Research Article

TEMPORAL ASPECTS OF STIMULUS-DRIVEN ATTENDING IN DYNAMIC ARRAYS

Mari Riess Jones, Heather Moynihan, Noah MacKenzie, and Jennifer Puente

The Ohio State University

Abstract—*Auditory sequences of tones were used to examine a form of stimulus-driven attending that involves temporal expectancies and is influenced by stimulus rhythm. Three experiments examined the influence of sequence timing on comparative pitch judgments of two tones (standard, comparison) separated by interpolated pitches. In two of the experiments, interpolated tones were regularly timed, with onset times of comparison tones varied relative to this rhythm. Listeners were most accurate judging the pitch of rhythmically expected tones and least accurate with very unexpected ones. This effect persisted over time, but disappeared when the rhythm of interpolated tones was either missing or irregular.*

Recent theories of visual attention distinguish two types of attentional control: goal-directed and stimulus-driven (Egeth & Yantis, 1997). Goal-directed attention involves voluntarily guided expectancies based on cue validity and instructions (see, e.g., Barnes & Jones, 2000; Posner, 1980). Stimulus-driven attending involves fast, possibly involuntary, attention shifts to a unique element, such as a single exogenous cue or a distinctive stimulus. The present research suggests that this dichotomy becomes less clear-cut in the case of attending to dynamic arrays. Using auditory sequences, we examined a form of stimulus-driven attention that is based on possibly involuntarily timed shifts of attention caused by nonunique stimulus properties. On the basis of our results, we conclude that attending and temporal expectancies are influenced by stimulus rhythms.

At a fundamental level, the act of attending requires synchronization of some internal attending activity with an external event. Synchrony is less constraining in static visual arrays than in dynamic ones because elements endure over time, affording a flexibility in the timing of one's attentional focus to a location. However, in dynamic arrays, whether visual or auditory, elements appear and disappear over time, meaning that to ensure synchrony attending must coincide with elements as they happen (Jones, 1976; Large & Jones, 1999). Thus, with an auditory sequence, one's attention must be timed to occur prior to the cessation of a sounded element, either by rapid reactive attentional shifts that follow sounded onsets,[1] by more sustained attentional shifts that anticipate such onsets, or by a combination of these two kinds of shifts.

The first means of achieving synchrony involves *reactive attending*. This sort of stimulus-driven attending is similar to that found in designs in which a single distinctive (exogenous) sound cue precedes an auditory target (e.g., Spence & Driver, 1994, Experiment 1), except that instead of an automatic shift of attention to the spatial location of a sound this involves a reflexive attention shift toward the temporal locus of the sound following its abrupt occurrence. This shift we term *temporal capture* (Barnes & Jones, 2000); it refers to the potential of a single (i.e., unique) element onset to engage a purely reflexive, adaptive shift of attention in time. Reactive attending may also operate to facilitate attentional synchrony in sequences of sounds in which many onsets are (by some criteria) abrupt.

In auditory sequences, a second means of achieving attentional synchrony involves *anticipatory attending*. This entails a temporal shift of attention that anticipates the onset time of a sound. We propose that anticipatory attending also represents a form of stimulus-driven attention because it is influenced by stimulus time intervals. This claim features a new role for abrupt onsets in sequences in which they are no longer unique (by definition). In addition to their localized role in temporal capture, abrupt onsets can serve a second, more global function: In dynamic arrays, recurrent onsets of elements mark time spans, interonset intervals (IOIs), that outline rate and rhythm. Thus, when IOIs are regular within a tone sequence,[2] they afford attention shifts in advance of tone onsets, thereby promoting anticipatory attending (i.e., stimulus-based temporal expectancies; see Starr, Aguinaldo, Roe, & Michalewski, 1997, for possible neurophysiological correlates). With regular rhythms, such expectancies can affect performance; for instance, people are more accurate judging time intervals ending expectedly in time than judging those ending unexpectedly, given a regular rhythm (Barnes & Jones, 2000; Boltz, 1993; Jones, 1976; Jones & Boltz, 1989; Large & Jones, 1999).

