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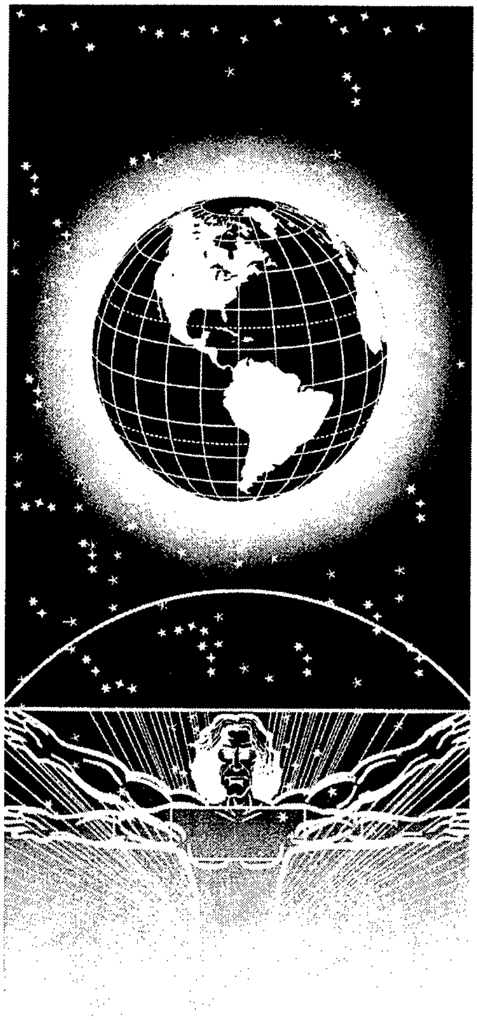

UNITED STATES AIR FORCE RESEARCH LABORATORY

ATTENTIONAL PACING AND TEMPORAL CAPTURE IN SLOW VISUAL SEQUENCES

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FOR THE COMMANDER

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Three experiments examined effects of temporally interleaved sequences of relevant and irrelevant information on selective attending to relevant visual items (letter pairs). In a serial monitoring task, viewers judged the physical match (same, different) of successive letter pairs in the relevant sequence under instructions to ignore irrelevant items. Irrelevant information comprised either visual information or tones. In all experiments the relative timing of relevant and irrelevant items was manipulated in slow visual sequences. Other manipulations included spatial formatting of irrelevant visual items (central vs displaced) and attentional set (speed vs accuracy). Results indicated that interleaved irrelevant information produced interference (slowed performance) relative to performance levels with relevant items alone only in certain timing conditions; in other conditions facilitation (faster responding occurred.

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ABSTRACT

Three experiments examined effects of temporally interleaved sequences of relevant and irrelevant information on selective attending to relevant visual items (letter pairs). In a serial monitoring task, viewers judged the physical match (same, different) of successive letter pairs in the relevant sequence under instructions to ignore irrelevant items. Irrelevant information comprised either visual information (small boxes in Experiments 1 & 2) or tones (Experiment 3). In all experiments the relative timing of relevant and irrelevant items was manipulated in slow visual sequences. Other manipulations included spatial formatting of irrevelant visual items (central vs displaced) and attentional set (speed vs accuracy). Results indicated that interleaved irrelevant information produced interference (slowed performance) relative to performance levels with relevant items alone only in certain timing conditions; in other conditions facilitation (faster responding) occurred. Patterns of facilitation and interference were consistent across experiments. Facilitation was more likely when relevant and irrelevant items formed a 'new' coherent rhythm whereas, interference was more likely following an ill-timed irrelevant item in a less coherent rhythm. Results were discussed in terms of the attentional pacing and temporal capture of attention.

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ATTENTIONAL PACING AND TEMPORAL CAPTURE IN SLOW VISUAL SEQUENCES

Adams and Pew (1989) remarked, "... in the real world of dynamic complexity, information does not usually arrive neatly packaged in task-by-task bundles." The workplace is filled with many dynamic visual and auditory sources of information designed to inform a human operator of status changes. Typically this information reaches the operator at different times, producing interleaved strings of elements from different sources. Perceptually, an intact string from a single source is experienced as an information "stream" (e.g., Bregman, 1990; Skelly & Jones, 1990; Sperling & Reeves, 1980). Selective attending while monitoring different sources of information, requires one to maintain an attentional focus to one sequence of relevant elements in spite of, potentially interfering, irrelevant information from other sources. Unlike a visual search where a person's focal attending can, in principle, voluntarily roam through an array of distinct objects, in temporal presentations the voluntary aspect of serial attending is necessarily more constrained because the to-be-attended objects are serially paced in time (cf. e.g., Bennett & Wolfe, 1996). In this scenario, one cannot revisit an earlier element to re-examine it focally, but must respond on a moment-to-moment basis. Further complicating the story, often the timing of naturally occurring strings is rhythmically complex. This introduces questions about how such environments affect one's ability to selectively attend *in time* to one of several different sequences of objects.

The present research addresses some of these questions. Using a serial monitoring task, we consider how rhythmically complex sequences, which involve co-occurring strings of information, affect selective attending. We are interested in the role of time in controlling attending to these sequences; we study this by manipulating a sequence's relative timing or rhythm. Thus, we ask: "In the rhythmical sequence that arises from temporal interleaving of irrelevant with relevant information, does the presence of irrelevant information necessarily cause interference when people must selectively attend to the relevant information?" The gist of this report suggests that the answer is "No." Instead, it appears that interference (or the lack of it) depends on the relative timing of irrelevant information.

Our perspective is influenced by research with auditory sequences where evidence exists that sequence timing and rhythm affect attending (e.g., Klein & Jones, 1996; Large & Jones, 1998). Studies of auditory rhythms suggest that relative time properties of sequences, such as isochony and grouping, are important in many tasks. Isochrony refers to uniform timing of elements; grouping refers to regular segmentation of several elements, usually by pauses. For instance, consider a sequence composed of two different tones, o and x, where o represents items relevant to a listener and x represents irrelevant ones. When interleaved, these tones might form a recurrent pattern, grouped in time as: xoxo xoxo xoxo. Particularly at slow rates, people often report hearing a single rhythmic stream involving both relevant and irrelevant elements (van Noorden, 1975). The perceived coherence of this rhythm depends on the relative timing among x and o tones. Coherence, in turn, involves the presence of both isochrony and regular grouping. These and other rhythmical properties can affect how people monitor the pattern from moment to moment (Dowling, Lung, & Herrbold, 1987; Jones, Kidd, & Wetzel, 1981; Klein & Jones, 1996). For instance, the final element in the xoxo group is often perceived as salient; this is particularly true if the grouped elements are isochronous, thereby permitting anticipation of "when" the group will end in real time (Jones & Boltz, 1989). Conversely, less coherent rhythms contain temporally deviant, i.e., unexpected, elements that may in fact, disrupt attending. Although these rhythmical properties appear to may systematically affect attending in auditory sequences, they may also affect visual attending (Crowder & Greene, 1987; Garner & Gottwald, 1968; Holleran, 1996; Klemmer, 1967; Marks, 1978; Watkins et al., 1992).

In general, the role of time in attending to visual sequences is not commonly examined as an explicit source of attentional control. In fact, relative timing i.e., rhythm, has rarely been manipulated in such contexts. Thus, in Rapid Serial Visual Presentation (RSVP) tasks where stimuli are fast sequences, the focus is not on relative timing of irrelevant visual items, but rather on the absolute duration of consequent interference which is estimated to last up to 500 ms independently of temporal context (Raymond et al. 1992; Reeves & Sperling, 1986, Shapiro et al., 1994; Ward et al., 1997). Similarly, in the visual search task, time is manipulated only implicitly as in attentional capture. Yantis (1996) has shown that sudden onsets, implicitly associated with a brief absolute time interval, within a search array can automatically engage attention. If the abruptly occurring element is not a target, but a distractor, then attention is drawn away from the to-be-detected target, and captured by the ill-timed distractor. (Yantis & Jonides, 1984; but see Gibson, 1996a,b; Yantis & Jonides, 1996). Finally, time again implicitly figures in the manipulation of motion in visual search. Driver and Baylis (1989) found that spatially distant nontargets (distractors), which share movement (or immobility) with a target, interfere more with attention than near ones which do not (e.g. due to "common fate"). In this case, interference arises from the fact that a coherent motion of a group of moving nontarget elements introduces a form of sustained attending which draws attention away from salient target elements. These findings, together with the Yantis data, not only implicate timing, but they also suggest that attentional capture can result from either an abrupt, i.e. unexpected, stimulus onset, or from a coherent grouping of moving objects (Jonides, Naveh-Benjamin, & Palmer, 1985: Jonides & Yantis, 1988; Yantis & Johnson, 1984; 1990; Yantis & Jonides, 1990).

A few studies have explicitly manipulated the relative timing in visual attention tasks. Using relatively slow visual sequences, Klapp et al. (1985) manipulated the rhythm of interleaved tones and lights; they found that people more accurately judged the ending times of combined (auditory/visual) sequences with simpler rhythms. In a related vigilance task, Scerbo Warm & Fisk (1987) required viewers to monitor a string of interleaved visual items (long and short vertical lines) where the timing of both long and short lines (relevant and irrelevant elements, respectively) was varied. They found that, overall, best performance occurred when the timing of both relevant and irrelevant items was isochronous, but performance was also good when the time patterns of both elements were random. However, performance was poor when the timing structures of the relevant and irrelevant sequences were dissimilar i.e., temporally incompatible. This suggests that conflict between sequences that leads to attentional interference (i.e., degraded vigilance performance) depends upon relative time properties. These experiments indicate that in certain attention tasks, the relative timing of visual stimuli affects performance.

In sum, the common approaches to visual attention tend to rely either on very fast visual sequences or on relatively static visual arrays where issues concerning the role of relative time and attention are difficult to investigate. Yet some research with auditory and visual sequences suggests that attending may be controlled by the time properties of sequences, particularly with relatively slow patterns. Therefore, the present research uses slow visual sequences to study the role of stimulus timing in attentional control.

