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LABORATORY NOTES

**Mari Riess Jones · Ralph Barnes · Riccardo Brunetti
Robert Ellis · Heather Johnston · Edward Large
Noah MacKenzie · Devin McAuley · Amandine Penel
Jennifer Puente**

News from the roar lab at the ohio state university

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Introduction

The ROAR Lab is concerned with research on attentional rhythmicity. It is part of the Psychology Department at The Ohio State University where this lab has been active for over 15 years. Ohio State University is one of the largest state funded universities in the US; it is located in Columbus, Ohio. The department of Psychology at Ohio State comprises about 50 faculty members; of these, eight are current members of the Cognitive Experimental Area. Mari Riess Jones is a Professor in cognitive experimental area of the Department of Psychology; she is also the head of the ROAR Lab. The Cognitive Experimental Area trains both undergraduate psychology majors, graduate students and postdoctoral fellows. Students and fellows at all these levels participate in the research of the ROAR Lab (http://www.psy.ohio-state.edu/roar/).

Over the last decade many different projects have consumed the interest of ROAR researchers. Much of this research is concerned with perception and attention of auditory events, namely music-like patterns; however, some researchers have explored timing effects in visual sequences as well. One line of research has examined the role of event timing on people's judgments of time intervals within isochronous and non-isochronous rhythms. This research is complemented by modeling efforts in which we have developed several versions of an entrainment model to address our findings. Our modeling efforts are based on the assumption that people track unfolding events such as speech and music in real time and that they use internal limit cycle oscillations to do this. This entails adaptive synchronizations, i.e., entrainments, in which both the period and the phase of attending oscillations change in response to event structure and thereby direct attending energy to the 'right' moments in time. Another line of research addresses whether or not rhythm can facilitate (or degrade) the accuracy of judging non-temporal aspects of a pattern, depending on the prevailing time structure. Closely related to these studies are the ones in which we investigate how the respective strengths of different kinds of accents within auditory events play off against one another to affect performance in pitch judgment tasks. Still other studies have examined how the dynamic structure of auditory patterns may stimulate attentional extrapolations in pitch space. Related work has examined the auditory kappa effect which concerns the perceptual inter-dependency of pitch space and relative time in simple auditory sequences. Finally, a large project funded by the International Foundation for Music Research (IFMR) entails a thorough lifespan examination of inherent preferences for certain periodicities (tempi) as indicated by their spontaneous tapping rates and their favorite judged tempi as well as their performance in synchronizing to events of different rates.

Judging time intervals within a rhythmic context

Large and Jones (1999) presented a new model of attentional entrainment which has paved the way for some of the recent research in the ROAR lab. The ideas associated with entrainment figure in earlier theories about the role of time in guiding attention (Jones 1976; Jones and Boltz 1989). Recently, entrainment theory has been advanced by specific models about how rhythmic contexts affect people's judgment of time intervals (and temporal acuity) that have been developed by Edward Large and Devin McAuley. The basic thrust of these models is that people need to be able to track the changing temporal structure of events momentarily as

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M. R. Jones (✉) · R. Barnes · R. Brunetti · R. Ellis
H. Johnston · E. Large · N. MacKenzie · D. McAuley
A. Penel · J. Puente
Department of Psychology, The Ohio State University,
Townshend Hall, Columbus, OH 43210, USA
E-mail: Jones.80@osu.edu

