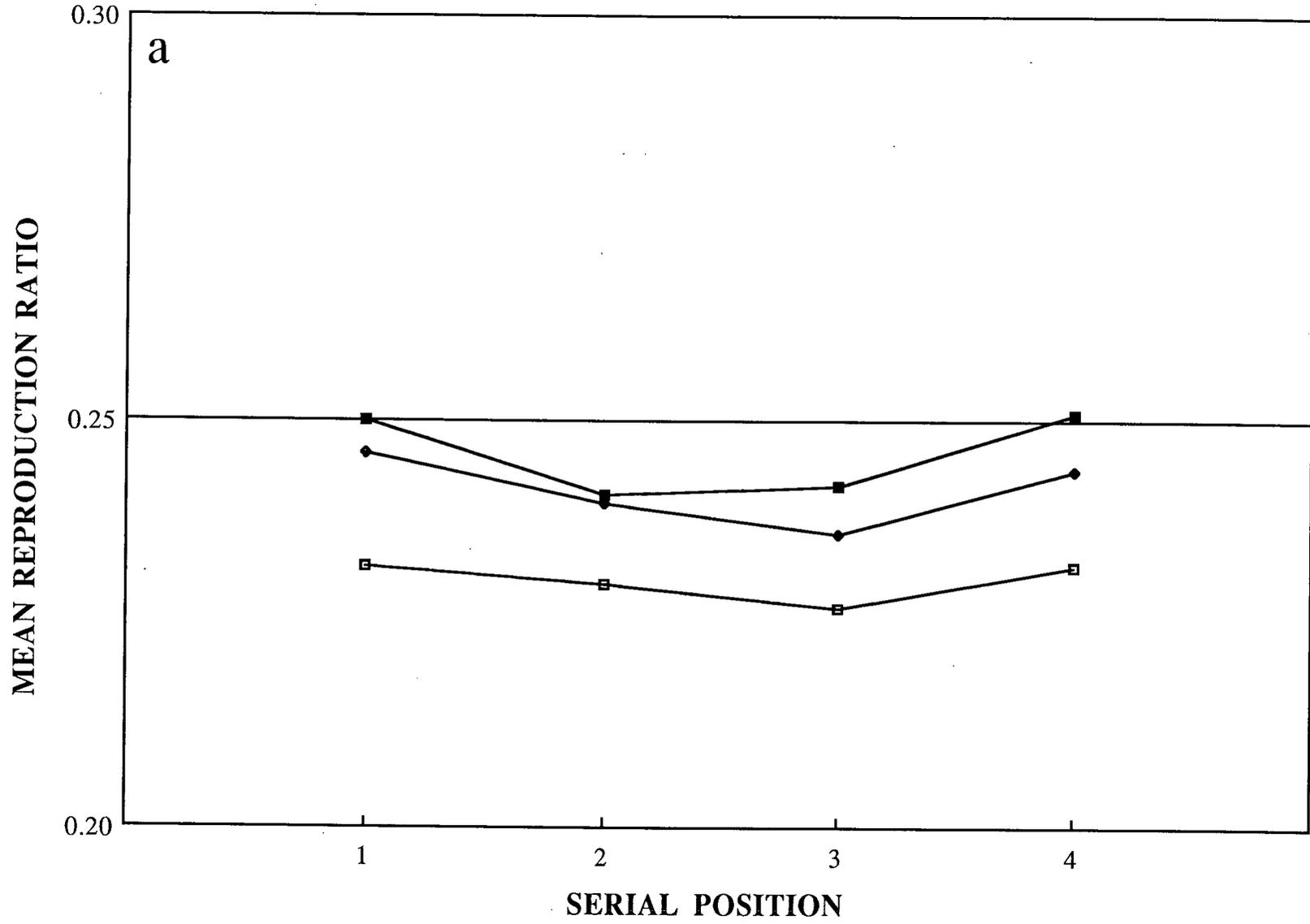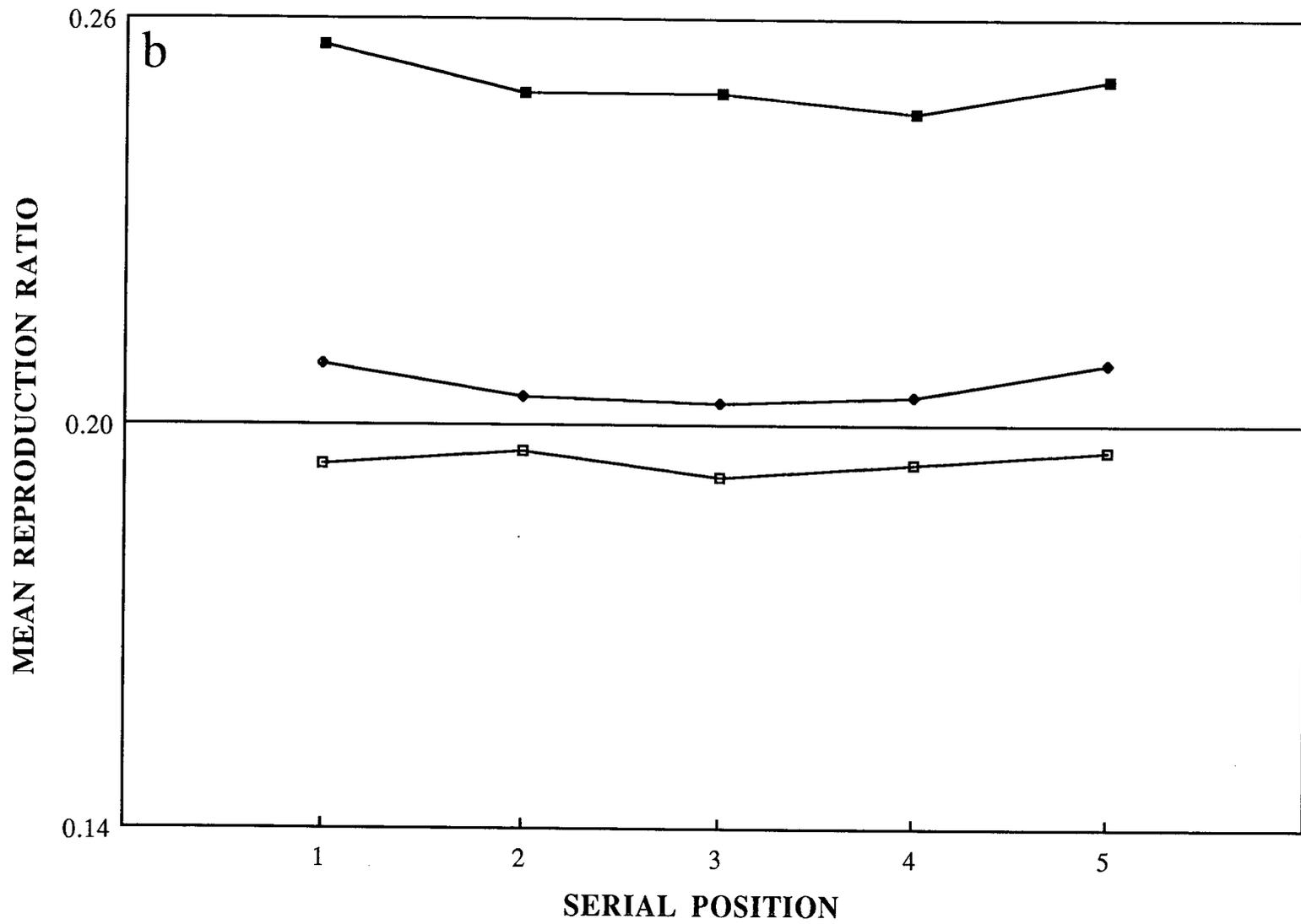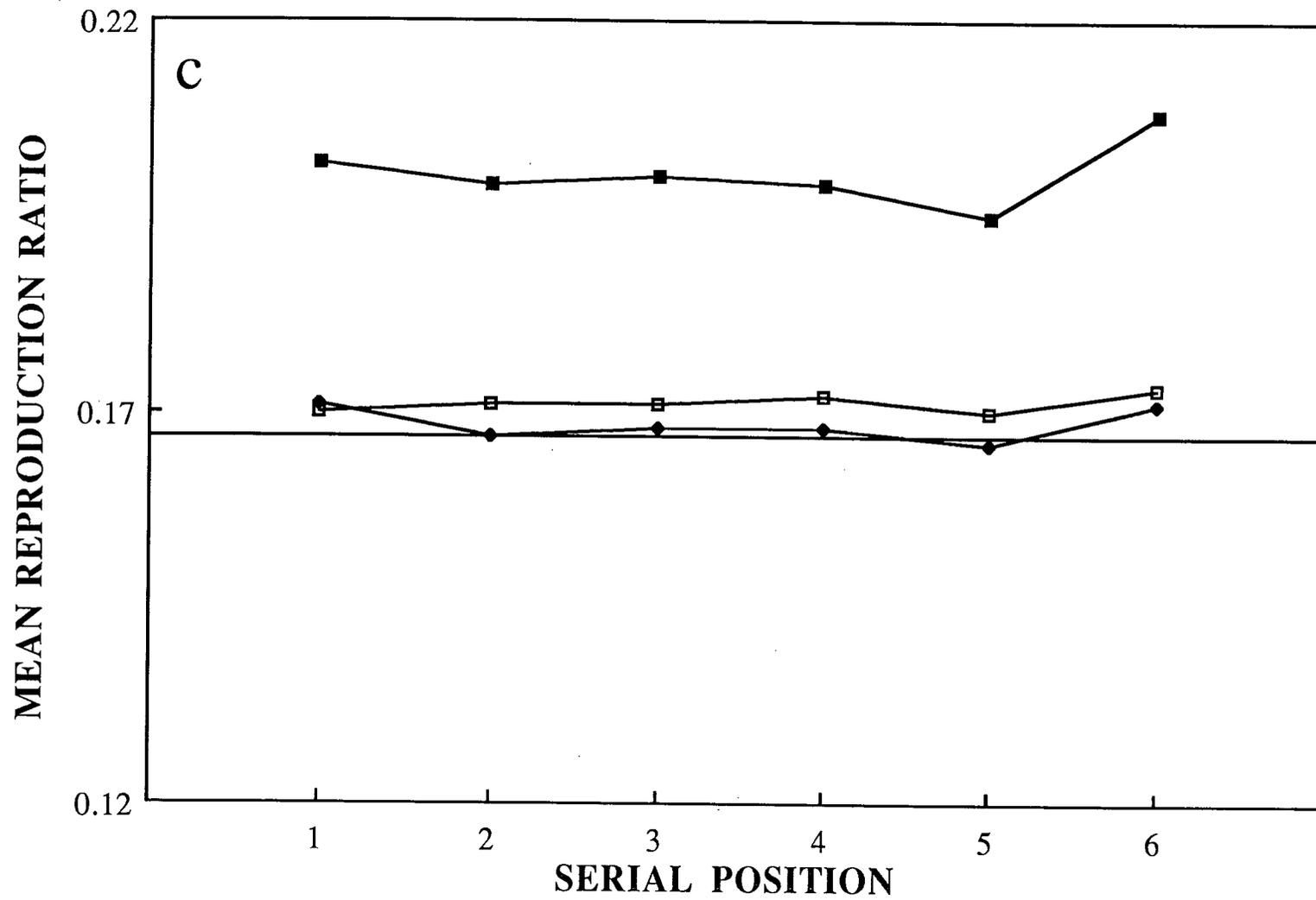