Such findings support a recent model of dynamic attending that distinguishes reactive from anticipatory attending (Large, 1994; Large & Jones, 1999). Attending is assumed to be inherently oscillatory; anticipatory attending involves an engagement of internal oscillatory periods with time intervals (IOIs) of a sequence, whereas reactive attending involves phase alignments to tone onsets. Figure 1 shows an oscillator adjusting (i.e., entraining) to these aspects of a regular rhythm and targeting an attentional pulse to future onsets. The pulse constitutes an attentional focus in time, which varies in location and width as a function of temporal regularities; its location realizes an expectancy for a point in time, and its width realizes a concentration of attending energy around that point. This model implies that temporal expectancies can be stimulus-driven. Clearly, this position runs counter to the belief that expectancy is strictly a top-down, goal-directed process. Instead, this account of expectancy fits our definition of stimulus-driven attending in that the timed shifts of anticipatory attending are directly induced by stimulus IOIs.

Relevant research has relied mainly on tasks involving time judgments (e.g., Barnes & Jones, 2000; cf. Boltz, 1993). It is important to determine whether temporal expectancies induced by the time structure of sequences reflect a general attending activity or whether their

Address correspondence to Mari Riess Jones, Psychology Department, 224 Lazenby Hall, 1827 Neil Ave., Columbus, OH 43210; e-mail: jones.80@osu.edu.

1. Clearly, both element durations and memory traces, if any, may also affect performance.

2. Although in the experiments we report here we manipulated the regularity-irregularity of IOIs only within tone sequences, this claim extends to IOI consistency within a session as well (e.g., see Large & Jones, 1999).

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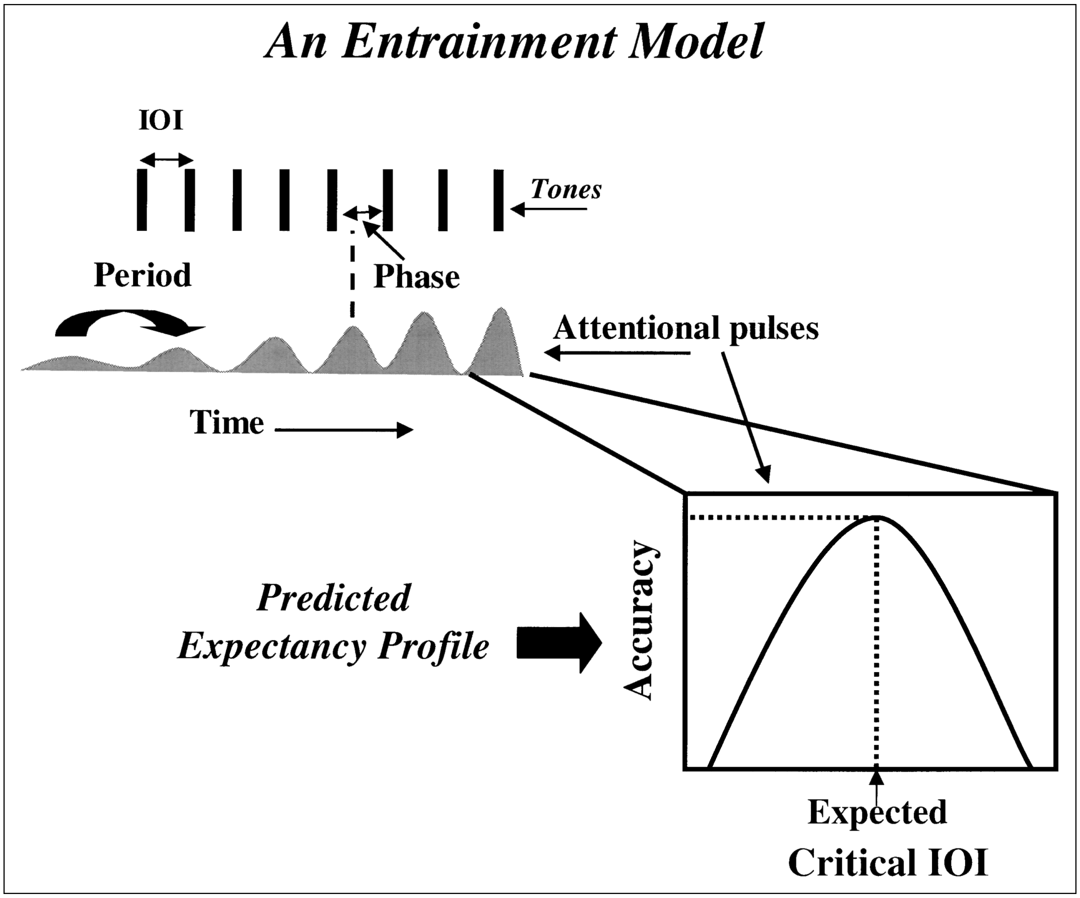

