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PACING VISUAL ATTENTION: TEMPORAL STRUCTURE EFFECTS

DISSERTATION

Presented in Partial Fulfillment of the Requirements for

the Degree Doctor of Philosophy in the Graduate

School of the Ohio State University

By

June J. Skelly, B.A., M.A.

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The Ohio State University

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The dissertation investigated the role of temporal relationships in how we attend to dynamic visual events. Specifically, those factors that are temporal in nature, i.e., the rate and rhythm of event sequences were the primary variables of interest. The research explored the possibility that persisting temporal relationships may be an important factor in the external (exogenous) control of visual attention, at least to some extent, was the focus of the current research. Five experiments attempted to identify the respective roles of rate and rhythm time parameters in a simple selective attention task involving two differently timed streams of information. Results from these experiments indicated that the rhythmic structure of integrated streams was a more powerful "pacing" factor than either of the rhythm or rate of single stream. Together, these experiments suggest that there may be two kinds of temporal "pacing" in visual attention: (1) a passive entrainment with external time patterns, and (2) the active "use" of timing relationships to shift and direct the focus of attention.

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To My Parents, Jenny and Jerry Skelly

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PACING VISUAL ATTENTION: TEMPORAL STRUCTURE EFFECTS

By

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The Ohio State University, 1992

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The purpose of this dissertation was to investigate the role of temporal relationships in visual attention. This topic is one that has received scant research attention in the past. While there is little research directly addressing how we attend to dynamic visual events, there is some evidence to suggest that individuals are sensitive to certain non spatial factors associated with these events. Specifically, those factors that are temporal in nature, i.e., the rate and rhythm of event sequences, are emerging as important variables contributing to how we perceive and attend to visual information.

The difficulty with this area of research is there is no comprehensive theoretical position that incorporates both temporal and spatial relationships into their approach. One approach that explicitly does incorporate Time into its models is the Dynamic Attending perspective (Jones, 1976; Jones & Boltz, 1989). This approach assumes that attention is sensitive to the temporal structure in our environment and it provides the theoretical framework for investigations presented in this dissertation.

This research explored the possibility that persisting temporal relationships may be an important factor in the control of visual attention. The idea that certain rate and rhythm time parameters may "pace" visual attention was the focus of the current research. In this research, pacing means that attentional focus may become synchronized (entrained) with certain time relationships associated with dynamic sequential events.

A series of five experiments attempted to identify the respective roles of rate and rhythm time parameters in a simple selective attention task involving two differently timed streams of events. Rate and rhythm manipulations were applied to integrated (combined streams) time relationships and/or separate (single) stream timing to ascertain the impact of each on a viewer's performance. Results from these experiments indicated that the rhythmic structure of combined streams was a more powerful "Pacing" factor than either the rhythm or rate of a single (relevant) stream. Together, these experiments suggest that there may be two kinds of temporal "pacing": (1) passive entrainment with external time patterns and (2) active "use" of timing relationships to shift and direct the focus of attention.

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CHAPTER I

INTRODUCTION

Nature of the Problem

In our everyday environment we must cope with a complex flow of visual and auditory inputs from multiple sources, a flow which consists of many changes over time. Somehow we manage to "move through" this changing flow of information to allocate attention over time and space. How do we do this?

Some changes in the flow of information occur naturally. If we stroll along a neighborhood street while listening to a companion (and ignoring other sounds), both the changes of the visual scene and the prosody of our companion's voice change in structurally smooth and predictable (seemingly natural) ways over time. Other changes over time occur in a more artificial way. For example, it is quite common in the workplace to have to deal with dynamic visual displays, often accompanied by auditory inputs, that inform the operator of system or environmental status/changes. This information typically arrives to the operator via multiple sources, and all at different times. The information each source produces changes over time and the resulting string of events/changes, etc. has been defined as an information "stream" (e.g., Bregman, 1990; Skelly & Jones, 1990; Sperling & Reeves, 1980). Each stream can be defined in terms of its rate and its rhythm. Rate simply refers to change per unit time, i.e., how fast or slow events (items) within a stream occur. Rhythm refers to how items within a stream relate to each other in terms of their timing (both successive items and non-adjacent ones), in complex multi-source environments. Rhythm also relates to timing of items in one stream relative to those in another information stream. That is, rhythm is defined by the relative timing relationships among events either within a particular stream or between different streams.

In any situation where several information streams occur, there is some potential for conflict associated with timing of events between two or more streams. For example, if one information stream in a workplace is associated with a temporal sequence of letters appearing at a rate of one per second on a computer screen, and another co-occurring stream is created by a beeper (from the PC's audio unit) occurring at a rate of three beeps per second, these two streams create a potentially conflicting rhythm when considered together. Conflicting timing streams can be conceived in terms of polyrhythmic timing structures (polyrhythm complexity is dealt with in a more formal way in Chapter III). Thus, as Adams and Pew (1989) note, in the real world of dynamic complexity information does not usually arrive neatly packaged in task-by-task bundles. Instead, multiple streams of information exist, and these are often interleaved in time.

Let's consider an example of a dynamic workplace that is most complex. This is the cockpit of a high performance aircraft. Here the pilot is exposed to as many as three hundred different information sources, with approximately seventy five of them appearing as dynamic visual displays. Figure 1.1 shows an example of one such display from an F-16 Head Up Display (HUD). It looks fairly benign as a static representation.

F-16 HEAD UP DISPLAY (HUD)

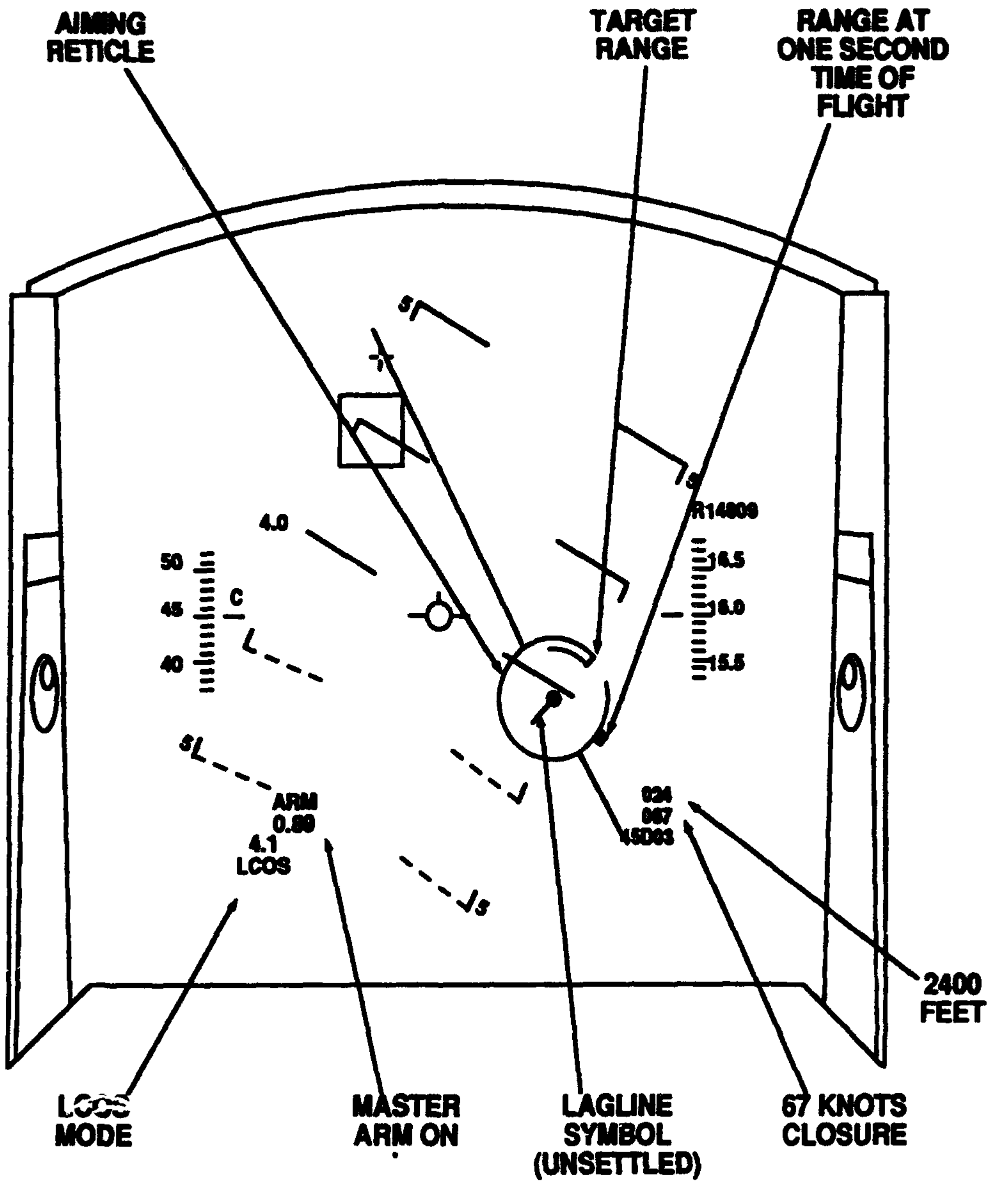

Figure 1.1 A sample display from an F-16 Head Up Display (HUD).

However, by definition, dynamic displays incorporate change over time, and so important questions emerge when we consider adding timing variation to static visual arrays. Consider Figure 1.1 again. When this particular display is operational, all information is moving either in a continuous manner (with different velocities), or discretely appearing at different rates. What is the influence of different timing patterns (associated with various information sources) on attending when we move from static visual arrays to dynamic elements? How do we selectively allocate attention over changing locations in space and over time? What controls attending in dynamic environments? Can we assume that attention is entirely under voluntary control in such contexts? The research presented here addresses a few of these questions and examines certain hypotheses related to temporal manipulations in visual displays and their impact on selective attending. The determination of whether temporal manipulations should have any impact on selective attending depends to a large extent on how selective attention is defined.

Selective Attention Defined by Capacity and Process Limitations

Selective attention refers to the perception and analysis of some information while other information is ignored (Kahneman, 1973; Kahneman & Treisman, 1984). The function of selectivity is most often considered as the consequence of system limitations. That is, the purpose of selectivity is to protect the brain's limited resources and processing capacity from information overload (e.g., Broadbent, 1971). The emphasis on system limitations has resulted in research concerned with identifying the nature of these capacity limitations and processing constraints. This is especially true in visual attention where selectivity is often conceptualized in terms of static spatial relations. For example, capacity limitations and processing constraints are often related to spatial location and the proximity of spatial fields, number of elements in a display, etc. (see reviews by Allport, 1989; Duncan, 1985; Hirst, 1986; Johnston & Dark, 1986; Shiffrin, 1988; Treisman, 1988). Thus, the core area of selective attention research is concerned with the detection of target stimuli or searching spatial locations for targets in situations where some of the target's characteristics have been defined in advance (Shiffrin, 1988). This is the essence of the search paradigm used most often to investigate processing constraints on attentional selectivity imposed by spatial relations (Shiffrin, 1988).

The emphasis on capacity limitations and processing constraints has spawned a number of popular metaphors for attention designed to explain what it is and how it operates. One popular metaphor for attention to emerge from this spatially oriented perspective is the spatial "spotlight". According to this view, attending is voluntarily directed to certain spatial locations where stimulus events illuminated within the beam receive additional processing (e.g., Broadbent, 1982; Posner, Snyder, & Davidson, 1980). This metaphor is the source of a number of selective attention models that endorse the idea of attentional movement. In almost all cases, though, movement per se is confined to the beam of the spotlight, not the stimuli. This is an important distinction for the present research. It means, for example, that the spotlight of attention can move through a static visual array to a target region. However, what happens to the course of an attentional "spotlight" when elements in an array begin to move either discretely or continuously, perhaps to abruptly appear or disappear, and even change direction?

Others have questioned the spotlight view of attention and the reliance on a spatially oriented view of attention as well. A prominent alternative is the object based view of attention that emphasizes hierarchical structural organization of object subparts and groups of objects, rather than spatial location or the proximity of spatial fields. Nevertheless, such alternatives share with spatially oriented perspectives (e.g., spotlight models) the view of capacity limitations (e.g., number of objects that can be attended to simultaneously) and limitations on selective processing (e.g., integration of features into objects). This issue and questions surrounding spotlight models (among others) are discussed in more detail in Chapter II.

Selective Attention Defined as Goal Directed

Allport, (1989) has recently questioned conventional definitions of attentional selectivity and research emphasis on capacity limitation and processing constraints. He has suggested that the theoretical preoccupation with issues of limited capacity and selectivity of "processing" (e.g., early versus late cognitive processing) have left us with bankrupt concepts of "bottlenecks", assumed monotonic processing stages, and selection processes operating primarily, or exclusively, in terms of spatial location (e.g., spatial "spotlights"): ".... after thirty years of vigorous experimentation we are no closer to realizing where and when processing becomes selective, or understanding the nature of the mysterious capacity limitations" (p.662). He suggests that questions about selective processing are the wrong questions, and that what would be a more useful heuristic is to focus on questions about mechanisms of attentional control that emphasize constraints on behavioral coherence. That is, Allport reasons that attentional functions have evolved to satisfy a range of positive, biological purposes, i.e., goal directed actions, and that attentional selectivity is in effect selection for the potential control of action. Thus, Allport suggests that our research on visual attention might be more appropriately related to questions about mechanisms associated with attentional engagement, coordination, maintenance, and redirection, all in the preparation and control of action.

In sum, two different views regarding the function of attentional selectivity have been described, each with assumptions that, if embraced, influence the theoretical framework and experimental paradigms chosen to study attentional selectivity. The first view is the currently prevailing one which emphasizes the limitations of the attentional system, e.g., limited capacity with selective processes that have certain constraints. From this viewpoint, the function of selectivity is most often viewed as preserving the limited attentional resource. On the other hand, the alternative view suggests that attentional selectivity functions not to preserve a limited reservoir of attention, but rather to maintain our basic need for coherent control of action. It does so by selection that is aimed at the preparation and potential control of some action. The latter view stresses that researchers should be concerned with identifying fundamental external and internal constraints on coherent behavior.

I favor this last view and discuss specific ramifications of this viewpoint in the next section, in terms of the topic investigated and presented in this dissertation, and the choice of a guiding theoretical framework.

Research Assumptions and Goals

The antithesis of chaos and randomness is structure, i.e., structure is a guiding force in any coherent behavior. A key assumption in this thesis is that something in the temporal structure of dynamic visual information actually affects attending. If we return to the introductory examples of information streams, I would maintain that something in the temporal structure of these information streams affects, indeed comes to control, attending. This idea derives from a structurally oriented view of attending which assumes that both rate and relative time (rhythm) of an information stream exert some control over selective attending, and that they do so amodally. That is, the timing structure of an information stream is perceived in essentially the same manner, regardless of whether it is in the auditory or visual mode. Constraints on attending in this approach are structurally based. The idea that temporal structure itself may facilitate visual selective attending in some situations, while in others it may interfere, represents a departure from the more traditional views of attention control. These ideas stem from Jones' (1976; Jones & Boltz, 1989) theory of dynamic attending that stresses the dynamic interplay between environmental structures and the attender (this theory is examined in more detail in Chapter II).

A primary goal of the present dissertation is to discover whether certain elementary aspects of temporal structure in dynamic visual displays have any systematic impact on attending. Specifically, this research examines the relative influences of rate and rhythm and how viewers adapt to changes in these time parameters.

The emphasis in this research upon determining influences of the dynamic structure of the environment represents a departure from the more popular models of visual attention. Therefore, the next section briefly reviews research supporting the idea that temporal structure can influence responses to dynamic visual information.

Supporting Evidence of Temporal Structure Effects

In general, research which manipulates temporal structure of stimulus arrays for the purpose of understanding its influence on selective attending is sparse. Some exceptions occur with auditory environments where manipulations of time parameters (tempi or rate and rhythm or relative time) in music and speech patterns affect perception and attending (Bregman, 1990; Handel, 1989; Jones, 1987). Variations in sequence tempo (rate) in conjunction with changes in pitch lead to auditory pattern streaming which influences selective attending. Rhythmic manipulations can influence how a listener "tunes into" and detects some events and not others (Handel, 1988; Jones, Boltz & Kidd, 1982; Jones, Kidd, & Wetzel, 1981). The idea is that manipulations of temporal aspects (rate and rhythm) of an auditory sequence can affect performance in part by influencing the temporal predictability of future events.

Although relatively little experimental research addresses selective attending in dynamic visual contexts, there is some evidence to suggest that temporal structure influences: (1) perception and memory of visual sequences (i.e., single streams); and (2) selective attention to multiple visual streams. This literature is briefly outlined in the next two sections.

Perception/Memory Tasks

This research derives primarily from perception tasks with single streams of visual events. For example, Garner and his colleagues found that the temporal arrangements of events in binary light patterns (e.g., run-gap rhythms) affected overall sequence perception (Garner & Gottwald, 1967; 1968; Garner, 1974). Furthermore, using serial patterns created by successive onsets of events (i.e., lights) drawn from a linear spatial array, Restle (1976) found that both spatial and temporal regularities determined viewers' abilities to anticipate the "when" and "where" of individual pattern elements.

Skelly and her colleagues also (Skelly, Hahn, and Jones, note 1) studied responding to dynamic visual sequences. However, they used serial patterns created by successive onsets of lights arranged in a circular array and found that manipulations of both a sequence's rhythm and its spatial configuration determined the likelihood that viewers detected certain deviations in the space (i.e., "where") and time (i.e., "when") of critical embedded events. Converging evidence that attentional activity was involved in responding to these dynamic arrays was found in follow-up studies that measured event related potentials (ERPs) to successive spatial changes within such sequences. Most relevant was the finding that rhythmic context significantly affected ERPs to an unexpected change in spatial location of one element in an unfolding sequential array. For example, both latencies and amplitudes of the N_2P_3 ERP increased when expected events became less temporally predictable as a function of increases in rhythmic context complexity (Skelly, Rizzuto, & Wilson, 1984).

Most of this research focuses simply on the influence of rhythm in tasks involving only visual stimulus patterns. However, there is some evidence that commonalities among the modalities exist with respect to temporal structure, thus supporting the idea that such psychological influences are amodal. Marks (1987) found that judgments of temporal pattern similarity, using different rhythmic patterns, were highly consistent across different modalities in cross modality studies (visual, auditory, and tactile).

Finally, none of these studies explicitly studied selective attending. That is, for the most part, the above research concerns relative timing influences upon responses to a single visual event. However, the rationale for presenting these studies relies upon the assumption that attentional selectivity is nonetheless involved in these tasks. I assume that attention operates over time with respect to certain temporal locations; people attend to certain points in time within a given stream and not others.

Selective Attention Tasks

Little research exists that examines selective attention when two or more streams of information (e.g., relevant and irrelevant) are involved. An important exception is found in the work of Sperling and his colleagues (e.g., Reeves & Sperling, 1986; Sperling, 1984; Sperling & Melchner, 1978; Sperling & Reeves, 1980). They have typically used a search task with two different streams of information (e.g., one involving a sequences of letters and the other a sequence of numerals) presented at rapid rates. Subjects are required to monitor one stream for a target and then to immediately switch attention to the other stream and report the first items they detect in it. Typically, memory for the order of items in the second stream is poor and often appears random with regard to presentation order. Reeves and Sperling (1986) explain this distortion of order as a function of the amount of attention items receive at input into short-term visual memory. They have determined that the associated attention span for this process is approximately 400 ms.

There is, however, another possibility for the distortion order found by Reeves and Sperling. We know from studies in auditory perception that memory for the order of a tone in a sequence is affected by the rhythmic structure of the sequence (e.g., Bregman & Campbell, 1971; Jones et al., 1981; Warren, 1982). Perhaps temporal structure is also a contributing factor to order distortion in this task. For example, Reeves and Sperling manipulated the rate of the second stream only (i.e., not the target stream), effectively changing the timing relationships between the two streams. Secondly, changes in the ratio relationship between streams also has implications for Sperling's notion of the span of attention. That is, Sperling's paradigm raises the question of whether the attention span might expand/contract depending on changes in the time ratios between the streams.

Scerbo, Warm, and Fisk (1986), on the other hand, did examine how two different timing streams interacted to affect performance in a vigilance task. Viewers had to monitor two temporally interleaved streams of discrete visual events (targets and noise) where irrelevant events (noise events) followed one set of temporal constraints and the relevant events (targets) could follow other time constraints. It turned out that viewers were best when time constraints associated with the two streams were similar (i.e., both regularly timed or both irregularly timed) than when they differed. These results suggest that timing streams with the same rhythmic structure (i.e., relative time properties) produce a temporal compatibility of concurrent streams that may be a crucial factor in determining selective attending.

In sum, the results of Scerbo et al. (1986) are intriguing, and in fact, their notion of temporal compatibility did generate a hypothesis tested in the preliminary studies discussed in Chapter III. The work of Sperling and his associates is especially important as well, in that their search paradigm (with minor modifications) offers rich potential for investigating rate and rhythm effects associated with rapidly moving information displays.

Chapter Summary

In summary, while little research directly addresses attending to dynamic visual events, there is some evidence suggesting viewers are sensitive to the rate and rhythmic properties of visual event sequences. This has important implications for theories of visual attention. First, there is little research that directly addresses whether elementary aspects of temporal context, such as rate and rhythmic structure, affect attending in dynamically complex environments. Secondly, there are no predictive models that incorporate temporal structure from either: (1) spatially oriented theories of visual attention; or (2) theories emphasizing Gestalt principles of organizations (e.g., structurally oriented perspectives). Some of these contemporary approaches to understanding selective attention generated from different space based, object based, and timed based orientations are discussed next in Chapter II.

CHAPTER II

CONTEMPORARY VIEWS OF SELECTIVE ATTENTION

Moray (1984) has suggested that traditional theories in psychology woefully neglect the study of attending to dynamic visual information. Recently, others have expressed a similar concern regarding the need to study dynamic aspects of visual attention (e.g., Adams & Pew, 1989; Marks, 1987; Scerbo, Warm, & Fisk, 1987; Tipper, Brehaut, & Driver, 1990). Tipper et al., (1990) for example, comment "... research on visual selective attention has largely examined filtering tasks in which stationary targets are selected from stationary distractors... these situations differ fundamentally from the ecological reality of how we respond selectively to individual objects in cluttered dynamic visual environments". Finally, Moray (1984) succinctly summarizes the current state of affairs in this domain when he criticizes the disproportionate use of time as a dependent variable. He argues that time should be more often investigated as an independent variable. How do our contemporary theories stand up to this criticism?

This chapter will review some of the most influential theoretical perspectives regarding visual selective attention with an eye towards evaluating how they deal with dynamic visual stimuli. This review is not meant to be an exhaustive review of the attention literature. That is far beyond the scope of this endeavor. Instead, I concentrate on three classes of models that are most relevant to the focus of this dissertation.

Models that have evolved from the perspective that focuses on limitations of the attentional system (e.g., limited capacity, limited processing capabilities, etc.) will be discussed first. The theoretical orientations presented in this section differ in terms of their respective emphasis on spatial dimensions and object organization. For convenience, they have been labeled as Space Based Approaches and Object Based Approaches. The second section offers an alternative position that has attempted to deal directly with the issue of attending to dynamic information, but not within the framework of a limited capacity system. This approach is labeled as a Time Based Approach. First, to give some historical perspective to this chapter, the next section provides a short background regarding the genesis of the area's most influential models of attention.

Background

In his recent review on the psychology of attention, Hirst (1986) reminds us that until a little over a decade ago, visual attention was often confused with foveating. Attending was not clearly distinguished from merely looking at an object, and thus the reflection of an activity was confused with the activity itself. This all changed with the emergence of experiments designed to study the nature of visual attention in detail. For example, the important studies of Posner and his associates (e.g., Posner, 1980; 1984; Posner, Nissen, & Ogden, 1978) demonstrated that subjects could attend to an area of space without looking directly at the area. They decoupled foveating from attending by requiring subjects to fixate centrally. This was followed by an informative cue regarding future locations of a target event. Results indicated response times were faster to cued locations than to nonattended positions. Schulman, Remington, and McLean (1979) also found that subjects could make attentional shifts to various target locations without making concomitant eye movements. They concluded that attention could move across a spatial field in a manner analogous to skilled eye and hand movements by demonstrating that a probe event located between the cue and target location received maximal facilitation compared to probes at other locations.

These studies were responsible for demonstrating that visual attention was something more than merely looking, it involved selection. An important legacy from these studies is that the nature of attentional selectivity was seen as a voluntary dynamic activity that could be decoupled from eye movements. The idea that attention could move across a visual field led to a spatial "spotlight" metaphor that has become popular in describing the movement course and boundaries of an attentional "beam". The spotlight models, along with other spatially-oriented models, will be discussed in the next section.

Space Based Models of Attention

Essentially, three classes of models can be described as space based. All assume that visual attention is a limited resource system and that attention can be voluntarily controlled such that people can shift attention to some locations independently of concomitant eye movements. One class of models relies explicitly on the "attentional spotlight" metaphor. Underlying this metaphor is the notion that attention can be directed to certain spatial locations where stimulus events illuminated within the spotlight's beam receive additional processing (e.g., Broadbent, 1982; Posner, Snyder,

& Davidson, 1980). A second class of models are those likened to a camera lens, these are the "zoom lens" models (C.W. Eriksen & St.James, 1986; C.W. Eriksen & Yeh, 1985). Here limited attentional resources can be directed to targets within bounded spatial regions where focal attention is expanded or contracted to correspondingly change resolving power. Finally, the third class of models are the gradient models of attention (e.g., Downing & Pinker, 1985; LaBerge & Brown, 1989; Shulman, Wilson, & Sheehy, 1985). Gradient models also assume that attention can be voluntarily directed to spatial areas of different sizes, but they differ from other spatially-oriented models in assuming that attentional resources fall off monotonically from the spatial center of a "peak", or focal attention locus. Duncan (1984) has classified these models under space based theories of attention because they all adhere to the idea the selectivity is limited by spatial location.

Researchers using space based models have relied heavily on search tasks. These tasks present stimulus items as spatial arrays in which both targets and non target items are embedded. Depending on the task requirements, people usually have to locate (search for) the target(s) within static arrays. Typically, subjects receive some advance information about the target, i.e., some cue and the probability of cue accuracy (i.e., relative to the target's location) is often manipulated. Common dependent measures are response time and accuracy.

The following section describes in more detail one class of models from this spatially oriented viewpoint. Spotlight models have been selected as exemplars from the spatially oriented perspective for two reasons. First, these models have enjoyed widespread popularity (and some notoriety) in recent years; and secondly, because these models explicitly deal with attentional movement, i.e., movement of the spotlight, they would seem to offer the most promise for explaining how we attend to dynamic visual information.

Spotlight Models

All spotlight models, according to Shepard and Muller (1989), have three important properties. These relate to how a spotlight moves, where and when it moves, and size of the spotlight's beam. First, the attentional beam of selectivity moves through space in an analog fashion (i.e., passing through all intermediate locations) where the movement velocity is seen as either constant, i.e., rate limited (e.g., Shulman et al., 1979; Tsal, 1983), or time-invariant, i.e., the cue-target distance or movement distance does not play a role in attentional reallocation costs (e.g., increased RTs). Movement speed is not constrained, movement velocity can speed up or slow down to cover the necessary distance between attentional shift in the time-invariant models.

The second important property of spotlight models is that shifts of attention from one location in the visual field to another correspond to movement of the beam. That is, attention is assumed to be distributed in contiguous regions of the visual field (Broadbent, 1982). When events occur within the region of the spotlight they are extensively processed, but when stimuli occur outside the spotlight (a non-contiguous area of the visual field), the spotlight must be moved.

The third characteristic of the spotlight is that the beam is narrow, about 1°. This is the minimal focus of the spotlight where all stimuli are processed. The specification of a narrow beam is supported by the finding that response times to a target letter decrease as the spatial distance in between the target and a distractor increases (Eriksen & Hoffman, 1972; Eriksen & Eriksen, 1974). These early data by Eriksen and his colleagues were seen as providing evidence for defining the area of selectivity, i.e., the limiting boundary of attention. Therefore, when distractors are more than 1° of visual angle removed from the target, they interfere little with the focus of attention. Thus, in attentional models incorporating movement of the spotlight, attention is seen as something with a limited focal area that can move through space and, depending on the particular model, at either a constant or a variable velocity. For purposes of the present research, the two versions of spotlight movement, i.e., constant velocity versus time-invariant are especially relevant. They are reviewed along with some supporting data.

Spotlight Movement as Time Limited. In this version of the spotlight model, attention has been estimated to traverse the visual field (i.e., from a fixation point to the target) at a constant velocity of approximately 8ms per degree of visual angle (Tsal, 1983). This implies that the spotlight moves with a fixed velocity. Predictions from a temporally limited model are that there should be a cost for targets appearing at each unexpected location (i.e., non cued location). For example, costs for targets appearing at each of two 5.65° unexpected locations should be equivalent, but less than that incurred for an 8° unexpected location (Egly & Homa, 1991). Tsal found that in a forced-choice discrimination task, where targets were presented at 4°, 8°, or 12° to the left or right of a fixation point, that reaction time (RT) to the target asymptotes of 83ms, 116 ms, and 150 ms were obtained for these respective eccentricities. The cue-target stimulus-onset-asynchrony (SOA) varied from 50 to 183 ms, and it had no effect on RT. Because SOA had no effect on performance, Tsal concluded that attention moved at a constant velocity of about 1° per 8ms on the grounds that for each 4° increment there was a 33ms increase in the asymptote.

Tsal's data have been criticized by on methodological grounds. Eriksen and Murphy, (1987) and Yantis, (1988) maintain that cue and target eccentricities covaried with distance that might produce asymptote differences. However, more recently Egly and Homa (1991) controlled for this by using a discrimination rather than a detection task to control for contamination of results due to retinal acuity and by varying distance independently of retinal eccentricity. Maximum eccentricity in these experiments were 4.5° to provide a severe test of beam breadth. They used a two-alternative, forced choice discrimination task to investigate RT costs for targets appearing in unexpected locations. They found the time required to reallocate the focus of attention is a function of the distance it is moved. Their data supported the findings of Tsal (1983). That is, the "costs" incurred to move attention were proportional to retinal distance.

The idea of analog movement, nevertheless, has been challenged by a number of researchers. For example, Egly and Homa (1991) note that not all Shulman et al., (1979) data are consistent with analog movement since performance difference between the 18° <u>expected</u> location and 8° <u>unexpected</u> location in an the opposite hemifield remained constant. The concept of analog movement of the spotlight is further challenged in the next section.

Spotlight Movement as Time Invariant. The distinction between a temporally invariant version of spotlight movement and the analog version (i.e., temporally limited) is that movement distance does not play a role in reallocation costs according to the temporally invariant position. Instead, attentional movement is assumed to occur either discretely or at a variable velocity. Essentially, the spotlight can speed up or slow down so that regardless of distance the time to reach the target is equivalent, and there should be no cost associated with unexpected locations.

To test this hypothesis, Remington and Pierce (1984) designed an experiment that required detection of a luminous signal (cue was accurate 80% of the time and incorrect 20%) in two different conditions that differed respectively in the distance separating expected and unexpected locations. They found equivalence in reallocation costs for the two conditions. These data led Remington and Pierce to conclude that attentional movement velocity may be proportional to the distance of the movement. Later, Rizzolatti, Riggio, Dascola, and Umilta (1987) arrived at the same conclusion, but from a premotor theoretical position.