The role of time in attentional control

In dynamic events, whether auditory or visual, it has been suggested that time is an important stimulus determinant of attention (Jones, 1976). By 'time' we mean the pattern of inter-onset-time intervals that arise when a succession of elements unfolds; relative time refers to relationships among these intervals. Such intervals create patterns in time (rhythms), which, in turn, influence "when" we might attend to forthcoming items (Large & Jones,1998*)*. In this way, stimulus timing may control attending. We distinguish between two types of time-based attentional control: sustained and transient. In the context of rhythmic manipulations of sequence properties, these may reflect different underlying mechanisms. In slow visual serial presentations, certain temporal properties of a rhythm, such as isochrony and grouping, support sustained attending, In this type of stimulus control, rhythmic properties guide attending, generating expectancies about "when" forthcoming items might occur. We propose that this sort of attentional guidance results from a time-based *stimulus-pacing of attention.* Next, given a rhythmically established pace, an ill-timed element can briefly capture the control of attending, reflecting a transient control of attention. We refer to this as the *temporal capture* of attention. Both kinds of attentional control are time-based and stimulus driven.

The present research considers the usefulness of this distinction in serial monitoring tasks. We manipulate sequence rhythm in order to study attentional monitoring of a succession of visual items. We consider three questions. First, at the rates involved, does inserting irrelevant information into a sequence of relevant items always interfere with responding to relevant targets? Second, when time patterns of relevant and irrelevant sequences are rhythmically combined, how does this affect attending? Third, is the distinction between attentional pacing and temporal capture useful in understanding moment-to-moment attentional monitoring?

Experimental Strategy

Our experimental strategy involved manipulations of timing sequences in a monitoring task where people received selective attending instructions. We presented people with different sequences, created by the interleaving of two different time patterns, one carrying relevant and the other irrelevant information. The time structure of relevant and irrelevant sequences was separately manipulated such that, when combined, different rhythms emerged. This allowed a determination of what timing combinations of relevant and irrelevant information help (facilitate) and hurt (interfere with) the speed and/or accuracy of performance. In all sequences, relevant items were letter pairs; irrelevant items were either visual squares (Experiments 1 & 2) or tones (Experiment 3). Viewers were told to attend exclusively to relevant items and to make judgments about certain ones, termed targets. Using a continuous version of a Posner task, a target was defined as a letter pair whose members could be "same" or (in other sessions) "different" with respect to a physical match.

Timing manipulations permitted assessment rhythmic properties such as isochrony and temporal grouping. Figure 1 shows the two different arrangements of inter-onset time intervals (IOIs) used to manipulate timing of relevant items. In one of the conditions, the IOIs yield an unbroken isochronous string of letter pairs; this is a regular (R) timing condition. In the other relevant condition, long and short time intervals alternate; this yields an irregular (I) timing comprising successive groups of relevant items. The same timing variations were applied to the irrelevant string (r,i). Next, elements from relevant and irrelevant sequences were interleaved; the result yields four distinct, and more complex, rhythmic patterns shown in Figure 2. These four conditions are denoted Rr, Ri, Ir, and Ii; the first letter (capitalized) refers to timing of relevant elements and the second letter (lower-case) refers to timing of irrelevant elements.

Viewers were exposed to the four experimental timing conditions in three different experiments where they had to monitor only the letter pairs. Other differences between relevant and irrelevant sequences were manipulated through spatial formatting (Experiment 1) and presentation modality (Experiment 3,); Experiment 2 varied instructions. All experiments included a baseline and an experimental phase. In the baseline phase, viewers received both regularly timed (R-base) and irregularly timed (I-base) sequences of relevant items (R-base, I-base) (see Figure 1); the R-base sequences were isochronous whereas the I-base patterns were grouped. In the second phase, they received the rhythmically interleaved sequences. In this phase, baseline performance levels provide a gauge for assessing effects of interleaving irrelevant information on selective attending in the four experimental sequences. The R-base response times are baselines for Rr and Ri experimental combinations; I-base response times are baselines for Ir and Ii combinations. The aim was to assess the degree of interference (slowed responding) or facilitation (speeded responding) relative to baseline levels that arises from addition of irrelevant information to the relevant sequence.

Theoretical Hypotheses

Theoretically, the impact of timing on attentional control should be evident in its effects on performance, including patterns of interference and facilitation. Accordingly, we have framed questions about performance in terms of interference as well as facilitation; these take the form of three hypotheses about the control of attention by stimulus timing. A generic interference hypothesis functions as a null hypothesis with respect to rhythm and attention. It states that, regardless of timing, adding irrelevant information to the to-be-attended (relevant) sequence will uniformly degrade performance, slowing responses to targets relative to baseline levels (e.g., see Dowling,et.al. 1987; Ericksen & Ericksen, 1974; Eriksen & St. James, 1986; Eriksen & Yeh, 1985). However, our primary interest lies with two hypotheses about interference and facilitation that may result from rhythmic manipulations of experimental sequence structure.

Hypothesis 1: Temporal Compatibility.

In this view, timing manipulations provide foreground/background rhythms associated, respectively, with relevant and irrelevant strings. The simplest form of this hypothesis is consistent with the views of both Klapp et al. (1985) and Scerbo et al. (1987): When the foreground timing pattern provided by relevant stimuli (letter pairs) is equivalent (i.e., compatible with) to that of background stimuli (squares), then background timing will facilitate (speed) performance in identifying letter pairs. However, when background timing is not compatible (i.e., dissimilar) with foreground timing, interference will occur. Overall performance in compatible conditions (Rr, Ii) should be facilitated relative to that of temporally incompatible conditions (Ri, Ir).

An interesting version of this hypothesis posits a special role for isochrony. It implies that isochronous timing (R, r) is an especially potent determinant of attentional control. Thus, in the compatible isochronous timing condition, Rr, the most facilitation in performance should be observed. By contrast, in the incompatible, Ir, the least facilitation should occur because the regularity in background timing (isochrony) can draw attending away from relevant (but irregularly timed) items.

Hypothesis 2: Rhythmic Integration.

According to this hypothesis people view an sequence as a single integrated rhythmic pattern, not as two separate strings. The coherence of the prevailing rhythm determines the allocation of attention in real time.

Rhythmic coherence involves two relative time properties: *isochrony* and *invariant grouping.* Isochrony refers to a series of identical IOIs; grouping refers to sets of elements, usually segmented by invariant pauses, where a pause is an IOI greater than 1.5 times the average within-group IOI (Fraisse, 1964). Figure 2 illustrates both principles. First, isochrony is evident in varying degrees in all conditions, but it is most p interleaved pronounced in the fully isochronous sequence, Rr. It is also prominent in the Ii condition where recurrent isochronous groups appear. (The Ir pattern contains two different isochronous subsets). Second, invariant grouping by pauses yields unambiguous groups of elements in two of the four conditions: Ri and Ii. However, these two conditions differ with respect to isochrony:

Groups in the Ii condition are fully isochronous, meaning that the time of occurrence of the final group element is predictable. Groups in the Ri condition, by contrast, are not fully isochronous; the final group element occurs unexpectedly early, rendering this rhythm less coherent than the Ii rhythm. Overall then, the Ii pattern, which manifests both isochrony and grouping, is most rhythmically coherent and hence should produce most facilitation; arguably, Rr and Ri pattern are least coherent and should result in least facilitation in performance.

By this account, the rhythm of a temporal pattern contributes to real time stimulus control of attending (Large & Jones, *in press*). If this is correct, then it can be corroborated by examining the effects of rhythmic control on attentional performance at specific points (target sites) in certain rhythms. The two rhythms which unambiguously afford such examination are the two grouped patterns: Ii and Ri. Consider the Ii condition. If grouping-plus-isochrony affords stimulus- paced attending, then in Ii, the viewers should be able to anticipate 'when' a group will end. Consequently, they should respond more quickly to targets that happen to occur at this final position (target site #2 denoted by ** in Figure 2) than to targets at other positions (see Garner, 1974; Garner & Gottwald, 1967; 1968; Handel, 1989; Jones, 1974, 1987; Martin, 1972 for related discussions of rhythmic grouping and accents). By contrast, in the Ri condition, the final group element breaks rhythmic continuity by occurring 'too early.' In turn, this disruption of attentional pacing should capture attention and slow responding to the *next* target (i.e., at target site #1, denoted by * in Figure 2) relative to baseline. In short, this hypothesis links different aspects of rhythmic structure, respectively, to attentional pacing and temporal capture. It predicts that facilitation should be greatest at target site #2 in Ii and least at target site #1 in Ri.

Experiment 1

The primary variable of interest in this study was experimental timing: Rr, Ir, Ri, Ii. We aimed to determine whether temporal manipulations differentially affect attending to relevant items in experimental sequences, as discussed in the introduction. In addition, in Experiment 1 we varied spatial formatting in order to assess its general effects on interference (if present). Relevant elements were always presented centrally within the visual field either following regular (R) or irregular (I) timing with regard to their onsets in both baseline and experimental phases. However, in the experimental phase, the spatial placement of irrelevant elements differed depending on whether viewers were assigned to a Central or a Displaced irrelevant sequence condition as shown in Figure 3. In the Central condition both relevant and irrelevant elements occurred in the same, central, location within the visual field (Figure 3a); in the Displaced condition, all irrelevant items were successively displaced to different off-center spatial locations as they alternated in time with the centrally appearing relevant items. This is shown in the Figure 3b.

In each of the two spatial formatting conditions, viewers were asked to selectively attend to the letter pairs. For any given block of trials they were instructed to respond only to a subset of the letter pairs that were targets (physically Same or physically Different). Thus, viewers had to scrutinize each letter pair with respect to one of two target criteria and respond accordingly in real time to those meeting this criterion.

The temporal compatibility hypothesis and the rhythmic integration hypothesis imply that performance is influenced by temporal relations among items in relevant and irrelevant sequences. Alternatively, if an interference interpretation prevails, it is possible that spatial, not temporal, relationships will primarily determine performance. That is, if viewers respond to an integrated sequence, then perhaps this is simply because all elements (relevant and irrelevant) appear successively in the same (central) location. In this case, the spatial displacement of irrelevant information should render it easier to ignore this information as well as diminish any effects of its timing. All of this implies that viewers receiving the displaced irrelevant information should exhibit less interference (or facilitation) and perform uniformly better than those receiving this information centrally. In fact, if the displacement of irrelevant information is successful in inducing viewers to *entirely* ignore this information, then performance of viewers in the Displaced condition will match baseline levels.

Method

Participants.

Twenty-one participants with normal or corrected visual acuity were recruited from The Armstrong Laboratory's participant pool. Participants were local university students between ages 18 and 34 years. One participant's data was excluded from the data analysis for failure to meet the performance criterion regarding error rates of 10% or less. Participants were randomly assigned in equal numbers (n = 10) to each of the two spatial formatting conditions (Central, Displaced).