these occur. The mathematics of attentional synchrony and predictions about when attentional synchrony can be achieved have been outlined in several theoretical papers about event time, entrainment and time judgments (Large and Jones 1999; McAuley 1995; McAuley and Jones 2003). These theoretical formulations were accompanied by the development of a paradigm in which people judge the duration of a comparison time interval relative to a preceding standard interval, given a preceding rhythmic context. Although these models speak of both time judgment tasks and time discrimination tasks, much of the subsequent research has relied on time judgment tasks. In one such task, used by both McAuley and Kidd (1998) and Large and Jones (1999), a standard time interval follows a specific rhythmic context, i.e., a sequence of related time intervals. This standard is then followed by a comparison time interval and listeners must judge whether the latter is the *same*, *shorter* or *longer* than the standard. In the research reported by Large and Jones (1999), the duration of the standard varied relative to the intervals in the preceding context (although the comparison was always yoked to the standard). One aim was to test predictions of the entrainment model that imply best performance should occur for the standard that ends as expected, given the context. The outcome of this initial experiment was consistent with predictions of the entrainment approach, in that people indeed performed best with standards that were congruent with the preceding rhythm.

In a research project undertaken by Barnes and Jones (2000) this topic was more thoroughly examined. We considered various influences of contextual timing manipulations on prospective time judgments. Again people judged durations of standard versus comparison time intervals in the context of a preceding induction (context) sequence. In some experiments, the rate of the induction sequence was systematically manipulated relative to the range of to-be-judged standard time intervals; in others, the induction sequence was omitted. Time judgments were strongly influenced by the rate of an induction sequence with best performance occurring when the standard time interval ended as expected, given context rate. An expectancy profile, in the form of an inverted U, indicated that time estimation accuracy declined systematically as a standard interval differed from a context rate. A similar expectancy profile emerged when the context rate was based on a harmonic subdivision (2) of an expected standard interval. Results are discussed in terms of various stimulus-based models of prospective time judgments, including those which appeal to attentional periodicities and entrainment.

Following the Barnes and Jones paper, McAuley and Jones (2003) offered a series of studies designed to compare predictions of a simple entrainment model with those of other prominent models of psychological timing. In the latter category, several versions of the interval clock model figure importantly (Gibbon et al. 1984). In this research, the two kinds of approaches are related within a common theoretical framework that is based on a discrete formalization of an oscillator with linear phase and period correction. The experiments are all variations on the paradigm of Barnes and Jones, but their aim is to more precisely manipulate certain relative timing properties of standard versus comparison time intervals in order to compare and contrast predictions of different timing models. Four experiments evaluated this framework by manipulating the timing of stimulus onsets that delineate standard and comparison time intervals relative to a preceding to-be-ignored context sequence. Tone onsets marking the *beginning* and *ending* times of to-be-judged time intervals were on time, early and late, relative to a continuation of the implied rhythm of the context. In three experiments, relative judgments about the comparison duration showed two different accuracy profiles: (1) a quadratic ending profile indicating best performance when the standard ended at the expected point in time and worstwhen it was early or late, and (2) a flat beginning profile (Experiments 1–3) indicating no effects of variations in beginning times of a to-be-judged interval. Only in Experiment 4, where deviations from expected onset times were large, did significant effects of beginning times appear (in time discrimination thresholds, JNDs and points of subjective equality). In general, the data and model fits of these data were more in line with predictions of the entrainment model than with various (less parsimonious) explanations of interval timer models.

Currently in progress is dissertation research by Riccardo Brunetti, a visiting scholar in the ROAR lab from the University of Rome. His research requires that people make judgments about time intervals embedded within different kinds of rhythms (isochronous and non-isochronous) and in this research, different categories of metrical rhythms (derived from music theoretic concepts). This line of research aims to clarify the relationship between a rhythmical surface (the actual timing between consecutive events) and the possible underlying metrical frameworks it may evoke. The experimental studies collect behavioral measures regarding which kind of regularities are detected and retained by subjects exposed to different rhythmical patterns. Recently, several experiments examined how isochronous and non-isochronous meters can be induced by rhythmical surfaces of different complexities. While isochronous metrical frameworks are extracted quite clearly from the simplest surfaces and are superimposed on subsequent events, the fate of non-isochronous meters is less clear. Preliminary results show that they can be detected (namely, the repeating pattern of the event is clearly detected, along with the detection of a regularity), but this recognition is somehow limited to elements of the highest levels of the metrical hierarchies. Thus, when a non-isochronous meter is induced, Western listeners can only clearly detect the regularity *between* the repeating patterns, while performing less clearly with regularities *within* those same patterns (specifically, compared to performances with patterns inducing isochronous meters). The results of this line of research also show a strong dependence between the complexity of the rhythmical surface and the strength of the induced meter, clearly showing that the more complex the rhythmic pattern (according to complexity measures), the weaker the induced metrical framework will be. Moreover, the results with certain isochronous sequences appear consistent with some aspects of entrainment models.