According to the premotor position, allocation of attention to a distant location from fixation is closely identified with the preparation to make a saccadic eye movement. Attentional movements are temporally invariant with regard to spatial locus, but there are cost differences for unexpected locations that reflect the time necessary to program the distance (although time required is not proportional to distance) and direction of a saccade. In the experiment by Rizzolati et al. (1987), subjects were required to respond to a geometric pattern appearing in one of four boxes along a column or a row centered around a fixation point. Cues to target location were accurate 70% of the time. They found that distance (4° vs 12°) did affect the magnitude of the reallocation cost, but they found that there was an additional cost at 4° if the horizontal or vertical meridian separated expected and unexpected locations. Even though the authors did find a distance related reallocation cost, they nevertheless rejected the interpretation of the analog model in favor of a premotor interpretation where a single mechanism controls both eye and attention movements. Their rationale was that a saccade to either an expected location or an unexpected location must be programmed prior to moving attention. Therefore, attention is delayed until the saccade can be reprogrammed to an unexpected location (e.g., different hemifield), hence the additional allocation cost. Thus, Rizzolatti et al., (1987) maintain that with respect to attention movement, different locations in space are assumed to require equivalent allocation times, the additional RT costs observed are a function of reprogramming a saccade.

A final set of experiments by Kwak, Dagenbach and Egeth (1991) is particularly interesting since they incorporated implied motion of stimuli in a discrimination task involving same/different judgments to either upright letters or rotated ones (Ts and Ls). Interletter distance in terms of visual angle (1.8° - 9.0°) and rotation angle of letters (0°, 90°, 180°, 270°) were manipulated. In both experiments, RT did not differ as a function of interletter distance. They interpreted these data as supporting the view that relocation of attention is time-invariant with respect to distance (see Chignell & Krueger, 1984 for an alternative explanation).

<u>Evaluation of Spotlight Models</u>

Do moving spotlights address attention to dynamic environments? Both versions of the spotlight models reviewed above incorporate time in that they envision a <u>moving</u> spotlight. However, it is important to distinguish between how these models incorporate time into attentional movement through a static array and the dynamics of the environment itself. Whether the spotlight is assumed to move at a constant velocity or make discrete jumps, it has not been applied to dynamic visual information. It is unclear how an attentional spotlight (or for that matter, a "zoom lens" or attentional gradient) would explain responses to visual displays that are not static. What happens to the course of an attentional "spotlight" when uncued elements in an array begin to move either discretely or continuously, perhaps abruptly appear or disappear, and even change direction?

Recent work of Baylis, Driver, and McLeod, (1990); Driver and Baylis, (1989); McLeod, Driver, Diense, and Crisp (1991) suggest that in dynamic displays, where time is added to the stimuli (in contrast to adding movement to an attentional mechanism), spotlight models encounter difficulties. They showed that movement in a display allows attention to be directed to noncontiguous regions in space. For example, in displays composed of both static and moving elements they found that distant distractors which share movement (or immobility) with a target produce more interference than near distractors. Furthermore, research by Jonides, Naveh-Benjamin, and Palmer (1985); Jonides and Yantis (1988); Yantis and Johnson (1990); Yantis and Jonides (1984); and Yantis and Jonides (1990) suggests that attention can be "captured" by external factors such as the abrupt onset of a visual stimulus; this poses converging problems for the "spotlight" view of attention. For example, in dynamic cockpit displays, the spotlight's movement to a specific spatial region could be disrupted by an abrupt appearance of a new display element or distant elements that have motion in common with a target in an expected spatial region.

In sum, a majority of the research which derives from space based orientations has emphasized distinctions between how a spotlight moves (e.g., analog or discretely), conditions of expansion and contraction of the beam determining "resolving power" (e.g., zoom lens model) or attention dispersion from the peak of focal attending (e.g., gradient models). It is not clear how the resolving mechanisms or movement of the beam would operate when information is dynamic, either moving among different locations or discretely changing in time at one spatial location. It is not uncommon to hear assertions that one cannot rule out the efficacy of these models simply because they do not address attending to dynamic information, or that these models could be modified to do so. That may be true. But the fact remains that they have not been. Until such time that the issue of dynamic information is addressed in these spatially oriented models, they are inadequate for predicting performance in complex dynamic environments as Moray (1984) has suggested.

Object Based Models of Attention

Object based models of attention offer an alternative viewpoint to those spatially oriented models just discussed. While sharing the view of limited resources, these models do differ markedly from the spatially oriented models. Object based models propose that attentional capabilities are limited by the number of separate objects (or subparts of an object) that can be attended to simultaneously, rather than by spatial region (Duncan, 1984). Theories from an object based perspective embrace the notion of selective processing as accomplished by two stages of stimulus analysis. These approaches, in turn, fall into two categories: those advocating early selection and those advocating late selection processing.

Early versus Late Selection Views

Early Selection. In the early selection models, the first stage is usually referred to as the preattentive stage where filtering of sensory information occurs before the stage of perceptual recognition (e.g., Broadbent, 1958; Johnston & Dark, 1986; Kahneman & Treisman, 1984; Treisman & Gelade, 1980). In this first stage, (preattentive) parallel processing is assumed to occur and attention is not considered necessary at this stage. For example, proponents of feature integration theory (e.g., Treisman, 1988; Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Souther, 1985) conclude that single features are analyzed in parallel (i.e., early), but that conjunctions of features defining objects requires attention (second stage processing), i.e., attention is the "glue" that puts features together. Thus, attention is associated with a second stage that involves serial processing to categorize information.

Late Selection. The late selection version of two stage processing assumes that segments in a visual field are analyzed in parallel and separate objects are organized on the basis of Gestalt principles. These organizing principles operate during the first stage of processing and are based on spatial proximity, continuity of contour, or shared movement. If there is a processing bottleneck, it can occur only later, if at all. From this perspective, selection among object occurs after semantic categorization (e.g., Deutsch & Deutsch, 1963; Duncan, 1980, 1984; Marcel, 1983; Norman, 1968; Posner, 1978; Schneider & Shiffrin, 1977, Tipper, 1985). It is during this second stage that resource limitations come into play, i.e., our ability to see several objects at once is constrained.

In sum, both versions of the stage processing models assume that stage one involves parallel processing, and that stage two is where serial processing occurs requiring focal attention. What comes early or late is selectivity which is represented generally as a bottleneck and specifically as a filter. Early selection models state that features are selected in parallel, but organized into objects in the second stage. Late selection models assume that organization of objects are based on Gestalt principles, and this occurs in the first stage while selection among objects occurs later.

Structurally-Oriented Views

The various models from the object based perspective that adhere to Gestalt principles can be considered as possessing a structurally oriented view of attentional control, i.e., the external structure of visual information exerts a powerful influence on how we allocate attention (e.g., Duncan, 1984; Driver & Baylis, 1989; Kahneman & Henik, 1981; Prinzmetal, 1981). The emphasis of structural factors on attention differs from the spatially oriented viewpoints where location in space is the primary driving force of selectivity. Recently, there has been some interest in applying the Gestalt principle of "common fate" to dynamic objects. Evidence presented earlier (Chapter I) by Driver and Baylis (1989) and McLeod et al., (1988) demonstrated that visual search can be restricted to items with a common motion to the exclusion of interleaved static items, and further, that distractor items with the same motion as targets produced more interference than static distractors.

In short, these reports are often cited as evidence of the inadequacy of a purely spatial account of visual attention. On the other hand, is a structurally oriented view based primarily on the principle of "common fate" enough to explain how we attend to dynamic objects?

The next section presents a review of one such structurally oriented perspective that attempts to deal with perceiving and attending to dynamic objects in a more comprehensive way. It is an object-centered approach developed by Kahneman and Treisman (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992; Treisman, Kahneman, & Burkell, 1983).

Object-Centered Approach

The object-centered approach developed by Kahneman and Treisman assumes a primacy of objects in determining the allocation of attention. This is an important departure from the primacy of spatial location assumed in space based perspectives. The approach states that object perception is a process of creating temporary "episodic" representations of real world objects that are called object files (or tokens). Object files are assumed to be the end product of perceptually processing a stationary scene. Each file contains information about a particular object in the scene. These object files are addressed by their location at a specific time, not by any feature or label. The next section presents the defining characteristics of object files and describes how they preserve the history of an object's movement.

Object Files. Object files are not a series of "snapshots" representing a real object, but rather an abstracted representation of successive states of an object that are linked and integrated. A temporary object file carries information about how an object changes over time. That is, as sensory information changes, a file is updated by comparator processes to yield the perceptual experience of a moving object.

Apparent motion is often used to explain how an object file operates. Consider a blue square that appears briefly and is replaced by a red circle in a nearby location. Under the appropriate spatiotemporal conditions, this display is seen not as two separate objects, but rather as a single moving object that changes shape and color. According to the object-centered approach, the square and the circle are interpreted as two moments in the history of a single moving object that are linked by an inferred trajectory, not by color or shape features. Therefore, the history of a real object in motion would be captured in an object file in successive states (i.e., moments) in the same manner as apparent motion.

It is important to remember that object files are temporary. They are kept open only as long as the object is in view and temporary occlusions are bridged by saccades. If a spatiotemporal gap between two successive appearances of the same object (e.g., two red squares) cannot be bridged, they are perceived as two distinct objects. These temporary object files are considered as distinct entities from representations stored in a long-term recognition network that we presumably use to label (i.e., name) objects and that contain the specific attributes of the objects. That is, object files are abstract representations and resolution within a file is limited. How then do we remember the attributes of a moving object?

This approach deals with what has been called the "binding problem". The binding problem refers to how the attributes of the real object are connected to the abstract object file representation. It is here that attention is invoked as the binding agent. Visual attention is assumed to be involved in the process of binding attributes to object tokens (files). Kahneman, et al., (1992) claim that the binding of attributes comes from an "object-specific advantage" where attributes are bound to object files so that moving objects carry their attributes along with them. That is, attributes are not bound to fixed locations.

Evidence cited by Kahneman, et al., (1992) for the object-specific advantage found in moving objects, emphasizes a previewing process. In experiments designed to test the notion of an object-specific advantage, subjects were presented briefly with two letters appearing each in its own box. Next, the letters disappeared, and the boxes moved along different trajectories, then paused. A new letter appeared in each box, one was cued. The authors found that subjects responded faster if the cued letter matched the letter that had appeared earlier in the same box, compared with a matching letter in a different box. They interpret these data as evidence for an object-specific advantage because it was not "where" in space the letters appeared, but "which" object they appeared in. It is never really clear in this approach how attention operates to bind attributes of object files.

These theorists have suggested that object files themselves may be targets of visual attention. There is some evidence suggesting a role for object files in controlling attention. Kanwisher and Driver (1992) report that the phenomenon of "inhibition of return", thought to be associated only with target location, was found to travel with a moving target (object) instead. Typically this phenomenon is realized by slower response times when a target appears in a previously cued target location. In the study they reported, two boxes moved around a fixation point, and it was found that slower responses were obtained with a previously cued object (target), rather than the previously cued location (Tipper, Driver, & Weaver, 1991). In this instance, the two objects had identical attributes. And finally, Kahneman, et al., (1992) cite the research on grouping effects (e.g., common fate) as additional evidence that object files are targets of attention. Specifically, they consider the structure of visual objects as being hierarchically organized and have extended this idea to include hierarchically organized object files as well. They use the example of a group of dancers considered as a higher level object, linked together by a common motion, whereas individual dancers could be considered objects too, but at a lower level. Each object in this hierarchy has an object file. Thus, the dancers moving in unison form a higher level object file, while a single dancer forms a lower level object file. It is assumed (and they note it is a tentative assumption) that object files are set up at the preferred level, which is determined by the controlled allocation of attention. However, the criteria for establishment of such a "preferred level" is not defined.

In summary, the object-centered approach is an attempt to address the inadequacy of the space based models. These theorists assume there is a primacy of objects in determining the allocation of attention, rather than a primacy of spatial location. From this approach, it is the abstract temporary representation of a moving object (i.e., object file) that carries information about the history of object changes or movement. Thus, movement information is not bound to a spatial location.

Evaluation of Object-Centered Approach

The object-centered approach is a major advance in recognizing the inadequacy of psychological theories in dealing with attention to dynamic visual information (e.g., Moray, 1984). This version of the original object file hypothesis (e.g., Kahneman & Treisman, 1984; Tresiman et al., 1983) is designed to address issues of perception, attention, and memory of moving objects, so it is reasonable to assess its merits at this point. Can we generalize this new approach to those issues of attentional control associated with multi-stream dynamic visual information?

At present, the approach does not provide clear guidelines for how people respond to visual streams with different rates and rhythms. The approach does address the idea of a structural hierarchy of visual objects where higher level objects are formed by grouped objects possessing a common motion (i.e., "common fate" principle). This is tantalizing. But the concept does fall short in that part of structure, temporal structure, (i.e., the timing relationships among levels in this moving hierarchy) is not explicitly addressed. That is, how do the various object levels that are defined by spatiotemporal relationships actually relate to one another? What exactly is the nature of the spatiotemporal relationships that are referred to repeatedly in this approach? Nevertheless, the concept of hierarchical relationships among objects and object files is a valuable one and certainly worth pursuing.

One troubling aspect in this new approach is the omission of how temporary object files that supposedly capture movement information help us to use this information to predict future events. We are told there is constant updating of files, etc., but it is not at all clear how this relates to generating an expectancy for "when" an object will occur. In fact, we are told that object files are temporary and can be discarded when the object disappears. Where does the movement information in the file go? Do we assume it is transferred to long-term memory? If so, how do we recapture motion information to use it for predictions?

The point is, that to appropriately allocate attention in dynamic environments the individual must stay "ahead" of the system (or information flow) to anticipate "where" and "when" new task relevant information will occur. There is an implicit assumption in the last statement that the individual extrapolates critical space-time relationships from the dynamic environment. At present, the object-centered approach has focused solely on interpolation of spatiotemporal information, with their emphasis on apparent motion. The approach is incomplete as it now stands. Nevertheless, the object-centered approach is an important step forward to understanding perception and attention to moving objects.

Time Based Approach

The time based approach to attentional control discussed in this section differs from the space-based and object-based orientations reviewed in previous sections, in that it explicitly addresses attending to dynamic visual information. This perspective is derived from the dynamic attending theory developed by Jones (1976), Jones and Boltz, (1989). Dynamic attending theory was originally developed within auditory perception and attention research. It is extended to visual attending in this dissertation.

The approach shares with object based models an emphasis on the primary importance of structural relationships in determining attentional allocation. Specifically, this view addresses how an individual picks up and uses dynamic structure in the environment to predict future events. There are a set of general assumptions associated with this view.

Specifically, this perspective assumes: (1) a viewer is able to abstract and extrapolate higher-order relationships (temporal and spatial) from dynamic information and "use" these extrapolations to reduce uncertainty and anticipate future events; (2) a dynamic (i.e., temporal) interaction between the viewer and a task environment; and (3) various dynamic and structural constraints determine observed behavioral coherence.

Dynamic Attending Approach

Most contemporary theories of attention do not incorporate time as an important structural dimension in their models. An exception is Jones' theory of dynamic attending (Jones, 1976; 1981; 1986; Jones & Boltz, 1989). The basic idea is that attending is inherently temporal, and that it is an activity that is guided to some extent by temporal structure (rate and rhythm) in our environment. A basic assumption in this theory is that temporal structure functions independent of modality to influence attending. Temporal structure here refers specifically to rate and rhythm of information streams in dynamically changing environments. That is, relationships in time are seen as important aspects of environmental structure in that they are assumed to control attention (at least in part) in both auditory and visual modalities.

The function of selective attention in this approach is in agreement with several ideas expressed by Allport (1989) and cited earlier in Chapter I. Specifically, in Jones' view attention functions to maintain coherent behavior by information selection that enables the viewer to prepare for and control some response component. That is, to attend to something that occurs at a given location in space, one must "time" attending in such a way that attentional energy is allocated to that location at the right time. Thus, the constraints on attentional allocation (and hence, coherent behavior) from this perspective reside primarily in the external structure of the environment and, most importantly, its space-time structure.

To be more specific regarding some of the constraints on attending within the dynamic attending framework, let us consider the concept of a Serial Integration Region, or SIR (Jones, 1976; Jones & Yee, 1992).

The Serial Integration Region Concept. The SIR defines a region of temporal pattern integrity. It is a psychological construct that defines the spatio-temporal constraints that limit a viewer's (or listener's) ability to perceive and attend to an unfolding serial pattern. The definition of "spatio-temporal" used here refers to the combined space/time structure of sequencing information. Whether the viewer perceives sequential events as a coherent temporal pattern, depends on both the base rate and relative timing relationships between adjacent events and non adjacent events in the particular serial pattern. The base rate is especially important to the SIR concept. Base rate is defined in terms of a unit time period, e.g., corresponding to an average stimulus-onset asynchrony (SOA). The base rate "shrinks" when the speed of a pattern increases and conversely expands when the pattern is slowed down. The SIR has an upper spatio-temporal limit or threshold that, if exceeded, will disrupt perceived temporal coherence. That is, if the pattern continues to speed up, there comes a point where an attender can no longer maintain temporal coherence, i.e., the pattern will appear to break apart into sub-streams, or to "stream" (Bregman & Campbell, 1971). Pattern coherence is also just as likely to suffer if the base rate is expanded past the lower limit of the SIR, i.e., the pattern is slowed to the point where the "time pattern" of the sequence is lost. When this happens, the viewer is likely to perceive small successive units or "chunks" of the pattern instead of a coherent and seemingly connected serial pattern. It is the lower limit of the SIR that has received the least attention in the literature, but is of most interest to this author. Thus, when the limits of the SIR are broached, serial pattern integrity is threatened. This, in turn, is reflected by a loss of attentional synchrony with the environment. The result is that a dynamic environment exerts less control on attention.

There is no absolute rate at which a serial pattern loses temporal coherence; rather, the specific rate is dependent partly on the associated rhythm of the pattern. For example, a time pattern with a simple rhythmic structure will be less likely to broach either the higher upper limiting threshold (i.e., when the pattern "steams") or the lower limiting threshold (i.e., when a pattern "chunks") than a more complex rhythmic pattern. That is, in extending Jones' concept, I assume that the effective SIR region, the region of pattern integrity, becomes narrower as rhythmic complexity increases. Effectively, this means that the more complex rhythms are particularly vulnerable to loss of coherence with rate manipulations. However, for the research presented in this dissertation, the emphasis is on exploring the lower limiting threshold of the SIR.

Viewer-Environment Synchrony. The viewer (or listener) in this approach is not a passive conduit of information, but rather is actively engaged in a continuous interplay with dynamic information structure. Dynamic interaction between the viewer and environmental structure is accomplished by an attentional mechanism that is conceived of as a set of graded biological rhythms that carry attentional energy. The term "graded rhythms" simply refers to a set of periodicities that range from small time periods associated with fast rates to larger time periods that are associated with slower rates, i.e., there is a hierarchy of biological rhythms. While these rhythms are conceived as periodicities, together they can control attending to a rhythmically patterned environmental sequence. Attending to such a rhythmic pattern relies on certain simple or complex combinations of graded attentional periodicities. Thus, the fact that attending itself is time based in this approach means that, to permit a synchronous, time locked response to changing elements in a dynamic display, there must be critical time properties within that display which engage the attending mechanism. What are these critical time properties, and how does the attentional system incorporate, or "use", these properties to prepare the individual for future action?

Internalization of Time Parameters. First, the critical time properties that stimulate attentional rhythms are: (1) the base rate within the SIR and (2) temporally invariant relationships among elements that are based on simple time ratios. That is, I am postulating that attentional rhythms may be entrained by simple time structures existing at optimal rates in the environment. This synchronization means that attentional energy is being temporally "paced" (regulated) by the rate and rhythm of the external time pattern. Synchronization will, however, only occur if the rate falls within the limits of the SIR. Furthermore, attentional synchrony is more likely where the rhythmic pattern involved is based on simple time ratios, e.g., 1:1 or 2:1 rather than complex ones such as 3:2 or 4:3. For example, synchrony would be unlikely to occur with a highly complex rhythmic pattern moving at either a high rate of speed or at an extremely slow rate. But how are invariant time properties "used" to prepare for some action?

This approach assumes that even as attention is being synchronized or "paced" by some external time structure, the viewer is actively abstracting those time relationships from the external environment that afford facilitation of task performance. The assumption is that learning to "use" timing relationships in this manner is a function of gradual internalization of complex timing relationships (e.g., ratio relationships) that define dynamic structure. The implication here is that implicit learning of temporal structure is an acquired attentional skill (e.g., Jones & Boltz, 1989).

An important assumption here is that internalized timing parameters are what we "use" to help us target attending in preparation for controlling some action. That is, internalized time parameters are what we use to generate time based expectancies that help us to appropriately "time" our attending to the appropriate local at the appropriate time. We adjust our expectancies (and attending strategies) based on information pickup that violates these expectancies. Hence, this is what is meant by dynamic attending.

There is, however, no assumption that the viewer is aware of the process of abstracting and "using" temporal properties to guide attention (Jones & Boltz, 1989). In fact, experiments by Lewicki and colleagues (e.g., Lewicki, Hill, and Bizot, 1988; Lewicki, 1985; Lewicki, Czyewska, & Hoffman, 1987) support the idea that people can abstract complex procedural knowledge and then apply this knowledge to facilitate subsequent performance without any awareness of the process itself. The point is that the idea of abstracting and "using" complex relationships from dynamic structure to facilitate performance is not without precedence. In the present context, this means that rhythms with simple time ratios are most likely to quickly entrain attending, (i.e., control attending) than ones with more complex ratios. However, with experience, more complex ratios can be internalized and "used" as well. Therefore, from a dynamic attending approach, selective attention to dynamic visual information is goal directed and constrained by certain powerful spatiotemporal relationships. Thus, the reference earlier to "staying ahead" of the aircraft (or tennis ball) is effectively what is meant by "using" temporal relationships to target attending.

Supporting evidence for this approach comes mainly from auditory research and has been mentioned earlier in Chapter I. Visual experimental support comes mainly from perception studies with single dynamic streams, with the exception of Scerbo, et al., (1986) also reported in Chapter I. One of the more relevant experiments from auditory research for this dissertation is from the series of experiments by Jones, et al., (1981) on "rhythmic capture". Rhythmic capture refers to the finding that the rhythm of an auditory pattern can direct attention to specific notes in a musical sequence and away from others. More recently, Klapp, Porter-Graham, and Hoifjeld, (1992) found evidence of this effect in visual patterns (polyrhythms) where subjects were required to tap to the rhythm of one stream and name digits in another. Interference in this task situation was produced by conflicting rhythms associated with different information streams. Thus, interference was produced not by the two motor tasks themselves, but rather the rhythmic structure of streams providing information for the two tasks.

Evaluation of Dynamic Attending Approach

This time based approach directly addresses the issue of how we attend to dynamic information streams. It emphasizes the importance of external information structure in guiding attention allocation and focuses on the functional affordances that temporal structure can bring to attentional selectivity. Specifically, the time structure of our dynamic information sources (auditory and visual) is viewed as a primary influence on attention, one that is amodal in nature.

The approach does offer a systematic framework for investigating issues of attentional control in dynamic information environments and some models have been developed for testing assumptions (e.g., Jones, 1976; Jones & Boltz, 1989). However, while advocating the amodal assumption of how we perceive, attend to, and remember dynamic information, this approach has only been tested with auditory patterns, in particular musical sequences. The ideas presented are broadly applicable to both auditory and visual domains, but it remains to be seen if they do in fact extend to the perception and attention of visual information sequences. This dissertation is a first step.

Thus, while offering a promising avenue for attacking problems of dynamic structural influences on attending, this approach is still incomplete in its present form.

Chapter Summary

This chapter has reviewed three general theoretical approaches regarding attention in dynamic visual environments: 1. The Space Based approach; 2. The Object Based approach; and 3. The Time Based approach. Of the three different approaches discussed, the spatially oriented views have made the least progress in addressing how we perceive, attend to, and remember dynamic visual information. The emphasis from the space based viewpoint is primarily on the constraints imposed by an element's location in a visual field. Most research has been devoted to examination of static spatial arrays, with dynamic information rarely used in these experiments. There is movement in the attentional "spotlight" perspective, but it is attention that is moving (e.g., spotlight movement) and not the information. In short, as Allport (1989) has argued, research emphasis on capacity limitations and processing constraints has done little to enhance our understanding of these selective processes and reservoirs of attention. And, most importantly, this approach has shed little light on what controls attention in dynamic visual environments.

The second approach, the object based view, and in particular the object-centered approach, has attempted to address what they refer to as the inadequacies of the spatially oriented perspectives of attention. These theorists have focused on the primacy of object/s structure, rather than on spatial primacy, in determining the control of attentional allocation. Their argument, unfortunately, is generally couched in terms of space versus objects. Until the recent work of Kahneman, et al., (1992) movement of objects and how this might affect attending has been excluded from examination.

Kahneman and Treisman's body of research on the object-centered approach is a major advance for the object based approach to attending. However, like the space based views, this one also falls short in helping us to understand attentional allocation in complex dynamic environments. The choice to extend the object-centered viewpoint by focusing on apparent motion explorations does not tell us much about how one anticipates information, i.e., how we are seemingly able to allocate our attention to the "when" and "where" of new upcoming information. Thus, at present, this new object-centered version of Kahneman and Treisman's approach is incomplete, but it is a promising avenue to pursue.

The final time based approach focuses on temporal structure (i.e., rate and rhythm) as a primary factor in how we allocate attention in dynamic environments. This is the only approach expressly developed to examine perception, attention, and memory to dynamic information. It is an amodal approach, but at present it, too, is incomplete, as most research supporting the dynamic attending approach has been with auditory information. This view is promising, but has yet to be tested in the area of visual attention.

In sum, at present there is very little research that directly addresses attention to dynamic visual information, and no comprehensive theoretical position that incorporates both temporal and spatial structures into their approaches regarding the function and purpose of visual selective attention.

CHAPTER III

RESEARCH PLAN

Chapters I and II introduced the idea that attention may be influenced by the temporal structure (i.e., rate and rhythm) of dynamic visual information. This research explores the possibility that structure associated with the timing of dynamic visual information may play a role in the control of attention. Attentional control has been conceived of in terms of two broad determining factors: external (exogenous) and internal (endogenous) ones. In the present context, I will address the way manipulations of temporal structure may (or may not) fit into this dichotomy.

With respect to the exogenous control of attention, certain aspects of the time structure itself may "capture" attention in an involuntary manner. For example, it is possible that an individual's attending may be "paced" or driven by certain time properties of a visual event stream such as its rate and/or rhythm. By "pacing" I mean that attentional focus may become entrained with certain time parameters (e.g., rate and rhythm) associated with a dynamic environmental event sequence. That is, attentional energy may become regulated by the rate or rhythmic structure of that sequence (stream). Pacing is therefore the synchrony of attending with the time structure of external events (see Chapter II, Dynamic Attending section). Operationally, such synchrony of attending would be reflected by stable timed responses i.e., more rapid and less variable reaction times (RTs) to event onsets. Thus, the idea of attentional "pacing" is that external timing structures may regulate the course of attentional allocation to dynamic visual events.

Specifically, this research focuses on the role of temporal parameters that summarize timing properties such as rate (tempo) and rhythm (relative timing) in selective attending tasks involving two different event streams. The terms tempo and rate are used interchangeably and refer to the relative speed of the information streams, whereas rhythm (and, synonymously, relative time) refers to a sequence of patterned durations. Within two different sources of information, i.e., two co-occurring streams, I consider whether selective attending is systematically affected by variations in rate and rhythm time parameters. In a two stream context, time parameters can relate to <u>global</u> or higher-order time structures associated with time relationships between the two streams, or they can relate to <u>local</u> time structure, which concerns the tempo or rhythm of events within a single stream. In short, one general objective of this research is to discover how certain rate and rhythm manipulations associated with global and local time structures might influence attending to dynamic visual events.

In sum, the goal of this chapter is to provide the research rationale and experimental objectives related to examining the issue of attentional control in dynamic visual environment. The chapter is organized into three major sections: (1) Preliminary Studies; (2) An overview of the present research; and (3) Chapter Summary. The first section, Preliminary Studies, provides the background for the present research from two earlier pilot studies. The second section presents a brief description of each of the three studies, including hypotheses. The final section is a summary of this research approach and projected outcomes.

Preliminary Studies

Two preliminary experiments were conducted to assess the influence of dynamic context (i.e., temporal and spatial relationships) on selective attending. The task was a continuous version of a Posner type classification task with consistent mapping (see Shiffrin, 1988) of relevant and irrelevant event streams. Viewers had to selectively attend to and classify letters which formed one stream (relevant) while simultaneously ignoring interleaved occurrences of squares which formed the other (irrelevant) stream. These studies serve as background for the present research.

Each experiment was conducted in two parts. Preliminary to the main part of each study, viewers received and responded to the relevant letter stream alone (baseline conditions). The baseline condition provided a data base from which to gauge facilitatory or inhibitory effects associated with adding the second (irrelevant) stream to a relevant stream. In the main part of the experiment (Part Two), viewers saw the two interleaved information streams, one relevant and one irrelevant to the classification task. Figure 3.1 presents an example of a baseline stream, as well as two examples of experimental patterns composed of relevant and irrelevant information.