Apparatus.

Timing of stimuli was controlled by a PC (Gateway 2000 model 486) and stimuli were presented on a standard video monitor. Luminance values were recorded and calibrated by a Minolta Luminance Meter. Luminance values ranged from 44.7 ft.L. (square alone) to 5.85 ft.L. (letter pair alone). Background luminance was 5.2 ft.L. Screen background was a medium gray with black letters, and with black and light gray squares.

Stimuli and Conditions.

Stimulus items in relevant and irrelevant sequences differed categorically as shown in Figure 2. Relevant items consisted of letter pairs that were created from combinations of four upper case letters, A,B,C,E, and four lower case letters, a,b,c,e. Targets were defined as letter pairs that conformed to a predesignated response mode category of Same or Different with respect to a physical match. Targets (either same or different) occurred randomly throughout a given session such that within a succession of four relevant items (two cycles) either 0,1, 2 or 3 targets could occur by chance. In addition, sufficient numbers of different target and nontarget letter pairs occur in the relevant sequence to insure a high level of uncertainty with regard to its content at any point in a session. Irrelevant items always consisted of single squares; by definition, these were always nontargets. The duration of all stimulus items (letter-pairs, squares) was 400 ms.

Baseline.

In baseline conditions, only relevant stimulus items were presented in sequences based on two relevant items within a cycle time of 3,600ms. In the R-base condition, the regular timing of relevant items within each cycle was realized in a fixed IOI of 1,800 ms, i.e. an isochronous rhythm. In the I-base condition, the irregular timing of relevant information took the form of alternating IOIs of 1,300 ms and 2,300 ms within a cycle. This yields the same average IOI (rate) for R and I sequences, namely 1,800 ms. See Figure 1.

Experimental.

Four experimental timing conditions result from a factorial crossing of regular and irregular timing of relevant and irrelevant sequence, respectively. All four experimental conditions had the same 3,600 ms cycle time, but addition of two irrelevant elements per cycle to the relevant sequence increases the overall rate of these sequences (relative to baseline). In experimental sequences the average IOI for all four conditions was 900 ms. See Figure 2.

In combining irrelevant with relevant items, the former was always delayed such that it occurred midway within the first IOI of the relevant sequence (e.g., 900 and 650 ms delays for R and I timings respectively). This insured that relevant elements always began a trial block and alternated with irrelevant items. Addition of the irregular irrelevant items to the relevant sequences, yielding the Ri and Ii conditions, always resulted in distinctive pauses that created well defined groups in these two conditions. By contrast, the addition of regular irrelevant items, yielding the Ir and Rr, did not result in distinctive pauses and temporal groups. Consequently, it is only in the two conditions in which irregular irrelevant items were interleaved that temporally segregated groups and unique locations within groups arise.

Other combinations of relevant and irrelevant sequences patterns were generated as fillers. In these, the two sequences began simultaneously (letter pairs sometimes appeared inside co-occurring squares). Filler patterns were designed to insure uncertainty about the rhythmic sequence on any given block of trials. Taken together with the experimental patterns, viewers experienced a range of different arrangements of squares and letter pairs. For instance, unlike the experimental patterns, some filler patterns contained two successive appearances of stimulus items from one of the two categories, relevant and irrelevant (i.e., two squares or two letter pairs); this introduced greater uncertainty over the session regarding the strict alternation of relevant and irrelevant information. Responses to these patterns were recorded but not fully analyzed.

Procedure.

Participants were seated in a low luminance sound attenuated experimental booth 60cm in front of the CRT. Letter pairs and squares subtended visual angles of .57330 and 1.430. degrees, respectively. A response panel, mounted with two response buttons labeled "Same" (left button) and "Different" (right button), was in front of the S. Participants were instructed to respond to target letter pairs as quickly and accurately as possible; they pressed the appropriate button with the index finger of the preferred hand. In the experimental conditions, where irrelevant items also occurred, they were told to ignore these. Each presentation of a relevant item constituted a trial (i.e., two trials per cycle). Each participant received four practice trials on relevant items only (i.e. letter pairs).

In the baseline phase of the experiment, only relevant elements occurred. All participants received 8 randomized blocks of 64 letter pairs alone, 4 blocks each of regularly (R-base) and irregularly timed (I-base) letter pairs, respectively. Equal numbers of Same and Different letter pairs appeared in a random order within each block. Participants were required to make only one type of response (Same or Different) per block of trials and to withhold the alternative response.

In the experimental phase, viewers received 18 randomized blocks of 64 trials; 4 blocks corresponded to experimental patterns, 5 to filler patterns. Again each trial block contained equal numbers of Same and Different letter pairs, randomly ordered. On half of the blocks, targets corresponded to a correct Same response; for the remaining blocks, targets corresponded to a correct Different response. These blocks were randomized throughout the session. A five minute rest break separated the experimental phase from the baseline phase.

Design and Scoring.

Baseline.

The design for baseline conditions was a one way repeated measures design involving two levels of the timing variable (R-base, I-base). Preliminary analyses of temporal position in the I-base condition, which comprises IOIs of different lengths alternate, were also planned.

Experimental Conditions.

The overall design for experimental conditions was a 4x2x2 mixed factorial design. One within-subjects factor was timing: Rr, Ri, Ir, and Ii, the other was response mode (Same, Different). The single between-subjects factor was spatial formatting of irrelevant stream elements (Central, Displaced). Planned contrasts concerned baseline versus experimental performance and comparisons among the four different timing conditions.

Separate ANOVAs permitted evaluation of viewers' performance at different target sites in the two grouped patterns. This design was a 2 x 2 repeated measures with timing (Ii, Ri) and target site (#1, #2) as factors. (Target sites #1 and #2 are, respectively, denoted by * and ** in Figure 2).

Scoring .

Accuracy (percent error) and response time (RT) were evaluated in baseline and experimental phases. The baseline RT reflects performance in the two relevant baseline conditions. In experimental conditions, response times were evaluated using both median response times and a Derived Response Time, DRT, score. A DRT was determined for experimental conditions by subtracting a median baseline RT from a median experimental RT for each timing condition for each subject. The DRT score is more informative than the median RT because it has the potential to reflect facilitatory or interfering consequences of interleaving irrelevant items into the relevant (baseline) sequence. A negative DRT indicates performance that is faster than average baseline responding and thus suggests facilitation whereas a positive DRT reflects responding that is slower than baseline and hence interfering.

Calculation of the median baseline RT for computation of DRT scores requires explanation. Four different medians exist in the baseline phase: I-base timing involving 'same' targets; R-base timing involving ‘different’ targets; and two corresponding I-base medians. Ideally the appropriate correction RT in baseline to calculate a DRT score is the one which corresponds to the same relevant event in both the baseline and the given experimental condition. However, in the I-base condition, target letter pairs can occur in two different positions, associated with different IOIs (1,300 ms, 2,300 ms). If baseline response times to these target items *do not differ* reliably, then they can be averaged to arrive at a single median baseline RT. Otherwise, to calculate DRTs for the I experimental sequences, separate baseline RTs are used as correction RTs for Ii, and Ir experimental sequences. This cautionary analysis only makes sense for the irregular baseline performance.

Results and Discussion

Results are discussed in three sections: baseline, experimental conditions, and target location. In both the baseline and experimental conditions, error rates were less than 2%, hence primary dependent measures involve response time, both median RTs and median DRTs were based only on correct responses.

Baseline.

Overall, the mean of the median RT in baseline conditions was 420 ms. The analysis of target location applied to the irregularly timed baseline performance did not reveal a difference between the two temporal locations within the I-Base pattern where a target could occur; hence data were collapsed across these two positions. Baseline analyses also combined data from viewers who served in central and displaced experimental conditions because both groups received identical baseline conditions. The only significant influence in this phase of the experiment was that between performance on the regularly timed (R-base) and the irregularly timed (I-based) relevant stream, $F(1,18) = 10.44$, $p < .005$. Although cycle time of the stimulus patterns is identical for the R-base and I-base conditions, the I-Base timing produced longer median response times than R-Base (427 ms vs 413 ms). Overall performance is somewhat slower in irregularly than in regularly timed sequences suggesting that real time attending is influenced by rhythmical properties.

Table 1. Mean DRT scores as a function of timing conditions and spatial format in Experiment 1

DRTs (ms)			
Timing Condition	Central	Displaced	Means (ms)
Ii	-12	-19	-15.5
Ir	-11	0	-5.5
Ri	-3	+18	7.5
Rr	-2	-4	-3.0
Means (ms)	-7	-1.25	-4.125

Experimental Conditions:

Overall, mean of the median RT scores in this phase of the experiment was 416ms. The DRT scores for the four experimental timing conditions are presented in Table 1 as a function of spatial formatting. Spatial formatting did not have a significant effect on either DRTs or errors; consequently, both baseline and experimental data were collapsed over the spatial formatting variable for all analyses. The remaining analyses compare the four experimental conditions. Here only DRTs are considered; these are the most relevant indices of the facilitation or interference of performance; they are more precise than RTs in that each participant served as his/her own control (i.e., baseline performance).

Overall analyses.

Preliminary ANOVAs of the DRTs indicated that response mode (Same versus Different) had predictably significant effects with the "same" responses faster than "different" ones, F(1,18) = 8.10 MSe = 1,254, p< .01. The difference in timing as a function of response mode is expected; commonly, different responses are slower than same responses. However, response mode did not interact with other variables; we therefore present data averaged over it when discussing DRT outcomes of remaining variables.

Of most interest is the finding that experimental timing significantly affects performance, F(3, 54)=3.29, MSe = 1054, p<.03. As the data in Table 1 indicate, overall people showed greatest facilitation in the Ii and least in the Ri conditions. Three of the four conditions produced facilitation (relative to baseline responding), but only viewers in the Ii condition were significantly faster than their baseline response times, F(1,18) = 5.95, Mse=400, p<.02. Planned comparisons among the four timing combinations indicate that the Ii differs significantly from both Ri and Rr , F(1, 18)=11.35, MSe = 453, p<.003, and F(1,18)=4.73, MSe =324, p<.04, respectively.

Target Site Analysis.