Judging tones in a rhythmic context

In several different research projects, researchers in the ROAR lab examined the extent to which people's ability to judge properties of a non-temporal pattern element depended upon the rhythm provided by surrounding elements in an auditory pattern. Preceding work on this by Klein and Jones (1996) indicated that in a sustained attending task rhythmic context does appear to affect detection of timbre changes within auditory events.

More recently, Jones et al. (2002) adapted the design described above (i.e., that used to study time judgments by Barnes and Jones), along the lines of a task that Deutsch (1972) introduced. Originally, the Deustch task was used to study effects of interpolated pitches on people's pitch memory for a standard tone that preceded a sequence of interpolated pitches. Our aim was to examine how the rhythm of interpolated pitches might affect people's attention to the comparison tone. People had to judge the pitch of the comparison relative to that of the standard. Three experiments examined the influence of sequence timing (of interpolated pitches) on comparative pitch judgments of two tones (standard, comparison) that were separated by interpolated pitches. Of special interest was the rhythm of the pitch sequence; we hypothesized that when isochronous, it should instill a form of stimulus-driven attending (i.e., entrainment) that results in temporal expectancies about 'when' a comparison tone occurs. If so, then people should be better in judging the pitch of comparison tones that occur at rhythmically expected times than in judging the pitch of unexpected comparison tones. In some 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 unexpected ones. This effect persisted over time, but disappeared when the rhythm of interpolated tones was either missing or irregular. Following this research, we refined some entrainment constructs which suggest that listeners rely upon both an *anticipatory attending* (based upon an oscillator's period) activity to further temporal expectancies and a *reactive attending activity* (based upon an oscillator's phase) to cope with expectancy violations in time.

In the preceding research, the interpolated sequences that were used represented semi-random pitch arrangements that varied from trial to trial. A different series of experiments used systematically patterned pitch sequences interpolated between the standard and comparison tone. MacKenzie and Jones (submitted) undertook this project. In a series of five experiments, we varied (among other things) pitch accent structure and rhythm. In this context, we also found that listeners were better at judging rhythmically expected comparisons than rhythmically unexpected ones. However, in addition, this research revealed some effects of accent structure and we discovered a clearly asymmetrical expectancy profile. Although people tended to be best with rhythmically expected comparisons, they were also significantly better in judging the pitch of unexpectedly late comparison tones than with unexpectedly early ones. Specifically, in terms of accuracy profiles, we found both quadratic and linear trends over the time line of comparison tone (i.e., from very early to very late, given the rhythmic context). These profiles vanished only with variable rhythms, or when the timing of an embedded pitch accent varied. These findings can be interpreted in terms of a periodic pacing of anticipatory attending, linked to the quadratic trend, and asymmetries in coping with expectancy violations associated with reactive attending that are linked to the linear trend. Specifically, regular sequence rhythms afford attending at the "right" time (anticipatory attending), and hence lead to best performance in pitch judgments for rhythmically expected comparison tones, while the asymmetry in performance between early and late comparison tones (with performance on early worse than that for late) reflects the increasing difficulty involved in responding to more unexpected events (reactive attending).