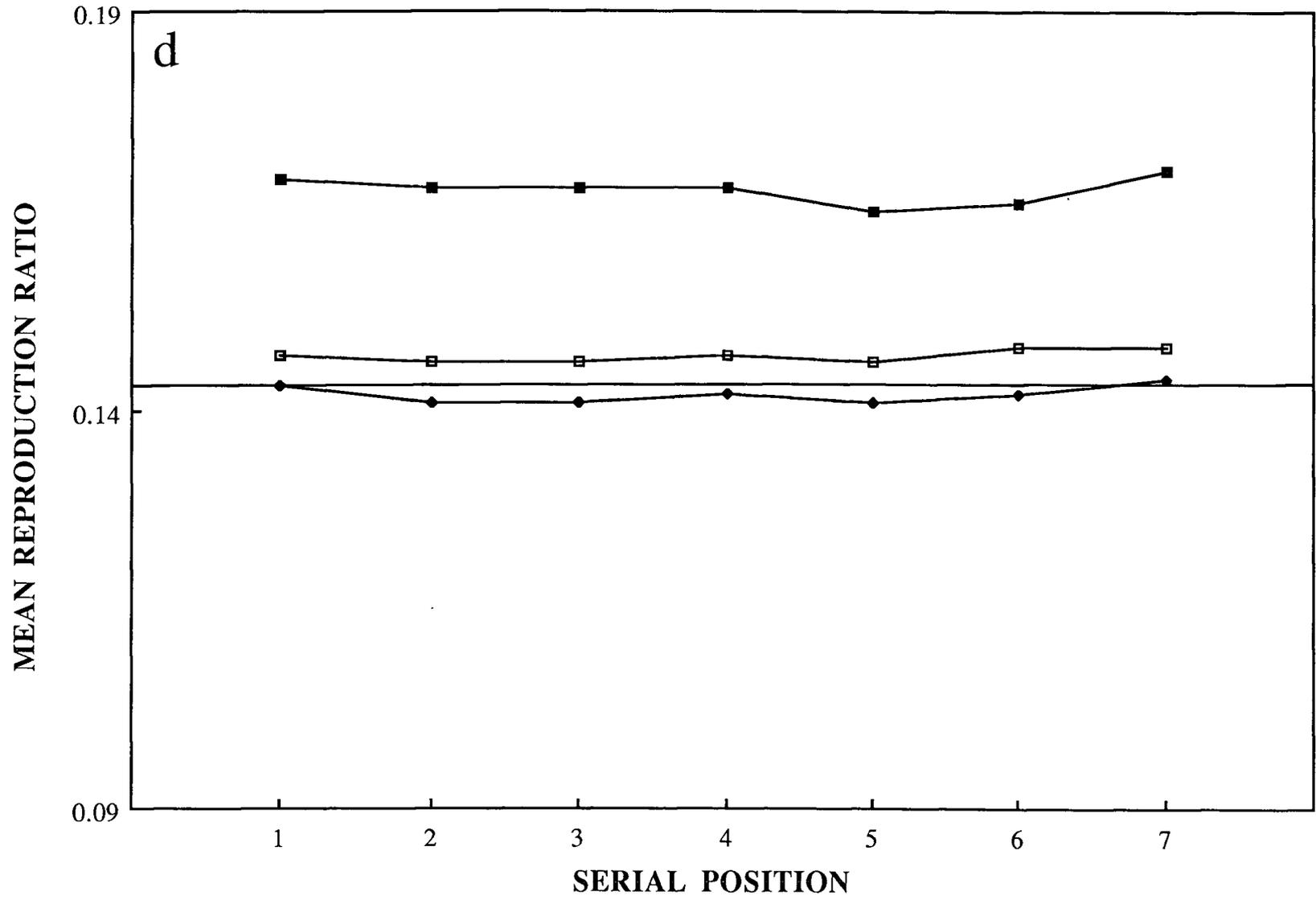
Possessing more frequent subintervals (i.e. 300 ms ISIs) may more strongly suggest grouping than when subintervals are less frequent (i.e. 400 ms ISIs).