Figure 4 presents mean DRT scores as a function of timing (Ii, Ri) and target site (site #1, site #2). It will be helpful to readers to refer to Figure 2 in this section. If relative timing of interleaved letter pairs and squares systematically affects moment-to-moment responding, then both timing and target site should reveal this. Specifically, the Ii should produce reliably more facilitation than Ri and, in general, responding should be faster (most facilitation) to targets occurring at target site #2 than to those occurring at target site #1 in both timing conditions. A 2 x 2 ANOVA indicated that generally Ii led to significantly more facilitation than did Ri, F(1,18) = 9.93, Mse = 2,081, p < .01. Although facilitation is evident at site #2 and interference at site #1, the target site variable only approached significance (p < .08). However, facilitation was marked at target site #2 (-21 ms) in the Ii rhythm where it differed significantly from baseline, (F(1,18) = 9.88, MSe = 438, p<.006. By contrast, interference at this site was slight in the Ri condition (+2 ms) and not significantly different from baseline. A planned contrast indicated that the Ri condition produced significantly less facilitation than the Ii condition at target site #2, F(1,18)= 16.43, MSe = 328, p<.0007. Viewers also showed facilitation at the first target site in the Ii (- 11 ms), while in Ri they showed interference (+11 ms). The DRT difference between Ii and Ri is significant at target site #1 as well, F(1,18)=5.46, MSe= 906, p<.03.

Taken together, these findings suggest that in slow visual serial presentations of interleaved sequences, the presence of irrelevant information does not routinely interfere with responding to targets. In fact, in many cases, irrelevant items actually appear to facilitate serial monitoring performance relative to baseline levels. An interference hypothesis predicts consistent and equivalent interference due to interleaved distractors in all four experimental timing conditions because all of these conditions had the same serial arrangement of relevant and irrelevant elements. Nevertheless, facilitation as well as interference is observed, depending upon timing manipulations. These findings are more in line with the two proposed timing hypotheses than with the interference explanation. However, one of the alternatives, the temporal compatibility hypothesis, also encounters problems. People showed most facilitation in one of the two compatible conditions (i.e., the Ii), but not in the other (i.e., Rr). One incompatible combination yielded poor performance as predicted (i.e., Ri), but the other incompatible combination, Ir, was actually second best.

The data are most consistent with the rhythmic integration hypothesis. This view correctly predicted the main effect of sequence timing where Ii produced most facilitation, overall. It also correctly predicted the finding of greatest facilitation at target site # 2, especially in the Ii condition. Interference was also predicted, primarily for the Ri condition and at target site #1. Although the latter pattern of outcomes was observed, the magnitude of interference in the Ri condition following a temporally disruptive element (target site #1) fell short of statistical significance.

Spatial formatting did not significantly influence performance. Others, using shorter and more rapid sequences, have also reported that spatial formatting manipulations involving visual target placements does not differentially affect performance (Ward et al., 1997). Here with longer and slower patterns, spatial differences involving targets and nontargets had nonsignificant effects as well. By some accounts such findings are surprising: If viewers spatially focus their attention strictly at the central location where relevant items appear, then spatially remote items should be generally less likely to cause interference (or facilitation), i.e., irrelevant items should be more readily ignored. But this did not happen. Instead, spatial displacement appeared to enhance rhythmic influences. In this respect, one outcome deserves comment. This involves the Ri experimental pattern; in the displaced condition, viewers responded 25 ms slower to target site #1 than they did to the baseline letter pairs; by contrast, no interference occurs with central formatting in the Ri condition. In fact, spatially displaced irrelevant items tended to generate greater levels of both interference and facilitation than observed in the central formatting condition. Although sometimes large, overall these differences are not statistically significant; nevertheless, they are important to note because they do not support the idea that rhythmic influences on performance diminish with spatial separation.

In summary, with attentional monitoring of slow visual sequences four conclusions emerge: 1. Contrary to an interference hypothesis, relative timing among relevant and irrelevant items differentially affects attentional monitoring, revealing facilitation as well as interference effects; 2. Temporal compatibility between relevant and irrelevant sequences is not sufficient to explain observed facilitation and interference effects; and 3. Viewers respond to a temporally integrated form of relevant and irrelevant sequences in which an emergent rhythm contributes to facilitation and interference effects observed at different temporal locations; 4. Spatial separation of relevant and irrelevant information, at least as manipulated here, does not significantly diminish facilitation and interference effects.

Experiment 2

One interpretation of the data from Experiment 1 is that an integrated time pattern of letters and squares guides attending, where guidance involves a pacing of attending by the pattern's rhythm. An alternative interpretation is that the speeded-classification instructions of Experiment 1 induce an attentional set in viewers to respond accurately and rapidly. In turn, this set changes the intrinsic nature of attending, biasing viewers to rely on immediately preceding and/or temporal aspects of the sequence and to engage in artifactual temporal anticipations. In other words, time constraints conveyed by instructions may force viewers to rely artifactually on sequence time structure to anticipate forthcoming elements. If the results of Experiment 1 are specific to attentional sets where viewers feel pressured to respond quickly, then removal of this pressure should eliminate differences due to experimental timing manipulations. Accordingly, in Experiment 2, we instructed viewers to respond accurately regardless of response time; as before we emphasized that they should try to ignore the irrelevant information.

To examine this we rely on central formatting of both relevant and irrelevant items to present visual sequences in Experiment 2. In Experiment 1, there was a suggestion that displaced irrelevant items might enhance rhythmic effects. In Experiment 2, where we use central formatting, any rhythmic effects that emerge should be strictly due to timing manipulations rather than speeded instructions and/or displaced irrelevant items.

Method

Participants.

Ten participants with normal or corrected vision were recruited from The Armstrong Laboratory's participant pool. None participated in the previous experiment.

Apparatus, Design, and Procedure.

Experiment 2 was identical to Experiment 1 with the following two exceptions: 1. Viewers received only centrally presented elements (relevant and irrelevant); and 2. Viewers were instructed that decision accuracy, not response speed, was most important.

Results and Discussion

As in the speeded classification tasks, error rates in both baseline and experimental conditions were low, less than 1%. Analyses on response times (DRTs) are discussed for correct responses in each of three sections as in Experiment 1.

Baseline.

In all respects, the pattern of baseline RTs for the variables of interest were similar to those reported for Experiment 1. Overall, the mean of the median RT for baseline responding was 444 ms, indicating generally slower responding than in the baseline phase of Experiment 1 (i.e., 444 ms vs 420 ms of Experiment 1). But in other respects, the data were similar. No significant difference obtained between response times at target sites (1,2) in the irregularly timed baseline condition, hence response times were averaged over sites 1 and 2 as before. Viewers also responded more quickly to regularly timed targets (R-base) than to irregular ones (I-base) (435 ms vs 453, respectively) $F(1,9) = 12.31$, $MSe = 246.33$, $p < .007$).

As in Experiment 1, stimulus isochrony in the baseline sequences influences attending. The most obvious difference between this experiment and Experiment 1 is that participants were noticeably slower. This indicates that they followed instructions. However, a separate ANOVA indicated that neither differences due to attentional set (Experiment 1 versus 2) nor any interactions of set with timing variables attained statistical significance in baseline performance.

Experimental Conditions - Overall analyses.

Although response mode was not significant, "same" responses were once again somewhat faster than "different" responses. Viewers responded overall more quickly in the experimental sequences than in the baseline conditions, with a grand mean RT of 416 ms.

Performance, indexed by DRT scores, did differ significantly as a function of timing manipulations in the experimental sequences, F(3, 27) = 7.78, MSe = 882, p<.007. Table 2 shows the DRTs for the four experimental conditions. Overall, all four conditions are faster than their respective baselines suggesting that viewers generally speeded up in the experimental conditions. Again, the Ii condition is the fastest with a mean DRT of -45 ms; the Ir condition is a close second place with a mean of -42 ms. Even the Ri condition shows a facilitation of -18 ms. The Rr condition produced least facilitation with mean DRT of -7 ms. Differences from baseline were significant only for the Ii and Ir conditions; F(1,9)=8.80, MSe = 1140, p<.02 and F(1,9) = 6.52, MSe = 1328, p<.03, respectively. Planned contrasts revealed that the Ii and Ir conditions both differed significantly from Rr as well as Ri, but they did not differ reliably from each other.

Table 2. Mean DRT scores as a function of timing condition in Experiment 2

Experiment 2	
Timing Condition	Mean DRTs (ms)
Ii	-45
Ir	-42
Ri	-18
Rr	-7

Experimental Conditions - Target Site analyses.

Figure 4 presents mean DRT scores as a function of timing condition (Ii, Ri) and target site (1,2). In a 2 x 2 ANOVA, the reliable difference between Ii and Ri is confirmed in this analysis, F(1, 9) = 24.99, Mse = 536, p < .001. Again viewers tended to respond faster to targets occurring at site # 2 than at site #1, but this difference was only marginally significant, F(1,9) =3.37, Mse = 1132, p<.09). No reliable interaction of target site with stimulus timing obtained.

Planned contrasts indicated that significant facilitation (relative to I- base levels) obtained at both target sites 1 and 2 for the Ii condition (- 37 ms, -51 ms, respectively, for these two sites) , (F(1,9)=5.39, MSe=1259, p<.04; and F(1,9)=9.55, Mse= 1363, p<.01). Although both target sites in the Ri condition also showed facilitation effects compared to R-base (-11ms, -24 ms), these effects were not significant. Contrasts between the Ii and Ri conditions at both target sites 1 and 2 were significant (F(1,9)=7.34 Mse=444, p<.02; F(1,9)=18.50, Mse=187, p<.002, for sites #1 and #2, respectively). Again, maximal facilitation occurred at the second target site in the Ii condition.

In sum, instructing viewers to concentrate on accuracy and not speed of responding does not alter the pattern of findings found in Experiment 1.

Experiment 3

Experiment 3 examines selective attending to the same visual items as in Experiments 1 and 2 but with interleaved tones as irrelevant elements instead of visual squares (see also Klapp et al., 1985). Timing relationships transcend both element content and modality. This modification permits us to determine whether or not timing relationships will continue to influence performance when the irrelevant information is presented in a different modality.