In both the baseline and experimental conditions the local time structure created by the succession of events within each of the two streams was manipulated: in relevant streams (of baseline and experimental conditions), letter pairs followed either a regular, R, or irregular, I, rhythm. Similarly in the irrelevant streams (of experimental conditions), squares occurred in either a regular or irregular rhythm (e.g., see Figure 3.1). In

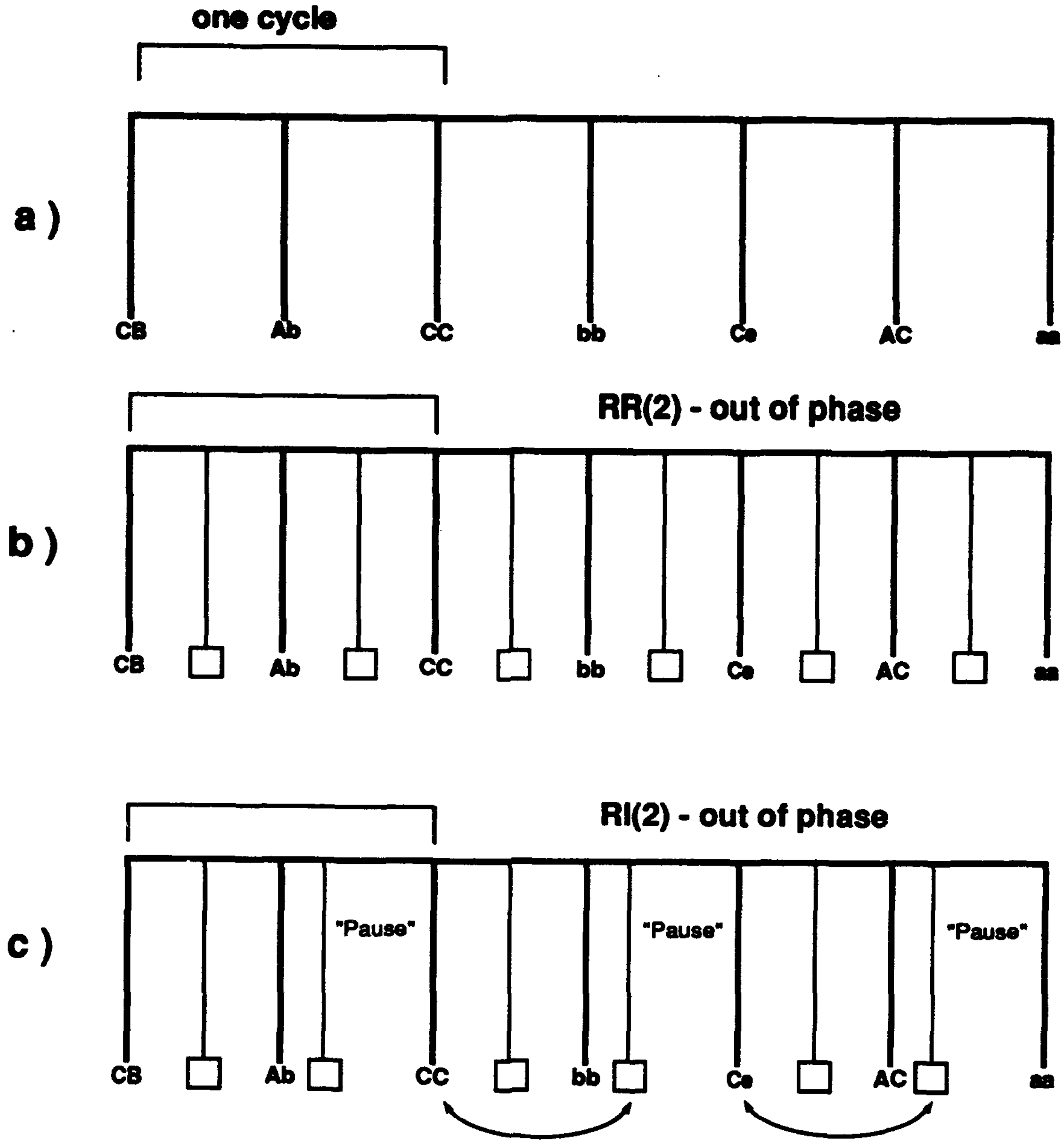

Figure 3.1. A baseline (panel a) and two experimental conditions (panels b, c). a: Relevant events (letter pairs) form a regularly timed (R-base) stream; b: Addition of a regularly timed irrelevant event stream (squares) to a regular relevant stream (letter pairs) yields RR(2), where first and second letters refer to timing of relevant and irrelevant streams, respectively, and where (2) indicates out-of-phase relations in which the two streams start at different times; c: Addition of an irregularly timed irrelevant stream to a regularly timed relevant one yields RI(2) when out-of-phase. The thickened lines outline a single cycle.

experimental conditions, timing between the relevant and irrelevant streams (i.e., global timing) was also varied via phasing relations. Performance in each two stream experimental condition (e.g., RR, RI, IR, II) was gauged against performance in the corresponding single stream (baseline) case (R or I).

The two experiments differed with respect to spatial formatting of irrelevant events. In both, relevant letter pairs were displayed centrally, but in Experiment 2 the squares were displaced from the centered letter pairs in four different loci, so that when they appeared successively in time, they moved in a clockwise manner (see Figure 3.2). The original hypothesis was that displaced irrelevant spatial information would be more easily ignored.

Several hypotheses relating to influences of these timing manipulations on selective attending were generated. Some of these related to interference effects. That is, the addition of an irrelevant event stream to a relevant one may function to add distractors. In this case, performance in the baseline condition should always be superior to the experimental conditions as addition of an irrelevant stream is assumed to create a situation where attention is diverted from the primary task.

Other hypotheses more directly addressed rhythmic variations. These concerned stream independence versus integration. If viewers treat relevant and irrelevant streams as separately timed streams, then local rhythmic variations within the irrelevant event stream should have no effect on performance of the relevant streams. However, if local time structures of the two streams interact (psychologically), then performance will be a function of their combined structure. In this case, it is possible that the rhythm of an

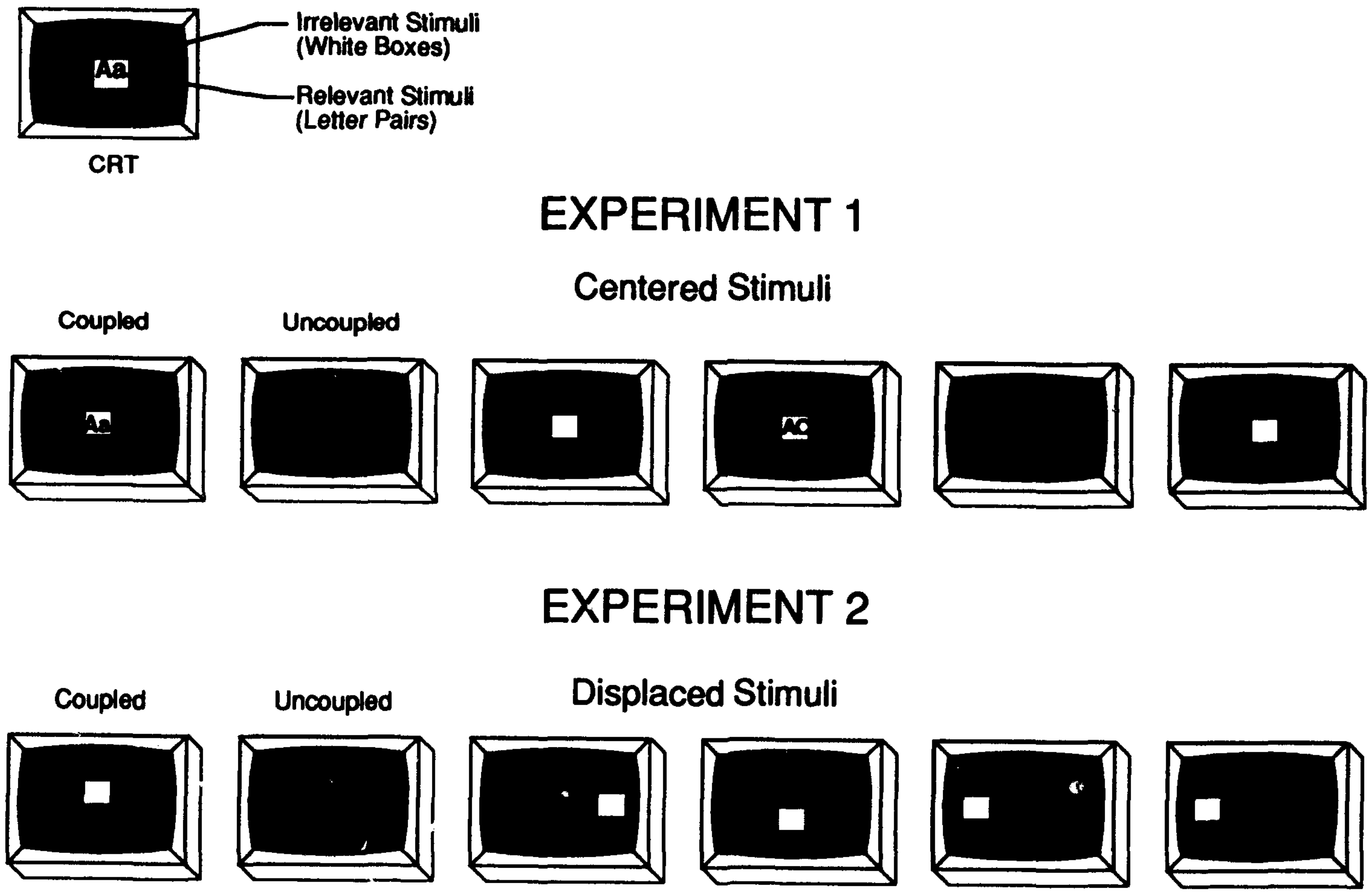

Figure 3.2. Spatial formats in Experiments 1 and 2 with centered and displaced irrelevant events respectively. Note the distinction between coupled and uncoupled events in both formats.

irrelevant event stream could actually facilitate attending to the relevant stream. That is, the combined streams would form new global rhythmic structures based on the integration of the two streams that are inherently different than the local timing associated with either single stream.

Results from both studies indicated that adding irrelevant information did not always produce interference effects. Rather specific aspects of emergent rhythms from the combined streams influenced performance, leading to facilitation in some cases and to interference in others. This was especially true for Experiment 1, where both relevant and irrelevant information appeared centrally on the CRT. Spatially displacing irrelevant information in some cases reduced its interfering effects, but in other cases increased it (Experiment 2).

In Experiment 1, facilitation was most apparent when the integrated time pattern yielded predictable rhythmic groupings containing both relevant and irrelevant events (i.e., isochronous timing of letters and squares within a group). These groups were typically segmented by relatively long pauses. Response times were slowest, (hence, interference greatest) when integrated time patterns lacked distinctive segmenting pauses. Response times were also long when the pauses which emerged bounded a group of temporally irregular letters and squares. However, comparisons among different emergent rhythms in these studies were difficult and possible only with the ad hoc development of metrics based on rhythmic grouping properties.

Experiment 2 considered the impact of changes in the spatial formatting of irrelevant events. This also caused difficulty interpreting the data. There appeared to be a conflict of attention allocation produced by both spatial and temporal structures that was impossible to tease apart in this study. Nevertheless, there continued to be substantial evidence of performance facilitation in some experimental conditions, as well as interference effects in others. However, the pattern of facilitation and interference effects was different than in Experiment 1. In this experiment, it appears that the rhythmic integrity of combined streams can be "broken", or at least threatened, by alternative structural relations (e.g., spatial relations between streams) which compete for attention. In short, although important, the role of spatial structure and its interaction with temporal structure is a complex one.

To sum up, preliminary dissertation research indicates that manipulation of local (single) stream timing does dramatically affect selective attending. However complications arising from emergent global rhythms associated with integrated streams (two streams) and spatially displaced irrelevant events lead to the present reliance on designs which: (1) control and systematically manipulate both local and global stream timing; and (2) do not incorporate spatial formatting manipulations.

Upcoming Experiments: An Overview

Three studies were designed to examine the effects of rhythmic context on selective attending to dynamic visual information. Essentially, the task described in the previous section was used to present both relevant and irrelevant events centrally on the CRT. However, tempo and rhythm manipulations of local stream timing were constrained in these experiments. Specifically, the nature of global rhythms which could emerge in the two stream case was carefully determined in advance.

Timing manipulations were achieved via use of the polyrhythm paradigm. A polyrhythm refers to a time pattern where two or more conflicting timing streams are presented simultaneously. The polyrhythm paradigm was borrowed from auditory research, where it is used to investigate effects of rhythmic structure emerging from co-occurring streams (e.g., Deutsch, 1983; Handel & Oshinsky, 1981; Handel, 1984; Jagacinski, Klapp, Marshburn, & Jones, 1988; Klapp, 1985; Pitt & Monahan, 1987). For example, both Jagacinski et al., (1988) and Klapp et al., (1988) used polyrhythms to manipulate the timing of auditory patterns. They present compelling evidence that the time structure of auditory patterns influenced perception and attention to auditory events. By adopting this paradigm to explore attending to dynamic visual events, there is a level of parsimony in the current research that might otherwise be lacking. Specifically, the use of polyrhythms provides the necessary means to gain precision in manipulating timing structure. Further, it provides a link between auditory and visual research. That is, one assumption behind this research is that timing structure is perceived, attended to, and remembered in an amodal manner. Therefore, if the amodal assumption is correct, then there should be some parallel evidence indicating that certain time parameters affect attention to visual events in a manner similar to that found in the auditory mode. Thus, using the polyrhythm paradigm for the current research is one method for investigating whether rhythmic structure is experienced in an amodal manner.

At this point, I would like to explain in more detail properties of a polyrhythm and how they can be used to manipulate global and local time structures. In the simplest polyrhythmic case, two co-occurring timing streams are involved and both are isochronous (regular SOAs). Further, as these co-occurring streams of events continue there are regular points in time where the events from both streams coincide. Figure 3.3 (a) shows an example of a polyrhythm formed from two isochronous streams. Note that this polyrhythm has a cycle defined by three events in one stream and two events in the other. As the polyrhythm unfolds, this cycle of events is repeated. This particular polyrhythm is known as a 3 on 2 polyrhythm; i.e., when considered relative to one another, a ratio of 3:2 events obtains between the two streams. The stream carrying the greater number of events is considered the fast stream (e.g., three events) relative to the slower stream carrying the fewest number of events (e.g., two events). The first two events in the cycle will always coincide, and this coincidence will be referred to as a coupled event; all other events in the cycle are separated in time and referred to as uncoupled events. In the top portion of the Figure 3.3 (a) and (b), the two streams are presented separately, while the bottom portion shows the serial pattern that is formed when the two streams are interleaved in time, i.e., temporally integrated. Global time structure refers to the rhythm and/or rate of this integrated pattern. Notice in panel (a) that the global timing produces an integrated time pattern with long, short, short, long intervals (e.g., 1-4). Local time structures refer to the rhythm and rate describing the single separate streams; note that all time intervals of separate streams in panel (a) are equivalent (i.e., isochronous).

An advantage of the polyrhythm paradigm is that one can manipulate relative time properties between (global) and within (local) event streams while maintaining the same absolute cycle time, i.e., global rate, across different polyrhythms. For example, not all

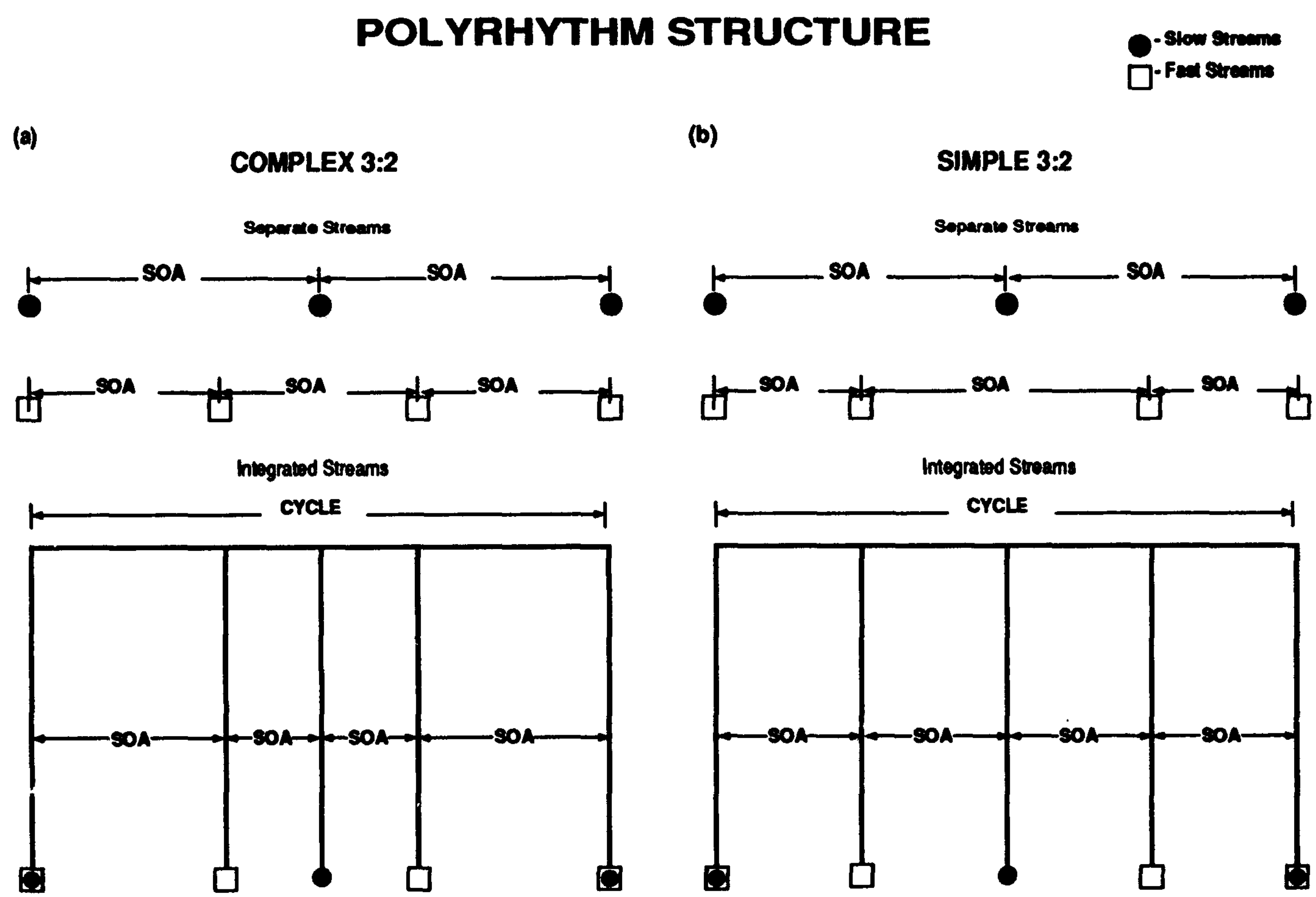

Figure 3.3. The timing structure for two different versions of a 3 on 2 polyrhythm where there are 3 events in the fast stream and 2 events in the slow stream. Panel (a) shows that two isochronous streams create an integrated serial pattern with variable SOAs. Panel (b) shows that a change to variable SOAs in the fast stream creates an integrated serial pattern with isochronous SOAs. Note the first event in each cycle is a coupled event.

polyrhythms are constructed from isochronous streams. Figure 3.3 (b) shows another version of a 3 on 2 polyrhythm, one in which the fast stream has variable time intervals (SOAs), while the slow stream remains isochronous. Notice, when these two streams are interleaved that they produce an integrated timing pattern with constant intervals within the cycle. That is, in contrast to the 3:2 polyrhythm of panel (a), this polyrhythm has a global rhythm that is isochronous. Thus, with one subtle change in the timing of the fast stream, a new 3 on 2 polyrhythm is created with a different global time structure than the one in panel (a). For these reasons, the polyrhythm in Figure 3.3 (a) has a Complex 3:2 global rhythm, while the other one shown in panel (b) has a Simple 3:2 global rhythm.

There is another experimental advantage of the polyrhythmic paradigm that bears discussion here and is important to the research presented in later chapters. So far, the discussion has centered on manipulations of rhythm while holding global rate (i.e., integrated cycle time) constant, but it is also possible to manipulate rate and hold rhythm constant. That is, as long as proportional relationships (e.g., ratios between successive events) are held constant, one can speed up or slow down the global rate of a polyrhythm while preserving the original rhythmic structure. Thus, the flexibility of the polyrhythmic paradigm permits systematic manipulations of rate and rhythm at both global and local time structures.

Manipulations of local and global time structures along these lines will be a major focus in examining the temporal determinants of attentional control in experiments 1, 2, and 3. In general, this research explores: (1) whether rate and rhythm time parameters may exert an involuntary "pacing" effect on attention; and (2) whether individuals can learn to "use" these time parameters of global and local time structures in an opportunistic manner, to either maintain or shift their attentional set in response to different task requirements.

Description of Experiments and Hypotheses

The same task is used in all three studies. The task parallels that already described for the preliminary studies: it is a version of the traditional Posner letter classification task. Here trials are presented in a continuous manner (i.e., there is no warning signal between trials) as in the preliminary research. Furthermore, within stream timing manipulations are developed in a manner similar to that used in earlier work as well.

Significant changes from the preliminary studies involve: (1) introduction of polyrhythms to control both the global (between stream) and local (within stream) time structures; and (2) use of variable stimulus mapping (Shiffrin, 1988) where either of the two information stream (letter pairs or shape pairs) can be designated as a relevant (or irrelevant) stream during a particular block of trials.

Experiment 1-Baseline

The first study is a baseline study. It examines classification judgments of events (either letters or shapes) within differently timed of streams. These streams all possess isochronous rhythms, but they are presented at each of several different rates (i.e., single stream presentation), rates later used to create the polyrhythms in Experiments 2 and 3. The purpose of the baseline study is twofold: (1) First, it provides baseline performance for all timing rates used in the later studies. It also provides a baseline for classification judgments at all rates when stimuli are presented as: a) Uncoupled events, (i.e., letters pairs or shapes pairs alone); and b) when they are presented as Coupled events (letters plus shapes). (2) Since the same subjects are participating in all studies, baseline data is planned for use in developing derived RT scores as a means of using each subject as their own control, in an effort to control for well known variability effects associated with RT measures.

Hypothesis. One hypothesis is tested in the baseline study: The Object File Hypothesis. This hypothesis maintains that when two objects occur at the same spatial location and at the same time (e.g., a Coupled event) that all features are processed, including those of the irrelevant information, and that this "new" object is encoded in memory as a single object file. Thus, the hypothesis predicts that Coupled events will produce longer Rts compared to Uncoupled trial blocks. This is because there are more features to process in a Coupled event than in an Uncoupled event. This hypothesis does not predict any performance variation as a function of stimulus rate.

Experiment 2

The Role of Temporal Relationships in Visual Attention

The purpose of this study was to gain insight into how global and local timing structures might influence the control of selective attention as reflected in changes in response time measures of speed and variability as well as error rate. The emphasis here is on determining the relative impact of rate manipulations at local and global levels of time structure. That is, the focus here is on investigating whether it is easier to adapt to a change in rate (global rhythm held constant) or rhythm (local rate held constant) of the task's polyrhytmic context. The experimental objectives were to: (1) determine if rhythm and rate influence maintaining an attentional set, and if so, whether these involve local or global influences; and (2) examine viewer adaptation to changes in rate and rhythm.

In this study rate and rhythm time parameters associated with local and global time structures are systematically controlled to produce two different polyrhythmic contexts for the classification task. The 3:2 polyrhythms shown in Figure 3.3 are the polyrhythms used in this experiment. Note that in both polyrhythms the slow streams are identical and the fast streams have equivalent rates, but different rhythmic structures. Different groups of subjects received the Complex 3:2 and Simple 3:2 polyrhythms. Relevant information was always presented in the slow stream that was identical for both polyrhythms. This permitted examination of possible performance differences as a function of global rhythm (Figure 3.3 lower section).

Hypotheses of major interest in this experiment, as well as the next, concern the respective roles of global and local time structures on the control of selective attending to the relevant (slow) stream.

The Global Precedence Hypothesis states that global time structures are the primary timing factors that influence attending. It maintains that if there is a simple higher-order time relationship between streams (e.g., constant relative timing as in the Simple 3:2 polyrhythm), then this should facilitate focused attending because all events would be temporally predictable and the relevant ones are more likely to be anticipated.

By contrast, a more complex global time structure (e.g., variable relative timing) would be less predictable and would not facilitate performance. Global rhythm is always more important than rate parameters from this perspective. Thus, the Global Precedence hypothesis predicts that if the global structures are maintained, then rate manipulations will have little impact on performance.

The Interdependence Hypothesis assumes there are two aspects of interdependence in any dynamic multistream task environment. First, this hypothesis states that a viewer's reliance on global versus local time properties is task specific. That is, this hypothesis maintains there is an interdependence between the attentional requirements of the task per se and the time structure of task relevant information. Secondly, the Interdependence Hypothesis states that there is an interdependence between rate and rhythm that determines whether viewers perceive sequential events as a coherent temporal pattern (see discussion of Serial Integration Region (SIR) in Chapter II). In Experiment 2, the predictions given this hypothesis bears substantial similarity to that of the Global Precedence Hypothesis since it maintains that viewers will rely to a large degree on global rhythm, and hence performance would be better in the Simple 3:2 than in the Complex 3:2 polyrhythm. It differs from the Global Precedence Hypothesis in that it also predicts a rate as well as a rhythm effect on performance. This hypothesis predicts a performance decrement occurring when global rhythms are slowed, (i.e., temporal coherence of the pattern is threatened). The effect would be most apparent in the Complex 3:2 group since temporal coherence is likely to suffer sooner in this polyrhythm compared to the Simple 3:2. Thus, the Interdependence Hypothesis predicts that if two polyrhythms have identical global time ratios, but different global rates, performance will be impaired in the polyrhythm with the substantially slower rate.

In summary, the study was designed to explore the possibility that certain rate and rhythm time parameters associated with extended events may contribute to the external control of attention to dynamic visual information.

Experiment 3

The Effects of Rate and Rhythm on Attentional Flexibility

The goal of this study is to determine whether temporal structure may be a factor in the flexible control of attentional allocation. That is, can we learn to "use" temporal structure in a somewhat voluntary manner to guide attentional selectivity? Here the issue is whether a viewer might be able to "use" rate and/or rhythmic structure in an opportunistic manner to target attention selectivity as stream relevance changes. The idea is that over time a viewer may learn to actively use time parameters to target attending. This addresses an aspect of attending that is different from the momentary, involuntary "capturing" of attention (e.g., an abrupt stimulus onset). Using timing structures to direct (target) attention assumes that the viewer has first been able to abstract and internalize certain time parameters associated with dynamic context.

The suggestion here is that effects of external timing structures may first influence attending in an involuntary way, but that later, after the viewer has had extended exposure to the task's temporal context, significant timing properties are abstracted and "used" more actively to direct attentional focus. That is, attention is targeted in a more active manner that reflects a tacit acquired skill.

Experiment 3 is a direct extension of Experiment 2. The same subjects participated in both experiments; the task and original polyrhythms remain the same. However, there are two critical changes in this experiment. The first involves a manipulation of stream relevance; relevant information was systematically shifted back and forth between the fast and slow streams of a given polyrhythm. This contrasts to experiment 2 where relevant information was only presented in the slow stream. This means the presentation rate (and sometimes rhythm) of the relevant information is systematically shifted throughout the experiment. In Experiment 2, however, with the exception of the Shift day, the presentation rate and rhythm of the relevant information was held constant. In Experiment 3, there is also a polyrhythm change in the Shift phase in addition to changing relevant stream timing. During this Shift phase, viewers are shifted to a completely new global polyrhythmic context that is different in both global rate <u>and</u> rhythm from their original context. This Shift phase differs from Experiment 2 where either rate <u>or</u> global rhythm was changed, never both.

The experimental objectives are related to exploration of these timing manipulations. The first objective is to determine the effects of systematic shifts in local stream relevance within a familiar global polyrhythmic context. That is, does it become easier to adapt to changes in local stream timing within certain global time structures (simple vs complex)? The second objective examines viewer adaptation to a new polyrhythmic context, one with a more complex global rhythmic structure and different global rate from their original. Here the emphasis is on whether there is any evidence to suggest that previous extended exposure to one polyrhythm facilitates (or constrains) adaptation, i.e., attentional flexibility, to a completely new polyrhythmic context. The two hypotheses guiding the evaluation of performance in this experiment are the two time based ones considered in Experiment 2, namely the Global Precedence hypothesis and the Interdependence hypothesis.

The Global Precedence Hypothesis maintains that regardless of task, there is a primacy of global time structure and people use this to direct attention. Consequently, in Experiment 3, this hypothesis predicts that as long as global polyrhythmic structure remains constant (e.g., Complex 3:2 or Simple 3:2) viewers would continue reliance on this time structure, regardless of the manipulation of local stream relevance. This hypothesis predicts that systematic shifts in stream relevance (fast or slow streams) should not create any problems for the Simple 3:2 group. This is because it is assumed that attention "paced" by the isochronous global timing is evenly distributed to all events (relevant or irrelevant) of the integrated streams (see lower portion of Figure 3.3b). That is, both relevant and irrelevant events would receive equivalent attentional energy. The hypothesis does, however, predict that shifting stream relevance should prove more difficult for the Complex 3:2 group since reliance on global structure in this experiment changes associations viewers may have made between specific time intervals and relevant events. For example, returning to Figure 3.3a, the integrated streams forming the global time pattern yield a pattern of relevant (R) and irrelevant (I) events that are associated with long and short SOAs in Experiment 2 as follows: R-long, I-short, R-short, I-long, R, etc. This pattern of events never changes because relevant information is always carried in the slow stream. However, in experiment 3, this pattern changes when relevant information is shifted to the fast stream: R-long, R-short, I-short, R-long, R, etc. These shifts should create problems for efficient attentional allocation to target events if global timing is "pacing" attention. Thus, the Global Precedance Hypothesis predicts there will a main effect of stream relevance only in the Complex 3:2 group. It will be more difficult for viewers in the Complex 3:2 to adapt to systematic shifts of stream relevance and therefore performance should suffer compared to the Simple 3:2 group.

With regard to shifting the task to a new polyrhythm, this hypothesis does predict that in general it will be easier to shift to a different temporal context if the new global rhythm is similar to the familiar context. Therefore, this hypothesis predicts the shift to a new more complex polyrhythm will be more difficult for the Simple 3:2 group.

The Interdependence Hypothesis states that reliance on temporal structure is dependent upon specific attentional requirements imposed by the task, i.e., it is task specific. This hypothesis assumes that after a viewer has internalized a polyrhythm's global structure that attentional flexibility will be enhanced. This is because the viewer is now able to selectivity use different timing properties to accommodate task goals. That is, a viewer is not automatically "paced" by global structure. The specific time parameters (global or local) that a viewer uses to facilitate performance depends on how efficiently the global or local time parameter can be used to accommodate changes in either the attentional requirements of the same task (e.g., in this case, shifting stream relevance within the same letter/shape classification task), or task changes, (e.g., changing from a classification task to perhaps a tapping task).

This hypothesis predicts viewers will quickly shift their attentional reliance from global timing and will attempt to "use" the local timing of the separate streams to accommodate the systematic shifts in stream relevance. The Interdependence hypothesis actually predicts the opposite results of the Global Precedence hypothesis. This hypothesis predicts both groups will attempt to respond to the changes in the task's attentional requirements by perceptually segregating the streams and actively shifting attention back and forth between streams. Initially, this will prove more difficult for the Simple 3:2 group since the fast stream for this polyrhythm has a variable rhythm and the slow stream has an isochronous one. On the other hand, reliance on local stream timing should be easier for the Complex group since both the fast and slow streams have isochronous rhythms. Thus, this hypothesis predicts a stream by group interaction where the Simple 3:2 group should produce poorer performance the fast stream carries relevant information as compared to the slow stream. On the other hand, in general the Complex 3:2 group performance should be superior to that of the Complex 3:2, since it should be easier to use local stream timing since both streams have isochronous rhythms. However, since this hypothesis predicts a rate effect, RTs to relevant information carried in the fast stream should be slightly faster compared to the slow stream.

Predictions in the Shift phase are not different from those of the Global Precedence hypothesis. Thus, this hypothesis predicts an overall advantage for the Complex 3:2 group in this experiment compared to the Simplex 3:2 group.

Chapter Summary

This chapter has described the general rationale for the present research and presented previous findings from two pilot studies. The research in this dissertation is designed to examine the role of temporal relationships in visual attention. Three new experiments examine viewers' performance on the same focused attending task (a simple classification task) over an extended period of time (i.e., a total of 12 days across the three experiments), exploring viewer adaptation (hence, attentional flexibility) to successive timing manipulations within the same classification task, i.e., attentional requirements are changed only in terms of timing manipulations in the task. Throughout these experiments, two time based hypotheses are presented for testing, the Global Precedence and the Interdependence hypotheses. These hypotheses are represented by their respective views of: (1) the task independent nature of global time effects (i.e., global time primacy); or (2) the task interdependent relationship with temporal structure (local and global) to affect performance.

