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David Sears
University of Arkansas, Fayetteville

PROCESSING SURPRISE TENSION IN TONAL MELODIES

By David Sears
Department of Music

Faculty Mentor: Elizabeth Margulis
Department of Music

Abstract

Expectation plays a vital role in understanding how we experience music. Processing music requires listeners to form expectations about upcoming events as they unfold. The formation and violation of these expectations has been empirically tested in harmonic priming paradigms, in harmonic priming during melodies, and in more general divided attention models. Recent research has also suggested that passive exposure to music leads to the development of implicit knowledge about musical expectations for untrained as well as trained listeners. Expectation has even been cited by the theorist Leonard Meyer as "the prime generator of musical affect" (qtd. in Margulis, 2005). Expectation therefore not only plays a role in how listeners process melodies, but might also provide evidence as to why musical events produce affective response in listeners. Unfortunately, much of the psychological research concerning expectation in music has appropriated a commonplace definition of the term "expectation," and in fact fails to address the difficulties in rendering the term more accessible to empirical scrutiny. Such a decision most likely reflects a lack of awareness of the dynamic nature of listener expectations. Is it possible to consider the subtle and more nuanced variations of expectation, such as events that invoke a sense of surprise, yearning, or foreboding?

The present inquiry considers the empirical study of surprise during the experience of music, an approach informed particularly by Elizabeth Margulis' model of melodic expectation. Margulis' model represents an ideal theory by which to predict and quantify moments of surprise as they are defined in the model, and the priming paradigm provides a method by which to empirically test the model's predictions. Until now, few studies outside of brain research have yet successfully produced a method to permit the study of musical events experienced in "real-time," and at a tempo adequately fast enough to represent real music. The primary goal of this study is to provide an empirical method to study just those sorts of violations of expectation—automatic, implicit expectations that build up in a musical piece at the local rather than global level. The results of this study have suggested that the psychological categories of melodic perception provided by the Margulis model—stability, proximity, and direction—may play an important role in determining how listeners process tonal melodies, as well as provide an explanation as to why certain moments elicit particular affective responses like surprise in listeners.

Introduction

Expectation plays a vital role in understanding how we experience music. Processing music requires listeners to form expectations about upcoming events as they unfold. The formation and violation of these expectations has been empirically tested in harmonic priming paradigms (Bharucha & Stoeckig, 1986; Krumhansl, 1990), in harmonic priming during melodies (Bigand & Madurell, 2005; Loui & Wessel, 2007; Margulis & Levine, 2006; Schmuckler, 1997), and in more general divided attention models (Berent & Perfetti, 1993; Bigand & McAdams, 2000). Recent research has also suggested that passive exposure to music leads to the development of implicit knowledge about musical expectations for untrained as well as trained listeners (Loui & Wessel, 2007; Margulis, 2006). Expectation has even been cited by the theorist Leonard Meyer as "the prime generator of musical affect" (qtd. in Margulis, 2005). Therefore, it not only plays a role in how listeners process melodies, but might also provide evidence as to which events produce affective response in listeners.

To study the psychological effect of expectations in music, researchers have primarily relied on the priming paradigm. The priming paradigm theorizes that the processing of incoming events is affected by the context in which they appear. Related events are primed, thus facilitating processing. The reaction time (RT) method provides a method by which to test these explanations. It is founded on the principle that, during the perception of highly unexpected events, listeners have to reevaluate and revise their mental representations of past events. This operation is assumed to demand more attentional resources than successfully embedding a highly expected event within the current representation. As a result, listeners are slower to react to competing secondary stimuli that occur simultaneously. Response time studies have repeatedly shown that participants are slower to respond to tonally unrelated chords and highly unexpected melodic events (Loui & Wessel, 2007; Schmuckler, 1997).