Fig. 1. Schematic illustration of an attending oscillator driven by a regular stimulus rhythm with fixed onset-to-onset time intervals between tones (i.e., fixed interonset intervals, or IOIs). Oscillator phase corresponds to the time difference between a pulse peak and a tone onset (dashed line). Oscillator period refers to the time interval between recurrent pulse peaks (arrow). The insert illustrates a predicted expectancy profile based on the shape of a single attentional pulse; accuracy (proportion correct) is shown to be greatest when the peak of an attentional pulse co-occurs with the onset of a comparison tone.

influence is specific to time-judgment tasks. If sequence timing can be shown to affect judgments of stimulus properties other than temporal ones, then this provides more convincing evidence for the idea that attending itself is a dynamic and temporally based activity. Accordingly, in the three experiments we report here, we used auditory sequences and a task that required people to judge pitch. Onset times of a to-be-judged comparison tone and the time structure of a context sequence were varied. To assess the influence of stimulus rhythm on listeners' attention, we rendered timing irrelevant to this task; following Yantis and Egeth (1999), we used pitch as both a defining and a reported dimension. Furthermore, listeners were explicitly told to ignore the potentially distracting context sequence, which carried the timing manipulations.

EXPERIMENT 1: EXPECTED AND UNEXPECTED TIMING

We adapted the *interpolated sequence task* to study effects of sequence timing on pitch judgments (see Deutsch, 1999, for a review). People judged the pitch of a comparison tone relative to an earlier standard that was separated from it by a series of interpolated (distractor) pitches (Deutsch, 1972; see Fig. 2). Our main modification of this task involved the relative timing of the comparison tone (see Method section). We hypothesized that to maximize performance, a listener must synchronize attention with the comparison tone. Furthermore, if interpolated distractors formed a regular (isochronous) time pattern, this would facilitate anticipatory attending and, hence, synchrony. Accordingly, we varied the IOI preceding the comparison tone, the *critical IOI*; equally often it assumed one of five values, with one designated as rhythmically expected. We predicted that listeners would perform best on sequences in which the critical IOI was expected, that is, in which it equaled the recurrent IOI of the distractor sequence.

Method

Subjects

Twenty-one individuals with normal hearing and fewer than 6 years of musical training participated in this experiment for credit in a psychology course at The Ohio State University.

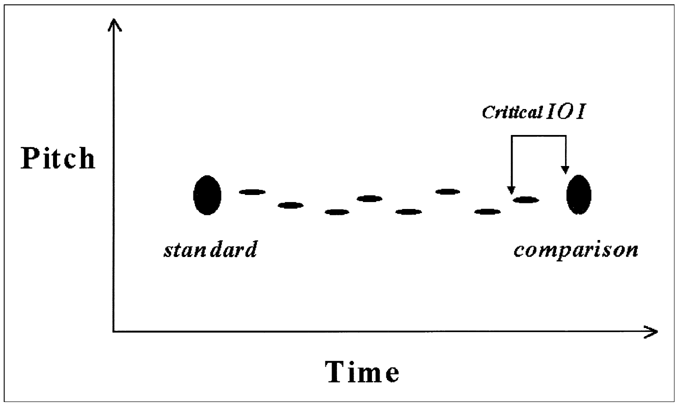

Fig. 2. Diagram of the pitch-judgment task used in Experiment 1. A listener judged the pitch of a comparison tone relative to a standard separated from it by interpolated (distractor) tones. In Experiment 1, the context rhythm of interpolated tones preserved a regular rhythm with invariant interonset intervals (IOIs) of 600 ms. Timing of the comparison varied with the value of the critical IOI.

Materials and conditions

Stimuli were generated with MIDILAB Version 6.0 software (Todd, Boltz, & Jones, 1989) interfacing with a Yamaha TG100 Tone Generator, and presented binaurally through Beyerdynamic DT 770 headphones at a comfortable listening level. Auditory sequences began with a standard 150-ms tone and ended with a comparison 150-ms tone; these two tones were distinguished from the eight interpolated tones (60 ms each) by duration and serial position. Stimulus IOIs were 600 ms except for the critical IOI, which preceded the comparison tone; equally often, the critical IOI was 524 ms (very early), 579 ms (early), 600 ms (expected), 621 ms (late), or 676 ms (very late).