CHAPTER IV

EXPERIMENT 1: BASELINE PERFORMANCE

The purpose of this study was to obtain baseline performance data. In subsequent studies, people will be required to selectively attend to one of two differently timed streams of events (letters or shapes). The streams to which people will be required to respond will be embedded in different polyrhythms in Experiments 2 and 3. All together four different timing rates will be associated with the separate streams in this study and subsequent experiments. In this experiment, the rhythmic structure of separate streams is held invariant (i.e., *isochronous*) over changes in rate. In general, the polyrhythms in which these streams will appear follow the formats described in Chapter III. As noted there, polyrhythms will be used to provide various temporal contexts for a simple classification task that requires focused attending. Therefore, in evaluating task performance within different polyrhythmic contexts presented in subsequent studies, it is important to first know how subjects respond to the same stimuli and task within each separate timing rate.

The primary goal of the baseline experiment concerns effects of stream rate on performance in tasks where viewers must selectively attend to one kind of stimulus event (e.g., letters or shapes) even when in some circumstances both events occur simultaneously (i.e., Coupled event streams). However, because the baseline paradigm must also manipulate event coupling it also offers a convenient setting for evaluating a selective attending hypothesis concerning the coupling variable as such. That is, because the procedure requires viewers to attend selectively to only one of the two streams, it is possible that this task will be more difficult when the attended stream is comprised of entirely coupled events than when it contains entirely uncoupled ones. For example, if pairs of letters and pairs of shapes co-occur (at the same location), people required to make a same/different physical match judgment only about e.g., letters within the letter pair may find it difficult to ignore shapes. The most relevant hypothesis that addresses this sort of selective attention requirement comes from Treisman's two stage Feature Integration theory (e.g., Kahneman & Treisman, 1983; Kahneman, Treisman, & Gibbs, 1992; Treisman, 1988; Treisman & Gelade, 1980; Treisman & Kahneman, 1983; Treisman, Kahneman, & Burkell, 1983). It is called the Object File Hypothesis.

This hypothesis maintains that information is first represented in memory by its physical structure, rather than as a semantic representation. This representation is based to a large extent on Gestalt principles of organization. For example, when two objects occur at the same spatial location and at the same time (e.g., a Coupled event) all their features are processed. This means that when two events co-occur in space and time, even if one is an attended-to (i.e., relevant) object and the other is irrelevant, features from both relevant and irrelevant objects will be processed during the first stage; no feature selectivity occurs in this stage. By contrast, if the two events only co-occur in time, not space, the theory does not predict processing of all features.

In this baseline study, the hypothesis maintains that Uncoupled events and Coupled events are both encoded as single object files, but the number of features within these single object files would differ. After events are encoded there is a second stage of processing, one that involves selectivity in that attention is allocated to specific "object files". During this stage, processing of a Coupled event involves sorting relevant from irrelevant features in order to enable a same/different judgment. The basic prediction of the Object File hypothesis is that processing of Coupled events should take longer than that of Uncoupled events. This is because features of the relevant event must not only be sorted out, but they must also be combined. According to Treisman, it is attention applied at this stage that is the "glue" responsible for integration of features. Thus, response times should be longer and errors more common with Coupled events than Uncoupled events.

In sum, this experiment examines effects of stream rate and event coupling on same/different judgments to events in single streams. Its main goal is to gather data on single stream performance with streams that occur at different rates. Effects of coupling can also be assessed; Treisman's theory applies to manipulations of this variable. However, because Feature Integration theory considers time relations primarily in terms of discrete events, (e.g., simultaneities in time and space resulting in coupling) it does not make predictions about stream rate. It should be noted that in Treisman's latest offering (e.g., Kahneman et al., 1992) timing has been addressed, at least in terms of continuous and apparent motion.

Method

Task

The task was a continuous version of a Posner type classification task. Pairs of stimuli (letter pairs; shape pairs) were presented in an unbroken series of non signaled trials (i.e., without warning signals); viewers made "same" or "different" judgments based on a physical match between stimulus elements in a pair. Stimulus pairs always appeared centrally on a CRT display.

Stimulus Events. Two sets of stimuli were used as shown in Figure 4.1; four shapes and four uppercase letters. An attempt was made to make the stimulus dimensions comparable across stimulus sets to equate the two sets of information as much as possible. Dimensions were size (large and small) and a specific structural component shared by two stimuli in each set. Thus, in shapes the pentagon and the triangle share similar angles at the top, and the square and octagon share a straight line top. Similarly, in the letter set two letters (T and F) share a horizontal line at the top, and the B and P share the same curved top. In general the letters were slightly smaller than the shapes so that when events from the two information streams occurred simultaneously (Coupled events) the letters would appear inside the shapes. In all cases, stimulus duration was 800 ms and elements in a pair always appeared simultaneously.

Design

The design was a 4 x 2 x mixed factorial with four within factors and two between factors. Within group factors were: Rate of presentation (SOAs of 1,500 ms, 2,000 ms, 3,000 ms, and 4,200 ms); Stimuli (letters, shapes); Events (coupled,

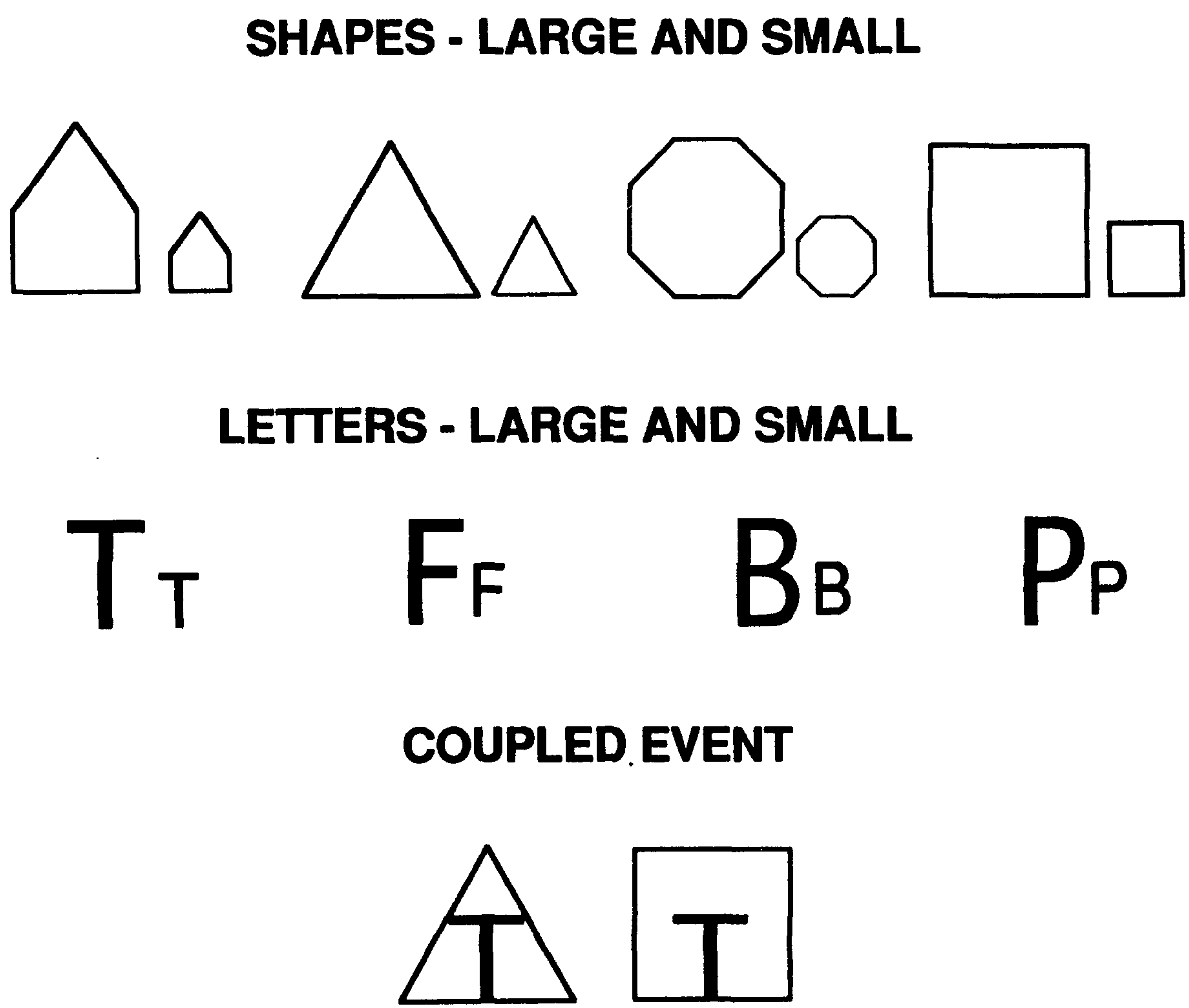

Figure 4.1. Two sets of stimuli, shapes and letters used to create stimulus pairs for Experiments 1-3. Note example of a coupled event.

uncoupled); Day (experimental sessions, Days 2-4); and Response Mode (same, different). The two between group factors involved counterbalanced orders of Timing and Stimuli. The Timing counterbalance was a basic Latin Square with four different orders of timing across the four days of the experiment (e.g., 4,200 ms, 3,000 ms, 2,000 ms, 1,500 ms; 3,000 ms, 2,000 ms, 1,500 ms, 4,200 ms; etc). Stimulus counterbalance had two levels where trial blocks of relevant events were arranged as L,S,S,L or S,L,L,S (L=letters relevant and S=shapes relevant). Dependent measures in these studies were response times and error rate.

Subjects

A total of 57 paid subjects with normal or corrected visual acuity from the Armstrong Laboratory's subject pool participated in this study. Subjects from this pool are local university students between the ages of 18 and 35 years of age who had extensive previous practice on Posner type classification tasks. Ten subjects failed to complete the study and 10 subjects failed to meet the performance criterion of less than 10% error rate and these data were eliminated from analysis. One subject's data were eliminated due to equipment failure. The final number of subjects whose data were used was 36.

Apparatus

Timing of stimuli was controlled by two Commodore 64 computer, and stimuli were presented on Panasonic video monitors. Subjects responded to stimuli on a touch sensitive keypad. Luminance readings for stimuli and monitors were measured using a Minolta Luminance Meter. Readings were done from the subject's viewing distance of

60 cm. Luminance readings for shape stimuli ranged from 8.05 cd/m^2 to 8.50 cd/m^2 and for letters ranged from 7.23 cd/m^2 to 8.22 cd/m^2. The reflection of the dark screen (monitor off) from the center of a 2 1/2" barium sulfate square was 17.13 cd/m^2 for both monitors. The barium sulfate square was held to the center of the screen and the amount of light reflecting off the monitor was recorded from the subject's viewing distance. The national standard of 99.98% equal reflectance of the two monitors was met.

Procedure

Subjects were seated in a low luminance sound attenuated experimental booth 60 cm in front of the CRT. Stimulus events subtended visual angles of .6685° for uncoupled events to 1.91° for coupled events. A response panel mounted with two response buttons labeled "Same" (left button) and "Different" (right button) was in front of the subject.

Subjects were instructed to respond as quickly and accurately as possible by pressing the appropriate button with their left index finger for "Same" and the right index finger for "Different". Each subject received two practice blocks (32 stimulus presentations per block) in each of the four timing rates on Day 1 for a total of eight blocks of practice trials. Practice trials included judgments to letter pairs alone and shape pairs alone. During a block of uncoupled event trials, subjects received either all letter pairs or all shape pairs; different stimulus sets were never interspersed within a block of uncoupled trials. However, in coupled event trial blocks, letter pairs and shape pairs appeared together (letters fit inside the shapes). On these trials, subjects were informed before the beginning of each block whether letter pairs or shape pairs were relevant. Again, within a block of trials, only one type of stimulus was relevant (e.g., letters or shapes). Performance feedback was given on Day 1 only. Subjects were not informed that rate would vary.

Subjects were assigned to one of the four timing counterbalance orders for the next four days. On each day (Days 2-5) of the experimental sessions, stimuli were presented in only one of the timing rates per day. Experimental sessions were conducted in two parts. In Part 1, subjects were presented with Uncoupled stimulus events of letter pairs and shape pairs in one of the two stimulus counterbalance orders. There were 64 (equal probability of "Same/Different") trials per block for a total of eight blocks. After a ten minute break, the session resumed with Part 2 where stimuli were presented only as Coupled events (i.e., letter pairs inside shape pairs). Stimulus relevance followed the same counterbalance order as in Part 1. That is, on any one block of trials there was only one set of stimuli designated as relevant. Again there was a total of eight blocks of trials. In both Parts 1 and 2, there was a 5 second pause between blocks of trials where instructions for the next block regarding letter or shape relevance appeared on the CRT. This same procedure was carried out on each successive day.

Figure 4.2 shows the experimental sessions over days. In this particular example, the sample shows a subject with a timing counterbalance (CBT) of 3,000 ms, 4,200 ms, 1,500 ms, 2,000 ms, and relevant stimulus counterbalance (CBS) of L,S,S,L meaning that the first blocks of trials in both Part 1 and Part 2 were letter pairs relevant, the second block were shapes relevant and so on.

EXPERIMENT 1

BASELINE - SIMPLE FOCUSED ATTENDING

EXAMPLE: S#1 (CBT - SOA - 3,000 ms, 2,000 ms, 1,500 ms, 4,200ms; CBS - L, S, S, L)

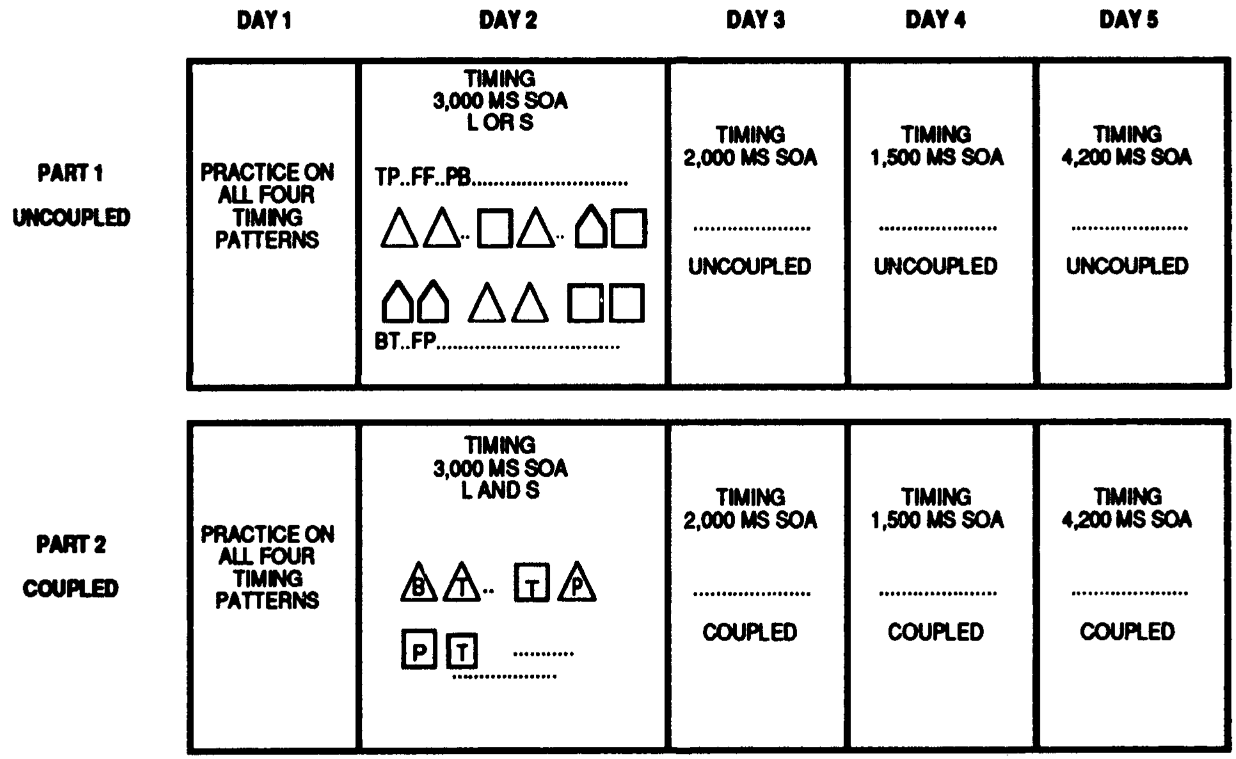

Figure 4.2. Experiment 1 experimental sessions. This example shows subject #1 having a timing counterbalance of 3,000 ms, 2,000 ms, 1,500 ms, and 4,200 ms SOAs over days 2-5. Each day included Part 1 and Part 2 where trials in Part 1 occurred as uncoupled pairs of letters and shapes and Part 2 presented stimuli as coupled events, i.e., letters inside shapes.

Results and Discussion

Since error rates were less than 2% across all conditions, these data were not analyzed, but totals for each timing rate do appear in Table 4.1 in parentheses. Median RTs were the primary response measure. Analysis of variance procedures applied to these data revealed significant main effects for timing rate, day, stimuli (Letters versus Shapes), response mode (Same/Different), and stimulus coupling (Uncoupled versus Coupled). There were no significant interactions.

Significant differences in RTs to the four different stream rates are shown in Table 4.1. Rate has significant effects on performance, $F(3,408) = 85.16$ $p<.0001$, RMSE = 31 ms; the mean RTs were the same for the two faster rates (1,500 ms SOA had mean RT of 450 ms; 2,000 ms SOA had mean RT of 449 ms) but they increased for the two longer rates (mean RTs for 3,000 ms and 4,200 ms SOAs were 469 ms and 500 ms respectively). However, inter-quartile measures of variability showed no appreciable difference in variability across the four timing patterns.

Subjects were highly practiced before beginning the experimental sessions. Nevertheless, a significant effect of day was observed, $F(3,408) = 46.95$ $p<.0001$, RMSE = 31 ms. Mean RTs show there was a steady decrease in response times from Day 2 to Day 5 (Day2 = 494 ms, Day3 = 469 ms, Day4 = 456 ms, Day5 = 450 ms) indicating an apparent learning effect over days. There was also the familiar Same/Different disparity effect $F(1,32) = 27.63$, $p<.0001$, RMSE = 16 ms, where "Same" responses were faster than "Different" responses; 457 ms and 477 ms respectively. And finally, there was no significant difference between timing counterbalance groups $F(3,32) = 2.33$, $p < .09$ (ns).

The Coupling variable had large and significant effects on response times. In general, these were consistent with predictions of the Object File hypothesis.

Table 4.1

Mean Response Time and Mean Inter-Quartile Range by Timing Pattern

Timing Pattern SOA, (msec) Errors	Mean Reaction Time (msec)	Mean Inter-Quartile Range (msec)
1,500 (1,752)	449.8	104.6
2,000 (1,428)	448.7	111.5
3,000 (1,331)	469.3	113.7
4,200 (1,199)	499.9	117.9

Responses to coupled events (mean RTs = 477 ms) were significantly slower than to uncoupled events (mean RTs = 457 ms), $F(1,32) = 115.64$, $p < .0001$, RMSE = 22 ms. Not only are these data consistent with Treisman's predictions, they replicate the results of the preliminary experiments in this respect. Differences between coupled and uncoupled events remained unchanged for both letters and shapes; no significant interaction obtained between type of stimuli and coupling, $F(1,32) = 2.19$ (ns) to suggest any asymmetry in the degree of interference produced by the type of irrelevant stimuli (letters or shapes) when an event was coupled. Thus, while response times to letter pairs were significantly faster than to shape pairs $F(1,32) = 39.03$ $p<.0001$, RMSE = 33 ms; mean RTs for letters were 458 ms and 476 ms for shapes, this does not modulate the coupling effect. These data suggest that overall, letter pairs were an easier discrimination than shapes, but that coupling interfered equally in decisions to both letters and shapes. In short, the data conform to predictions of the Object File hypothesis. Additional analyses on stimuli are found in Appendix A.

Although the Object File Hypothesis nicely predicts performance differences between coupled and uncoupled events, it is inadequate for addressing performance changes as a function of event rate such as that found in this study. What is particularly intriguing about the rate manipulation is that RTs increase as a function of increased SOAs, while response variability remains constant. It seems logical to assume that longer response times would be associated with longer intervals by the introduction of some degree of temporal uncertainty between events. If this were the case, one would also expect to see increased response variability as intervals became longer. This was not the case in the present study, i.e., response variability across all timing rates remained constant. The pattern of results here suggests that perhaps tempo was regulating or "pacing" attention. One implication of this finding is that there is a time locking of focal attending to different tempos such that as the information flow becomes slower, so does the entire attentional system. The obvious question provoked by these data is how an overall slowing of the more complex polyrhythmic contexts might affect performance in the classification task. This question is examined in a little more detail in the next study.

Chapter Summary

In summary, the primary objectives of the baseline study objectives were met. Four separate performance baselines were determined for coupled and uncoupled event streams, respectively, each corresponding to a different rate. These data can be used in later analyses of performance with polyrhythms that engage two streams where the stream rates differ. A secondary finding in the present study concerned effects of event coupling. Coupled event streams are responded to significantly more slowly than uncoupled ones, regardless of rate or type of stimuli. The latter findings support Treisman's Feature Integration Theory.

CHAPTER V

EXPERIMENT 2

THE ROLE OF TEMPORAL RELATIONSHIPS IN VISUAL ATTENTION

The purpose of this study is to examine how the dynamic context of a simple selective attention task might affect attending over an extended period of time. The emphasis here is on the examination of possible exogenous or external control factors that are temporal in nature. Exogenous factors are usually defined as involuntary, discrete spatial shifts of attention in response to a sudden movement in the periphery, a flash of light, or other abrupt onsets of stimuli. Such stimuli are said to "capture" attention (e.g., Remington, Johnston, & Yantis, 1992; Yantis & Jonides, 1984).

The idea of external control factors used in the present research differs somewhat from the above view. It enlarges upon the idea of how attention is captured to include capturing of attention by the time properties of a visual stream (e.g., rate and/or rhythm). In this respect it rests on the assumption that attention extends over time and can be captured, indeed "paced" in response to the rate or rhythm of an extended temporal sequence of events. That is, I assume that focal attending is not merely shifted in response to an abrupt onset of a spatial object, but rather can be entrained by persisting time relationships among various event onsets which make up a visual stream.

In displays of dynamic information such as the cockpit displays mentioned earlier, both continuous and discrete time relationships can be found among display elements. To respond appropriately, a viewer must sustain attending over various time periods. When display elements arising from distinct sources are differentiated by various formal and physical properties (e.g., letter symbols versus geometric shapes), they in turn constitute distinct visual streams. In general, a stream may consist of continuously moving events, or it may be a pattern of events which change discretely over time. The present experiment focuses on the latter sort of visual stream.

Consider again the example of the cockpit display shown earlier (Figure 1.1) as a static representation. To illustrate more concretely the complexity of such displays when operational and dynamic, a return to Figure 1.1 shows: (1) Two vertical scales to the left and right side of the HUD that present concurrently, two different sequential information streams that change at different rates; (2) A trio of alphanumeric data, below the scale to the right, that can yield as many as thirteen different interleaved information streams (depending on the display mode) but, here information streams occur at the same rate; (3) Other information (e.g., lagline symbol, pitch ladder, and the one second time of flight range indicator) that appear in continuous motion, but at different velocities. Thus, these are just a few examples of the different visual streams that may appear concurrently to a pilot who must monitor these multiple co-occurring information streams, and be prepared to shift and redirect attention rapidly.

Several practical questions can be distilled from this example: In general, do time parameters (rate, rhythm) exert some systematic external control over attending? Does the joint (i.e., integrated) time structure of several streams that confront the operator contribute to a viewer's (pilot's) ability to maintain and/or shift attentional focus? Are time parameters that define integrated (global) temporal structures of several streams more likely to influence attending than those associated with separate (local) timing streams?

The present experiment is designed to investigate some of these questions. Specifically, this experiment presents two different groups of viewers with different global polyrhythmic contexts (described in Chapter III) in which the local rate and rhythm of one stream, the task relevant (attended to) stream, is identical. Thus, by holding constant the stream delivering task relevant information, assessment of possible influences of global rhythm on task performance can be obtained. In addition, questions surrounding the influence of rate and rhythm on the control and adaptability of attending are considered. Systematic changes in either rate or rhythm of the polyrhythm on which each group is initially trained, is used to assess the relative impact of these time parameters on performance.

Three objectives of this experiment are to: (1) determine conditions under which rate and/or rhythm affect performance in selective attending; that is, are local or global time structures most influential in controlling attending; (2) examine viewer adaptation (or lack of) to changes in rate or rhythm; and (3) determine whether there are significant "carry over" effects on performance as a function of a timing change that might affect attentional flexibility (facilitate or inhibit performance).

The experiment examined global polyrhythmic influences on selective attending over three different experimental phases: (1) An initial training phase, Phase One, in which two different groups received training on performing a simple selective attention task within polyrhythmic contexts differing in their respective global rhythms; (2) A shift phase, Phase Two, in which some participants from Phase One received changes in either the global rate or rhythm of their initial polyrhythm; (3) A final post-shift phase, Phase Three, in which all subjects returned to their original polyrhythms of Phase One. The next section describes each phase in more detail and this is followed by a section outlining possible outcomes over these phases.

Experimental Phases

Phase One: Training

The primary focus of this experimental phase concerns how the timing of co-occurring information streams affects maintaining an attentional focus when only one stream carries task relevant information. Is attention to some extent controlled by the combined (i.e., integrated) structure of two separate streams? If so, then global rhythmic properties (rather than local rate or rhythm of a relevant stream) should determine performance. For instance, if time relationships occurring between streams (global rate and rhythm) exert a greater impact on performance than those of the task relevant stream (i.e., its local rate and rhythm) then this would suggest that attention is influenced more by integrated temporal patterns. Whereas if the opposite results obtain, i.e., local timing affects performance more than global timing, then this result would tend to support a view that people are able to keep different co-occurring streams separate.

To assess these ideas experimentally, one group of subjects received these streams in a complex polyrhythm context while the other received them in a simple polyrhythm. For both groups, the task relevant stream (slow stream) was identical in all respects (local rate and rhythm). The two polyrhythms are shown in Figure 5.1. The polyrhythms shown in panel (a) and (b) are the same ones introduced in Chapter III. The Complex 3:2 polyrhythm is shown in panel (a) where both the fast and slow streams have constant time intervals (i.e., both are isochronous), and together these produce a variable global rhythm. The Simple 3:2 polyrhythm shown in panel (b) combines an isochronous slow stream with a variable rhythm fast stream, and together these two streams produce an isochronous global rhythm.

Experimentally, the important features of these two polyrhythms are: (1) their global rates are identical; (2) the rate and rhythmic structure of both slow streams (designated relevant stream) are identical; and (3) the average rate of the fast streams in both polyrhythms is identical. Most critical for the present undertaking, however, is the manner in which simple and complex polyrhythms differ. There is a subtle, but very important difference between the fast trains in the two polyrhythms that is responsible for creating the different global rhythms, i.e., in panel (a) the fast stream has constant relative timing, while panel (b) shows a fast stream with a variable rhythmic structure. It is this small difference in the fast streams that when combined with identical slow streams produces the different global rhythmic structures.

In short, in order to distinguish between possible effects of global and local time structures, the polyrhythms in Phase One are designed to hold the local timing structure

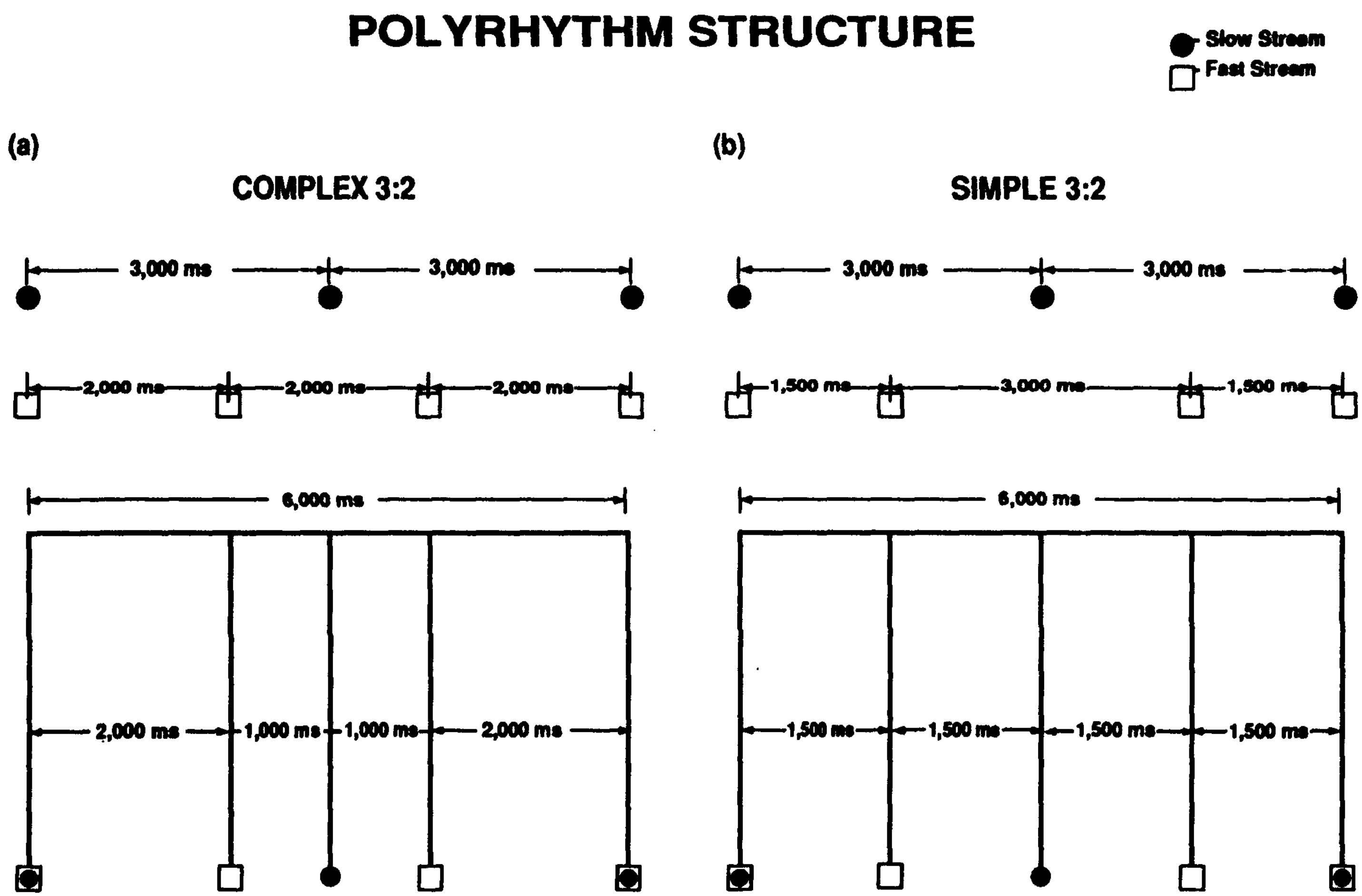

Figure 5.1. Temporal structure of two different versions of a 3 on 2 polyrhythm. Panel (a) shows the Complex 3:2 where the fast and slow streams have isochronous timing, but integrated streams have a variable SOA pattern. Panel (b) shows the Simple 3:2 where the fast stream has variable SOAs that are the average SOA of the fast stream in panel (a). The Simple 3:2 integrated pattern yields isochronous timing.

of the designated relevant event stream constant (i.e., both its rate and rhythm) and to vary the global rhythm of the polyrhythm in which this stream is embedded. In both polyrhythmic contexts, the fast stream is functionally irrelevant with regard to attentional requirements of the task; that is, it never carries relevant information and so, in principle, it can be ignored by the viewer when performing the task.