Early research employing the priming paradigm privileged harmony as the primary indicator of expectancy in music (Bharucha, 1986; Krumhansl, 1990). However, recent studies have begun to investigate other potential indicators of expectancy. A divided attention model permits theorists to conceive of music as an exercise in divided attention among several different musical attributes where harmony, melody, rhythm, and timbre are allocated cognitive resources in the formation of a unified musical percept (Loui & Wessel, 2007). Newer reaction time studies have therefore approached expectations from the standpoint of melody (Schmuckler, 1997), timbre (Margulis & Levine, 2006), and voice leading and polyphony (Bigand, 2000 & 2005).

Unfortunately, much of the psychological research concerning expectancy in music has appropriated a commonplace definition of the term "expectation," and in fact fails to address the difficulties in rendering the term more accessible to empirical scrutiny. Such a decision most likely reflects a lack of awareness of the dynamic nature of listener expectations. Is it possible to consider the subtle and more nuanced variations of expectation, such as events that invoke a sense of surprise, yearning, or foreboding?

In "Surprise and Listening Ahead: Analytic Engagements with Musical Tendencies," Elizabeth Margulis (2007) considers both musical analyses and empirical research in order to draw attention to the various uses of the term "expectation," as well as the dangers of being unaware of how analysts and psychologists might be appropriating (or misappropriating) the term in their own research. Margulis proposed a model of melodic expectation derived from Gestalt psychology and the work of music theorists Fred Lerdahl and Eugene Narmour. The Margulis model attempts to separate the experiences stemming from expectations into three types in order to "make a preliminary step toward a richer taxonomy of the multiple dimensions of musical experience" (2005, p. 697).

The present inquiry considers the empirical study of music from a more nuanced view of listener expectations, an approach informed particularly by music theory and analysis. However, an approach that grounds the psychology of expectation in the theoretical study of music is not entirely unique to the body of research concerned with expectation, as attempts have already been made in studies concerned with the perceptual principles governing voice leading (Huron, 2001; Poulin-Charronnat & Bigand, 2005) and consonance and dissonance (Bigand & McAdams, 2000; Loui & Wessel, 2007).

Until now, few studies outside of brain research have successfully produced a method to permit the study of musical events experienced in "real-time" and at a tempo adequately fast enough to represent real music. In 2007 psychologists Loui and Wessel tested listener expectations by having subjects respond with contour information about the melody at the note-to-note level (whether the note event was higher or lower than the event before it). However, at an interval of 1600 msec between note events, the tempo was far too slow to permit subjects to store more than a note or two of the melody in short term memory, nor did that tempo adequately represent "real" music.

The flaw in employing a contour task is that subjects simply cannot accurately respond to the contour of melodies at faster tempos, especially considering that note-to-note events within melodies primarily move by step, which makes a contour decision particularly difficult. In 1986 psychologists Bharucha and Stoeckig employed an intonation task to provide data about the expectedness of harmonic events; subjects had to detect whether the melodic event was in tune or out of tune. Though this task was generally much easier both for trained and untrained listeners, the study was concerned specifically with the relatedness of a prime harmonic event to a target harmonic event. Listeners therefore only heard two chords contiguously. Margulis' model of melodic expectation theorizes, however, that listener expectations build up over several melodic events at the local level, and that sudden violations of expectation produce a surprise response in listeners that is both automatic and largely unconscious. The primary goal of this study is to provide an empirical method to study just those sorts of violations of expectation—automatic, implicit expectations that build up in a musical piece at the local rather than global level. Secondly, this study will attempt to provide empirical support for the Margulis model of melodic expectation.

A RT method employing an intonation task should provide access to the symptoms that characterize surprise in tonal melodies as well as empirical evidence supporting predictions about violations of expectation. Margulis' model of melodic expectation will then offer access to the potential cause of those symptoms, as it represents an ideal theory by which to predict and quantify moments of surprise in tonal music. Her model provides quantifiable predictions about the note-to-note expectancies of tonal melodies. It weighs expectancies for surprise tension through a series of musical characteristics derived from Gestalt perceptual psychology. The model presents three factors as the primary determinants of the expectancy of a melodic event: stability, proximity and direction.