Standard tones randomly assumed one of six frequencies (musical pitch values in parentheses): 415 Hz (A-flat$_4$), 440 Hz (A$_4$), 466 Hz (B-flat$_4$), 622 Hz (E-flat$_5$), 659 Hz (E$_5$), or 698 Hz (F$_5$). Equally often, a comparison was the same pitch as its standard or higher or lower by one semitone (the distance between two adjacent piano keys). Interpolated tones varied randomly within three semitones (544.4 to 789 Hz) centered on 659 Hz if the standard was 415 Hz, 440 Hz, or 466 Hz; and they varied within three semitones (370 Hz to 523.3 Hz) centered on 440 Hz if the standard was 622 Hz, 659 Hz, or 698 Hz.

Two additional modifications of the Deutsch (1972) task were made. First, given that repeating the standard pitch in an interpolated sequence boosts accuracy in this difficult task, we repeated the standard once as the final interpolated tone; pilot studies indicated that this also prevented spurious biasing from the pitch difference between the final interpolated tone and the comparison.[3] Second, participants were told to "ignore all intervening tones." If followed, this instruction should benefit performance and eliminate rhythmic effects.

Design and procedure

Six standard pitches were crossed with three comparison pitches (higher, same, or lower) for each of five critical IOIs (a repeated measures variable). This yielded 90 unique sequences.

Listeners were told to ignore distractor pitches and to judge comparison pitches as "higher," "same," or "lower" relative to presented standards. After 15 practice trials (with corrective feedback), they received 180 experimental trials (each sequence was repeated once), randomly arranged in four blocks (with no feedback). Within each block, sequences were presented randomly (the five critical IOIs occurred equally often). Finally, listeners responded to a brief questionnaire on their musical background, the task, and the strategies they used.

Results and Discussion

Figure 3 presents the mean proportion correct (PC) over the five levels of critical IOI (averaged over subjects and sequences in each condition).[4] Listeners were best in judging pitch when the critical IOI was expected (equaled 600 ms) and worst when the critical IOI was unexpected (very early and very late), $F(4, 80) = 3.79$, $MSE = 0.012$, $p = .007$. A post hoc comparison (Tukey HSD) confirmed significant differences between the very early and expected conditions ($p = .02$) and between the expected and very late conditions ($p = .03$). A significant quadratic trend over temporal expectancy levels verified the profile, $F(1, 20) = 9.27$, $MSE = 0.005$, $p = .006$. Hereafter, we refer to the outcome of this trend over time as an *expectancy profile*.

These results suggest that stimulus timing compels attention, inducing temporal expectancies about future onsets. Because performance was best when the critical IOI equaled the rhythmically expected one, we think that time intervals within the (irrelevant) interpolated sequence tacitly directed anticipatory attending.

Is it possible that Gestalt grouping by temporal proximity explains these data (Bregman, 1990)? A proximity rule predicts a monotonic PC function over critical IOIs where maximal and minimal temporal proximity obtain, respectively, for very early and very late critical IOIs. Because PC followed a quadratic function, temporal proximity does not explain these data.

EXPERIMENT 2: EXTRAPOLATED PERIODICITIES

One interpretation of the findings in Experiment 1 appeals to an internal periodic process that aligns with stimulus onsets and persists to promote anticipatory targeting of an attentional focus to an expected comparison time. Experiment 2 examined the persistence of a temporal expectancy by introducing lengthened critical IOIs; to accommodate these lengthened intervals, we also increased the very unexpected time changes. If an underlying periodicity is involved, then the expectancy profile should show higher accuracy for a lengthened critical IOI that is equal to twice the sequence IOI (i.e., the induced oscillator pe-

3. Over all three experiments reported here, we eliminated the data from 6 subjects whose questionnaire responses or high accuracy on the task indicated they realized that the standard was repeated. We also eliminated the data from 1 subject who performed below chance. Finally, to ensure no systematic biasing, we eliminated the data of any subject who generated a significantly disproportionate number of "same" responses overall (27 subjects of 122 total, including subjects in an experiment involving manipulation of instructions, mentioned in the discussion of Experiment 2).

4. We selected PC as the dependent variable for two reasons: First, because our main independent variable was time, we avoided a temporal dependent measure (response time). Second, PC tends to correlate with d' in related time-judgment tasks (Barnes & Jones, 2000).