Two lines of thought lead to the prediction that the modality difference should distinguish performance in Experiment 3 from that in Experiments 1 and 2. Both perspectives imply better performance with the relevant sequence in Experiment 3 than previously observed. According to a physical distance view, enhanced selective attending will result from the increased physical difference between relevant and irrelevant items. In auditory perception, for example, large frequency differences between two interleaved tone sequences enable listeners to focus attending on one tone sequence and ignore the other (e.g., van Noorden, 1975). Presumably, modality differences should be more effective in this respect than the spatial displacements used in Experiment 1. The second view comes from multiple resource theory where task specific attentional resources are associated with visual and auditory modalities, respectively (Wickens, 1980; Wickens, Sandy & Vidulich, 1983). This implies that different attentional resources will be engaged by visual letter pairs and tones, respectively. In this case, people are not necessarily ignoring the tones; it is simply that any resources expended in listening to them will have no effect on performance with relevant items. Thus, both views suggest that people should more readily "tune in" to the relevant visual items in Experiment 3 than in Experiments 1 & 2; in the best case scenario, they should respond to relevant items much as they do in the baseline conditions. If so, then the only rhythmic effects to be observed would those associated with the relevant stream; as in baseline, target response speeds would order as: Rr = Ri > Ii = Ir (from slowest to fastest).

Method

Participants.

Ten participants with normal vision were recruited from The Armstrong Laboratory's participant pool. None participated in either Experiment 1 or 2.

Apparatus, Design, Procedure.

Experiment 3 was identical to Experiment 1 with the exception that tones replaced squares as irrelevant items. The tones were computer generated at 261 Hz (middle C) and presented through Realistic SA-10 Solid State Stereo Amplifiers to Realistic PRO-60 Headphones.

The other important change in this study was the inclusion of more baseline trials. As before, baseline trial blocks occurred at the beginning of the experimental session; but they were also placed in the middle and at the end of an experimental session in this experiment. This change permits us to address the possiblity that facilitation effects in experimental conditions that were observed in prior experiments result from changes in learning throughout a session.

Results and Discussion

As in the previous experiment, errors were few (less than 1%) and people responded reliably faster with same than different responses. The basic pattern of outcomes was the same as in earlier experiments.

Baseline.

We found no significant difference among the three baseline sessions, suggesting that learning effects are not involved; the three baseline scores were averaged. In many respects these data parallel those in Experiment 1, but the advantage of R-base over I-base in response speed was attenuated (424 versus 431 ms) and not statistically significant.

Table 3. Mean DRT scores as a function of timing condition in Experiment 3

Experiment 3	
Timing Condition	Mean DRTs (ms)
Ii	-14
Ir	-7
Ri	+8
Rr	+9

Experimental Conditions - Overall analyses.

Overall, the mean RT for experimental sequences was 426 ms. In general, the mean DRTs show the same pattern of outcomes as a function of experimental variables as in Experiments 1 & 2. The Ii condition produced greatest facilitation and Rr along with Ri the least, as shown in Table 3; the main effect of timing was significant, $F(3, 27) = 3.78$, $MSe = 665$, $p< .02$. Planned contrasts indicate that performance in the Ii condition differed significantly from that in both Ri and Rr ($F(1,9)=4.60$, $MSe=468$,

$p<.05$; $F(1,9)=12.44$, $p<.006$). In addition, Ii facilitation (- 14 ms) differed significantly from baseline levels (0 ms), $F(1,9) = 6.13$, $MSe = 158$, $p<.04$.

Target Site analyses.

In a 2 x 2 ANOVA, timing (Ii, Ri) and target site (1,2) were separately examined. No overall effect of timing emerged in this analysis, but again people showed more facilitation when a target appeared at the second rather than the first target site, $F(1,9)=5.99$, $Mse=1099$, $p<.04$. Figure 4 presents mean DRTs as a function of target site and timing condition. Facilitation was greater in the Ii than the Ri pattern at the target 2 site (-21 ms vs -3ms); at this target site, Ii produced facilitation that was significantly different from baseline, ($F(1,9)=5.74$, $Mse=372$, $p<.04$, but Ri did not. For the Ri pattern, although interference again was evident at target site 1 (+20 ms), it was not significantly different from zero.

Facilitation and interference effects at the two target sites are similar to those observed in earlier experiments, but here differences between the Ii and Ri did not attain statistical significance at either site. However, a Dunn comparison indicated that performance in the Ii timing condition at site #2 (-21ms) was significantly different than performance in the Ri condition at site 1 (+20 ms), $t_D(9) = 4.37$, $p<.01$ for $C = 7$. As indicated in Figure 4, interference was maximal at target site #1 in the Ri rhythm, and facilitation was maximal at target site # 2 in the Ii rhythm. It is this profile of interference and facilitation that is consistent with predictions of the rhythmic integration hypothesis.

In Experiment 3 subjects "saw" only the relevant stream of elements, much as they did in the baseline conditions. Nevertheless, when irrelevant tones are interleaved with visual letter pairs, the same general pattern of results emerges as in Experiments 1 and 2. The telltale profile of facilitation and interference points to over-riding effects of the integrated, cross-modal, time pattern on performance. That is, despite physical differences in presentation modality, relevant and irrelevant elements do not form separate streams; rather, the auditory and visual elements coalesce to form a single rhythmic pattern that appears to guide attention much as in strictly visual patterns. Furthermore, contrary to specific predictions from resource theory, these findings indicate that people are sensitive to integrated timing properties of mixed modality patterns (see Klapp et al., 1985). Using a different paradigm, others have also shown cross-modal attentional dependencies between stimuli presented visually and acoustically (Spence & Driver, 1996).

The findings of Experiment 3 also suggest that sensory masking is an unlikely explanation of the interference effects observed in Experiments 1 & 2. We have interpreted the interference effects in terms of temporal capture. More generally, some have dismissed attentional capture as an instance of forward masking (Gibson, 1996a,b). However, the present data do not support this interpretation. Here interference is most obvious in the Ri sequence at target site #1 where viewers were 41 ms slower than in the Ii sequence at target site #2. At target site #1 in the former condition, the target letter pair follows the occurrence of a temporally unexpected tone; the interference observed here suggests that the tone disrupts ongoing attending and captures it. Neither forward nor backward masking accounts for findings in the Ri condition for two reasons. First, at these slower rates, neither forward nor backward masking explanations apply (e.g., DiLollo, 1980). Second, masking explanations are not relevant to the present experiment in which tones are substituted for irrelevant visual items resulting in the same pattern of facilitation and interference as in Experiments 1 and 2.

A Combined Analysis: Experiments 1,2, & 3.

In order to confirm that the modality manipulation of Experiment 3 did not produce a different pattern of responding than observed in earlier studies, in this section, we consider the data from all three experiments. We performed ANOVAs on both DRTs and RT s which combined these data with experiment included as a factor. The outcomes for both dependent measures confirmed that the basic pattern of findings observed in each of the three experiments is essentially similar. No significant differences emerged for either the experiment factor or its interactions with other variables. The profile of facilitation and interference effects as a function of rhythm manipulations is consistent across the different experiments.

Because we have already discussed DRT scores, we now focus on overall RT scores. The means of median RT scores (in ms) for the four experimental timing conditions, averaged over the three experiments, were: Ii = 412, Ir = 420, Ri = 422, Rr = 421. Planned contrasts indicated that people were significantly faster in responding to targets in the Ii than to those in the Ri condition, F(1,36) = 7.05, Mse = 313, p < .01 and marginally faster in Ii than in Rr (p <.06).

This analysis also permits us to assess whether or not observed facilitation and interference effects in individual studies are due entirely to differences in baseline performance levels. In all three experiments viewers were faster in responding to R base than to I base sequences (although this difference falls short of significance in Experiment 3). This reinforces the idea that isochrony is an important influence on attending, but it may also contribute to the observation of greater facilitation effects in the Ii and Ir conditions than in other conditions. That is, viewers were generally faster in the R baseline than in the I-baseline; in experimental sequences, therefore, the DRT performance indicates that irrelevant information added to the former creates rhythms that slow responding whereas the same information added to the I base sequence speeds responding.

We also examine the overall RT performance of the two conditions in which unambiguous predictions about facilitation and interference are based on grouping properties of combined rhythms. Figure 5 presents means of median RT scores, averaged over the three experiments, for the conditions with clear rhythmic groups (Ii, Ri). In these, we examine target site effects much as we did with the DRT scores for target sites #1 and #2. A 2 x 2 ANOVA with timing and target site as factors, verified that the Ii conditions created reliably faster response times, overall, than the Ri condition, F(1,36) = 5.83, Mse = 1,524, p< .02. In addition, responding was significantly quicker at target site #2 than at target site #1, F(1,36) = 12.06, Mse = 1.065, p< .001. Viewers scored 406 ms, on average, in the Ii condition at target #2, the site predicted to be easiest to anticipate temporally, due to grouping and isochrony. By contrast they scored 429 ms in the Ri condition at target site #1, the site predicted to be most difficult due to disruptive timing. There was no significant interaction of timing with target site.

In sum, the pattern of findings involving overall response times conform to those found with the DRT analyses. The analyses of overall RT scores suggest that performance differences observed with DRT scores are not entirely due to baseline differences between R base and I base response levels. Both DRT and RT data suggest that people are systematically responding to rhythmic properties of integrated patterns.

General Discussion

We have shown that in a serial monitoring task where viewers attend to sequences of relevant items (baseline sequences) and to combinations of relevant and irrelevant items (experimental sequences), the temporal structure of sequences systematically influences performance. In baseline, where simple rhythms are involved, people respond more quickly to sequences that are isochronous than to ones that are not; in the more complex rhythms of the experimental sequences, people respond more quickly to sequences containing groups of isochronous items than to ones containing irregularly timed groups. In the latter, groups comprised both relevant and irrelevant items, suggesting that people respond to timing properties of integrated (relevant plus irrelevant) sequences. This was a general finding, consistent across all three experiments.

The finding that the timing of irrelevant plus relevant items in a sequence influences attentional performance is informative. To consider how it informs us, we return to three questions posed in the introduction. The first question relates to effects of introducing irrelevant items into a sequence of relevant items presented at relatively slow rates. In all three experiments we find that the presence of interleaved irrelevant information, whether visual or auditory, does not consistently interfere with attending to relevant visual items. Instead, interference effects, when evident, appear to arise from disruptive stimulus timing and not from the mere presence of an irrelevant item. Further, we note that in these contexts irrelevant items do not routinely cause interference; sometimes they actually facilitate performance! Consequently, in these settings it is misleading to uniformly refer to irrelevant items as "distractors", implying that they necessarily interfere with performance. Depending on the context, it seems that irrelevant items can also be "facilitators." All of this implies that it is not merely "what" is interleaved with relevant items but "when" it is interleaved that matters. We conclude that these data are not consistent with a simple interference hypothesis.