It has been theorized that listeners expect relatively more stable pitches than less stable pitches (Margulis, 2006). The model further theorizes that four categories of stability exist within a key. From maximally stable to minimally stable they are: the tonic; the third and fifth; other diatonic pitches; the remaining chromatic notes (which are deemed to be maximally unstable). Stability ratings can also change according to the tonal context of the events. For example, before a melody modulates from C to G, a G will receive a rating of 5 as the fifth of the tonic chord, while after the modulation, a G will receive a rating of 6 as the root of the new tonic chord. Proximity indicates that listeners should expect pitches that are closer more than pitches that are farther away. Finally, direction indicates that listeners should expect that melodies will reverse direction after large intervals, while melodies will continue in the same direction if the intervals between each note are smaller. These three factors make up the basis by which the model determines note-to-note expectancies for melodies (Margulis, 2006).

This study specifically considers the notion of surprise in music. It is predicted that during periods of surprise in the chorale melodies, as indicated by the Margulis model of melodic expectation, subjects will be slower to react to a competing secondary stimulus that occurs simultaneously.

Method

Subjects

Twenty students from the University of Arkansas at Fayetteville participated in the study. All of the subjects volunteered in return for credit in undergraduate psychology courses. The mean age of the subjects was 20.4 years. The subjects averaged 2.6 years of musical training, and they also reported listening to an average of 16.8 hours of music per week.

Apparatus and Test Stimuli

The chorales and melodies were recorded by the researcher with an M-Audio Keystation keyboard that used a recorded Grand Piano sample from Propellorhead Reason software. Subjects heard the recordings on stereophonic headphones at a computer terminal. DirectRT software (Jarvis, 2002) was used to record subject responses.

Each of the 64 melodies was composed in a random key (32 in major, 32 in minor), and a piano noise track was inserted between each melody to clear the subjects' minds of the tonality of the previous melody. There were five noise tracks, each consisting of 5 seconds of random piano notes played within a 3 octave range of C2 to C5. They were chosen at random. Each melody consisted of a 16 to 20 note chorale presented in 2:1 melodic events to harmonic events, at a rate of 800 ms per note. The length of the interonset interval (IOI) was chosen so as to provide evidence of real-time expectations at a tempo adequately fast enough to represent real music. During the test melodies, the computer monitor flashed green with the word "respond" at the onset of the target event, and subjects had 1600 ms to respond. Out of tune events were pitched a ¼ tone higher than the target note.

The attack velocity of the melodies at the note-to-note level was adjusted so as to mimic human performance. However, note velocities were kept within a range of 64 and 88 on a scale of 1 to 127 in standard MIDI, and expressivity due to note velocities and rhythmic duration was carefully controlled during the "surprise" events of the melody so as to prevent it from affecting response times. The melody was also presented at a 40% louder volume than the remaining three-voice accompaniment in order to promote listener attention to the melody.

For each of the eight test groups, a visual cue was inserted after the onset of variously expected melodic events as they are indicated by the Margulis model. Each melody group was composed so as to create an A melody consisting of highly expected events that were in tune, and a B melody consisting of highly unexpected events that were in tune. The cued events in the C and D melodies were analogous to the first two melodies, but they were out of tune. The harmonic events of every version of each group were identical until the onset of the cued event. The melodic events in the first bar of all four permutations of each chorale group were adjusted so as to prevent the subject from becoming too acquainted with any one melody. However, the melodic events leading up to the target event were preserved so as to also preserve the expectations theorized by the Margulis model.