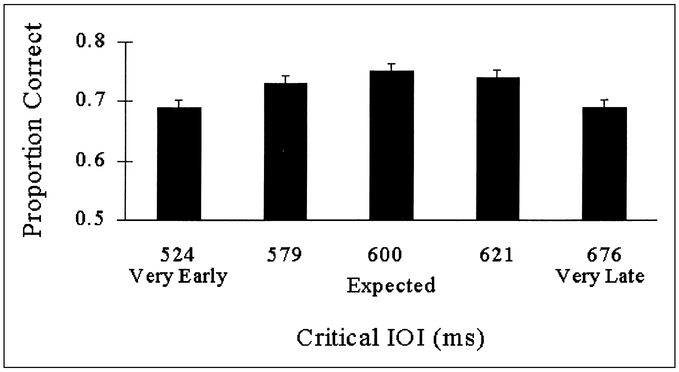

Fig. 3. Mean proportion correct in Experiment 1 as a function of the critical interonset interval (IOI).

riod) than for a lengthened critical IOI that is not a simple multiple of preceding IOIs.

With lengthened critical IOIs, listeners may respond only to the range and mean of these intervals in a session, not to sequence rhythm. If so, control listeners who receive trials lacking all but the final interpolated tone should show an expectancy profile identical to that of experimental listeners who receive the full interpolated sequences. Furthermore, for experimental listeners to perform equivalently to control listeners, they must succeed in complying with instructions to ignore the interpolated tones.

Method

Subjects

Twenty-nine subjects, recruited as in Experiment 1, were randomly assigned to the experimental (n = 13) and control (n =16) conditions.

Experimental condition

The method and stimuli in this condition were identical to those of Experiment 1, except that 600 ms was added to all critical IOIs. Equally often, sequences with five different critical IOIs occurred: 1,085 ms (very early), 1,185 ms (early), 1,200 ms (expected), 1,215 ms (late), and 1,315 ms (very late). The absolute time deviations for the two very unexpected conditions were larger than in Experiment 1 but yielded smaller Weber fractions for the expected critical IOI (i.e., .13 and .096 for Experiments 1 and 2, respectively; Allan, 1979; Grondin, 2001; Killeen & Weiss, 1987).

Control condition

Stimuli in the control condition lacked all interpolated tones except the final one, which subjects were told to ignore. The lengthened critical IOIs were thus equivalent to those of the experimental condition.

Results and Discussion

Control listeners performed well with all five critical IOIs, yielding an average PC of .95 and a flat expectancy profile. These data illustrate potential gains for listeners who succeed in "tuning out" irrelevant interpolated tones. They contrast dramatically with the data from experimental listeners, shown in Figure 4. Experimental listeners had an average PC of .69 and produced a significant quadratic expectancy profile, $F(1, 12) = 31.92$, $MSE = 0.004$, $p < .0001$. Postsession questionnaires confirmed that all the experimental subjects attempted to ignore the interpolated tones, reporting them as "annoying." Nevertheless, the timing of the to-be-ignored sequences, rather than the mean or the range of the critical IOIs, determined the expectancy profile.

If the experimental listeners had succeeded in ignoring the distractors, as instructed, they should have performed equivalently to the control listeners, but they did not. One interpretation of this finding is that an attentional activity is guided, perhaps tacitly, by the time structure of an interpolated sequence even when this stimulation is an unwanted influence that is detrimental. If this is the case, explicit instructions to attend or not to attend to the interpolated sequence should have little impact on the expectancy profile. Related experiments confirm that explicit instructions regarding attentional set exert little effect on performance. In an unpublished experiment using the stimulus sequences of Experiment 2, we explicitly instructed different groups of listeners to attend either to the pitch, to the timing, or to both the pitch and the timing of the distractor tones. Listeners in all three groups displayed expectancy profiles similar to those observed in Experiment 2 (i.e., no differences in quadratic trends were observed vis-à-vis the experimental listeners of Experiment 2). Although many of these listeners confessed to trying to "tune out" distractors despite attentional instructions to the contrary, their behavior indicated that they failed to do so; that is, their performance, like that of their experimental counterparts in Experiment 2, differed significantly from the performance of Experiment 2 control listeners who received no distractors. Thus, the findings of Experiment 2, taken together with related findings on instructional manipulations, suggest that attending is strongly influenced by the presence and time structure of interpolated pitches regardless of the nature of instructions.