Two other explanations that, along with a simple interference hypothesis, do not engage rhythmical timing assumptions are also called into question by these data. One is a masking hypothesis; as we have seen, it is ruled out by the findings that irrelevant tones produce a similar facilitation/ interference profile as do irrelevant visual stimuli (Experiment 3 versus Experiments 1,2). A second hypothesis that has not been previously discussed involves encoding time. According to such a view, facilitation and interference depend on the amount of processing time allowed following a given target (i.e., target site). For instance, perhaps people are faster with the Ii sequence because the target at target site #2 is followed by a relatively long pause. This explanation is also an unlikely one because people responded to that target, on average, *before* the pause ensued (i.e. a mean RT of 406 ms to an item of 400 ms). More generally, an r^2 between the median RT to a target and the amount of time following it was .0516 across all patterns; the r value was not significant (i.e., r = .22, df = 41). Furthermore, the observed r was not negative as predicted by an encoding time hypothesis.

The role of relative time is the subject of a second question posed in the introduction. What, if any, are the effects of rhythmical combinations of relevant and irrelevant information on performance? The present studies indicate that we cannot draw conclusions about combinations of relevant and irrelevant sequences without considering their respective time structures. The data reveal unequivocally that it is the pattern of IOIs, and not the physical content of sequences that influences performance in this task. In all four timing conditions the alternating arrangement of relevant and irrelevant items is identical, yet some timing conditions produced, overall, faster responding than others. Because the four conditions differed *only* in relative timing properties, we focus on hypotheses that address timing. One is the temporal compatibility hypothesis. It correctly predicts that performance should be relatively good overall with the Ii (i.e. temporally compatible) combination and relatively poor with the Ri (i.e., incompatible) combination. However, it incorrectly predicts that best performance should occur with the Rr condition when, in fact, this condition tended to produce relative poor (slow) overall responding. Nor does this hypothesis provide a predicted profile of facilitation and interference at different target sites. Yet across the three experiments, the role of time in the combined sequences is evident in differential responding at certain target sites as a function of the rhythmic context.

In several respects the integrated rhythms hypothesis provides a better overall account of attentional monitoring than the temporal compatibility hypothesis. This hypothesis posits that integrated timing can facilitate performance when the emergent rhythm is coherent, in terms of isochrony and temporal groups, and that it can lead to interference when the rhythm itself is temporally disruptive. In particular, it correctly predicts that the Ii rhythm, a coherent one, should generate best performance, especially at target site #2. However, we also found that performance is very good in the Ir condition. Both the Ii and Ir condition possess isochrony, but in the Ii condition, a single isochronous group is distinguished by an invariant pause. In the Ir condition, on the other hand, two different isochronous groups appear; however, they are not segmented by a distinctive pause, suggesting that pause-based group segregation may not be the only basis of effective grouping. Nevertheless, it appears that both isochrony and some form of regular grouping are important because poor performance tends to be associated with a violation of one (or both) of these principles. Thus, this hypothesis also correctly predicts that performance should be worst in the Ri rhythm, especially at target site #1. This is because, in this rhythm the within group isochrony is violated by the sudden, unexpected, arrival of the final group element. In the Rr condition, the grouping principle is violated by unbroken isochrony and performance here is generally poor as well. By contrast, the conditions in which performance is relatively good (i.e., Ii and Ir) violate neither principle; regular breaks in isochrony help attentional tracking. The present experiments demonstrate that irrelevant information becomes rhythmically integrated with relevant information in this situation, and that performance depends on the coherence of the emergent rhythm.

The third question concerns the usefulness of concepts such as attentional pacing and temporal capture. Is this distinction helpful in explaining moment-to-moment monitoring? These two aspects of the stimulus control of real time attending remain to be fully evaluated. But the present data provide some clues to their nature especially in terms of different profiles of facilitation and interference across target sites in different conditions (e.g., Figure 4 shows the pattern of DRTs for target site by experimental condition across the three experiements). To explain these data, we find the distinction between stimulus-controlled attentional pacing and temporal capture fruitful. Clearly, they evoke related constructs of attentional guidance and capture commonly engaged to describe performance in spatial search tasks; consequently, it is reasonable to ask whether additional qualifications are necessary to understand temporal monitoring.

Attentional guidance in visual search refers to a top-down orientation of attention toward the future that is conferred both by task goals and expectancies as well as stimulus-related factors (Bacon & Egeth, 1977; Cave & Wolfe, 1990; Wolfe, 1994, 1996; Wolfe, Cave & Franzel, 1989). In the present task, viewers are guided by both task goals and stimulus related factors much as are viewers in a visual search paradigm, but the stimulus-related factors to which they respond involve the time properties of the sequences. In slow serial visual presentations, it is the rhythmic aspects of the serial presentation that guide attending. This does not appear to be true in spatial search where the rate of serial search is a dependent variable, i.e., it is free to vary. By contrast, in the present monitoring task, the serial pacing of elements constrains voluntary guidance of attending. People are forced to attend in a timely fashion to perform accurately; they must not only attend at the correct spatial location but also *at the correct time*. The robust and consistent effects of timing manipulations in our studies suggest that the rhythm paces attending in serial presentations in a way that is unlikely in spatial search tasks. Evidence for this claim comes from facilitation of performance at certain temporal locations in particular rhythm conditions. For instance, people's attention is paced very effectively by the Ii rhythm, such that they come to anticipate targets at certain points in time. In serial monitoring, these anticipations reflect low level expectancies that are driven by stimulus timing (e.g., isochrony, temporal grouping). In this case, the term expectancy does not imply a top-down construct associated with the content and properties of a goal item; rather it refers to future-oriented aspects of attentional pacing. Pacing represents a sustained exogenous control of attention. Time itself becomes the stimulus that provides this exogenous control. Finally, in spite of these differences, a parallel obtains between attentional guidance in visual search and serial monitoring tasks: it draws on the respective roles of space and time (e.g., Folk et al., 1992; Wolfe, 1994; 1996). In visual search, the relative spatial locations of irrelevant items can guide the allocation of attention to other spatial regions in an array; similarly, in serial monitoring, the relative temporal locations of irrelevant items can guide the allocation of attention to other (future) temporal regions in a sequence.

Our use of the term capture is qualified by the adjective *temporal* because it depends upon the temporal context when someone is engaged in moment-to-moment monitoring of the environment. It presumes that attentional guidance is paced by the stimulus timing, as described above. In our interpretation, temporal capture depends upon the prior existence of attentional pacing because it involves a disruption of it. This differs from the traditional interpretation of capture in which a short-term usurpation of attentional control by stimulus factors occurs which over-rides a long term, top-down, control of attention. Temporal capture refers to the impact of a temporally deviant element. Such an element usurps a prevailing rhythmic pace and overrides instructions to attend to relevant events; it is both attention-getting and surprising (cf., Gibson & Jiang, 1998). Basically, ill-timed elements derail stimulus-driven attending to bring about temporal capture. In this respect, we interpret the observed interference in the Ri condition as a consequence of temporal capture. Here, a violation of expectancy occurs when the established isochrony is broken by the abrupt, early, occurrence of an irrelevant item. In other words, "suddenness" is relative: it is *predicated* on a sense of "when" an element *should* appear.

In sum, in order to explain how people attend in real time to dynamically complex information, new interpretations of terms such as attentional guidance and capture are helpful. Constructs such as attentional pacing and temporal capture permit a justifiable emphasis on stimulus time properties of to-be-monitored sequences. As described, here attentional pacing and temporal capture are inter-dependent phenomena and both are exogenous attentional control factors. Together, they motivate an interpretation of attending to slow visual sequences as a dynamic activity that is driven, moment-to-moment, by the time structure of simple and complex events.

AUTHOR NOTE

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FIGURE CAPTIONS

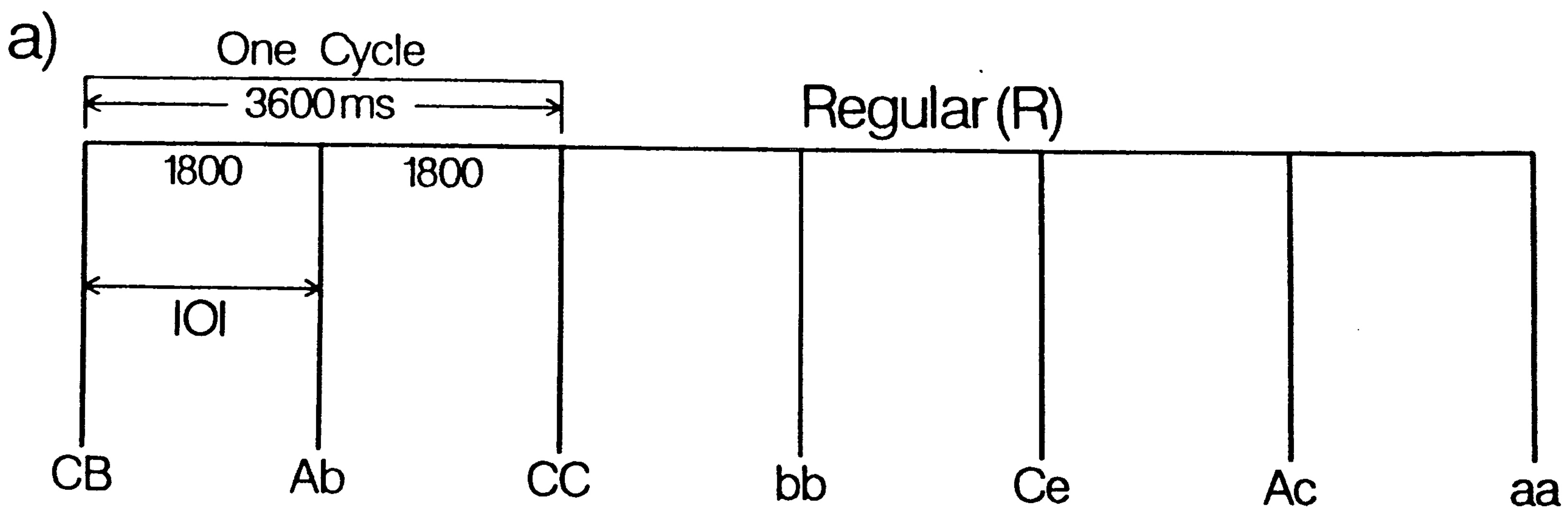
Figure 1. Two different time patterns used to successively present relevant letter pairs. a) Isochronous inter-onset-intervals (IOIs) yielding a regular (R) timing condition with IOIs of 1,800 ms; b) Alternating IOIs of 1,300 ms and 2,300 ms yielding an irregular (I) timing condition. Brackets define equivalent time cycles of 3,600 ms in R and I time patterns.