The proportional error data showed that subinterval durations of 300 ms were best reproduced. Subinterval durations of 400 ms were consistently underestimated while subinterval durations of 200 ms were consistently overestimated. One speculative explanation for the latter finding is that subjects have difficulty in reproducing such rapid patterns unless they are well-practiced. In Experiment 2, patterns with the 200 ms intervals were reproduced _faster_ than the criterion patterns, but in that study subjects reproduced each of seven patterns at that rate over 30 separate trials. Intuitively, however, it would not seem that difficult to produce keyboard taps at a rate of five/second.

Why should PE be high for longer intervals in the 200 ms patterns but not for the entire pattern duration? To speculate, if subjects do have difficulty in producing the 200 ms intervals, and realize it, then perhaps they compensate by shortening the subsequent longer intervals. As a result, the PE scores for the total pattern durations are low. That this is not the case for the 200/200/200/200/800 ms pattern may be because the relative timing of short-to-long intervals in this pattern (4:1) is very familiar in Western music and maintaining relative timing may dominate the need to maintain absolute timing.

The relative timing data are interesting for at least two reasons. First, they show that timing is well maintained in patterns that display no evidence of grouping through accenting. Does accurate relative timing result from the application of some other strategy? Or is interval lengthening, a measure shown to be useful in several of the studies reported in this work, an incomplete measure of perceptual grouping in reproduction tasks? Or, perhaps, the processes of memory, and not immediate perception, are responsible for being able to reproduce a longer interval just subsequent and of similar duration to a series of shorter intervals? Future research may provide an answer to this question.