In the work by MacKenzie and Jones, basic ideas about the nature of reactive attending versus anticipatory attending, inherent in the entrainment approach, were further developed. Reactive attending was associated with a phase shift of attending to unexpected elements, and this stimulus-triggered activity was contrasted with anticipatory attending, which was associated with a contextually driven periodicity that realizes temporal expectancies. Although these constructs derive from the original Large and Jones model, their constraints in the research of MacKenzie and Jones suggest certain modifications of this version of the oscillator model.

Other research by Penel and Jones (2005) indicates that people respond more quickly to pitch changes that terminate a sequence when these are accompanied by a large (versus a small) temporal expectancy violation that is related to the isochronous rhythm of the preceding sequence. This suggests that reactive attending contributes to reaction times and that it operates on temporal contrast (i.e., expected minus observed timing). In this regard, the reaction time data converges with time discrimination findings reported by Large and Jones (1999) where people are found to be more sensitive to larger violations from a temporal expected point in time than to smaller temporal expectancy violations.

Follow- up research in progress by Robert Ellis examines the respective roles of temporal and pitch accents on the development of expectancy profiles in these pitch judgment tasks. In addition, this research systematically manipulates the metrical structure of interpolated tone sequences using different kinds of accents (temporal, pitch) as markers, e.g., binary versus ternary metric frames. Previous research had suggested that durations of tones provide strong accentual information than their pitch values. In Ellis' research this issue is pursued by systematically varying the magnitudes of duration and pitch interval changes within simple auditory patterns. We compared listener's ratings of metric groups (two tones versus three tones) based on different degrees of pitch and time changes within each sequence. One aim was to evaluate listeners' development of (1) a sense of meter in tone sequences with both pitch and duration accents whose strengths were perceptually equivalent and (2) their concomitant temporal expectancies. Using a seven-point scale, listeners rated the sequences as to the metrical framework they heard. Accent type (pitch, duration) was always factorially crossed with accent strength (ranging from 2 to 5 values across experiments). A separate group of listeners marked the location of perceived accents in the tone sequences. Once the psychological strength of pitch and duration accents were equated, new melodies with both pitch and duration accents were created. One of three possible metrical frameworks (binary, ternary, neutral) was present in both the pitch accent pattern and the duration accent pattern (factorially crossed). Listeners again rated the metrical framework they heard. These data were then used to assess and explain the influence of meter on the development of temporal expectancies during a pitch judgment task.

Finally, other research by Jones et al. (2005) examines how well people can judge the pitch of tone embedded within patterns that differ in their rhythmic and pitch arrangements. In three experiments, participants listened for a targets pitch change embedded within recurrent nine-tone patterns where these patterns had largely isochronous rhythms. The patterns differed in pitch structure of initial (context) and final (target distance) pattern segments. Also varied were probe timing (Experiments 2, 3) and instructions about probe timing (Experiments 2, 3). In all the experiments, identification of a recurrent target was poorer in patterns with wider context pitch intervals (in semitones) than in others. Effects of probe timing also occurred, with better performance for temporally expected than unexpected probes. However, when listeners were explicitly told to ignore probe time variations (Experiment 3), the advantage for rhythmically expected probes was reduced in certain pitch patterns. Five theoretical approaches to the respective roles of pitch and/or time structure were assessed. Although no single approach accounted for all results, a modification of one theory (a Pitch/Time Entrainment model) provided a reasonable description of the findings.