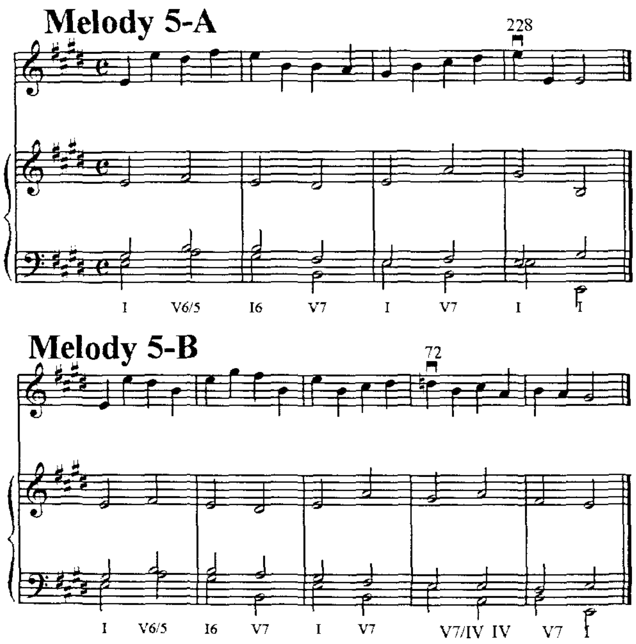

Figure 1: Sample melody stimuli.

Melodies 5-A and 5-B are shown in Figure 1as examples. The visual cue occurs at the same moment in both melodies; however, both the melodic and harmonic events at the cue diverged according to their expectancy ratings. The proximity of the events in both of the cues was preserved across all of the test groups in order to ensure that proximity did not affect response times. All of the chorales observed rules of good voice leading according to common practice western harmony. Figure 2 presents the numerical values of expectedness in melody pair 5 as it is expressed in the Margulis model. The y-axis is inverted to depict unexpected events as a function of graph height. The cued event occurs at the 4th note. In melody 5-B, the D is therefore highly unexpected, as is indicated in this graph.

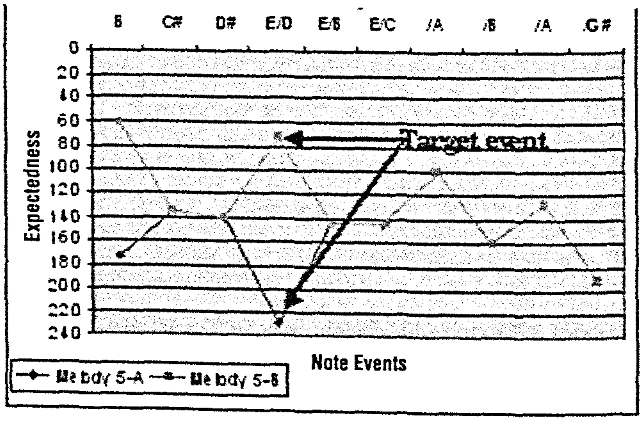

Figure 2: Margulis model predictions of every event in Bars 3-5 of Melody 5.

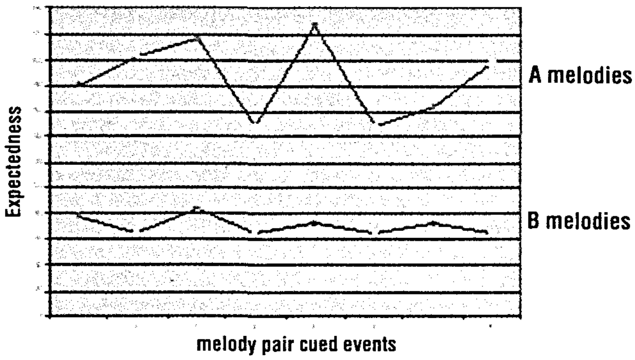

Figure 3: Melody expectancies of target events in all 8 melody groups.

Figure 3 illustrates the expectancy ratings for the cued events in both the A and B melodies. According to the model, some of the melodies should provide better results concerning response times than others. This graph demonstrates the variability of melodic expectancy as predicted by the model for the expected (A) melodies.

Procedure

Subjects were presented with eight groups of 4 four-part chorales alongside 32 fillers. They were told to attend to the melody of these chorales. At specific moments in the music, the computer monitor flashed green, at which point they were told to respond to whether the note they just heard was in tune or out of tune. They responded by pressing one of two corresponding buttons. Subjects were provided with ten practice melodies before they began the experiment in order to acquaint them with the task. The practice generally took no longer than 5 minutes of a 45 minute session. Accuracy and RT data were collected.