The second reason these data are interesting and important is because they show the inadequacy of measuring only the relative timing of rhythmic patterns. If one were to look at just the relative timing data, then the deviations in the reproduction of absolute interval durations, and their potential significance, would be overlooked.

GENERAL DISCUSSION

The focus of this second section of studies was on how selected variables influence the grouping of pattern elements into equal intervals suggested by pattern structure. For simple rhythmic patterns, the organization of elements into two intervals of equal duration occurs when each interval is initiated by an external-world event. In more elaborate rhythmic contexts, such as music, this need not be true. But for brief patterns of identical elements separated by only two different durations, there is insufficient context to suggest equal interval grouping if one interval contains no elements (unless they are well-learned as with the Canic & Franks, 1985 study cited earlier). In these cases, subjects organize a pattern as two intervals of unequal duration with the subdivided interval displaying evidence of agogic accenting.

Several models of rhythm perception focus solely on relative timing and discount the role of absolute interval durations in grouping (e.g. Povel & Essens, 1985). An attempt was made here to determine if perceptual grouping would occur for grouping-intervals up to 1800 ms. It was found that this duration does represent an approximate upper limit to the grouping of subintervals. There was also weak evidence that non-subdivided intervals longer than 1800 ms were poorly reproduced. This interpretation is clouded by the fact that intervals less than 1800 ms were poorly

reproduced at the fastest subinterval rate (200-ms ISIs) in Experiment 4.

The suggestion that adjacent levels in the hierarchical organization of a rhythmic pattern must relate as simple integers less than 5 was tested. Although such relations virtually exhaust the rhythmic organizations of Western music, rhythm perception and rhythmic action, in general, extend far beyond this context; there is little reason to suggest that a greater number of intervals cannot be coherently grouped. And, in fact, this is what was found. Patterns of up to 7 elements can be grouped together as long as the total pattern duration does not exceed (roughly) 1800 ms.

In the discussion of Experiment 3, possible explanations were given for the finding that grouped intervals and longer intervals are underestimated in reproduction. Two possible explanations have received some support in the time perception literature. The first is the notion of an "indifference interval" - that intervals longer than around 700 ms are underestimated while shorter intervals are overestimated. This concept fits quite well with the reproduction data in Experiment 3. However, it did not fit at all well with the data in Experiment 4. Longer intervals were almost always overestimated and grouped intervals often were (see Table 13).