Accordingly, if attending is influenced largely by the local time properties of the relevant (slow) stream, then performance will not differ for subjects receiving the two different polyrhythms. This finding would suggest that viewers somehow are able to keep the two streams separate and indeed "tune out" the irrelevant one. However, if performance differs significantly between the two polyrhythmic groups, this would suggest that viewers are integrating the two streams to form a single (combined) serial pattern based on the relative timing of both letters and shapes. This result would support the idea that global rhythm exerts some, probably involuntary, control over attending.

Phase Two: Shift

The objective in Phase Two is to assess viewers' adaptability to various kinds of timing changes from the polyrhythms encountered in Phase One. What happens when a viewer encounters a uniform shift in the global rate of the polyrhythm to which she/he has grown accustomed? Alternatively, what effect does the shift of the global rhythm have on attending to a relevant event stream that continues at a constant rate? For example, if a viewer's attention has been entrained to some extent by the global rhythm, then this shift should affect performance. These questions are addressed in the shift phase of this experiment by presenting different groups of viewers with such changes.

In Phase Two, viewers continue to perform the task with the slow stream as the designated relevant stream. However, in this part of the experiment, some viewers (Rate Shift) now experience a shift in the global rate at which their Phase One polyrhythm occurs: the polyrhythmic pattern (either Simple or Complex 3:2) remains unchanged, but it is uniformly slowed down. Thus, some viewers experience a rate change, but for all Rate Shift viewers the global rhythm is preserved. Other viewers experience a shift in the global rhythm (Rhythm Shift), but global rate is held constant. For these subjects, the relevant slow stream remains entirely unchanged. In fact, if they are attentionally locked into the relevant timing stream and are responsive strictly to its local rate and rhythm properties, then the shift phase should leave them unaffected. What changes for these viewers is the local rhythm of the fast (irrelevant) event stream; viewers who experienced a Complex 3:2 polyrhythm now experience a Simple 3:2 and vice versa. A final set of viewers function as a Control group: they receive neither a global rate nor a global rhythm shift in Phase Two. They continue with their Phase One polyrhythmic structures unchanged.

In sum, three different shift conditions, Rate, Rhythm, and Control permit assessment of the relative impact of various time parameters on viewer adaptability to dynamic change.

Phase Three: Post Shift

The objective in this phase is to explore whether viewers experience any "carry over" effects associated with the timing changes in Phase Two. Carry over effects can also index attentional flexibility. If subjects who were shifted in Phase Two show improved performance in the post-shift phase, it implies that they are resistant to potentially long lasting and distracting effects of certain shifts in structure. In this phase viewers are shifted back to their original polyrhythmic contexts of Phase One. Thus, for example, if viewers experiencing a rate or rhythm shift on the shift day, then display post-shift performance that "bounces back" to the level of that exhibited by control groups. This suggests a certain amount of attentional flexibility.

Post Shift performance can be evaluated not only with respect to control group performance, but it is also possible to gauge it relative to the viewers' earlier levels of performance (Phases One and Two). In this regard, the minimum performance requirement indicating a viewer has successfully adapted to post shift changes would be that their performance levels are equivalent or better, relative to asymptotic Phase One performance levels.

In summary, this study was designed to explore: (1) the impact of global versus local rate and rhythm time parameters (Phase One); (2) the relative impact of shifts in global rate and rhythm (Phase Two); and (3) "carry over" effects of shifts in global rate and rhythm (Phase Three). The way in which these timing manipulations affect selective attending within a constant (single) relevant timing stream has some potential for revealing dynamic influences associated with the external control of attention.

Hypotheses

Three hypotheses can be framed that speak to the manipulations of global rate and rhythm that have been described in the preceding sections. One, termed the Interference Hypothesis, functions as a null hypothesis with respect to manipulations of global time structure. The other two are referred to respectively as The Global Precedence Hypothesis and the Interdependence Hypothesis. The latter two hypotheses suggest different ways in which global rhythm and global rate might affect performance in attending tasks.

Hypothesis 1. The Interference Hypothesis. This hypothesis maintains that baseline performance should be superior to performance in any two stream experimental condition, regardless of timing manipulations. It functions as a null hypothesis in that it maintains that the addition of any irrelevant event stream will divert attention from the relevant events. Thus, responses in both polyrhythmic contexts will be generally less accurate and more variable than in baseline performance (Experiment 1).

The Interference Hypothesis does acknowledge the possibility of viewers showing some performance improvement over the three phases of the experiment. The hypothesis maintains that viewers may become more efficient "filtering" irrelevant from relevant events over time. However, since this hypothesis ignores timing manipulations, any performance improvements associated with enhanced "filtering" of irrelevant events would produce equivalent results across the two polyrhythms. This is because the order and probability of event occurrences (both relevant and irrelevant) are identical in both the Simple 3:2 and the Complex 3:2 polyrhythms. Thus, while viewers may demonstrate performance improvement over time, there will always be some cost associated with "filtering" irrelevant information, such that performance within either polyrhythmic context should be less accurate and more variable than performance observed in baseline conditions (i.e., relevant events alone).

Hypothesis 2: The Global Precedence Hypothesis. This hypothesis is loosely based on the Gesta't notion that the whole is different from the sum of its parts and, furthermore, 'hat perception of the whole precedes those of its parts (Kohler, 1930, 1971, cited in Kimchi & Palmer, 1985). More recently, a global-to-local hypothesis has been proposed (Navon, 1977, 1981) that views perceptual processing in general as proceeding from global structuring toward analysis of local detail. The Global Precedence hypothesis, as formulated in this dissertation, extends these ideas to include dynamic global and local structures of visual stimuli. Specifically, this hypothesis states that global polyrhythmic structure is a primary and immediate factor in the external control of attending. Thus, there is an implicit assumption of this hypothesis that the effects of global time structures are task independent, i.e., dynamic global structures should exert the same effect on a viewer's attending across different tasks.

The Global Precedence hypothesis is inspired in part by auditory research regarding the development of highly skilled performance in generating two differently timed motor sequences (e.g., Deutsch, 1983; Jagacinski, Klapp, Marshburn, & Jones, 1988; Klapp, Hill, Tyler, Martin, Jagacinski, & Jones, 1985). For example, Deutsch has suggested that performers (e.g., pianists) must develop a representation of a pattern as an integrated whole before they can successfully generate the two streams in parallel. That is, in order to accurately tap to events in two co-occurring streams, people must perceive and internalize the relative time aspects of global rhythmic structure first, before they can attend to the local time structures (i.e., perceive separate streams). This is an active use of global rhythm; furthermore, it assumes that once global structure is internalized it can be "used" to anticipate upcoming events in either stream. Accuracy in monitoring or generating the timed sequences is related to the structural simplicity of the temporally integrated pattern (e.g., Klapp et al., 1985). That is, structurally simple time patterns (e.g., isochronous rhythms) are encoded faster and are easier to apply than temporal patterns that are structurally more complex (e.g., long-short-short-long variable rhythms).

The adaptation of these ideas in the present context takes the form of an hypothesis that maintains that the presence of a simple and constant global rhythm between streams will facilitate focused attending to all events, namely to events in both relevant and irrelevant streams. That is, the Global Precedence Hypothesis predicts that a Simple 3:2 polyrhythm will make both relevant and irrelevant events more predictable in time and therefore more likely to be anticipated. Anticipatory attending is assumed to yield faster, less variable response times to relevant events. Further, the structural simplicity of the Simple 3:2 polyrhythm is predicted to enhance response accuracy. By contrast, the presence of a temporal context where time relationships between streams vary (as in the Complex 3:2 long-short-short global rhythm) will yield a global context where events are less predictable and anticipatory attending to events in either stream is less likely. This will be evident by increases in both response times and variability, as well as a decrement in response accuracy compared to the simpler global context.

This hypothesis is a general statement regarding the primacy of global rhythm across various tasks and it does not predict that rate (local or global) should necessarily affect people's use of polyrhythmic structure. Thus, its predictions about Phase One (training phase) performance are fairly straightforward; it simply predicts that the two polyrhythmic groups will differ in performance as a function of global rhythm differences. In Phase Two (shift phase), however, it suggests that the most detrimental shift should be found in subjects who experience a rhythm shift (i.e., the Rhythm Shift group). Specifically, viewers who shift to the Complex 3:2 global rhythm will immediately slow their responding due to greater complexity in the new global rhythm, whereas those who shift to a Simple 3:2 polyrhythm will display a significant improvement. The subjects in Rate Shift conditions (where polyrhythmic ratios remain unchanged), will perform equivalent to the no change Control subjects according to this hypothesis.

Finally, in Phase Three (post shift phase), this hypothesis predicts "carry over" effects in the final phase only as a result of shifts in rhythm. That is, this hypothesis does not predict either negative or positive "carry over" effects in Phase Three as a function of rate change. What is not clear, however, is the nature of possible rhythmic "carry over" effects; should it be more difficult for viewers to return to a Complex 3:2 after experiencing a simpler rhythm on the shift day, or should it be harder for them to re-adjust to a Simple 3:2 after coping with the complex polyrhythm in Phase Two? In this respect, the present design explores attentional flexibility in ways not yet spelled out by hypotheses such as the Global Precedence hypothesis.

Hypothesis 3. <u>The Interdependence Hypothesis.</u> This hypothesis differs from the previous hypothesis in that rate assumes an important role in determining how a viewer perceives rhythmic structure. In the present experiment, this hypothesis shares with the

Global Precedence hypothesis an assumption that viewers will rely on global, rather than on local rhythmic properties, particularly in Phase One. It differs from the Global Precedence hypothesis, howeve.., in its incorporation of possible effects of global rate. This hypothesis maintains that part of what makes a rhythm simple and coherent is its rate; when a time pattern based on identical time proportionalities (of e.g., long to short to short durations) is slowed down too much, it will psychologically present to a viewer as a different rhythm. This means that a change in rate can be as disruptive as a change in rhythm.

The impetus for this hypothesis comes from Jones' theory of dynamic attending (Jones, 1976; Jones & Yee, 1992). She introduces the concept of a Serial Integration Region, or SIR, in which rate specific limits are suggested for rhythmic coherence. The SIR defines a structural region where people are assumed to be most receptive to certain global rhythmic relationships that determine serial integrity of a to-be-attended sequence of events. The SIR is a psychological construct that defines the limits of a viewer's (or listener's) ability to perceive and attend to an unfolding event sequence. Within this region, the global rhythm determines the ease with which a person abstracts out polyrhythmic properties, such as their global rhythmic time relations (i.e., isochronous versus variable global rhythm ratios). Simple and constant time relations (Simple 3:2) are abstracted more readily than variable ones (Complex 3:2). However, the critical aspect of this analysis from the perspective of the current experiment is that this abstraction is rate dependent, meaning that a rate change should have some effect on performance. What is not spelled out in Jones' theory is whether a rate change is equally detrimental to Simple and Complex global rhythms.

Thus, this approach makes the same predictions as does the Global Precedence hypothesis for Phase One. Here both hypotheses predict that initially the Simple 3:2 polyrhythm will yield faster responding than the complex one. The Interdependence Hypothesis differs from the Global Precedence Hypothesis largely with respect to Phases Two and Three. According to the Interdependence Hypothesis, shifts in both rate and rhythm can affect attentional control. Whether the viewer perceives sequential events as a coherent temporal pattern or not depends on both the base rate and time ratios of the particular serial pattern. If SIR limits are at play, then when a rhythmic pattern is shifted to a distinctly slower rate the viewer is likely to perceive successive, but unrelated, units (or chunks) of the pattern instead of a connected whole. Thus, when a rate shift is imposed on the original rhythm in Phase Two, it should result in poorer performance and slower response times. This may be more evident in one of the two polyrhythmic groups than the other.

With respect to Phase Three, the Interdependence Hypothesis like the Global Precedence Hypothesis is not currently framed to address long term attentional flexibility. It does allow for the possibility that either rate or rhythm "carry over" effects from earlier phases may affect post-shift performance, but the nature of these effects are not specified.

In sum, the Interdependence and Global Precedence Hypotheses make similar predictions about Phase One performance, namely that errors and response times should be greater with more complex polyrhythms because attentional control is "paced" less effectively in these contexts. In Phase Two, the Global Precedence Hypothesis predicts systematic effects only for rhythm shifts, while the Interdependence Hypothesis predicts effects for both rate and rhythm changes. The final post shift phase is addressed specifically by neither hypothesis. This phase permits an assessment of various carry over effects that relate to attentional flexibility, and so data from this phase offer some potential for extending these approaches in various ways.

Method

The task, stimuli (letter pairs/shape pairs), apparatus, and instructions are identical to those used in the baseline study. All 36 subjects in this study participated in the baseline study; thus, they were highly practiced with the classification task.

Design

Three primary statistical designs obtained depending on the questions and comparisons of interest: (1) designs that assessed Phase One performance relative to Experiment 1, baseline performance; (2) designs addressed to an overall analysis of multiple phases in Experiment 2; (3) designs appropriate to specific within phase comparisons.

1. Comparisons with Experiment 1 baseline. This design was a simple mixed design with one between factor and one within factor. The between factor was Polyrhythm Group (Complex 3:2; Simple 3:2) and the within factor was Day (1,2).

2. Multiple Phase Designs. An overall design combined Phases Two and Three. This involved a mixed 2x3 factorial with two between factors and three within factors. The between factors were the Initial Polyrhythmic groups (3:2 Complex; 3:2 Simple) and

the Timing Change Group (No Change, Rate Change, and Rhythm Change). Within factors were Phase (Shift, Post-Shift). Remaining factors were: Response Mode (Same, Different); and Stimuli (letter pairs, shape pairs).

3. Within Phase Designs. Separate ANOVAs, as well as planned contrasts associated with Global Precedence and Interdependence Hypotheses predictions constitute these designs.

Dependent measures were response times, response variability, and errors. Both response times and response variability were adjusted to reflect changes from a progressive baseline. The scoring method is reviewed later.

Conditions

Conditions refer to variations in polyrhythmic properties and these vary depending on phase:

Phase One: Training. In this phase, the two conditions of primary interest is the two polyrhythms: Simple 3:2 and Complex 3:2 (Figure 5.1). Constraints in constructing the 3:2(S) and 3:2(C) are as follows: (1) slow streams of identical rate (SOA=3,000ms); (2) fast streams of identical average rate (per cycle), SOA=2,000ms; (3) identical global average rate (cycle=6,000ms); (4) fast streams of different rhythms: 3:2(S) embeds a fast train with alternating SOAs of 1,500ms and 3,000ms to create a short, long, short rhythm, whereas the 3:2(C) embeds a constant SOA of 2,000ms to create an isochronous rhythm; and (5) different global rhythms: the 3:2(S) has an isochronous (constant) global rhythm the while the 3:2(C) has a long, short, short global rhythm. These global (and local) rhythms can be formalized respectively in terms of a "successive time ratio" one that is based on successive SOAs at times t-1 and t within the combined sequence of events: SOA_t/SOA_{t-1}. Thus, the 3:2(S) global rhythm has a successive time ratio of 1.0, while the 3:2(C) has three different time ratios of .5, 1.0, 2.0.

Phase Two: Shift. In this phase six polyrhythmic conditions realize two levels each of the Time Change variable: (1) Rate Shift, where two new polyrhythms were created, respectively, for separate groups of Ss by slowing the rate of the original 3:2(S) and 3:2(C) rhythms. Slow streams had SOAs=4,200ms and fast streams had SOAs=2,800ms in 3:2(C); Slow streams had SOAs = 4,200ms and fast streams had alternating SOAs of 2,100ms and 4,200ms in 3:2(S); (2) Rhythm Shift, where two rhythm shift conditions were created by assigning a 3:2(C) polyrhythm to some Ss receiving 3:2(S) in Phase One, and a 3:2(S) polyrhythm to some Ss receiving 3:2(C) in Phase One; and (3) Control, where two no shift conditions were created for Ss who continued either with 3:2(S) or 3:2(C) from Phase One.

Phase Three: Post Shift. In this phase all Ss are returned to their original 3:2 polyrhythms from Phase One: 3:2(C) and 3:2(S). Phase conditions are illustrated in Figure 5.2.

Subjects

Eighteen subjects were assigned to each of the two polyrhythms in Phase One. In Phase Two they were randomly assigned (n=6) to one of three subgroups: Rate Shift, Rhythm Shift, and Control. In Phase Three all subjects were transferred back to their original polyrhythm of Phase One.

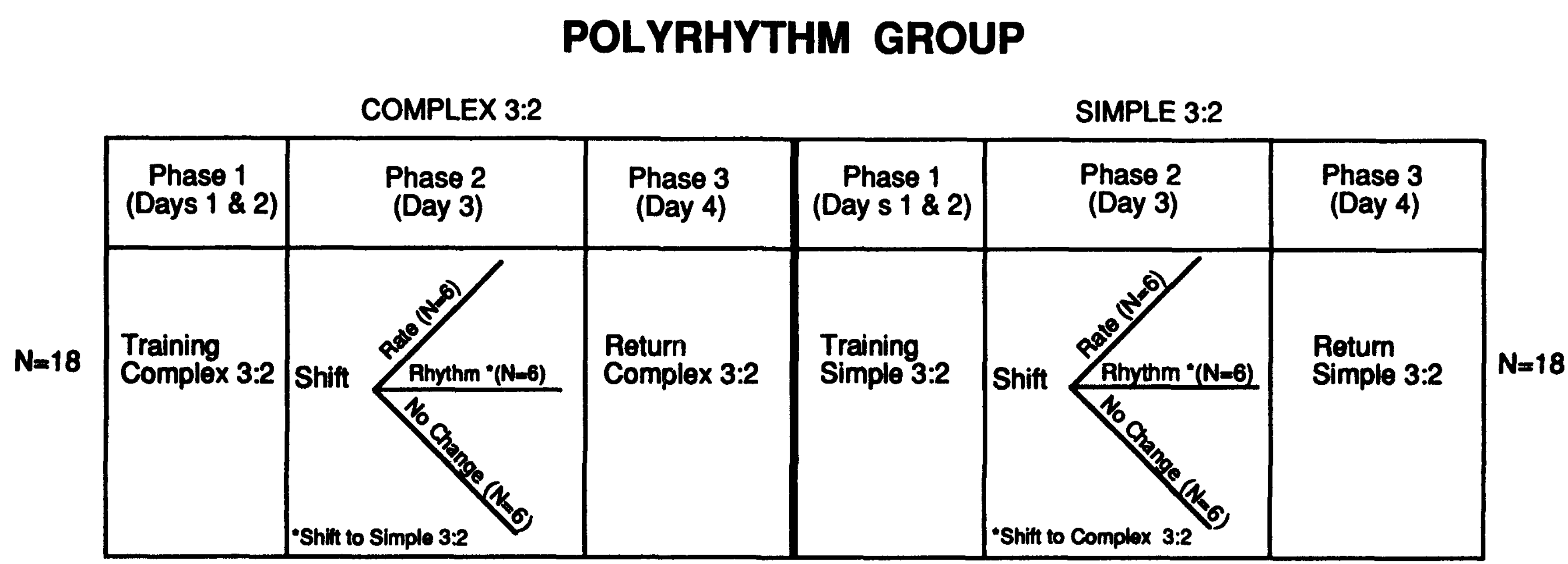

Figure 5.2. Description of experimental phases in Experiment 2 for the Complex 3:2 and Simple 3:2 polyrhythm groups. Phase 1: Training on task within designated polyrhythmic context on Days 1-2. Phase 2: Subjects shifted to either a slower polythythm (rate shift), a different polyrhythm (rhythm shift), or no shift (control). Phase 3: All subjects return to their original polyrhythm context of Phase 1.

Procedure

The study was conducted over a four day period. Viewers were presented with eight blocks of trials each day where blocks were presented in the L,S,S,L order from Study 1 for a total of four blocks each for letters relevant and shapes relevant per day. Relevant events (letters or shapes) always occurred in the task relevant slow timing stream in all phases of the experiment. In Phase One-Training (days 1 and 2) subjects performed the task in the temporal context of their initial polyrhythm. In Phase Two-Shift (day 3) subjects either shifted, or did not shift temporal context change group and continued to perform the task as before. In Phase Three-Post Shift (day 4) subjects were returned to their original temporal context. In all other respects, the procedure follows that described for Experiment 1.

Scoring Methods

Performance in all phases assessed both accuracy (error scores) and response times. Response times are evaluated using both median response times and a Derived Response Time (DRT) score adjusted to accommodate both baseline data from Experiment 1 and asymptotic Phase One performance. The DRT scores are merely difference scores. In both cases, they are determined by subtracting a median reaction time score for each subject that reflects performance in a given reference condition (i.e., either the baseline condition or Phase One conditions). Medians are used because the response time distribution is skewed. Thus, for each subject in Experiment 2, there are four medians obtained for a given condition from each block of trials: coupled/same, coupled/different, uncoupled/same and uncoupled/different events. In this scoring technique the correction factor takes the form of a changing "yardstick" where the reference condition can change to reflect the subjects' experience and adaptation as they are progressively shifted to new temporal contexts and/or attentional conditions. For that reason, each subject served as his or her own control, and all DRTs are based on their own baseline performance.

Derived measures of response time variability involving the inter-quartile range (Q-range) were constructed in the same manner as the DRTs for response times. Derived inter-quartile ranges (DQR) were constructed for each block of trials (e.g., four cells per block). These DQR scores represent performance variability relative to progressive referent conditions following the procedure outlined for DRTs.

Results

Results are presented in three sections which consider respectively the three experimental phases. Within each section, three dependent measures are discussed: response time (DRTs), the corresponding response time variability measures (DQRs), and error scores.

Phase One: Training

Phase One data analyses are divided into two parts. The first part considers comparisons of Phase One performance when viewers selectively attend to the slow stream within a polyrhythm context relative to performance on the same stream when it occurs alone as a single stream (Experiment 1, baseline data). The second part of Phase One data relies on DRTs corrected for baseline to evaluate polyrhythmic effects over Days 1 and 2.

Comparisons with Experiment 1 baseline data. The primary interest in evaluating selective attending to the slow stream across experiments 1 and 2 concerns evaluation of the Interference Hypothesis. This hypothesis predicts that performance in the polyrhythmic context of Experiment 2 should be significantly poorer than in the single stream context of Experiment 1. With respect to response times in Phase One, DRTs are based on subtracting the median baseline response times (Experiment 1) from those in Phase One (days 1 and 2 only). Resulting DRT scores then are assessed relative to a null value of zero.

Average median baseline reaction times (Study 1, 3,000ms timing) for the 3:2(C) and 3:2(S) polyrhythm groups are respectively 510ms and 500ms. Figure 5.3a shows DRT scores for Phase One (Days 1 and 2). These data indicate some support for the Interference Hypothesis on Day 1, but not on Day 2. On Day 1 both groups show an increase in response times over baseline. In fact, the increase for the Complex group, (39ms) was significantly different from baseline $F(1,17) = 15.56$, $p<.001$, RMSE = 10ms. However, even on this first day, the 16ms increase in response times for the Simple group is not significantly different from zero $F(1,17) = 2.0$, $p<.18$. By Day 2 both groups seem to have adapted to the polyrhythm context; the Complex group shows a significant ($F(1,17) = 17.46$, $p<.0007$, RMSE = 7 ms) decrease of 29ms from Day 1 and the Simple group shows an even greater improvement from Day 1 (41ms), $F(1,17) = 48.5$, $p<.0001$, RMSE = 6 ms. In fact, the decrease on Day 2 for the Simple group was also significantly below baseline (25ms), $F(1,17) = 5.5$ $p<.03$, RMSE = 11ms. A general performance improvement with practice observed in both groups is consistent

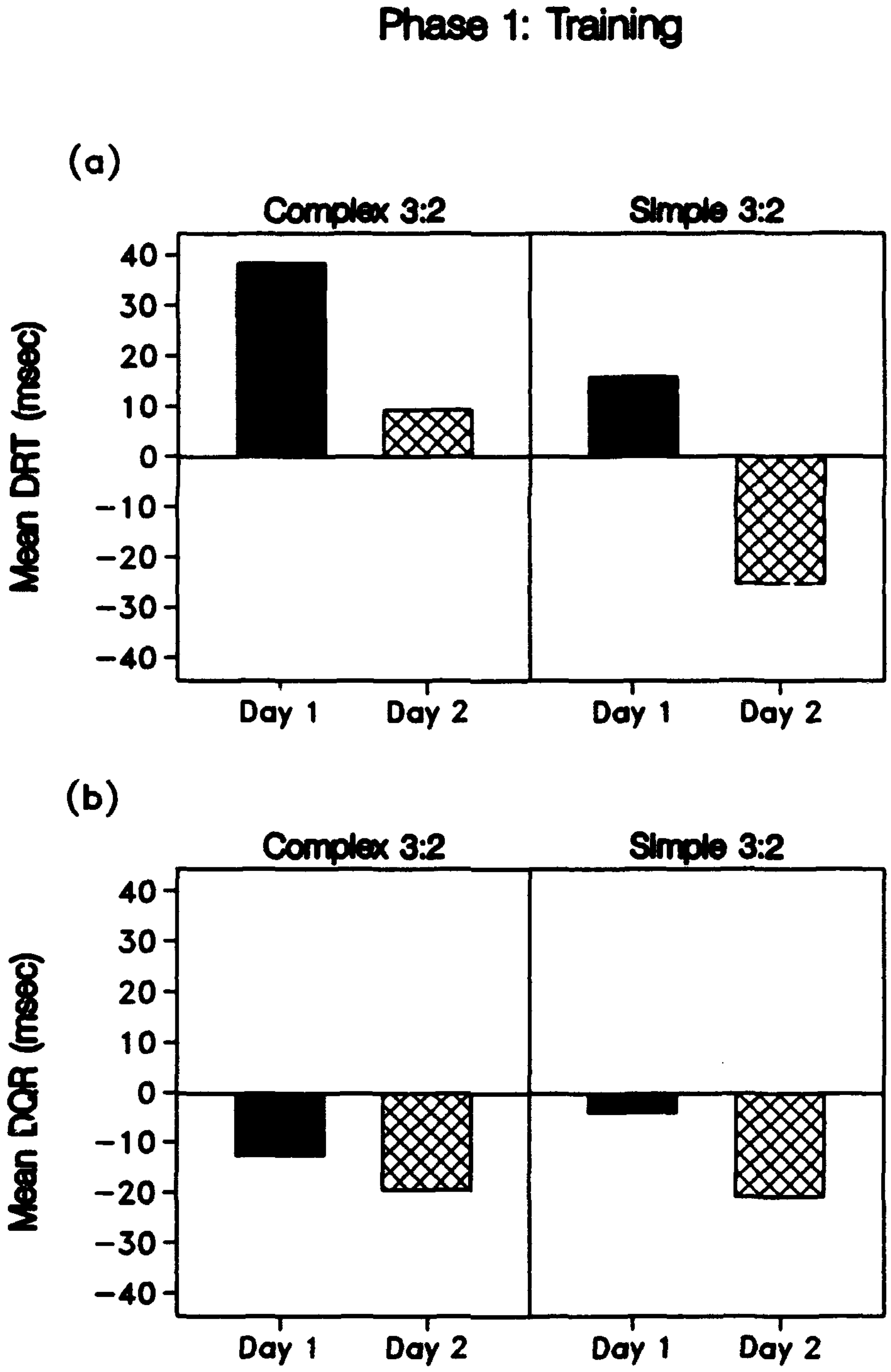

Figure 5.3. Training (Days 1-2) performance as a function of polyrhythmic group, Simple 3:2 and Complex 3:2. Panels (a) and (b) show the derived response time (DRTs) and response variability (inter-quartile) measures (DQRs) as deviations from baseline performance in Experiment 1.

with the Interference Hypothesis. However, the significant decrease in DRTs below baseline for the Simple group on Day 2 does not support this hypothesis. Interestingly, response time variability as measured by DQRs does not increase in either polyrhythmic context even on day 1 (Figure 5.3b).

Converging with the above findings are those which show that errors also decreased for both groups on Day 2. The comparison of error data between baseline and Phase One was based only on the baseline errors obtained from the 3,000ms SOA timing condition in Experiment 1. Because of differences in total number of responses between the baseline condition (16,384) and Phase One of this study (9,216 per day), percent errors are used for comparison purposes. Within each polyrhythm condition there is no significant difference between errors obtained in baseline conditions and those observed over Days 1 and 2 of this experimental phase. However, while not significant, there is nevertheless an increase in error percentages from baseline for both polyrhythmic conditions on day 1. On Day 2 both groups stabilize to baseline levels. Table 5.1 shows these data. Thus, the error data to some extent are consistent with the Interference Hypothesis.

Polyrhythmic Comparisons. The primary interest in comparing performance on the two polyrhythmic contexts in experiment 2 stems from predictions of two hypotheses: the Global Precedence Hypothesis and the Interdependence Hypothesis. Both predict that the Simple 3:2 polyrhythm should produce better performance than the Complex 3:2 polyrhythm. In general, this finding holds for response time data but not for accuracy. In the following sections, these data are assessed in detail using DRT scores (and response variability measures, DQR) and error scores.

Table 5.1

Phase One Errors Comparing Baseline to Polyrhythms.

		Polyrhythm	
		Complex	Simple
	Baseline (3000 msec)	3.06%	3.93%
Phase 1	Day 1	4.22%	5.72%
	Day 2	3.28%	3.78%

Response Time Data. The data in Figure 5.3a reveal significant main effects as a function of polyrhythmic context in Phase One (Complex versus Simple) $F(1,34) = 4.50$, $p<.04$, RMSE = 57 ms. Viewers were faster in responding to the Simple polyrhythm than to Complex one. Overall, viewers were 24ms slower than baseline in the Complex polyrhythm whereas they were 5ms faster than baseline levels in the Simple polyrhythm. In addition, a significant learning effect occurred over days with viewers showing a drop of roughly 35 ms in response times from Day 1 to Day 2, $F(1,34) = 59.10$, $p<.0001$, RMSE = 19 ms. The Day by Polyrhythm interaction was not significant.

The derived response variability scores (DQRs) shown in Figure 5.3b indicate that the two polyrhythmic groups are less variable than their baseline conditions, and that both become more stable with practice (i.e., variability declines). The drop in DQR scores from Day 1 to Day 2 is significant $F(1,34) = 23.87$, $p < .0001$, RMSE = 10 ms. Separately, the mean decrease is -7ms for the Complex group and -17ms for the Simple group.

Error Data. Overall, errors in Phase One were minimal. They amount to roughly 4% of the total responses from this study. Nonetheless, on Day 1 people in the Simple polyrhythm condition make significantly more errors than do those in the Complex condition, $X^2(1)=20.79$, $p<.0001$ (Simple=527 errors vs Complex=389 errors). This finding is inconsistent with predictions of both the Global Precedence Hypothesis and the Interdependence Hypothesis. However, by the second day of training these polyrhythmic differences had essentially disappeared (Simple=348 errors vs Complex=302 errors).

To sum up, in Phase One there is mixed support for the Interference Hypothesis from response time data. That is, baseline DRT performance on an isochronous single stream of relevant information was not always better than performance on two stream sequences. In fact, Day 2 performance in the Simple group shows a facilitation effect relative to baseline (single stream condition).