Results

The graphs in Figure 4 provide accuracy and RT information for the cued events across all 4 conditions. As predicted, subjects were much less accurate and much slower in their responses to the unexpected/in tune condition, condition B, than to the expected/in tune condition, condition A. The main effects for both accuracy and response time were significant: $F(3, 57) = 59.22$, $p < .00001$; $F(3, 57) = 28.843$, $p < .0001$. Further, paired comparisons between the A, B, C, and D conditions both for accuracy and response time indicated that paired differences between the A-B, A-C, B-C, and B-D conditions were all significant. A paired samples test for the A-B, B-C, and B-D comparisons provided the most robust effect, with all three registering an effect of $p < .0001$.

There was a strong bias to judge targets to be in tune when related and out of tune when unrelated. All 20 subjects showed both an accuracy and a reaction time advantage for the in tune expected condition (A), while the accuracy data for the in tune unexpected condition (B) indicates that subject responses were nearly no better than chance. A paired comparison of the C and D conditions both for accuracy and response time did not approach significance.

The results from the intonation method used in this experiment were also broadly consistent with the findings of Bharucha and Stoeckig (1986). They first used the intonation method to test harmonic priming between a prime chord and a target chord. Their accuracy data is provided in Figure 5. However, the Bharucha and Stoeckig study found a robust staircase effect between the B, C, and D conditions, and a paired comparison between the C and D conditions was significant. This discrepancy between the two studies is likely caused by the fact that out of tune events were pitched an 1/8th tone higher in the Bharucha and Stoeckig study, while this study pitched events a ¼ tone higher. Events in this study were therefore so out of tune that the out of tune expected condition (C) was much easier to detect than it was in the Bharucha and Stoeckig study.

Of the 20 subjects, 7 indicated having at least 5 years of formal training, 5 of which further reported being music majors. A paired comparison of accuracy data in condition B for trained vs. untrained subjects provided significant results, $F(1, 18) = 4.974$, $p < .04$, though response time data did not also indicate this effect. Figure 6 indicates that untrained subject responses were slightly worse than chance, while

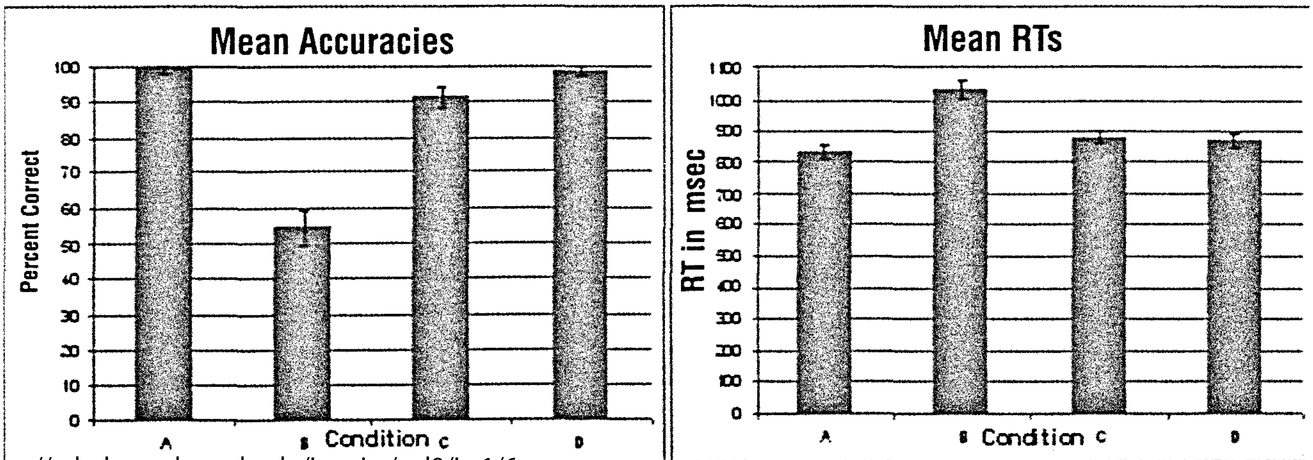

Figure 4: Mean accuracy and reaction time data across conditions.