A second finding in Experiment 3 was that, for X-type patterns, filled (subdivided) intervals were frequently

reproduced longer in duration than unfilled (non-subdivided) intervals. This was not supported in the results from Experiment 4. There is seemingly no systematic way in which the reproduction of longer, grouped or unfilled intervals deviates from the criterion duration.

It may be that phenomena observed in time perception (the perception of single intervals) are not found in the more complex context of rhythm perception. It should also be noted that the indifference interval and filled interval illusion have been questioned by some researchers of time perception. Ornstein (1969) has reviewed findings and concluded that the former is unreliable while Fraisse (1963) has reached a similar conclusion regarding the latter.

A final post-hoc finding in Experiment 3 was that patterns with an even number of subintervals were reproduced more accurately than patterns with an odd number of subintervals. There was no evidence for this finding in Experiment 4. As a result, there is no apparent explanation for the observation that X-type patterns are not always reproduced more accurately than E-type patterns.

While the findings in this section have provided general answers to the questions asked, the use of absolute timing, relative timing and ordinal relationship measures have yielded much data about which we can only speculate. Further research is required to develop a theoretical framework that can integrate the results obtained through all of these measures.

SUMMARY / CONCLUSIONS

In the General Introduction it was asked how we perceptually organize and how we plan in advance the reproduction of rhythmic patterns. A recurring theme throughout the studies reported here is that of "coherence". When is a stimulus pattern or a response pattern treated as a coherent whole? What factors influence the coherence of stimulus/response patterns? Issues of response coherence were central to the first section. It was suggested that when program implementation processes act on the entire response pattern, then that pattern is treated as a coherent whole. Simple, isochronous rhythms served as stimulus patterns. RT, which is thought to reflect the duration of program implementation processes, was the measure of primary interest. RT was found to increase linearly for patterns with IRIs up to 300 ms. These rates are apparently rapid enough to necessitate that the response pattern be treated as a coherent whole. Of course, this does not mean the entire pattern is programmed prior to response initiation. It may be that, in terms of Sternberg and his colleagues (1978), the first response unit is search/retrieved from an increasingly large pool of response units.

Response rate cannot be the only factor that determines response coherency. RT would undoubtedly not continue to increase for rapid, isochronous patterns indefinitely long. An upper limit - either in terms of number of response units or total response duration - should be evident here. Later

segments of long response patterns <u>can</u> be prepared on-line - concurrent with execution.

Perhaps the question being asked here is not quite right. A more important question may be: How much of a head start, in terms of programming time, is required so that on-line programming does not fall behind the demands of task execution? It may be that a RT ceiling is the by-product of temporal scheduling of on-line and execution processes, and not explainable solely in terms of a salient output parameter.

If we are asked to produce a movement of continuous duration then duration may be a salient parameter. If we are asked to produce a number of discrete movements then number may be a salient parameter. Yet, consider that many tasks are ambiguous in that there may be more than one salient output parameters. They may not demand an invariant pattern of organization and processing. It may be that our cognitive organization of a task determines the way in which the task is planned and executed. And, for many tasks, cognitive organization will vary among individuals.

Issues of perceptual coherence were central to the second section of studies. Stimulus patterns were structured so as to suggest the division of the entire pattern into two intervals of equal duration. This further suggested the grouping of subintervals that spanned the duration of one "interval". The lengthening of the first and last subintervals in a suggested interval - agogic accenting - was

taken as evidence of grouping. It was shown that in a simple context such as this, the _suggested_ grouping does not occur unless both intervals are initiated by external-world events. Grouping occurs, but more as a result of what _is_ there than what _isn't_. In Gestalt terms, perceptual organization is only as good as the patterns allow. Grouped intervals of unequal duration are thus perceived.