With respect to differences in performance over days as a function of polyrhythmic context, both the Global Precedence Hypothesis and Interdependence Hypothesis find some support in the present data. Both predict that performance should be superior in the Simple 3:2 polyrhythm conditions and, with the exception of accuracy scores on Day 1, this turns out to be the case.

Phase Two-Shift

Analyses of both Phase Two and Phase Three data follow from an overall analysis of performance (DRTs) including both phases in a multiple phase design. Thus, a preliminary analysis used derived response time scores in which the subject's asymptotic (Day 2) in Phase One provides the "new" baseline from which to gauge performance in Phase Two. Thus, response times in Phase One are subtracted from Phase Two and Phase Three performance. Resulting DRTs are subjected to a multiple phase analysis of variance with experimental phase (Shift versus Post-Shift) as a factor. The outcome of this preliminary ANOVA is presented in detail in Table B.1 of Appendix B. For the purposes of the present undertaking the most relevant outcome was the finding of a three way interaction of Polyrhythmic Group (Simple, Complex) with Phase (Shift, Post-Shift) and Time Change (Control, Rate Change, Rhythm Change), $F(2,30) = 5.75$, $p < .007$, RMSE = 54.7 ms. This interaction justifies separate examinations of Phase Two (and shortly Phase Three) data.

In the following sections, predictions of the Global Precedence Hypothesis and the Interdependence Hypothesis are evaluated in Phase Two data. These two hypotheses make similar predictions about the effects of rhythm changes in this phase (i.e., shifts to simple, or complex polyrhythms should produce respectively improved and degraded performance) but they differ with regard to the effects of a rate change. The Global Precedence Hypothesis predicts that no detrimental effects should attend a rate change, whereas the Interdependence Hypothesis predicts that slowing down a rhythm can negatively affect performance.

Response Time Data. Phase One median response times that were used to correct for Phase Two performance via calculation of DRTs were 519ms and 476ms respectively, for Complex 3:2 and Simple 3:2 polyrhythm groups. Phase One inter-quartile ranges used in calculating the DQR response variability scores were 116ms and 97ms for the Complex and Simple groups respectively. Figure 5.4a,b shows respectively DRT and variability scores (DQRs) for the three Time Change groups in Phase Two. The zero score here indicates no change from asymptotic (Day 2) Phase One performance level.

The overall ANOVA applied to Phase Two data show a main effect for Time Change group, $F(2,30) = 5.43$, $p < .01$, RMSE = 57 ms. There was no main effect for polyrhythmic context. However, an important interaction between Time Change and Polyrhythm did obtain, $F(2,30) = 4.36$, $p < .02$, RMSE = 57 ms.

Viewers receiving no change of their polyrhythmic context in Phase Two constitute the two control groups. Figure 5.4 show that in terms of derived median response times (DRTs) and variability (DQRs), subjects either continued on as in Phase One (Complex) or they improved somewhat (Simple). However, in neither of these control groups is the performance change relative to Phase One levels statistically significant.

Consider next the Rate Change groups; viewers in both the Simple and Complex groups had difficulty with a slower polyrhythmic context. Post Hoc tests of the Time Change main effect revealed that overall a Rate Change produced the largest increase (+22ms) from Phase One and this group was significantly different from both the No

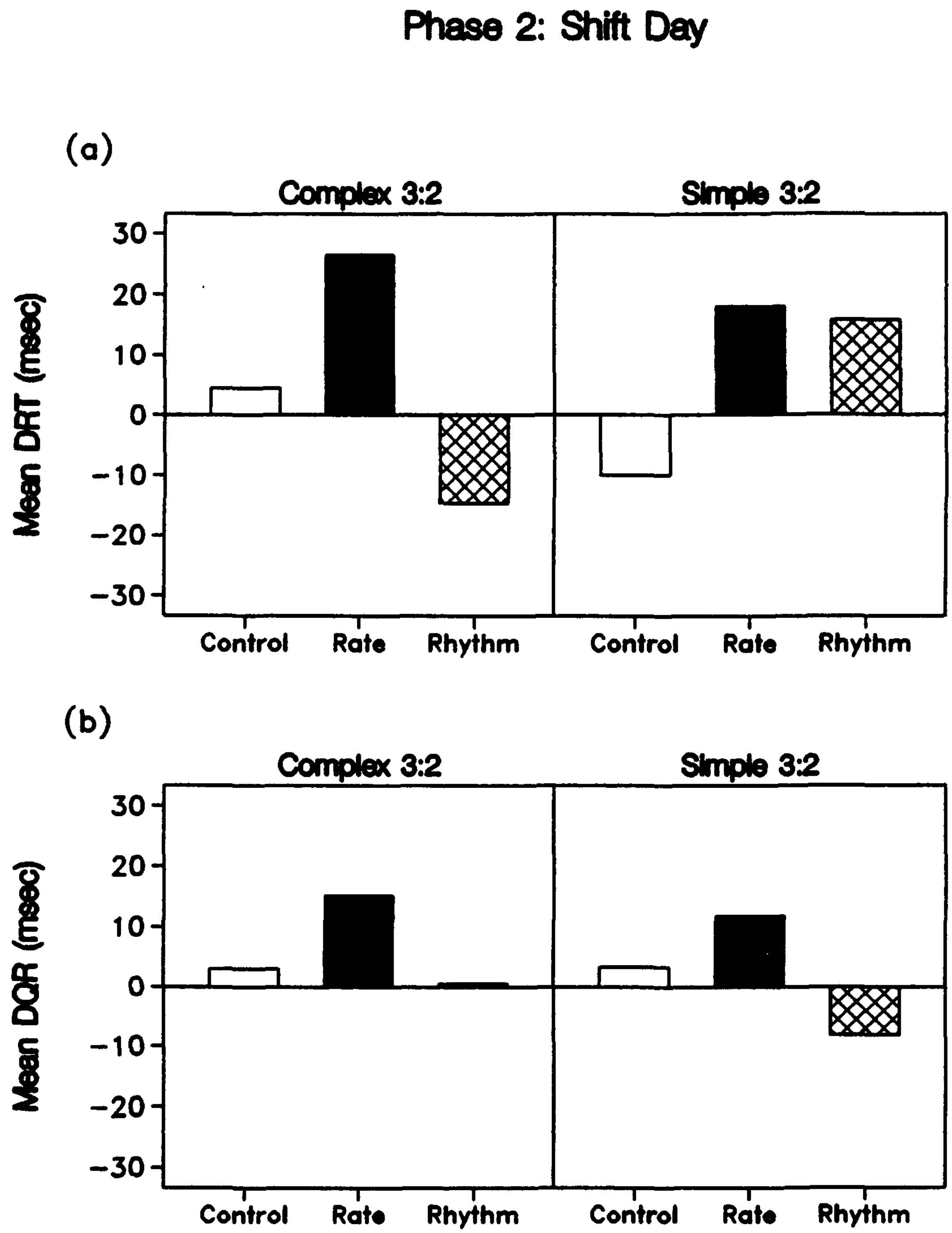

Figure 5.4. Shift Day (Day 3) results as a function of Time Change condition. Panels (a) and (b) present respective response times (DRTs) and response variability (inter-quartile range) measures (DQRs) as deviations from Phase 1 (Day 2) performance.

Change and Ratio Change groups, ($F(1,30) = 9.205$, $p<.005$, RMSE = 8 ms and $F(1,30) = 7.0$, $p<.01$, RMSE = 7.3 ms respectively), while the No Change and Ratio Change groups produced virtually no change from the zero baseline (-3ms and +1ms respectively).

Relative to pre-shift response levels, the viewers in the Complex group became more variable and increased their response times by 27ms when a slower relevant stream was introduced. Similarly, they were much slower (+22ms) than Control subjects who experienced no rate change. While these differences are substantial, it is surprising to find that they fall short of statistical significance (i.e., $F(1,5) = 4.40$, $p<.09$, RMSE = 13ms for DRT differences from zero and $F(1,10) = 2.33$, $p<.15$, RMSE = 14 ms for comparison with control subjects). Again, this result appeared to be largely due to the deviant performance of a single subject in this group. Viewers receiving a slower Simple polyrhythm also suffered performance loss; relative to pre-shift levels their response times showed significant increases in variability (DQR=+12ms) $F(1,5) = 16.00$, $p<.01$, RMSE = 3 ms and response time; DRT (18ms) $F(1,5) = 8.58$, $p<.03$, RMSE = 6 ms. These subjects were also significantly slower (DRT=+28ms) than control subjects, $F(1,10) = 6.60$, $p<.03$, RMSE = 11 ms. Overall, the Rate Change findings are more consistent with the Interdependence Hypothesis than they are with the Global Precedence Hypothesis.

Next consider a rhythm shift across the two polyrhythms. A change in rhythm produces different results for the two polyrhythm groups. As predicted by both the Global Precedence and the Interference Hypotheses, a change from a complex rhythm to a simpler one (Complex group) produced significant decrease in DRTs (15ms), $F(1,5) = 6.84$, $p<.04$, RMSE = 6 ms and little change in variability. On the other hand, a shift to a more complex rhythm (Simple group) produced an increase of 16ms, $F(1,5) = 5.0$, $p<.07$, RMSE = 7ms; although this change was not statistically significant, it was accompanied by a significant decrease in variability $F(1,5) = 13.8$, $p<.01$, RMSE = 1 ms, indicating that most of the subjects showed this sort of decrement. In fact, the lack of significance in the DRT data above was due largely to the performance of a single subject and when his data were removed from the analysis the increment is statistically significant $F(1,4) = 12.25$, $p<.02$.

Converging with these findings are comparisons of the Rhythm Change subjects with Control subjects. In the Complex group, a shift to a simpler rhythm produced a significant decrease relative to the control condition (-19ms), $F(1,10) = 5.1$, $p<.04$, RMSE = 8 ms. In the Simple group, a shift to the more complex polyrhythm produces a significant increase (+26ms), $F(1,10) = 5.1$, $p<.05$, RMSE = 12 ms from the control condition. The response time data obtained to a rhythm shift are in general agreement with predictions from both the Global Precedence and the Interference hypotheses.

Error Data. Table 5.2 presents total errors for Phase Two as a function of polyrhythmic group and shift condition. These data indicate that overall there were fewer errors in the Complex group, e.g., 343 versus 362 in the Simple, but this difference was not significant. There is a significant difference among the time shift groups, however [$X^2(2)=33.94$, $p<.0001$]. Viewers who experienced a rate change produced more errors (307) than either the control groups (209) or the rhythm change groups (189).

To sum up, Phase Two data are largely consistent with the Interdependence Hypothesis. This hypothesis correctly predicts that shifts from simple to complex global rhythms should be more difficult than the reverse shift. Overall, shifting to a new rhythm does not necessarily impair performance; rather, it is the nature of the shift which counts. People are uniformly slower when shifted from a simple to a complex rhythm, suggesting that this shift is difficult for all subjects. The Interdependence Hypothesis also predicts that changes in rate should negatively affect performance and this was evident in both response time and error data.

Table 5.2.

Phase Two Errors: Polyrhythm by Shift Group for Time Shift Day.

		Polyrhythm		
		Complex	Simple	
	No Change	104	105	209
Shift Group	Rate Change	157	150	307
	Rhythm Change	82	107	189
		343	362	705

Phase Three: Post Shift

In this phase results are examined to determine if there is any evidence of "carry over" effects when viewers are returned to their original polyrhythm contexts after experiencing either a rate or a rhythm shift. Neither the Global Precedence nor the Interdependence hypotheses make specific predictions regarding the nature of "carry over" effects, with the exception that if they occur, the Global Precedence Hypothesis implies that they should be restricted to effects of rhythmic shifts, not rate shifts. The Interdependence Hypothesis allows for the possibility that long lasting effects may arise from either rate or rhythm. Minimally, any carry over effects that occur in Phase Three can be gauged with respect to asymptotic pre-shift (Phase One) performance: Do viewers return to their pre-shift levels unharmed by a time change? However, it is also pertinent to ask how they compare on day 4 (Post Shift) to subjects who have received no time changes at all (i.e., Control subjects).

Response Time Data. Figure 5.5a and b respectively present DRT scores and variability (DQRs) for Phase Three groups.

Consider first the overall group performance relative to their Phase One performance. As a group, subjects in the Complex group showed an overall performance improvement revealed by a significant decrease (-23ms) in response time (DRTs) from their pre-shift performance, $F(1,15) = 7.3$, $p < .02$, RMSE = 9 ms. This was not the case for the Simple group, their group average change from pre-shift performance was only -5 ms.

Consider next the performance of Control subjects. Relative to their Phase One performance levels, these subjects improve over days in both groups. There is a general reduction in response times for both polyrhythmic groups along with stable variability scores, especially in the Complex group. The change in average response time is

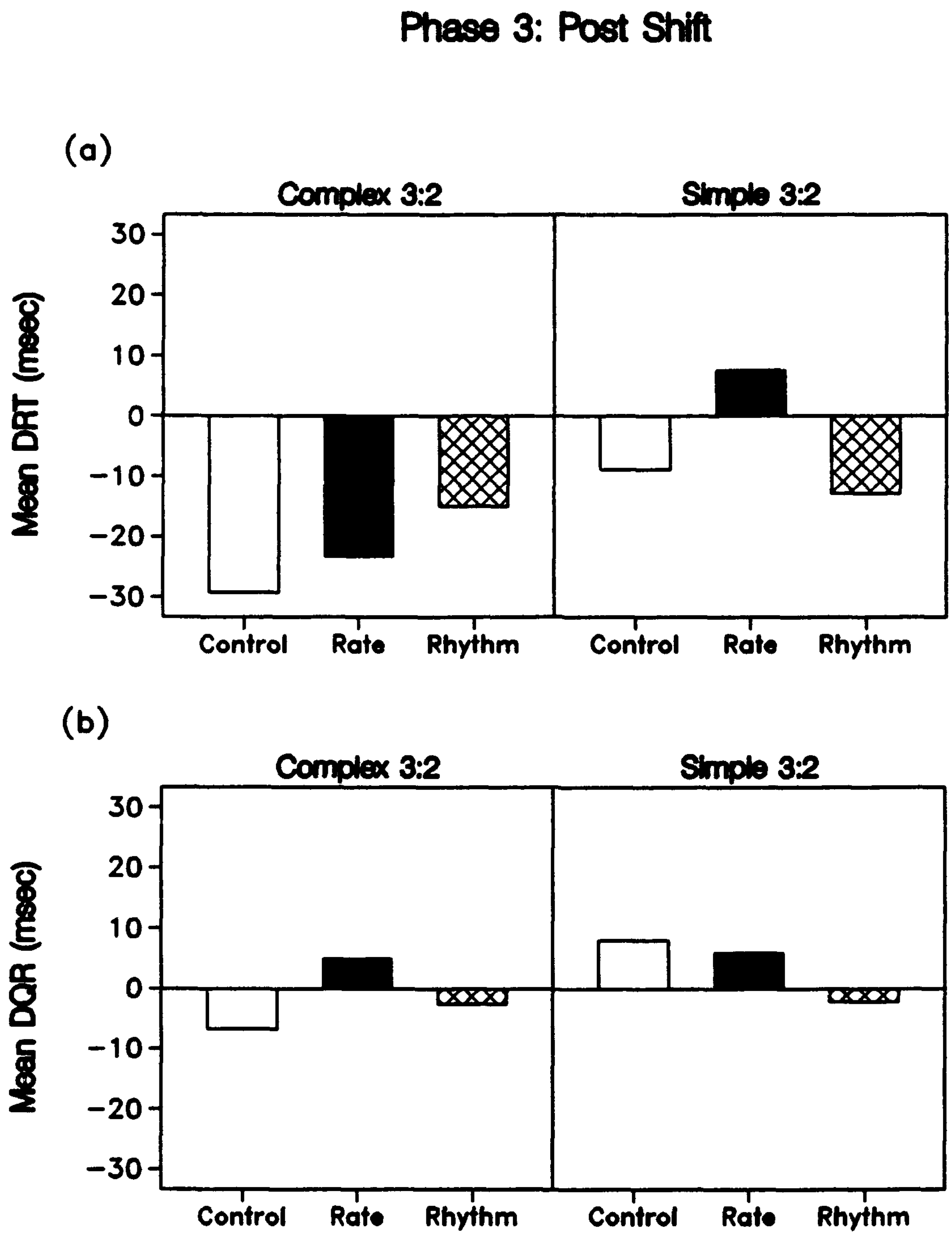

Figure 5.5. Post Shift (Day 4) performance on original polyrhythms from Phase 1. Panels (a) and (b) present respective response times (DRTs) and response variability measures (DQRs) labeled according to former Phase 2 Time Change grouping.

statistically significant only for those in the Complex polyrhythm (-29ms) between Phase One and Three), $F(1,5) = 7.3$, $p < .04$, RMSE = 11 ms.

Next consider how people who experienced some change in dynamic structure fare relative to these control subjects. People who returned to a Simple polyrhythm after experiencing a Complex one perform at a level equivalent to their control subjects indicating that no harmful "carry over" effects accrue to these folks. Similarly, those subjects who returned to a Complex polyrhythm after experiencing a Simple one did not differ significantly from their control group. Again, it appears that rhythmic shifts do not drastically deter performance. A similar picture emerges for subjects who experienced rate changes on the shift day; neither of these groups differed significantly from their respective control groups. The converging data from the DQR measures show that response variability was not affected by experiencing a change in either rate or rhythm. Thus, response time data are fairly clear in indicating that viewers can quickly adapt to a return to their original rate and rhythm.

Table 5.3

Phase Three Errors: Post Shift Polyrhythm by Time Shift Group

		Polyrhythms		
		Complex	Simple	
	No Change	114	109	223
Shift Group	Rate Change	126	153	279
	Rhythm Change	72	138	210
		312	400	712

Error Data. Error data for Phase Three appear in Table 5.3. Error data in post-shift performance do reveal some effects of polyrhythmic structure and time changes. A Chi-Square analysis on error frequency showed a significant difference $X^2(1)=10.9$, $p<.001$ between the two polyrhythmic groups. Total errors in Phase Three were 312 and 400 for Complex and Simple polyrhythmic groups respectively. There was also a significant Polyrhythm by Shift group $X^2(2)=12.79$, $p<.002$ interaction where errors decreased in the Complex polyrhythm for viewers experiencing a rhythm shift compared to the control condition, but were equivalent to the control condition in the Simple polyrhythm. In both polyrhythms, viewers experiencing a rate change had more errors than both control conditions and rhythm shift groups.

To sum up, Phase Three error data suggest that viewers experienced some residual effects when returned to their Phase One temporal context after an intervening change in rate, but not rhythm. Response time data, however, showed no reliable evidence of "carry over" effects due to rate (or rhythm). Overall, the pattern of findings cannot be attributed easily to a speed accuracy trade-off because DRTs, while not statistically significant, were in the same direction as error data. In general, these data indicate that viewers are remarkably adaptable in adjusting to the current rhythmic context.

Phase Three data also reveal one final development and this concerns overall performance of subjects in the two polyrhythmic groups relative to their Phase One levels. It is interesting to observe that the greatest improvement from Phase One levels occurs in the subjects who experience the Complex 3:2 polyrhythm: by the final day, all of these subjects are performing more quickly and accurately (i.e., relative to their pre-shift levels) than those in the Simple 3:2 group. It should be noted that at the end of Phase Three, the non-corrected mean RTs for these two groups show that the Simple group is still faster (471ms) than the Complex group (497ms). These findings make a good case for suggesting that the speed of abstraction/internalization of time relationships associated with a particular, originally difficult, rhythmic pattern is slower than for a simple rhythmic pattern.

General Discussion

Over the three phases of the present study, there is modest support for some version of an Interference Hypothesis, but more substantial support for the two time based hypotheses, particularly the Interdependence Hypothesis.

The Interference Hypothesis in its simplest form maintains that single stream selective attending will be superior to that in polyrhythmic contexts. In this form it does not acknowledge any differential effects of timing or polyrhythmic structure which might modulate interference effects. The data from Phase One indicate that while some interference effects are clearly evident (i.e., relative to baseline data collected in Experiment 1), they are confined largely to the complex polyrhythm condition.

With respect to "what" aspect of dynamic time structure is controlling or "pacing" attending, the data in Phase One also give a clear answer. Because the rate and rhythm of the relevant stream are identical for both groups of viewers responding to Simple and Complex polyrhythms, the fact that they differ significantly in performance during this phase points to the impact of global time ratios, i.e., global rhythm, on attentional control. Viewers in the Simple group were significantly faster and less variable than those in the Complex group. These findings suggest that viewers temporally integrate the two streams and are "paced" more by global time structure than local.

The data obtained in Phase Two reinforce this view. In fact, they are more revealing with respect to what aspects of global time structures do pace attention. For example, the consistent detrimental rate change effect found in both polyrhythms suggests that slowing a rhythmic structure may in fact cause viewers to shift attentional reliance to local stream timing. Specifically, the Interdependence Hypothesis predicts that when the base rate is too slow, perceptual organization of the serial pattern is undone and must be reorganized to accommodate the slower rate, (as suggested by the SIR construct of this hypothesis). This idea is also consistent with subjects in both polyrhythm groups reporting they perceived a "new" pattern in the rate change conditions, rather than a slower version of their polyrhythm. That is, slowing the polyrhythm may reduce the impact of global rhythm, and as a result viewers may have relied more on local timing that was identical for both polyrhythms. The results obtained in the rate change groups support the Interdependence Hypothesis.

Unlike the consistent effect of a rate change across polyrhythms groups, the effects of a rhythm change are not consistent. The results are consistent with predictions from both the Global Precedence and the Interdependence hypotheses. That is, it should be easier to shift to a simpler rhythm than to a more complex one. The DRT and error data support this prediction since viewers both were slower and made more errors when shifting to a complex rhythm. Thus, at the end of Phase Two, the pattern of performance results show that both rate and rhythm time parameters significantly affected performance, and that the Interdependence Hypothesis did predict these results better than the Global Precedence Hypothesis.

With regard to viewer adaptation to changes in the temporal context of their task, Phase Three of the experiment shows that all subjects in both groups generally adapted quickly without substantive performance decrements, i.e., there were no significant "carry over" effects after a temporal change when viewers returned to their original polyrhythmic context. However, subjects experiencing either a rate or rhythm shift in the Complex group, at first, appear to have adapted more efficiently to these shifts than the Simple group. Further, the Complex control group did show a significant improvement in performance from Phase One and this was not the case for the Simple control group. The Complex group also had fewer errors than the Simple group. That the Complex group should show more improvement in Phase Three, rather than the Simple group, is somewhat puzzling and not predicted by either the Global Precedence or Interdependence hypotheses. Why does performance facilitation appear to accelerate for the Complex group and diminish for the Simple one?

One plausible explanation alluded to earlier is that the process of abstraction/internalization for a simple time structure occurs much faster than for a more complex one. While this makes intuitive sense, the performance pattern across the four days does seem to support this conclusion as well. For example, recall that on Day 2 in Phase One, performance facilitation was much greater for the Simple group than the Complex group, and that further performance improvement for the Simple control group had leveled off by day 3. This was not the case for the Complex control group. On Day 4, this group showed a dramatic performance improvement indicating that they may have finally reached asymptotic performance. Thus, a closer examination of performance across these four days suggests that rather than diminished performance efficiency later in the experiment for the Simple group, there was actually an accelerated abstraction/internalization of rhythmic structure early in experiment that promoted performance facilitation early in Phase One as well. That is, the Simple group was able to "lock into" the task's time structure early, and performance facilitation from this synchronization occurred early too, remaining stable for the rest of the experiment. In the Complex group, however this process developed much slower and did not accelerate until later in the experiment, where maximal performance facilitation did occur.

Chapter Summary

This experiment examines the role of temporal relationships in a visual selective attention task. Specific objectives involved first determining the conditions (i.e., global or local time structures) under which rate and/or rhythm affected performance. A second objective involved examining viewer adaptation to changes in either the rate or rhythmic structure of the task's temporal context.

Significant findings from this experiment indicate that it is the global integrated rhythm of the visual information streams that most affected performance, rather than the task relevant local time structure. Further, that slowing a polyrhythm's global rhythm produced more performance disruption than did changing the global rhythm while holding the rate constant. While all viewers did adapt quickly after experiencing these changes, viewers trained on a complex global rhythm showed a steady improvement over the four days, while those trained on the simple rhythm quickly reached their performance asymptote early in the experiment (i.e., Day 2). These data suggest that a viewer does gradually come to internalize a complex time structure, albeit at a slower pace than a simpler structure.

Thus, this experiment supports the assumption that visual attention can be entrained, or "paced", by the persisting rate and rhythm time relationships of an extended sequence of events.

CHAPTER VI

EXPERIMENT 3

THE EFFECTS OF RATE AND RHYTHM ON ATTENTIONAL FLEXIBILITY

This experiment builds on the findings from Experiment 2 and continues examination of the role temporal relationships may have in pacing visual attention. The major finding in Experiment 2 is that performance in a simple focused attention task is influenced by global temporal relationships (i.e., integrated streams), rather than local (i.e., single stream), task relevant timing. It is an intriguing discovery and one that is a catalyst for the research focus developed in the present experiment.

One issue addressed in the present experiment evolves from the cumulative findings of the research presented so far, in particular Experiment 2. It concerns the consequences of visual attention that can be controlled (or paced), to some extent, by the persisting time relationships of a visual information flow. As discussed earlier in this dissertation, the idea of pacing assumes attention has become "locked in" (synchronized) to a set of external timing relationships. The results from Experiment 2 suggest that attentional pacing by global time parameters has an effect on performance when local time relationships are held constant. That is, when the rate and rhythm of the relevant timing stream never changes. Would global time structures affect performance in the same way when local time relationships are not held constant, i.e., systematically changed? Are global time relationships the primary temporal "pacing" factor of attention? What is the duration of global timing effects on attention? These questions are investigated in the present experiment.

A second issue addressed in this experiment concerns the impact of global (and/or local) time parameters on attentional flexibility, i.e., the flexibility of the attentional mechanism to adapt to changes in temporally structured information over time. It should be noted that this interpretation of attentional flexibility is from a time based, functional view of attention (see Chapter II, The Dynamic Attending Approach). Specifically, the idea is that attention is sensitive to temporal structure in the environment and this information is used to determine actions. The next section briefly describes the genesis of a time based view of attentional flexibility.

Attentional Flexibility as Time Based

The background for this idea is a functional view of attention that has its origins in the classic works and wisdom of William James (Allport, 1985). This viewpoint is shared by a number of contemporary psychologists to varying degrees (e.g., Allport, 1989; Jones, 1976; Jones & Boltz, 1989; Neisser, 1976; Neumann, 1987). Allport (1989) for example, states that the function of attention is goal oriented and that selectivity is in effect selection for the potential control of action (see Chapter I). Neisser (1976) shares this general view and proposes that, "attention is nothing but perception: we choose what we will see by anticipating the structured information it will provide" (p. 87). The opinions expressed by both Allport and Neisser are in keeping with a basic tenant of James, "what holds attention determines action".

With regard to what "holds" attention, James (Allport, 1985, p. 149) and more recently (Jones 1976; Jones & Boltz, 1989), present positions explicitly stating that attention is inherently rhythmical and as such, attention is sensitive to rhythmical changes in our inter al and external environment. James has referred to this rhythmicity as "pulses of attention".

Within this view of attention provided by James and others, I postulate that persisting time relationships, such as rhythm and rate, can "hold" our attention and determine the course of shifting our attentional focus in time. That is, once attention is synchronized (or paced) with some external timing structure, we may be able to employ these time relationships in a flexible manner to facilitate our performance. To "use" time relationships in this way, implies that attentional flexibility is an acquired tacit skill. Thus, the idea presented here is that flexible attending is inherently rhythmical, resonating to environmental rhythmicities, and it is a tacit skill.

Given this interpretation of attentional flexibility, there is a problem of how to investigate and measure the effects of time structures on flexible attending. As mentioned earlier, to be able to attend in a flexible manner means that our attentional mechanism can quickly and efficiently adapt to changes in the temporal structure of information over time. How does the idea of attentional "pacing" fit with the notion of attentional flexibility? Are these ideas at opposite ends of a continuum? The answer is no; "pacing" does not mean that attention is rigidly locked into a particular time structure. However, it is assumed that there are some temporal relationships (i.e., temporal pacers) that promote flexible attending more than others. The process of "pacing" is itself viewed as a continuum where upon initial exposure to a set of time relationships produces pacing effects that are very weak and exert little influence on selective attending. However, if these temporal relationships persist, and they present certain recurring periodicities at the appropriate base rate (see discussion of the SIR in Chapter II), then abstraction/internalization of the time structures occurs and people may be able to begin to "use" this implicit knowledge in an opportunistic manner to facilitate performance. It is at this point that effects of temporal "pacing" may impact performance in a more voluntary way. There may be a concomitant rise in performance efficiency at this point, e.g., sharp decrease in response times and variability, with fewer errors. Thus, the present experiment is designed to examine the progress of adaptation to several different timing manipulations within both global and local time structures. Specific global and local timing manipulations are associated with different experimental phases.

There are three phases in this experiment and they parallel those of Experiment 2. In the current experiment, Phase One is also a training phase and it is designed to examine viewer adaptation to changes in the rate, and sometimes rhythm, of the task relevant timing stream (i.e., the timing stream presenting relevant stimuli to the viewer). In this phase there is no change in the global rate and rhythm of the polyrhythmic contexts. They are the same Simple 3:2 and Complex 3:2 polyrhythms used in Experiment 2. The same viewers assigned to those groups in Experiment 2 are participants in the current experiment and retain their respective group designation. The objective of this phase is to determine if global rhythm affects performance in the same manner as in Experiment 2.

Phase Two is a shift day for all subjects in the two polyrhythm groups. All subjects are shifted to the same new polyrhythm, one that is different in both global rate and rhythm from both original polyrhythms. It is assumed that at the start of Phase Two viewers have adapted to the first change associated with local time structures. The local time changes applied in Phase One remain in Phase Two as well. The objective in this phase is to determine if adaptation to a completely new polyrhythm with a new set of global time structures proceeds in the same way for Simple and Complex groups. That is, is adaptation facilitated if the new global time parameters (e.g., rhythm or rate) are similar to the viewer's old polyrhythm.

Phase Three is the post shift day for all subjects. In this phase all viewers are returned to their original polyrhythmic conditions of Phase One. The objective in this phase is to determine if the shift to a new global rhythm and rate has any "carry over" effect when the viewer resumes task performance within their old polyrhythm. These effects could be either positive or negative. The next section describes each phase in a little more detail with an outline of possible outcomes for each phase.

Experimental Phases

Phase One: Training

In this phase, the aim is to examine the progress of viewer adaptation to systematic changes in relevant stream timing. Recall, that in Experiment 2 only one stream, the slow stream, carried relevant information. The timing of this stream was identical in both rate and for rhythm the two 3:2 polyrhythms (i.e., Simple and

Complex). Only global rhythms differed between these groups.

In the present experiment, relevant stimuli are shifted back an forth between both the fast and slow streams. This effectively creates a situation where the task relevant timing stream periodically changes rate, and in the case of the Simple polyrhythm, rhythm changes as well. A return to Figure 5.1 shows that the fast stream for the Simple polyrhythm possesses a short, long, short, alternating rhythm, whereas the fast stream for the Complex one is isochronous. An important point to remember is that this stream manipulation in no way changes global rhythm or rate of either polyrhythm, they remain the same as in Experiment 2.