The quadratic profile that emerged in Experiment 2 when experimental listeners attempted to ignore interpolated tones suggests that the rhythm established by distractors may implicitly induce a persisting internal periodicity. The extrapolation of this periodicity through a lengthened critical IOI accounts for anticipations of a temporally expected comparison. This profile also eliminates another Gestalt expla-

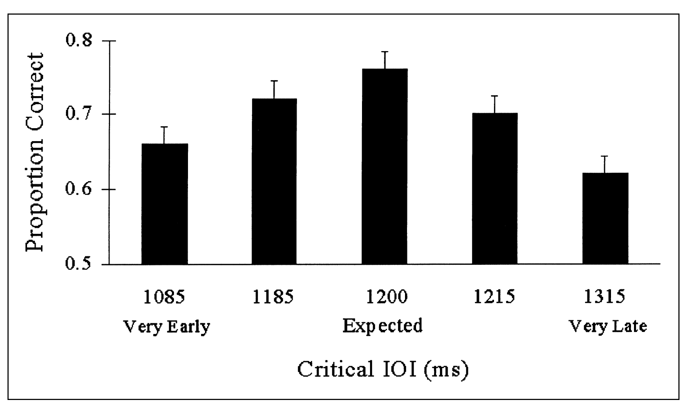

Fig. 4. Mean proportion correct in Experiment 2 as a function of the critical interonset interval (IOI), for experimental listeners told to ignore interpolated tones.

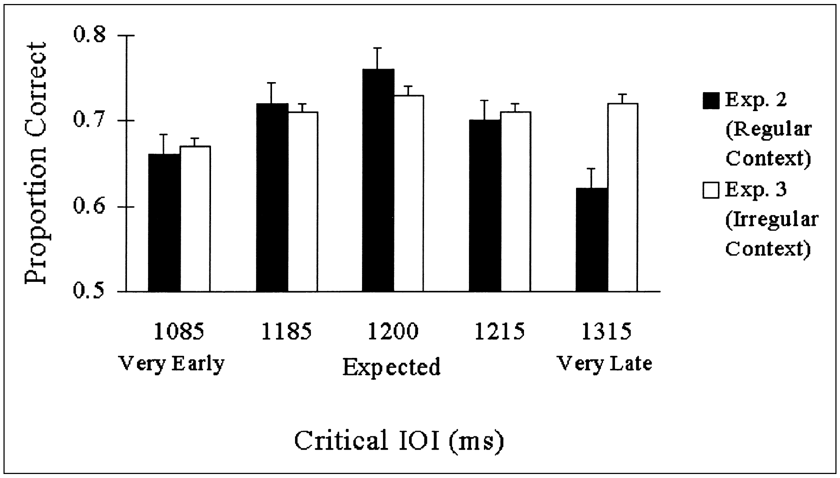

Fig. 5. Mean proportion correct in Experiment 3, with irregular timing of distractor tones, and in Experiment 2, with regular timing of distractor tones, as a function of the critical interonset interval (IOI).

nation, which appeals to grouping by similarity of absolute time intervals.[5] In Experiment 1, the expected critical IOI was most similar to interpolated IOIs (i.e., both were 600 ms); it is possible that the Experiment 1 data resulted from similarity matching. In Experiment 2, however, no such match obtained. Instead, similarity between expected and interpolated IOIs declined monotonically from very early to very late comparisons. The absence of a corresponding PC trend rules out this interpretation. It also casts doubt on a simple forgetting explanation. The absolute time interval between a standard and a comparison pitch is essentially a retention interval; thus, if forgetting is involved, either from decay (control subjects) or from decay plus interference (experimental subjects), then accuracy should decline over time. This did not happen in either condition. The data suggest that timing is relative to a given context rather than strictly absolute in its impact on performance.

In sum, Experiment 2 indicates that the timing of a distractor sequence induces a periodic expectancy that persists over time, even when listeners report attempting to ignore interpolated tones.

EXPERIMENT 3: IRREGULAR TEMPORAL CONTEXT

Prior experiments suggested that an isochronous series of tone onsets induces an underlying attentional periodicity that cyclically targets a focus of attention to expected temporal locations. If this account is correct, then reducing temporal regularity should remove the quadratic expectancy effect and yield a flat expectancy profile. Indeed, the dynamic attending model predicts that the narrow attentional focus that characterizes responses to regular rhythms (portrayed in Fig. 1) will widen if one is presented with irregular rhythms. Experiment 3 tested this hypothesis.

Method

Eleven individuals were recruited as before. The method and stimuli (including lengthened critical IOIs) were identical to those of Experiment 2 with two exceptions. First, no control condition was used. Second, sequence timing was altered to create two irregular rhythms (Set 1 and Set 2) with the following characteristics: (a) Mean IOI was 600 ms; (b) IOIs ranged from 200 to 850 ms; (c) two IOIs, one following the standard and the other preceding the last interpolated tone, were 600 ms; (d) standard deviations were 211 ms for Set 1 (IOIs were 600 ms, 627 ms, 793 ms, 430 ms, 267 ms, 692 ms, 791 ms, and 600 ms) and 249 ms for Set 2 (IOIs were 600 ms, 240 ms, 774 ms, 330 ms, 683 ms, 748 ms, 825 ms, and 600 ms). The two rhythm sets were crossed with 90 different distractor patterns, yielding a total of 180 unique sequences.