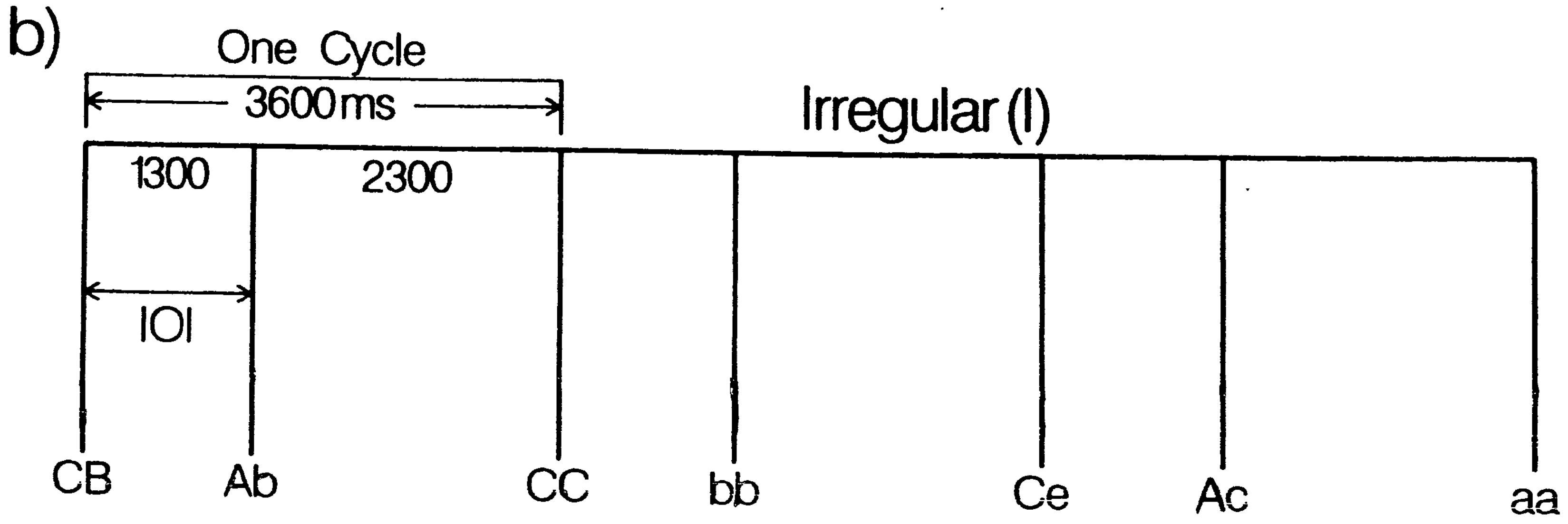
Figure 2. Four experimental rhythmic patterns used in Experiments 1,2, and 3; all are based on interleaved relevant and irrelevant events. Brackets identify grouping and astericks identify sites 1 (*) and 2 (**) of targets for rhythmically grouped experimental sequences, Ri and Ii.

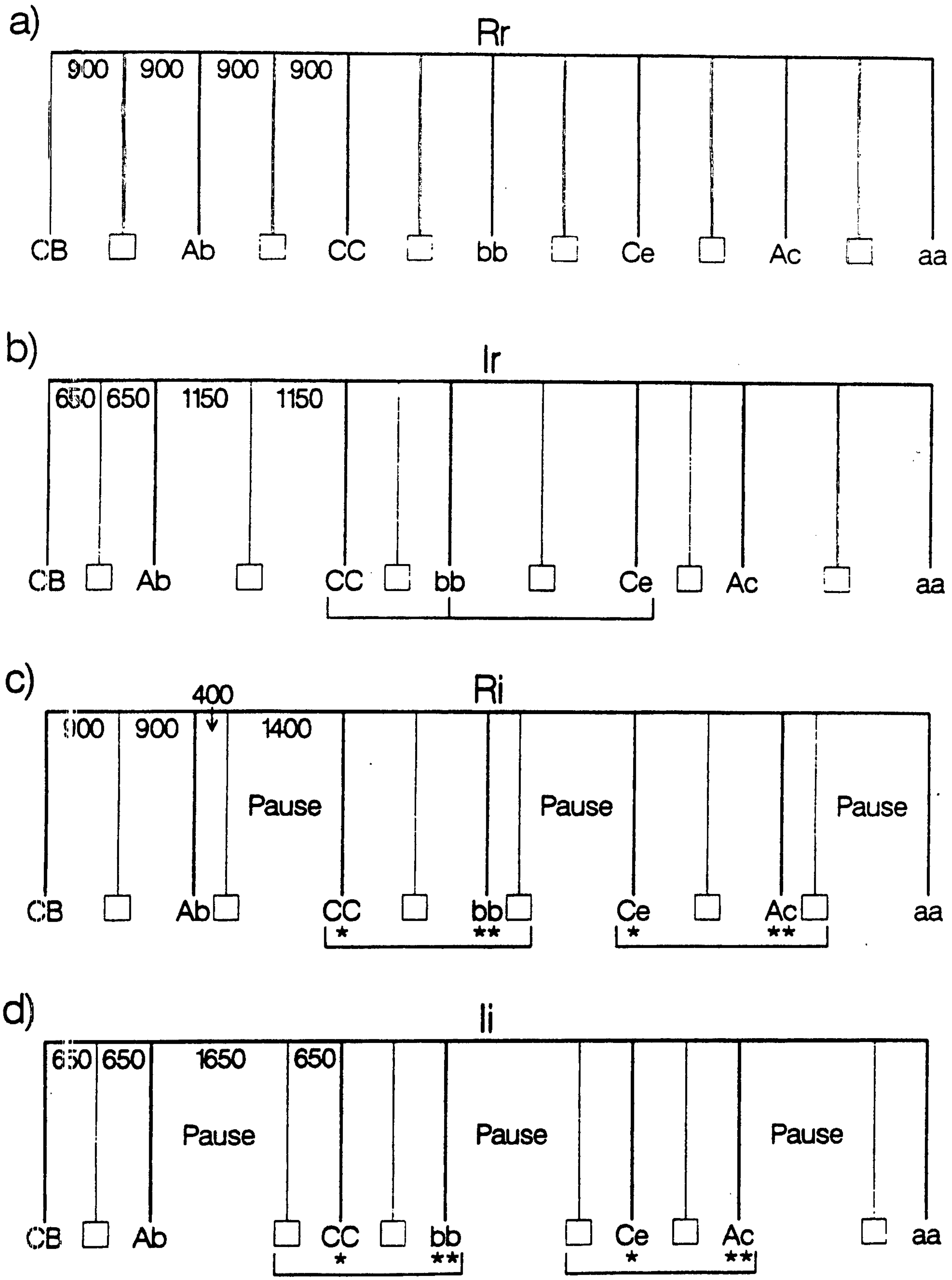
Figure 3. Spatial formats used in Experiment 1. a) Central formatting in which alternating letter pairs and irrelevant squares always appear centered on the CRT; b) Displaced formatting in which letter pairs appear centrally and the alternating irrelevant squares appear displaced in four excentric locations.

Figure 4. Means of median DRTs for target sites 1 and 2 for experimental conditions Ri and Ii for Experiments 1, 2, and 3, respectively.

Figure 5. Means of median response times for target sites 1 and 2 for experimental conditions Ri and Ii, collapsed across Experiments 1,2, and 3.