If a viewer has been relying on global time structures to time attentional targeting (no assumption that this is a conscious reliance), the timing of events in the integrated (global) serial pattern will not change. However, the pattern of relevant (R) and irrelevant (I) events will change every time relevant information is shifted to a different stream. In Figure 5.1, note that when the slow stream is the relevant timing stream, the pattern of sequential events is R,I,R,I, etc. However, when the fast stream becomes the relevant timing stream, this sequential pattern changes to R,R,I,R,R,I, etc. The two patterns of R and I events are exactly the same for the Simple and Complex polyrhythms.

One possible consequence of this timing manipulation is that adaptation may be easier for viewers in the Simple group. In this polyrhythm, global rhythm is isochronous, producing regularly timed intervals for all events, both relevant and irrelevant ones. Thus, the regularity of the rhythm may ameliorate any attentional problems associated with R and I sequencing changes between the fast and slow streams.

On the other hand, it may be quite difficult at first for the Complex group to adapt to this time change. This is because their global rhythmic pattern of long, short, short, long has up to this point (i.e., through the completion of Experiment 2) always been associated with a pattern of R,I,R,I. Thus, everytime the relevant timing streams changes, so does the association between temporal intervals and stimulus relevancy (i.e., R and I patterns). Thus, a reliance on global rhythm to time attending, would predict that the Simple group should exhibit superior performance, compared to the Complex one. And further, that the difference between the two groups will be greater than in Experiment 2, i.e., there will be a performance decrement in the Complex group relative to their Experiment 2 performance, but not in the Simple group.

There is another possibility, and that is, viewers somehow psychologically separate the streams and rely on local time relationships (e.g., rate and rhythm) to time their attending. This implicit attentional strategy would be more likely to occur if viewers had internalized the temporal structure of their polyrhythm. That is, the assumption is that the viewer had gradually, over time, acquired implicit knowledge about global, as well as local time structures and could "use" this information to flexibly target attention between the two streams.

This alternative actually predicts superior performance for the Complex group. This is because both streams in the Complex polyrhythm possess isochronous rhythms and only differ in rate. Whereas, in the Simple polyrhythm fast and slow streams differ in both rate and rhythm. Therefore, if viewers in the Simple group were psychologically separating the two streams and shifting attention between them, they would encounter more timing changes than the Complex group. Thus, a reliance on local timing relationships (i.e., separate streams) to time attending should facilitate adaptation for the Complex group, but not for the Simple group.

Phase Two: Shift Day

The objective in this phase is to determine if there is any evidence for a "temporal transfer of training" effect associated with prolonged exposure to a specific polyrhythmic time structure. That is, could prior experience with certain rate and/or rhythmic time parameters transfer to affect adaptation to a new set of temporal structures?

In Phase Two viewers in both the Complex 3:2 and Simple 3:2 groups are shifted to a completely new polyrhythmic context, one that involves changes in both rate (slower) and global rhythmic structure (more complex) from their old polyrhythmic structure. A question that the timing manipulations in this phase addresses, is whether it is easier to adapt to a new temporal context when it is rhythmically similar to one's current polyrhythm. If there is a primacy for global rhythm, then temporal adaptation in this phase should be easier for the Complex group than the Simple group. This is because the new polyrhythm has a variable global rhythm similar to the rhythm of the Complex polyrhythm, but quite different from the isochronous global rhythm of the Simple polyrhythm. If there is an effect of global rate, it should be constant for both the Simple and Complex groups.

Phase Three: Post Shift Day

This last phase was designed to assess any possible temporal "carry over" effects from experiencing the change to a polyrhythm with new a global rate and rhythm in

Phase Two. As in Experiment 2, all subjects were returned to their old polyrhythm of Phase One. If there are no disruptive effects from experiencing this time change, then performance should be equivalent to Phase One, or even superior. However, if the shift to the new polyrhythm has any lingering disruptive effect on performance, it should be more pronounced for the Simple group. This is because the difference between the global structure of the Simple polyrhythm and the new polyrhythm is greater than for the Complex group.

Hypotheses

The two hypotheses tested in this experiment are the Global Precedence Hypothesis and Interdependence Hypothesis from Experiment 2.

Hypothesis 1. The Global Precedence Hypothesis. Recall, that this hypothesis maintains that higher-order time relationships are always inherently the most important relationships governing attention. Individuals must first internalize a pattern's global structure before they can use these timing relationships to target attending. This hypothesis states viewers are less likely to "use" any temporal aspect of the pattern other than global rhythm, if the global rhythm is simple. The hypothesis does not predict any rate effects, thus global rhythm is the primary temporal factor influencing attention.

The Global Precedence Hypothesis predicts that as in Experiment 2, viewers in the Simple group should present superior performance over the Complex group. Shifting stream relevance should have little impact since attentional energy should be equally distributed across all events (R and I) occurring in the integrated serial pattern (global pattern). Thus, this hypothesis does not predict a stream effect.

However, this hypothesis does predict considerable performance disruption initially for the Complex group as described earlier in the Phase One description of alternative outcomes. Thus, the Global Precedence Hypothesis predicts a main effect for polyrhythm in Phase One, i.e., a significant effect of global rhythm, but no main effect for stream relevance (i.e., fast or slow).

The hypothesis does not make any specific predictions regarding possible "temporal transfer of training" effects in Phase Two, or "carry over" effects in Phase Three. This hypothesis predicts equivalent performance for both groups in Phase Two, i.e., no significant main effect for polyrhythm. In Phase Three, the hypothesis predicts the same pattern of results obtained in Phase One, i.e., superior performance for the Simple group compared to the Complex.

Hypothesis 2: The Interdependence Hypothesis. This hypothesis shares with the Global Precedence Hypothesis the general idea of global timing primacy. It differs however, from the Global Precedence hypothesis in that it assumes there is an interdependence between the temporal context of the task and specific task requirements. This hypothesis maintains that as task relevant information requirements change (e.g., shifting stream relevance) people will "use" whatever time relationships (global or local) most efficiently accommodate these changes. That is, viewers should be able to shift reliance to different aspects of temporal structure in order to prepare for, or to complete some task goal. Thus, the Interdependence Hypothesis views global rhythmic structures as primary, but not necessarily absolute. The implication is that either global or local time parameters can assume the primary pacing role at any one time, to facilitate adaptation to temporal structure changes.

The Interdependence Hypothesis, in general, predicts results opposite to the Global Precedence Hypothesis in this experiment. This hypothesis predicts viewers will be able to psychologically separate the two steams and "use" this information to efficiently target attention between the two streams. (see separate stream alternative in Phase One section). That is, performance should be superior for the Complex group in Phase One since viewers are likely to rely more on their local stream structures (constant local rhythm) and less on their global rhythm (variable) to time attending.

This hypothesis also assumes that a complex global time ratio (Complex polyrhythm) should produce a less cohesive integrated pattern than one with a constant global time ratio (Simple polyrhythm). The implication is that the global time pattern of the Complex polyrhythm should be perceptually easier to separate into two streams. Further, since there is a constant time ratio <u>within</u> each of the streams in the Complex polyrhythm, but not the Simple polyrhythm, performance should actually be superior for viewers in the Complex group.

Since this hypothesis does predict a rate effect, it predicts RT performance will be faster in the fast stream relevant condition, than the slow stream relevant one for the Complex grouponly. As the Simple polyrhythm has a variable fast stream rhythm, RTs should be longer in this condition than when the slow stream is relevant. Thus, the Interdependence Hypothesis predicts an overall advantage for the Complex group as compared to the Simple group in Phase One.

In Phase Two, the Interdependence Hypothesis does suggest a "temporal transfer of training". That is, the more similar two pattern's rhythmic structures are, the easier it will be to adapt to the new temporal context. This hypothesis predicts that performance will be superior for the Complex group in Phase Two even though both the Simple and Complex groups have exactly the same polyrhythmic context in this phase. And finally, this hypothesis like the previous one, makes no strong predictions about "carry over" effects in Phase Three. This phase is exploratory and there is no real basis for predictions about residual time effects in either hypothesis.

Method

The task, stimuli, apparatus, and instructions were the same as in Experiment 2. Subjects were never apprised of the systematic changes in stream relevance, i.e., presenting relevant information alternately in the fast and slow streams.

Conditions

The two polyrhythms used as temporal contexts were the same used in Experiment 2: Complex 3:2 and Simple 3:2. There was a new polyrhythm introduced into this study, a Complex 4:3. This polyrhythm had global rate of 12,600 ms, and a variable global moving time ratio of .33, 2, 1, .5, 3,. Local time ratios however, were a constant in both streams, the fast stream had a constant SOA of 3,150 ms, (approximately the same SOA as the slow stream in the 3:2 polyrhythms), and the slow stream had a constant 4,200 ms SOA. The overall structure of this polyrhythm was similar to the Complex 3:2 in that it had a variable global rhythm and constant local rhythms. Figure 6.1 shows the Complex 4:3 polyrhythm presents a highly irregular

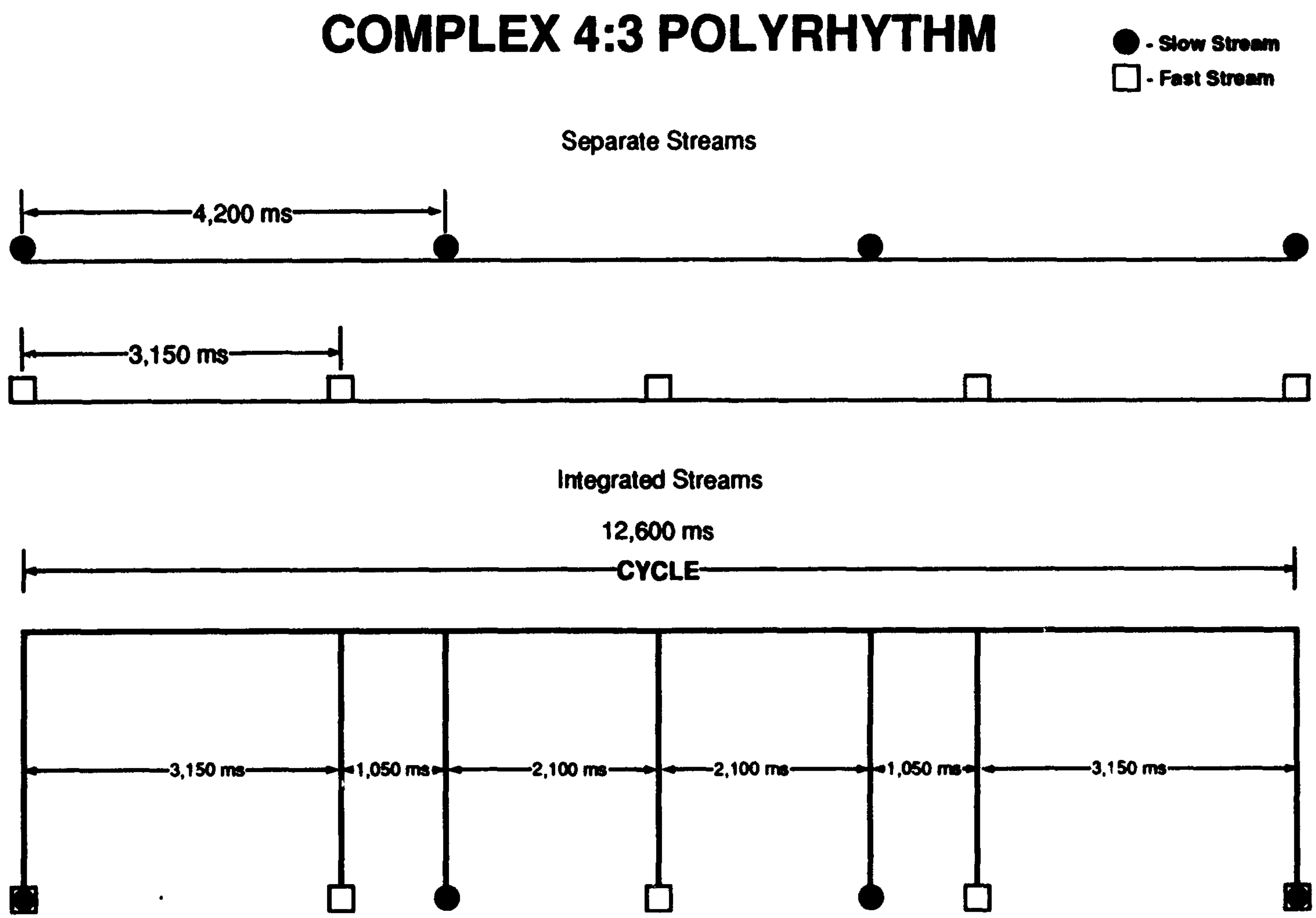

Figure 6.1. Temporal structure of a Complex 4:3 polyrhythm used in Experiment 3. Separate fast and slow streams have isochronous timing. Integrated stream pattern has complex variable SOAs.

integrated time pattern. Combined with this event irregularity, the cycle period is a little over twice as long as the two 3:2 polyrhythms making this polyrhythm the most structurally complex of the three.

<u>Subjects</u>

There were a total of 24 subjects in this study, 16 subjects had participated in Experiment 2, eight from each 3:2 original polyrhythmic group. Eight additional subjects were recruited to participate in the 4:3 polyrhythmic control group. These subjects had participated in the baseline study, but not Experiment 2. For simplification, the 4:3 polyrhythm will hereafter be designated simply as the Control group. The Control Group experienced the conditions of Experiment 2 to equate their time on task with subjects in the other groups. Thus, subjects in the Control group were at the same experience level at the beginning of Experiment 3, as subjects in the other two groups.

<u>Design</u>

The design was a mixed design with two between factors and four within. The between factors were the polyrhythmic groups (Complex, Simple, and Control) and stimulus counterbalance order (L,S,S,L or S,L,L,S) where L = letter pairs relevant and S = shape pairs relevant. Within factors were Day (1-3) where Day 2 (Phase 2) all subjects were shifted to the 4:3 polyrhythm and Day 3 (Phase 3) were returned to their former polyrhythm. Remaining factors were: Response Mode (Same, Different); Stimuli (Letter pairs, Shape pairs); and Stream (fast, slow). Dependent measures were response times, response time variability, and errors. Experimental Phases are shown in Figure 6.2.

EXPERIMENTAL PHASES

POLYRHYTHM GROUP	PHASE 1 (DAY 1)	PHASE 2 (DAY 2)	PHASE 3 (DAY 3)	
	TRAINING	*SHIFT DAY	RETURN	
COMPLEX 4:3	4:3C S,S ↔ F,F ↔ S,S ↔ F,F ↔ S,S	4:3C S,S ↔ F,F ↔ S,S ↔ F,F ↔ S,S	4:3C S,S ↔ F,F ↔ S,S ↔ F,F ↔ S,S	N=8
COMPLEX 3:2	3:2C S,S ↔ F,F ↔ S,S ↔ F,F ↔ S,S	4:3C S,S ↔ F,F ↔ S,S ↔ F,F ↔ S,S	3:2C S,S ↔ F,F ↔ S,S ↔ F,F ↔ S,S	N=8
SIMPLE 3:2	3:2S S,S ↔ F,F ↔ S,S ↔ F,F ↔ S,S	4:3C S,S ↔ F,F ↔ S,S ↔ F,F ↔ S,S	3:2S S,S ↔ F,F ↔ S,S ↔ F,F ↔ S,S	N=8

S= SLOW STREAM RELEVANT
F= FAST STREAM RELEVANT
*= ALL GROUPS COMPLEX 4:3

Figure 6.2. Experimental Phases for Experiment 3. Phase 1: Task training on shifting streams (fast/slow) within designated polyrhythmic context. Phase 2: All subjects shifted to Complex 4:3 polyrhythm. Phase 3: All subjects return to original polyrhythmic context.

There were a number of planned comparisons involving only the two 3:2 polyrhythms. The Control group (4:3) was analyzed with the Simple and Complex groups only in Phase 2.

Procedure

The study was conducted in over three days, one day per phase. Before the experimental sessions began, all subjects were reacquainted with their original polyrhythmic context. There had been delay of one month between the end of Experiment 2 and the beginning of Experiments 3. During each phase, there were a total of 10 trial blocks, 640 trials per day. The first two blocks of trials on every day began with relevant stimuli presented in the slow stream (exactly as in Experiment 2). Revelant stimuli for the next two blocks were moved to the fast stream. This alternation continued for 10 blocks (see Figure 6.2). Subjects were given a ten minute break between blocks five and six each day.

Stream relevance (fast or slow) and stimulus relevance (letters or shapes) were never changed together. For example, when stimulus relevance changed on a subsequent block of trials, there was never a concomitant change in stream.

On the first day (Phase 1: Training) subjects performed the task within their original polyrhythmic context for the 10 blocks. On Day 2 (Phase 2: Shift Day) all subjects from the Simple and Complex groups were shifted to the 4:3 polyrhythmic context. The Control group continued as before in Phase 1. On Day 3 (Phase 3: Post Shift) all subjects from the Simple and Complex groups were returned to Phase 1 conditions, i.e., returned to their old polyrhythmic context.

Scoring Methods

Performance in all phases assessed accuracy (errors) and response times in terms of median RTs and derived response times (DRTs). Response variabiiity was also measured using inter-quartile range (Q-range) measures and derived Q-range (DQRs). The procedure used to adjust response time data is exactly the same as described in Experiment 7. It is simply a difference score using a specified referent performance condition to reflect adaptation progress (see Chapter V for details).

Results and Discussion

Results are presented in three sections which correspond respectively to the three experimental phases. Within each phase, the three dependent measures mentioned in the scoring section are discussed.

Phase One: Training

The analysis of this training phase is shown in Figure 6.3. The ANOVA was applied to the median RTs and Q-range data directly without adjusting to a referent performance level. The RT and Q-range data are plotted to show adaptation progress across the entire experimental session.

Response Time Data. The were no main effects for Polyrhythm group or timing stream (fast/slow) in the RT analysis. There was however, a significant Stream Timing by Polyrhythm interaction $F(4,52) = 2.75$, $p < .03$, RMSE = 24 ms. The change from Fast Relevant to the Slow Relevant blocks produced a decrease of 24 ms for the Simple group, but an increase of 12 ms for the Complex group. Because of the variability between subjects, the large difference in RTs between the Simple and Complex groups

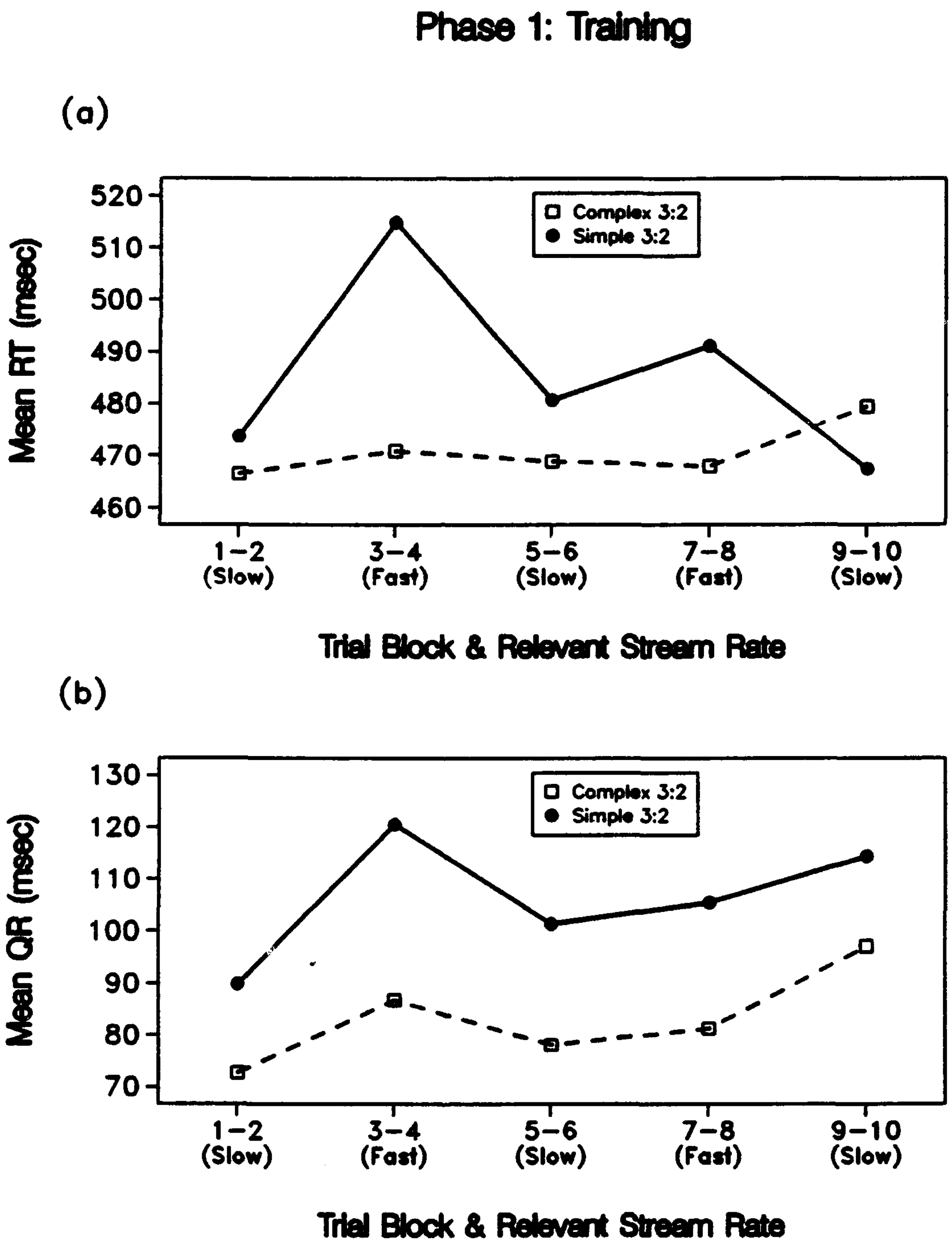

Figure 6.3. Training (Day 1) results as a function of trial block and relevant stream rate for Complex 3:2 and Simple 3:2 groups. Panels (a) and (b) present respective mean response times (RTs) and mean inter-quartile ranges (QRs).

(44 ms) on blocks 3-4, (the first set of Fast Relevant blocks) was not significant ($F(1,13) = 1.82$, $p < .2$ ns). Nevertheless, the pattern trend does suggest that the Simple group was having more difficulty adapting to relevant information presented in the fast stream. There is virtually no difference between groups when the slow stream carries the relevant stimuli.

There are also no significant effects in the Q-range analysis either. However, the data do suggest that overall, the Simple group was more variable in their responding.

Error Data. Phase One error data are shown in Table 6.1.

Table 6.1

Phase One Errors: Polyrhythm Group By Fast/Slow Streams During Training

		Stream		
		Fast	Slow	
	Control	77	77	154
Polyrhythm Group	Complex	85	89	174
	Simple	71	90	161
		233	256	489

The error data show that there were no significant differences as a function of polyrhythm group. Only the Simple group shows an increase in error frequency when responding to relevant information in the slow steam.

In summary, the results indicate that by the end of Phase One both the Simple and Complex groups have adapted quite well to the first time change in the series. In fact, by the end of Phase One their average RTs are virtually identical. However, in the early blocks, Simple group performance suffered when relevant stimuli appeared for the first time in the fast stream. This was not the case for Complex group, performance in the two streams are not different.

These data tend to suggest that viewers were not using global rhythm to gauge their attending, but rather local rhythms instead. Phase One data in general support the predictions of the Interdependence Hypothesis over the Global Precedence.

Phase Two: Shift to 4:3 Polyrhythm

Derived Scores. At the end of Phase One, asymptotic performance on Slow Relevant blocks (9-10) and Fast Relevant blocks (7-8) were averaged and used as referents for creating DRTs for subsequent analyses in Phases Two and Three. The DQRs were constructed similarly. The mean values for RTs and Q-ranges used as referents for derived scores are respectively: (1) Simple = 479 ms, 110ms; (2) Complex = 474 ms, 89 ms; (3) Control (4:3) = 511 ms, 116 ms.

Response Time Data. The analysis of all subjects' performance in the 4:3 polyrhythm is shown in Figure 6.4. The DRTs and DQRs are shown respectively in panels (a) and (b). The ANOVA applied to the DRT data shows significant main effects for Polyrhythm Group ($F(2,10) = 4.56$, $p < .02$, RMSE = 49 ms) and Relevant Stream timing ($F(1,19) = 5.11$, $p < .03$, RMSE = 13 ms. Responses in the Fast Relevant stream averaged 8 ms longer than for the Slow Relevant stream. Planned contrasts showed that the Simple group's performance on the 4:3 polyrhythm differed significantly (54 ms) from the Control group ($F(1,13) = 12.96$, $p < .008$, RMSE = 15 ms. The difference

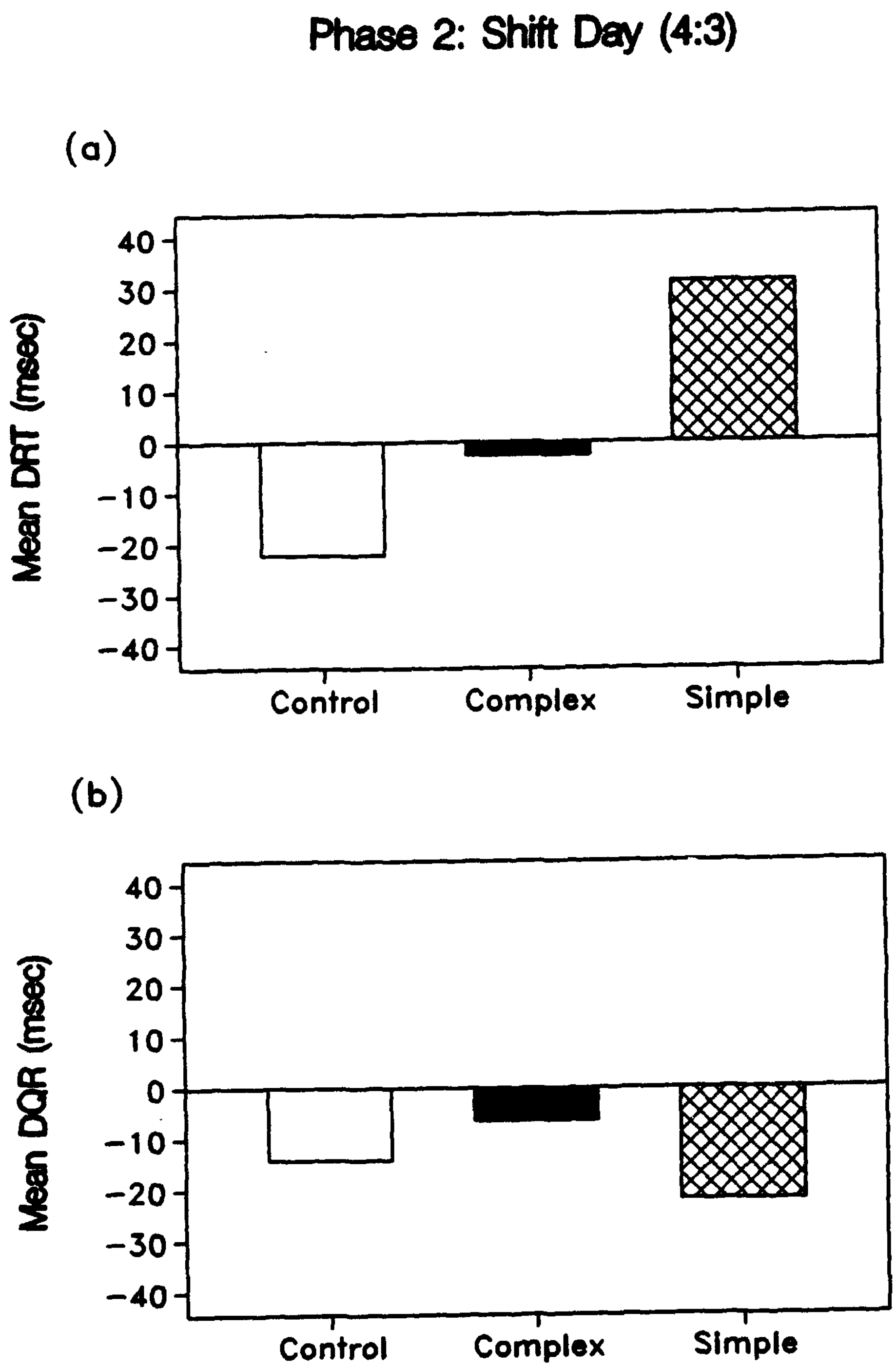

Figure 6.4. Shift Day (Day 2) performance. All subjects from the original 3:2 polyrhythmic groups shifted to the 4:3 polyrhythm and are shown with the 4:3 polyrhythmic control group. Panels (a) and (b) present respective response times (DRTs) and response variability (inter-quartile range) measure (DQRs) as deviations from Phase 1 performance averaged over blocks 7-10.

between the Simple and the Complex was 34 ms and approached significance (F1,13) = 2.86, $p<.07$ ns. Both the Simple and Control group differed significantly from their Phase One referent level performance. The Simple group showed an increase in DRTs of 31 ms ($F(1,8) = 7.45$, $p<.03$, RMSE = 11 ms) and the Control groups showed a decrease of 22 ms ($F(1,8) = 6.25$, $p<.04$, RMSE = 9 ms). The Complex group did not differ from their Phase One performance.

The analysis of the DQR data showed a significant main effect for Stream Relevance ($F(1,19) = 12.49$, $p<.002$, RMSE = 13 ms) where responding in the slow stream was less variable (-14 ms) than responding in fast stream (-7 ms).

Together the DRT and DQR analyses show that it was less difficult to adapt to the new 4:3 polyrhythm for the Complex group than for the Simple one. For the Complex group there was virtually no difference in response time performance between in Phase One and Phase Two. This suggests that for the Complex group there was considerable ease of adaptability. While not significant, it is still interesting to note that the Simple group's stability of responding improved from Phase One, even though there was an increase in their DRTs.

Again, these response time data are more consistent with the Interdependence Hypothesis than the Global Precedence Hypothesis.

<u>Error Data</u>. Error data for Phase Two are shown in Table 6.2.

Table 6.2

Phase Two Errors: Polyrhythm Group By Stream, Shift To 4:3 Polyrhythm.

		Stream		
		Fast	Slow	
Polyrhythm Group	Control Group	180	133	313
	Complex Group	64	66	130
	Simple Group	53	104	157
		297	303	600

These data show that overall, the Control group produced the most errors, approximately twice as many as the other two groups. This is interesting since all groups are performing the task within a 4:3 polyrhythm and the Control group has had the most experience. There is a significant Polyrhythm Group by Stream Relevance interaction, $X^2(2)=24.0$, $p<.0001$. Errors are stable across fast and slow streams for the Complex group. However, in the Simple group, there are twice as may errors when the slow stream is the relevant stream. This is opposite of the error pattern in the Control group. Thus, the error data do provide converging support to the response time data analyses in supporting the position that adaptation was less efficient for the Simple group compared to the Complex group.

In sum, performance results in Phase Two, where all subjects are using a 4:3 polyrhythmic, are most consistent with the predictions of the Interdependence Hypothesis. Again, performance was generally superior for the Complex group in a comparison between the two original 3:2 polyrhythmic groups. That is, the Complex group had little difficulty adjusting to the new temporal context in Phase Two, whereas, the Simple group had considerable difficulty as measured by increased DRT and error scores. Interestingly, response stability improved for this group more than either the Control or the Complex group.