Is the perceptual coherence of a pattern of stimulus events dependent upon the total duration of a suggested grouping-interval, or limited by number of subintervals? The results presented here strongly suggest that grouping of events occurs up to a span of around 1800 ms. Events that span longer intervals are not so coherent. Indeed, the absolute durations of non-subdivided intervals are well-reproduced up to 1800 ms, at which point a quantum increase in proportional reproduction error occurs.

Subinterval frequency may also play a role in the coherence of a grouping-interval. There was some evidence that a grouping-interval can be longer (2100 ms) if it possesses many subintervals (i.e. 7 X 300 ms subintervals).

It seems intuitively correct that perceptual coherence is not limited by the event rates that limit response coherence - namely, around 300 ms. Living organisms have an invariant tendency to organize experience, and it is to our advantage to be able to perceptually group events that are separated by more than 300 ms. (It is also to our advantage,

however, not to perceptually group events spanning large periods of time, for if we did, our experience would be largely heterogeneous, perhaps too complex to interpret or too general to convey specific meaning).

On the other hand, the capacity to act quickly, and to initiate complex actions rapidly, is also to the advantage of human organisms. If response coherence were observed for long and/or slow response patterns, then response initiation would be slow - clearly a biological disadvantage.

As defined here, perceptual and response coherence are not subject to the same limits. And with learning, these limits extend in opposite directions. The perception of rhythmic relationships in a complex piece of music seems to develop with increasing exposure. New and complex higher-order groupings are realized, the previous limits of duration and number of subintervals having dissolved. The programming of rhythmic patterns can similarly transcend previous limits. With learning, the time required to prepare a first response, and the additional time required as the response pattern becomes longer, decrease asymptotically.

Rhythm exists within us and all around us. Understanding coherence, in the perception and production of rhythmic patterns, is crucial to the greater understanding of human perception and action. The studies reported here are a thrust in that direction.

REFLECTIONS

Work is done, then forgotten.
Therefore it lasts forever.

Achieve results,
But never glory in them.
Achieve results,
But never boast.
Achieve results,
But never be proud.
Achieve results,
Because this is the natural way.

                              Lao Tzu

There can be no challenge without the risk of failure.

                              Yuichiro Miura

Progress
During your journey it may at times seem as if you are
not progressing, that you are no nearer to your goal.
You may have to descend into a valley before you can
climb a mountain. Thus the paradox of progress. Things
are not always what they seem. Utilize foresight. Keep
the true path.

                              MJC

Great ideas need landing gear as well as wings.

                              C.D. Jackson

Be liberal in allowing hypotheses and conservative in
confirming them.

                              MJC

He could have gone for general, but he went for himself
instead.

                              Captain Willard

FOOTNOTES

[1] Farnsworth (1958) reported of early Christian missionaries to Africa who observed natives to beat on their drums seemingly at random. Their conclusion, that the natives were "poor" in rhythm, was later shown to be in error - the African rhythms were very precise but too complicated to be perceptually organized by the foreign listeners!

[2] I thank Prof. R.W. Schutz for this suggestion.

[3] The reported p values for repeated measures effects are adjusted according to the Huynh-Feldt procedure when epsilon is greater than or equal to 0.75, and according to the Greenhouse-Geisser procedure when epsilon is less than 0.75, as recommended by Huynh and Feldt (1976).

[4] The total number of IRI's in all of the multi-IRI patterns is 27 (i.e. 2+3+4+5+6+7). The total number of IRI's in the last serial position is 6. Therefore, by chance, long IRI errors should occur in the last serial position 6 out of 27 times - or 22%.

[5] Of 8 temporal patterns with more than two equal-duration ISIs, Povel (1981) found agogic accenting of the first and last intervals in the reproduction of 7 of them. Garcia-Colera and Semjen (1987) found similar evidence in 6 of 10 multi-IRI patterns. In each study, for one additional pattern, no intermediate interval was longer than the first or last interval. Of course, without statistical tests, the formal generalizability of this finding is limited.

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