a)
One Cycle
3600ms
Regular (R)
1800
1800
IOI
CB
Ab
CC
bb
Ce
Ac
aa


b)
One Cycle
3600ms
Irregular (I)
1300
2300
IOI
CB
Ab
CC
bb
Ce
Ac
aa


a)
Rr
900
900
900
900
CB
Ab
CC
bb
Ce
Ac
aa
b)
Ir
650
650
1150
1150
CB
Ab
CC
bb
Ce
Ac
aa
c)
Ri
400
900
900
1400
Pause
Pause
Pause
CB
Ab
CC
bb
Ce
Ac
aa
*
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*
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d)
Ii
650
650
1650
650
Pause
Pause
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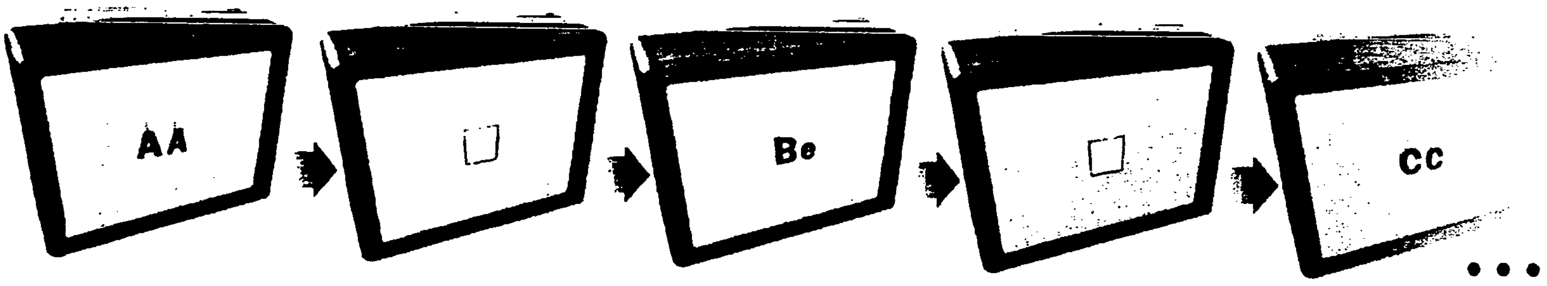
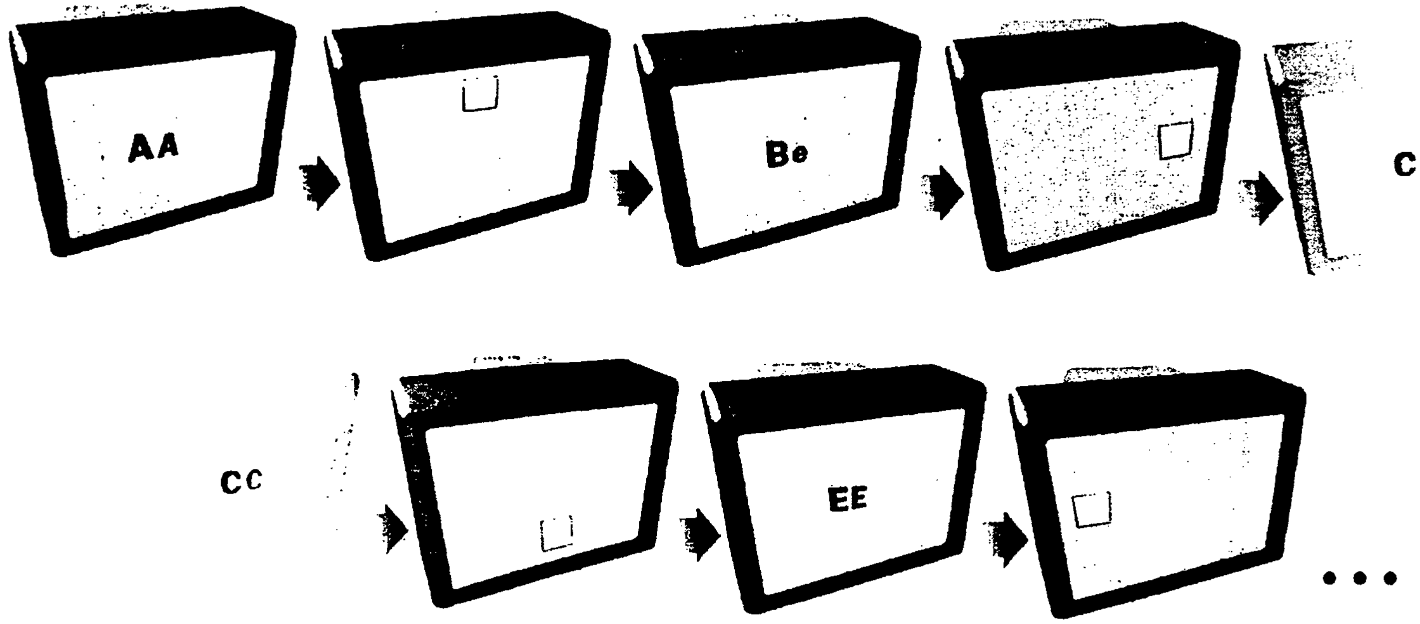
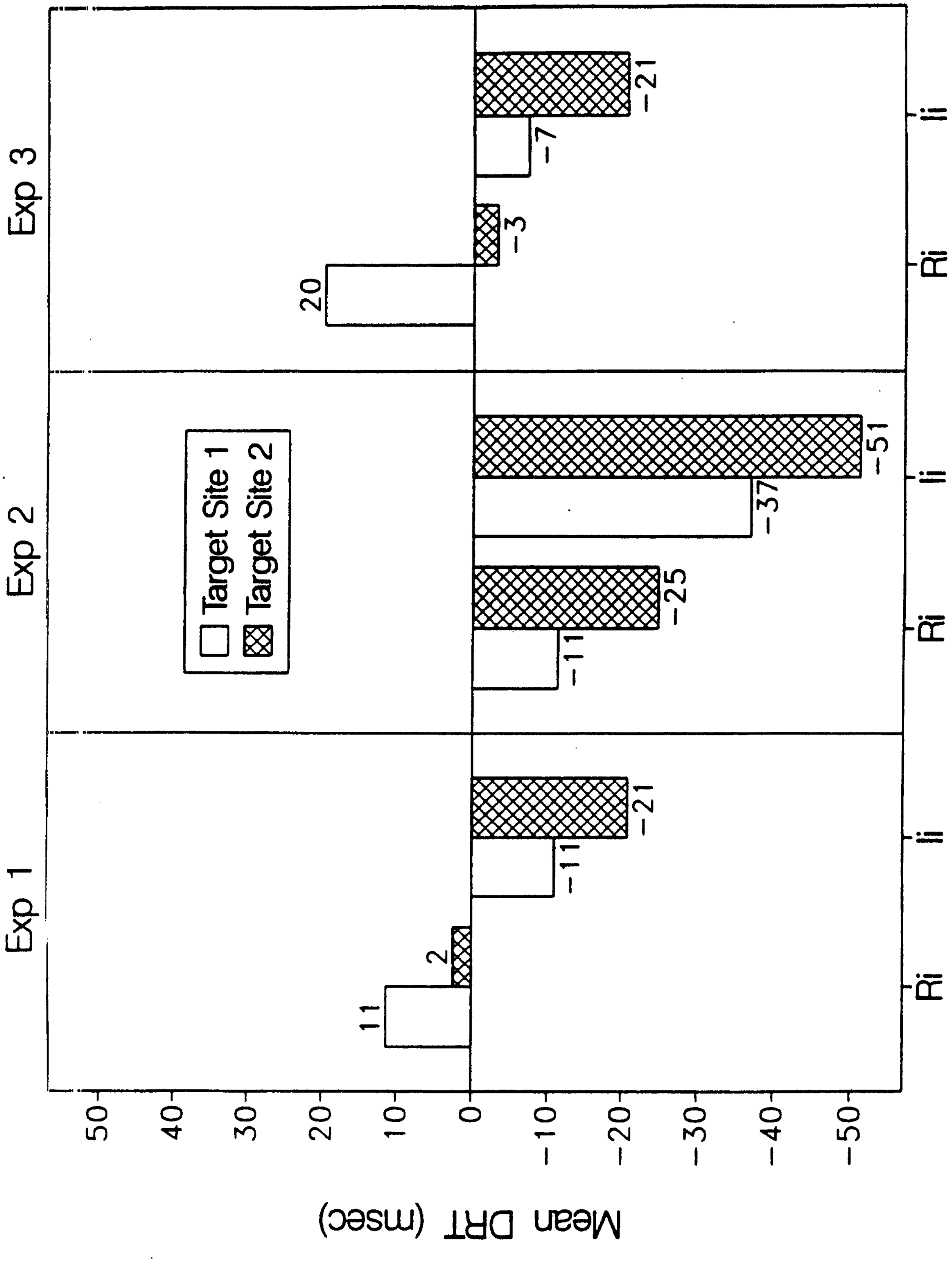
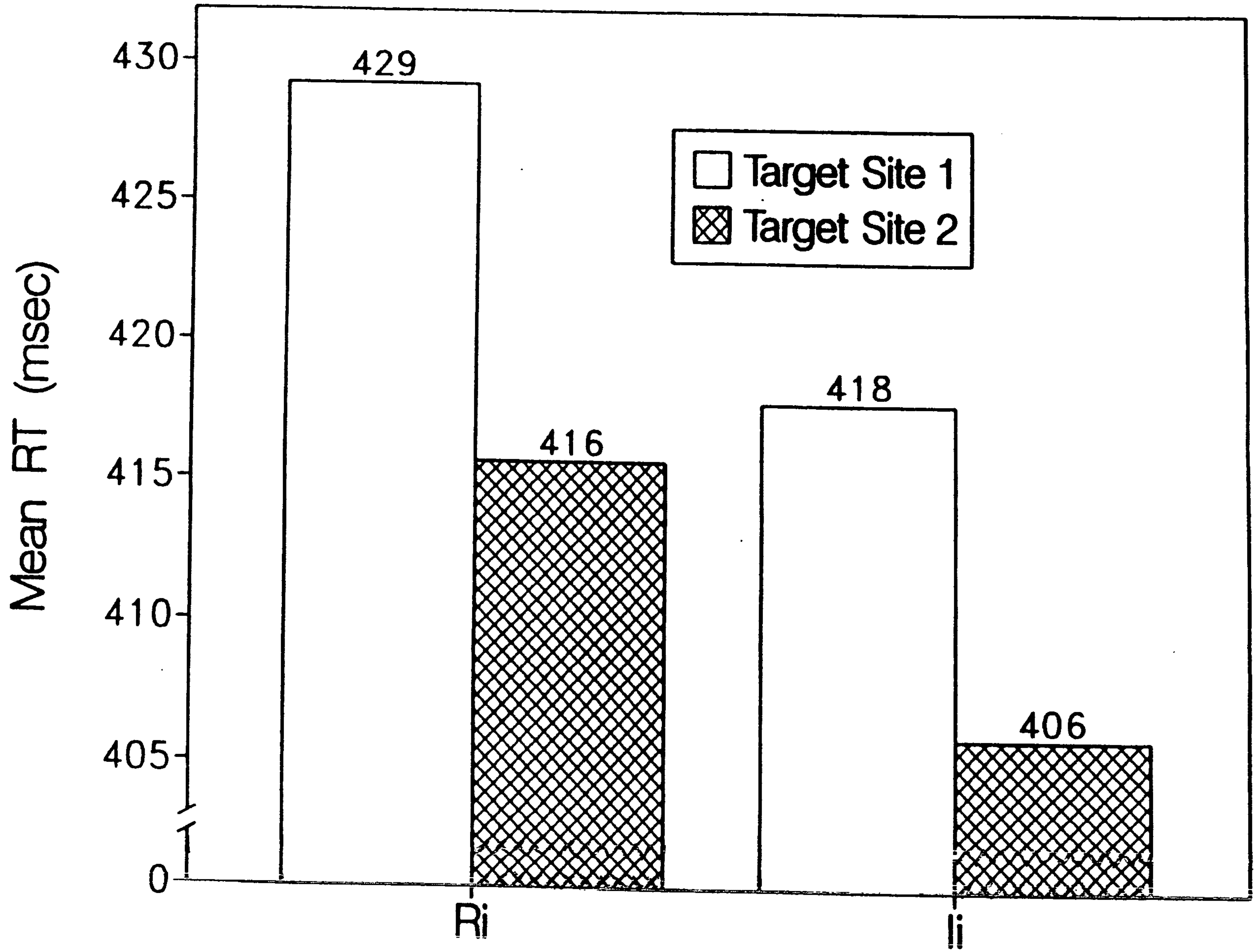
a) Centered Stimuli



b) Displaced Stimuli




Exp 1
Exp 2
Exp 3
Target Site 1
Target Site 2
Mean DRT (msec)
50
40
30
20
10
0
−10
−20
−30
−40
−50
11
2
−11
−21
−11
−25
−37
−51
20
−3
−7
−21
Ri
Ii
Ri
Ii
Ri
Ii


Mean RT (msec)
430
425
420
415
410
405
0
429
416
418
406
Ri
Ii
Target Site 1
Target Site 2