Phase Three: Post Shift

Response Time Data. The response time data are shown in Figure 6.5., DRT and DQR respectively in panels (a) and (b). The ANOVA procedure applied to the DRT data compare performance in Phase Three for the two original 3:2 polyrhythmic groups, the Simple and Complex. The results of this analysis show a main effect for Polyrhythm Group only, $F(1,13) = 9.44$, $p < .008$, RMSE = 24 ms. The difference between the two groups was 28 ms. At the end of Experiment 3, the Complex group showed a significant performance facilitation effect relative to their Phase One referent level performance (-36 ms), $F(1,7) = 17.64$, $p < .005$, RMSE = 8 ms. There was also a slight improvement for the Simple group but this difference was not significant.

The DQR analysis did not show a significant difference between response variability between the two groups. However, there was a significant difference in response variability as a function of the Relevant Stream timing (fast/slow), $F(1,13) = 5.19$, $p < .04$, RMSE = 14 ms. Viewers produced less variable responding in the Slow Relevant stream (-22 ms) than in the Fast Relevant stream (-10 ms).

In sum, the response time data suggest that overall, the Complex group showed faster adaptation in all change conditions across Phases One through Three. Thus, at least for the Complex group there was an overall facilitation effect across days, such that

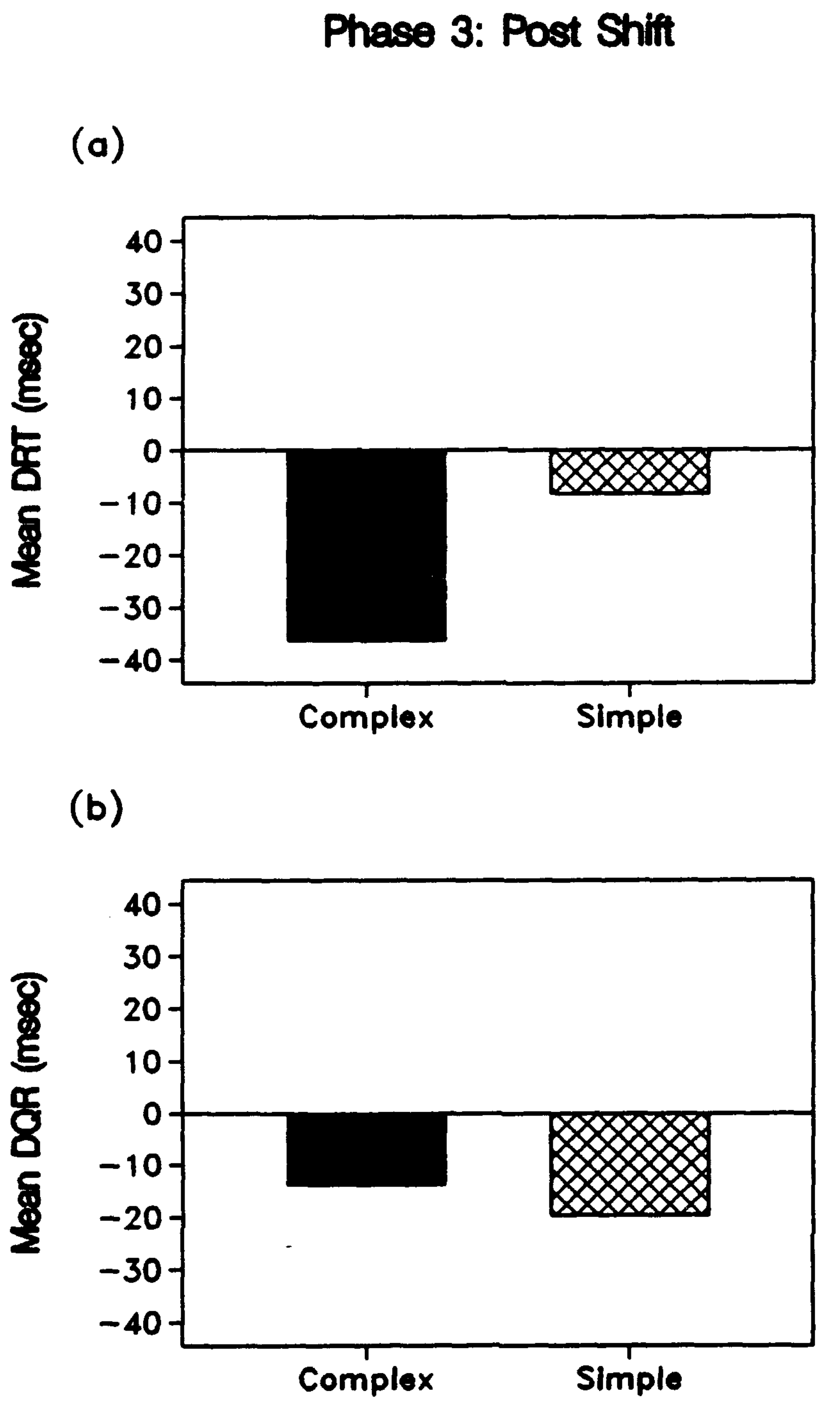

Figure 6.5. Post Shift (Day 3) performance. Subjects from the two original polyrhythmic groups, Simple 3:2 and Complex 3:2 are shifted back to these same polyrhythms. Performance measures (DRTs) and (DQRs) are derived from Phase 1 performance (blocks 7-10). Panels (a) and (b) present these respectively.

by the end of Phase Three, their performance had surpassed that of the Simple group.

Error Data. Error data for Phase Three are shown in Table 6.3

Table 6.3

Phase Three Errors: Polyrhythm Group By Stream For Post Shift Day.

		Stream		
		Fast	Slow	
	Control	193	214	407
Polyrhythm Group	Complex	91	69	160
	Simple	68	65	133
		352	348	700

The error data pattern is not significantly different for the two polyrhythm groups. There is however, a slight decrease in errors for the Complex group for the Slow Relevant stream from Phase One to Phase Three. Otherwise, error patterns do not discriminate across groups in this Phase.

In summary, data from Phase Three suggest that experiencing a new polyrhythm in Phase Two did not produce any lingering disruptions to performance when viewers returned to their original polyrhythm. That is, relative to their referent level performance, viewers in both the Simple and Complex groups did show effective adaptation. Surprisingly, performance was actually facilitated for the Complex group. Not only did this group not suffer any performance disruption, but the experience of working with a new complex polyrhythm actually seemed to enhance adaptation. Thus, data from this Post Shift phase do not show any negative carry over effects associated with a global rate and rhythm time change.

4:3 Control Group Performance. While Control group performance was most relevant in Phase Two, a separate analysis across days was applied to this group's performance measures. There was a significant decrease in response times over the three days, $F(2,12) = 5.7$, $p < .02$, RMSE = 13 ms. Median RTs over the three days were respectively: 517 ms, 487 ms, 491 ms suggesting performance for this group was asymptotic at Day 2. There was also a significant Day by Timing block interaction, $F(8,48) = 2.86$, $p < .01$, RMSE = 18 ms, obtained in the Q-range data analysis. These data are shown in Table 6.4.

Table 6.4

Mean Inter-Quartile Range Scores

	RELEVANT STREAM				
DAY	SLOW (1-2)	FAST (3-4)	SLOW (5-6)	FAST (7-8)	SLOW (9-10)
1	109	109	112	119	113
2	87	103	91	125	93
3	104	90	93	109	128

* Numbers are in milliseconds

Control Group (4:3): Mean Inter-Quartile Range Scores By Day and Relevant Stream.

Inspection of these data over days indicates no difference in response variability in Phase One across all trial blocks. However, on Day 2, a pattern emerges that shows there is more response variability with Fast Relevant streams than with Slow Relevant. Then on Day 3, this pattern actually reverses and response variability seems to increase for the Slow and decrease for the Fast Relevant streams! Perhaps viewers in this group are perceptually reorganizing the pattern, or maybe they are just attentionally fatigued (like the reader) by structural complexity.

General Discussion

This experiment is a direct extension of Experiment 2. The issues addressed in this experiment continue the examination of the role temporal relationships play in visual selective attention. Over the three phases of this experiment the question of whether global rhythm is the primary temporal "pacer" of visual attention is addressed. The hypothesis developed from this viewpoint is the Global Precedence Hypothesis.

Related to the issue of global rhythm primacy is how such temporal "pacers", (e.g., rhythm and rate) might affect attentional flexibility. Within the context of this research, attentional flexibility is viewed as time based, i.e., it is inherently rhythmical and a skill that can be developed. Thus, flexible attending is evaluated in this experiment in terms of adaptation to changes in temporally structured information. The Interdependence Hypothesis was developed from the notion that attentional flexibility is inherently rhythmical.

Over the three phases of this experiment there is substantial support for the Interdependence Hypothesis. The predictions from the Global Precedence Hypothesis were only moderately supported. For example, in Phase One, this hypothesis predicted the Simple group would show superior adaptation in response to shifts in relevant stream timing. This was not the case, there was no difference between the Simple and Complex groups at the end of Phase One. In fact, it was the Simple group that encountered performance disruptions when relevant information was shifted to the fast stream, not the Complex group as predicted by the Global Precedence Hypothesis. However, it was expected that there would be some initial disruption for the Complex group when information was first shifted to the fast stream, but that they would quickly surpass the Simple group. Instead, the Complex group showed no change in RTs across the entire session. The efficient adaptation of the Complex group suggests that perhaps they were using local time structures, rather than global ones to time their attending. That is, the Complex group produced equivalent performance across fast and slow relevant trial blocks suggesting that the two isochronous local rhythms may have facilitated their attentional shift.

The initial disruption to Simple group performance caused by shifting relevant stimuli to the fast stream (i.e., Fast Stream Relevant condition) is surprising and suggests this group may also have been relying on the local variable rhythm of the fast stream instead of the global isochronous rhythm. The dramatic increase in response times occurred only for the first set of Fast Relevant timing, but there was significant adaptation after that point. Thus, in Phase one, the data are generally not consistent with predictions from the Global Precedence Hypothesis.

The data are more consistent with predictions from the Interdependence Hypothesis instead. This hypothesis predicted superior performance by the Complex group, but also predicted a difference between streams as a function of rate. That is, the

Fast Relevant stream was predicted to produce RTs faster than the Slow Relevant stream. This effect did not materialize. Local rhythm was predicted to influence the Simple group more than local rate. The data in Phase One do seem to suggest viewers may actually be relying more on local rhythms than global in what could be interpreted as an attempt to accommodate the experimental manipulation occurring at the local level. Thus, at the end of Phase One, support for absolute primacy of global time relationships over local ones, is questionable.

In Phase Two where all subjects are shifted to a 4:3 polyrhythm, there is a clear difference between group performance. The data support the prediction made by the Interdependence Hypothesis that adaptation to this time change would be facilitated when temporal structures (both global and local) between the old and new polyrhythms were more similar. The Global Precedence Hypothesis makes no predictions about adaptation or carry over effects and predicts equivalent performance for the two groups. Clearly these two groups are not adapting to the new polyrhythm structure at the same speed.

And finally, the fact that in Phase Three there was complete adaptation after Phase Two Shift shows a high degree of attentional flexibility for all subjects, especially those in the Complex group. That there were no apparent residual effects from Phase Two seems to suggest that experience with "change", in and of itself, enhances attentional flexibility. Perhaps this is the reason that over the seven days (Experiments 2 and 3) viewers in the Complex group continue to improve until they finally surpass the Simple group performance levels. That is, the predictable small changes in their global rhythm may keep attention energized for viewers in the Complex group. Whereas, the monotony of the global isochronous rhythm, i.e., lack of change, may permit attentional energies to dissipate.

In summary, the data across all phases of this experiment are most consistent with the Interdependence Hypothesis over the Global Precedence Hypothesis. Global rhythms may indeed be the most important temporal factor influencing or "pacing" attention, but viewers do not always appear to rely strictly on global temporal relationships to time their attending. That is, it appears that when performance can be facilitated by relying on local timing properties, viewers will "use" these structures to facilitate perfor-
There does appear to be an interdependence between attending and the att
requirements associated with task goals. Therefore, the pattern of results for the Sin.
and Complex groups across days may have been produced by the dual role of rhythmic structure. Thus, along with the role of <u>directing</u> attentional energies for timing shifts, certain rhythmic structures may facilitate timed attending by maintaining the appropriate attentional energy levels for optimal pickup of information.

<u>Chapter Summary</u>

This experiment continues examination of the role of temporal relationships in visual attention. Objectives involved determining whether global rhythms were the most influential temporal factor influencing attention and how global rhythms influenced attentional flexibility.

Significant findings from this experiment suggest that it is rhythm in general (both global and local) that has a more significant effect on performance, rather than rate per se. In this experiment there was no evidence for any rate effects. The different pattern of results obtained for two polyrhythms, (e.g., continued improvement by the Complex group) may be suggestive of a dual role for rhythmic structure in visual attention. That is, global rhythms may be important for maintaining heightened attentional energies for the pickup of information, while local rhythms may be "used" for precise targeting of that energy.

In sum, this experiment did provide evidence for the importance of global rhythm as an attentional "pacer" in visual attention. There was also evidence to suggest local rhythms can play an important role in "pacing" attention where precision is required.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Introduction

The research presented in this dissertation represents some exploratory steps in the investigation of the role temporal relationships may have in controlling visual attention. This topic is one that has received scant research attention in the past. While there is little research directly addressing how we attend to dynamic visual events, there is some evidence to suggest that individuals are sensitive to certain non spatial factors associated with these events. Specifically, those factors that are temporal in nature, e.g., the rate and rhythm of event sequences, are emerging as important variables contributing to how we perceive and attend to visual information.

Presently, most evidence supporting the notion of temporal patterning sensitivity is found in the auditory domain; most notably in music and speech research. There is some research using dynamic visual sequences that suggests time structures associated with visual events influence how we selectively attend. The research available at present, that speaks to this issue, is found mainly in perceptual-motor research, where typically only single streams of dynamic visual sequences are used. There are few studies that have attempted to deal with multistream dynamic displays. The research presented here has begun such an investigation.

The experiments presented in this dissertation are exploratory, but they are couched within a theoretical framework that incorporates time as an important component. This is Jones' theory of dynamic attending (e.g., Jones, 1976; Jones and Boltz, 1989). The basic idea is that attending is inherently temporal and that it is an activity guided to some extent by temporal structure (rate and rhythm) in an amodal manner. That is, the fact that individuals appear to be sensitive to the timing information of visual sequences suggests the that we may experience time relationships in an amodal manner. It is this assumption of a common sensory experience to temporal structure in our environment that is explored in the present research. The amodal assumption has influenced the experimental designs and task paradigm used in this dissertation.

In the next sections, I summarize the major findings from this series of experiments and briefly consider their implications for the study of exogenous (external) temporal factors controlling attention. It is clear there is always danger in overgeneralizing from a particular set of experiments and experimental conditions. Nevertheless, the results from these experiments point to a number of consistent and I believe important conclusions.

Preliminary Experiments

The first evidence to emerge suggesting that visual attention may be influenced to some extent by the timing properties of a continuous stream of visual events, was revealed in the first two preliminary experiments of this dissertation. In these two experiments, it was found that viewers did not separate different streams of visual information (i.e., one relevant and one irrelevant stream), but rather they integrated the two streams. Performance measures (RTs, errors) changed as a direct result of particular emergent rhythms created when the two streams were combined. Some rhythms facilitated performance, while others interfered with performance in this simple selective attention task. Even when the two streams were spatially separated (preliminary experiment 2, Chapter III), the integrated time patterns produced performance changes. In this experiment, the integrated rhythm of the two streams appeared to set up a conflict situation where the timing of the two streams was integrated, but the spatial separation between the two streams prevented spatial integration. These two experiments revealed that the rate of the integrated time pattern was also affecting performance. That is, slower rhythms produced slower response times and faster rhythms generally produced faster response times. However, in these studies rate was somewhat confounded with the complexity of the emergent rhythms. Nevertheless, these two experiments provided the first evidence that non spatial external (exogenous) factors that were temporal in nature, i.e., rate and rhythm, did affect performance in this focused attention task.

Thus, in these two experiments the impact of rhythm and rate appeared to be solely a function of the global time structures produced when the two timing streams combined, rather than the rate or rhythm of the separate, local, time structure of the relevant event stream. This set in motion the idea to explore the relative influence of global versus local time structures in the later experiments. These data were also the genesis for developing one of the hypotheses tested in later experiments, the Global Precedence Hypothesis.

To clarify the role of these two time parameters, three experiments were designed to examine rate and rhythm parameter effects on attentional set. The first experiment, a baseline study, examined the effects of rate.

Experiment 1: Baseline

The experiment was designed with a dual purpose in mind: (1) provide baseline performance for later experiments, and (2) examine the effects of rate when rhythm was controlled. In this baseline experiment, rhythm was controlled in that all time patterns were isochronous. Rate was varied in single stream presentations only, i.e., even when two different information sources were used (e.g., letter pairs and shape pairs) they occurred in the same spatial location and with the same timing (e.g., coupled events). Exposure to each rate was extensive (e.g., 1,024 trials per timing rate) and the results indicated that response times increased with concomitant increases in SOAs. That is, response times appeared to be time "locked into" (entrained) to specific rates. The increase in response times could not be interpreted as a simple stimulus uncertainty effect, since response time variability remained constant across the different rates. These data support rate as a possible exogenous control factor in a more clearcut manner than in the preliminary studies.

The notion that attention may be "paced" by external temporal factors began to take form during this experiment and was to evolve over the course of this dissertation. The results of the baseline experiment suggest that visual attention may come to be "paced" in an involuntary manner (exogenous) by a persisting rate pattern. Slower rates seem to produce what appears to be an involuntary slowing of the attentional system, reflected in slower response times, as information appearances are delayed in time. Further, the lack of variability in response times across different timing rates indicates that attention was time locked, or entrained by the different rates. This experiment provided the first clear evidence that rate may be an important time parameter that influences the speed with which attention is allocated. Thus, the speed of attentional allocation may in fact be proportional to the time span between visual events.

In the next two experiments, rate manipulations were incorporated within more complex dynamic situations where the emphasis was on rhythmic manipulations. Temporal structure (rate and rhythm) was manipulated both within (local time structure) and between (global time structure) two visual information streams that were temporally organized into different polyrhythmic structures.

Experiment 2: The Role of Temporal Relationships in Visual Attention

Experiment 2 was the first attempt to pit the effects of global time structures against those of local time structures. Operationally, this meant presenting relevant information only in the slower of the two information streams where the rate and rhythm of this particular stream were identical for both polyrhythmic structures. Thus, if attention were to become entrained by this local time structure (slow stream), then performance should be equivalent for both polyrhythmic groups. On the other hand, if the rhythmic structure of the global time pattern produced by the integration of the two timing streams were the primary temporal factor influencing attention (i.e., global rate is constant), as was the case in the preliminary studies, then performance should differ between the polyrhythmic structures.

Two hypotheses generated from the Time Based approach made predictions as to how rate and rhythmic time parameters might affect maintaining an attentional focus, or set. The Global Precedence Hypothesis predicted that if attention is influenced by temporal structure, it will be associated with global rhythmic structure and not local time structures. This hypothesis maintains that simple global structures are more apt to facilitate performance, rather than complex ones. This hypothesis makes no predictions regarding pattern rate. That is, if a particular rhythm is presented at a slightly slower rate, performance should not be significantly affected as long as the rhythm's relative timing relationships are preserved. And finally, this hypothesis states that global rhythm effects are task independent i.e., global rhythms would produce similar effects across different task situations. An important implication of the task independence assumption is that global rhythms are more likely to produce only involuntary "pacing" effects on attention.

The other hypothesis, the Interdependence Hypothesis, does share with the Global Precedence Hypothesis an emphasis on the importance of global time structures, at least initially when one is first exposed to a new rhythmic structure. This hypothesis however, differs in several important ways from the Global Precedence Hypothesis. First, rate and rhythm are assumed to be interdependent. That is, slowing (or speeding up) a rhythm can result in the subjective experience of a changed rhythm, rather than the perception of same rhythm occurring at a slower or faster rate. Extreme changes in rate can result in the loss of pattern coherence. Secondly, there is also an interdependence between the task requirements and the temporal structure of the task information. That is, this hypothesis maintains that over time an individual can learn the temporal structure of the task environment and then selectively "use" different aspects of the structure (either global or local) to target attention in an anticipatory way to pickup task relevant information. Therefore, this hypothesis differs from the Global Precedence Hypothesis in that it is task dependent, i.e., there is an interdependence between task requirements and the temporal context of the task environment itself. This interdependence is assumed to affect attentional allocation strategies. The important implication of the task dependence assumption is that attentional "pacing" can become a more deliberate activity. That is, this hypothesis supports the idea that temporal factors operating to "pace" attention can do so in both an exogenous (involuntary) or endogenous (voluntary) manner.

The first major finding from this experiment indicated that performance was more affected by the global temporal structures (both rhythm and rate) than local time structures. Viewers in the Complex polyrhythm group had significantly longer response times and produced more variable responding than those in the Simple polyrhythm group. These data however, did not distinguish between the two hypotheses.

The second important finding was that slowing a global rhythm produced comparably increased response times in both polyrhythmic contexts. However, shifting to a different rhythm (no change in rate) produced differential effects across the two polyrhythms. In general, slowing a polyrhythm's rate had a more deleterious effect on performance than shifting to a different rhythm. The equivalent impact of a rate change across the two polyrhythmic contexts suggests that the rate of the information flow produced attentional entrainment (pacing) in much the same manner as in Experiment 1. Thus, data obtained regarding a global rate effect are more consistent with the Interdependence Hypothesis predictions as this hypothesis does predict an interdependence between rate and rhythm time parameters.

In sum, this study did not definitively distinguish between the two hypotheses, i.e., the global rhythm effect was predicted by both hypotheses. However, the results of the rate manipulation support the Interdependence Hypothesis.

The final experiment in this series was an attempt to clarify how rate and rhythmic time manipulations at global and local time structure were affecting the viewer's flexible attending to different temporal aspects of the task environment.

Experiment 3: Rate and Rhythm Effects on Attentional Flexibility

This experiment builds on the findings from Experiment 2. The first objective of this final experiment was to determine whether there is a basis for considering global rhythm as the primary temporal "pacing" factor in visual attention. A second objective, related to the first, was to examine how rate and rhythm time parameters affect attentional flexibility. Throughout this dissertation, the view of attention has been that attending is time based and sensitive to external temporal structures. Hence, attentional flexibility is viewed, as well, within this framework. It is evaluated in this experiment in terms of viewer adaptation efficiency to temporal changes associated with task relevant information.

Operationally, addressing the two experimental objectives listed above was accomplished by using the same polyrhythms, procedures, and subjects from Experiment

2. Timing manipulations were designed to tease out temporal effects of local time parameters, from global ones. This involved first manipulating the relevant stream timing (local) while holding global timing constant. The second timing manipulation involved changing both global and local timing relationships by shifting all viewers to a new polyrhythm context. The final manipulation involved shifting all viewers back to their original familiar polyrhythm context. Throughout these manipulations, the simple selective attention task itself was never changed. Thus, the only change made to the two polyrhythms from Experiment 2 was that relevant information could now occur in either the fast or slow streams. Re ll, relevant information was only presented in the slow stream in Experiment 2.

It was expected that if viewers were using global timing, (as predicted by the Global Precedence Hypothesis), to time their attending, that viewers in the Complex group would have more difficulty adjusting to the new local timing manipulations than viewers in the Simple group. On the other hand, if somehow viewers were able to "use" the local time relationships to separate the streams, the advantage would be with the Complex group. This is because both streams in their polyrhythm possessed the same simple rhythmic structure (isochronous) and thus, anticipatory attending should be facilitated. The Interdependence Hypothesis predicted viewers would attempt such an attentional strategy in order to "use" timing structures most congruent with periodic changes in the task. That is, they would tend to "use" global or local time parameters on the basis of whichever was most congruent with task demands.

The results of this experiment revealed that performance across the three day experiment was consistently superior for the Complex group. They adapted to the series of timing manipulations faster and with less variability than their counterparts in the Simple group. This outcome is consistent with the Interdependence Hypothesis, but not the Global Precedence one.

Perhaps the most important finding in this experiment is that viewers did appear to be able to flexibly shift their attention between the two different streams, i.e., to psychologically separate the streams, and precisely target their attentional energies in response to manipulations regarding relevant stream timing (fast/slow). Viewers in the Complex group demonstrated a high degree of attentional flexibility by their efficient adaptation to frequent temporal changes, especially their adaptation to a new mo complex polyrhythm. While viewers in the Simple group showed adequate adar patterns, the Complex group demonstrated consistent performance facilitation three day experiment. Finally, by the end of the experiment, viewer perf Complex group had surpassed that of the Simple group.

The results from this experiment are intriguing, especially the performance of the Complex group. This group showed a pattern of performance improvement across the seven days of the two experiments that was not apparent in the Simple group. Why is this? It is speculated that perhaps the small, but predictable rhythmical changes of the Complex polyrhythm keeps the attentional mechinism energized, i.e., "paced" while the monotony of an isochronous global rhythm (Simple) and lack of rhythmical changes, has a somewhat dulling effect on the attentional system, i.e., the "pacing" effect is weak.

These data from Experiment 3 suggest that viewers are able to selectively use different aspects of their temporal context (global or local time parameters) to accommodate changes in the demands of the task. The data are not consistent with a view of absolute global structure primacy, i.e, the Global Precedence Hypothesis. They are however, consistent with the Interdependence Hypothesis and the view that there is a constant interplay between a viewer and the environment. And further, these results indicated that viewers can pickup and internalize temporally structured information to be "used" later to facilitate performance. This is the essence of dynamic attending.

In sum, significant findings from these experiments are that temporal relationships do affect attention in a visual selective attention task and that time parameters of rate and rhythm can assume different roles in the "pacing" of attention, such as attentional energizers (passive pacing) and directors of attentional energies (active pacing). Some of the specific findings are: (1) There is no strong support for the notion that the primary temporal factor influencing attention is always global rhythm (Experiments 1 & 3). (2) Rate and rhythm time parameters operate to influence, or "pace" attention at both global and local time structures (Experiments 2 & 3). (3) There is evidence to suggest that experience with one global rhythm can transfer to facilitate adaptation to a new one (Experiment 3). (4) Slowing a rhythmic pattern interferes more with task performance than changing the rhythm (Experiment 2).

Conclusions

The experiments presented in this dissertation have demonstrated that attention can be entrained, or "paced" by persisting temporal relationships (rhythm and rate) associated with a dynamic flow of visual information. These findings lend support to the notion that attention is itself dynamic, i.e., *time based*. And further, that *time* is perceived and attended-to in an amodal manner. The present research, however, did not explicitly test this amodal assumption and it remains now for future research to test it and to explore other issues raised in this dissertation.

One important issue raised by the early preliminary experiment (Experiment 2) is how joint temporal and spatial structures might affect allocation of attention. This study showed that attentional conflict could arise as a function of certain combinations of space-time structures. Therefore, follow on research should attempt to determine those important space-time relationships that are most likely to affect attentional allocation. Further, future research must be concerned with developing predictive models of dynamic attention that incorporate temporal and spatial parameters in terms of both global and local structural relationships. And finally, models of dynamic attention must be tested across a wide range of paradigms to determine the relative impact of joint space-time parameters on establishing, maintaining, and shifting one's attentional focus.

At present, the most promising theoretical perspective for pursuing the issues just mentioned appears to be the Dynamic Attending approach (discussed in Chapter 2). While the theory is incomplete at this time, nevertheless, it is the only structurally oriented theory that *explicitly* incorporates both temporal and spatial structure into its approach (e.g., Jones, 1976).

APPENDIX A

CHAPTER IV SUPPLEMENTAL DATA

Table A.1

Mean RTs for Baseline Experiment: Stimulus Analysis on Coupled Events (1).

Time Pattern	Response Mode (S/D)	Stimulus Compatibility (Incompatible/Compatible)	Mean RT
1500	DIFF	COMP	454
1500	DIFF	INCOMP	481
1500	SAME	COMP	440
1500	SAME	INCOMP	464
2000	DIFF	COMP	456
2000	DIFF	INCOMP	482
2000	SAME	COMP	439
2000	SAME	INCOMP	463
3000	DIFF	COMP	480
3000	DIFF	INCOMP	504
3000	SAME	COMP	456
3000	SAME	INCOMP	479
4200	DIFF	COMP	510
4200	DIFF	INCOMP	531
4200	SAME	COMP	483
4200	SAME	INCOMP	515

* Numbers are in milliseconds

Table A.1 shows mean RTs for a significant three way interaction of timing pattern by response mode by stimulus compatibility, $F(3,34) = 3.38$, $P < .02$, RMSE = 30 ms. Stimulus Compatibility refers to response compatibility (SAME/DIFF) between relevant and irrelevant stimuli in a coupled pair. These data show that RTs to a compatible coupled pair were consistently faster than when the coupled pair was incompatible. RTs are virtually identical for the 1,500 ms SOA and 2,000 ms SOA rates. However, RTs do increase as the timing pattern SOAs increase (e.g., 3,000 ms

& 4,200 ms).

Table A.2

Mean RTs for Baseline Experiment: Stimulus Analysis on Coupled Events (2).

Response Mode S/D	Relevant Stimulus LETTERS/SHAPES	Stimulus Compatibility (Incompatible/Compatible)	Mean RT
DIFF	LETTERS	COMP	467
DIFF	LETTERS	INCOMP	484
DIFF	SHAPES	COMP	483
DIFF	SHAPES	INCOMP	515
SAME	LETTERS	COMP	445
SAME	LETTERS	INCOMP	473
SAME	SHAPES	COMP	464
SAME	SHAPES	INCOMP	488

* Numbers are in milliseconds

Significant interaction as a function of Response Mode (SAME/DIFF), Relevant Stimulus (LETTERS/SHAPES) and Stimulus Compatibility (Compatible/Incompatible), $F(1,35) = 16.52$, $P < .003$, RMSE = 30 ms. These data show that RTs were significantly longer when the coupled pair was incompatible. Different responses were typically longer across all conditions.

APPENDIX B

CHAPTER V SUPPLEMENTAL DATA

Table B.1

Experiment 2 DRT Mean Values Associated With Significant Main Effects.

Shift Condition	DRT
Shift (Day 3)	6.7
Post Shift (Day 4)	-13.6
Stimuli	DRT
Letters	-8.2
Shapes	1.3
Stimulus Type	DRT
Coupled Events	6.4
Uncoupled Events	-13.3
Response Mode	DRT
Different	4.8
Same	-11.7

Table B.1 presents the results of the overall ANOVA applied to the DRT data showed significant main effects for Stimuli (letters, shapes), and Response mode (same, different), and Stimulus Coupling (coupled, uncoupled). A description of these now familiar main effects are as follows: (1) Letters were consistently faster (8 ms) than shapes, $F(1,30) = 11.52$, $p<.002$, RMSE = 34 ms; (2) Same responses were significantly ($F(1,30) = 13.11$, $p<.001$, RMSE = 55 ms) faster than different responses by 16 ms; and (3) Uncoupled events were consistently faster than coupled events by 18 ms, $F(1,30) = 31.62$, $p.<.0001$, RMSE = 42 ms. There was also a significant main effect for Day ($F(1,30) =$ 19.92, $p<.0001$, RMSE = 55 ms) showing an overall increase in response times on day 3 (shift) of +7 ms and a decrease on day 4 (post shift) of -14 ms relative to day 2 (pre shift).

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