Extrapolation of pitch pattern structure

One area of research investigated within the ROAR laboratory has been concerned with the role of auditory context on pitch perception. Various related lines of research (see above) within the ROAR lab have demonstrated that rhythmic context can affect the accuracy of judging the pitch of single tone. The line of research initiated and carried out by Heather Johnston considers whether and how pitch and intensity structure of sequence affects judgments about the pitch of a final tone. This issue is explored by studying in detail the documented phenomenon of *auditory representational momentum* (RM). Under the auditory RM paradigm, listeners hear a sequence of context tones that increase or decrease in pitch, followed by a target tone that is either the same pitch as the final context tone or higher or lower in pitch. Listeners are asked to judge whether the final context tone and the target tone are the same pitch or different. Typically, results indicate that listeners are biased towards responding 'same' when the pitch of the target tone is shifted in the direction consistent with continuation of the immediately preceding context sequence. Work by Johnston and Jones has extended the limited research on auditory RM in many ways. Johnston and Jones (2005) have found that this bias reflects a listener's continuation of the pitch structure with both linear (ascending or descending) and periodic pitch patterns (undulating up-then-down). They have also found that greater bias is obtained with faster rates and smaller pitch shifts between context tones, and not underlying pitch velocity. In addition, Johnston (2005) has recently demonstrated that intensity variations within the context sequence also influence pitch judgments. Specifically, when pitch and loudness linearly increase (or decrease) together the typical biases are obtained; however, when pitch and loudness change in different directions bias was greatly reduced. These results indicate that pitch perception is strongly influenced by the ways in which an auditory pattern context elicits attentional extrapolations in pitch space. The underlying mechanism has been interpreted as a dynamic attentional extrapolation of the pattern structure.

Auditory kappa

Noah MacKenzie has pursued issues relating to the psychological inter-dependence of pitch and time in his dissertation research. These studies have examined the *kappa effect*. The kappa effect refers to a phenomenon whereby spatial relationships among stimuli affect judgments of temporal relationships among those stimuli. Events widely separated in space will be perceived as being further apart in time than events spaced closer together. Though this has been primarily studied in vision, the effect is also present in the auditory domain, where space is now interpreted as pitch space. One explanation for the existence of the kappa effect appeals to the apparent motion-like properties of the stimuli. Three experiments on auditory kappa were conducted. In experiment 1, a listener judged whether the second tone in a sequence of three tones that ascended (or descended) in pitch (a *kappa cell*) was *closer in time* to the first or the third tone. A critical variable was the pitch of the middle (second) tone, which assumed different values. Listeners were most accurate in rendering temporal closeness judgments of the second tone, when the pitch of this tone was also close to either the first or third tone. Experiments 2 and 3 added serial context immediately preceding the kappa cell. It was found that a serial context preserving the motion-like properties of the kappa cell preserved the kappa effect, whereas a context that did not preserve these properties abolished it.

Changing tempi over the lifespan

The hypothesis that originally stimulated a line of research associated with tempo judgments over the lifespan dates back to 1976 (Jones 1976), where it was proposed that infants and young children are attentionally biased to rely on relatively fast rates (attentional oscillations) whereas with maturation the average period of oscillations that we tend to rely upon to guide attending lengthens. The basic idea is that one's preferred tempo slows with age and this means that the things we effectively 'tune into' change with age.

This hypothesis was originally examined in the research with Drake et al. (2000). We found that younger children spontaneously tapped faster than older children and, moreover, they preferred to synchronize taps to faster tempi levels within complex rhythms than did older children (and young adults). Over the last 5 years McAuley et al. (2005) have vigorously pursued this hypothesis using 305 participants ranging in age from 4 to 95 years. We continued to find that spontaneous motor tempi shift with age, such that people over 75 tapped over twice as slowly as those under 8 years. However, we also demonstrated that this was highly correlated with perceived tempo and that systematic differences emerged in synchronize and continue tapping, indicating differential responses to event rates as a function of age. In this research (which is still in progress) we develop several hypotheses about entrainment and age-related slowing.

Future directions

Future research will be both empirical and theoretical. Empirically, plans are under way to examine effects of rate on attentionals extrapolations of pattern structure; these studies extend work in progress by Johnston and Jones (described above). Other studies involve closer examination of the role of pattern context on people's ability to make fine time discriminations. Theoretically, ROAR lab participants are contributing to ongoing refinements of attentional entrainment models. Several possible models are under examination, some of which can be applied in interesting ways to synchronization tapping which changes as a function of age. This extends the theoretical work of McAuley and Jones on lifespan changes in entrainment (described above).

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