Results and Discussion

Figure 5 presents the data from Experiment 3 along with those from the (comparable) experimental condition of Experiment 2. Listeners exposed to irregular timing (Experiment 3) produced a flatter expectancy profile than those who experienced regular timing (Experiment 2). In fact, the quadratic expectancy profile disappeared in Experiment 3, $F(1, 10) = 3.45$, $MSE = 0.002$, n.s. Combining data across these two experiments revealed a significant interaction of context timing (regular vs. irregular) with comparison timing (five critical IOIs), $F(4, 88) = 4.9$, $MSE = 0.009$, $p = .001$, but no overall difference in accuracy, $F(1, 22) = 0.039$, $MSE = 0.58$, $p = .84$. Relative to listeners hearing regular rhythms, those who heard irregular rhythms were poorer with expected and better with unexpected comparisons; in fact, they were significantly better with very late comparisons ($p = .002$, Tukey HSD).

5. We thank Charles Spence for this similarity hypothesis. It implies that harmonic similarity obtains between interpolated IOIs (600 ms) and the critical IOI (1,200 ms), and this is partly our point. However, we suggest that this relationship influences expectancy, an anticipatory aspect of attending, and not grouping by similarity, which must occur after the fact. A grouping-by-harmonic-similarity interpretation is inconsistent with other evidence that indicates when tones are grouped, listeners' identification accuracy of individual tones within a group decreases rather than increases (e.g., Jones, Kidd, & Wetzel, 1981). Thus, a grouping hypothesis incorrectly predicts poorest accuracy for the critical IOI of 1,200 ms.

The flatter expectancy profile observed in Experiment 3 (vs. Experiment 2) indicates that sequence timing, rather than the mean and range of session IOIs, contributes to expectancy profiles. Experiments 2 and 3 were identical with respect to mean and range of critical IOIs, and differed only in sequence rhythm. It is unlikely that the differences due to sequence rhythm arose from differential "learning" of the rhythms in the two experiments because subjects had many opportunities to learn both regular and irregular rhythms during the course of a session. We think it is more likely that irregular timing complicated periodic attending, leading to a wider attentional focus and a flatter expectancy profile (Large & Jones, 1999). If temporal irregularities widen the temporal span of an attentional focus, then listeners should be more receptive to very unexpected tone onsets, as indicated by the results of Experiment 3. In some respects, these data resemble those showing that visual capture of attention by abrupt onsets is more likely in an unfocused than in a focused state (Remington, Johnston, & Yantis, 1992; Theeuwes, 1991; Yantis & Jonides, 1990). Thus, one interpretation of the data is that temporal capture by unexpected elements (e.g., a very late onset) was more likely in Experiment 3 than in Experiments 1 and 2 because of a wider attentional focus; the regular rhythm used in the previous experiments induced a narrow attentional focus. In other words, reactive attending to a singular abrupt onset is more likely following irregular rhythms than following regular rhythms.

GENERAL DISCUSSION

Generally, timing properties of auditory sequences influenced pitch judgments of average listeners (nonmusicians with an average of 1.47 years of musical training). Pitches of tones occurring at unexpected times, given regular sequence timing, were less accurately evaluated than pitches of tones occurring at expected times. Theoretically, this should not happen if people attend to pitch independently of time (see Krumhansl, 2000, for a review), group tones according to Gestalt rules of temporal proximity or similarity (Bregman, 1990), or successfully ignore stimulus timing (control listeners in Experiment 2). Nevertheless, the quadratic expectancy profiles for pitch judgments were most pronounced when a regularly timed stimulus sequence preceded the to-be-judged comparison tone. One interpretation of these findings appeals to the activity of a persisting and periodic process that synchronizes with an external event, an activity that tacitly continues despite listeners' attempts to ignore an interpolated rhythm. The specificity of this process with respect to sequence timing is confirmed by the presence of a sharper expectancy profile with regular rather than irregular or missing rhythms.

These results with pitch judgments extend earlier findings that revealed expectancy profiles in time judgments (Barnes & Jones, 2000; Large & Jones, 1999). Together, data from both time- and pitch-judgment tasks support the hypothesis that in dynamic arrays not all stimulus-driven attending is brief and transient. Despite listeners' reported intentions and despite the fact that it was detrimental to performance, people's attention was influenced by task-irrelevant timing properties (Yantis & Egeth, 1999). In arrays with regular timing, temporal aspects of stimulus-driven attending include a pacing of attention that leads to temporal extrapolations (i.e., temporal expectancies). This constitutes anticipatory attending, and it facilitates attentional synchrony. This type of stimulus-driven attending is based on recurrent IOIs created by regular repetitions of tone onsets; it is not to be confused with reactive attending, which is also stimulus-driven, but initiated by a single unexpected onset.

Other interpretations of expectancy rest heavily on cue validity or instructions (Kahneman & Tversky, 1982; cf. Barnes & Jones, 2000). Typically, a valid cue is used to determine slow voluntary expectancies that orient attention to regions of real and auditory space (Downing, 1988; Posner, 1980; Spence & Driver, 1994). The valid, or endogenous, cue is an arbitrary symbol whose meaning is acquired over a session from its likelihood of signaling a target. However, the expectancies we report differ; they are specifically timed anticipations that are sensitive to sequence structure. Their presence suggests a role for stimulus rhythm in establishing expectancies about when a target may occur. The possibility that different aspects of dynamic arrays may give rise to different kinds of expectancies is consistent with event-related potential (ERP) research. Reaction times (RTs) were found to reflect voluntary expectancies, whereas the P300 reflected largely automatic, but slow expectancies related to sequence structure (Matt, Leuthold, & Sommer, 1992). Although this research (see also Donchin & Coles, 1988; Large & Jones, 1999; Naatanen, 1990) does not specifically examine sequence time structure, it reinforces the hypothesis that there are several types of expectancy (e.g., Kahneman & Tversky, 1982).

Time structure may influence expectancies even in tasks that involve endogenous cues because targets generally follow these cues within a specified time region. Although the latter qualification is rarely acknowledged, the common finding that RTs decrease as this time region lengthens may reflect a temporal expectancy for the late target. Indeed, recent research reveals such expectancies. People responded more quickly to visual targets preceded by a valid symbolic (visual) cue for the specific time of a target's appearance than to targets preceded by invalid time cues, but this was true primarily for invalidly cued early targets (Coull, Frith, Buchel, & Nobre, 2000; Coull & Nobre, 1998; Kingstone, 1992; Miniussi, Wilding, Coull, & Nobre, 1999; Rothstein, 1973). Thus, RTs were faster for invalidly cued late targets than for invalidly cued early targets, suggesting that people reorient attention in anticipation of the late target. These RT data indicate that temporal expectancies can be controlled by discrete symbolic (i.e., endogenous) cues. They also suggest another explanation for the finding, reported in Experiment 3, that people were better in judging late comparison tones in the irregular rhythm than in the regular rhythmic context. It is possible that instead of widening the attentional focus, irregular timing encourages listeners to simply "wait" for late comparison tones.

Finally, the dichotomy between goal-directed expectancies and stimulus-driven capture turns out not to be so clear-cut when considering attending to dynamic auditory arrays. Typically, voluntary expectancies have been associated with endogenous cues and capture with exogenous cues. Although it appears that temporal expectancies can be manipulated by endogenous cues, the present research suggests they can also come under the control of stimulus time structure. This raises the question of where sequence rhythm fits into this dichotomy: Is it an endogenous or exogenous cue? The answer is not straightforward. In endogenous cuing designs, people are instructed to use a relevant symbolic cue to direct attention in some way. However, in our task, listeners are instructed to ignore task-irrelevant rhythmic information. Moreover, a stimulus rhythm is neither discrete nor symbolic in nature; indeed, it may not even be a "cue" in the traditional sense, because it is an extended time pattern. In other words, our paradigm differs from an endogenous cue-target design (as described) in which people come to associate different time intervals with discrete symbols, a process important to "telling time" by clocks. Yet our stimuli and task also do not conform neatly to classic exogenous cuing procedures, which involve uniquely distinctive items to which people automatically respond. Instead, we provided an extended rhythm in which the stimulus IOIs appeared to establish a direct connection with forthcoming critical IOIs. In short, sequence rhythm fits neatly into neither cue category. Nonetheless, we propose that stimulus timing has an immediate and primitive impact on attending and expectancies. When encountering a dynamic array bearing rhythmic information, people respond in the moment with expectancies that are driven, perhaps involuntarily, by the stimulus timing itself.

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