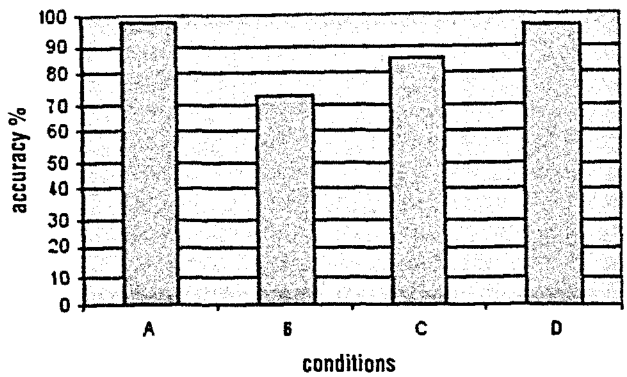

Figure 5: Barucha and Stoekig accuracy data.

trained subjects were generally much better at identifying the unexpected condition as in tune. The high variability in the trained responses, as indicated in the standard error bar, is an effect of having data from only 7 subjects.

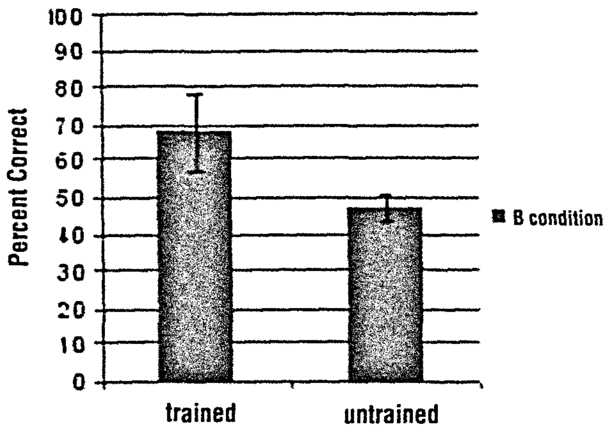

Figure 6: Accuracies in the B Condition for trained vs. untrained subjects.

Discussion

The results of this experiment suggest that several components of the priming paradigm provide researchers with an accurate method to detect musical expectations in listeners. First, the intonation task offers researchers an innovative response method for testing subject responses to music for trained as well as untrained listeners, since it permits listeners to respond to single events within the melodies at an adequate tempo to represent music. Second, this experiment successfully isolated stability within the Margulis model to provide empirical evidence about its role in listener expectations.

However, in order to isolate the category of stability, both proximity and direction had to be removed from the chorale melodies. In both the A and B conditions, the interval between the preceding event and the target event was preserved so as to ensure the proximity of the event did not affect listener expectations. Direction only has a pronounced effect on listener expectations in the Margulis model if there is a large interval between the preceding event and the target event, which always implies a directional reversal. However, within the test melodies, no intervals larger than a major 2nd approached the target event. Thus, two of the three potential factors in determining surprise in the expectation of melodies were effectively removed from the experiment in order to specifically consider the role of stability in listener expectations of tonal melodies.

The results of this experiment suggest that stability plays an important role in how listeners process melodies in real time. Margulis explains that "tonal stability is a central concept in both music theory and music cognition. Stability captures the intuition that, in general, listeners expect relatively stable melodic events" (2008, 675). Margulis' model adopts Fred Lerdahl's event governance rules, which select an operative chord and key in which stability may be evaluated. By weighing the stability ratings of events in terms of an operative chord or key, Margulis appears to have accurately predicted that stability is a central factor in listener expectations. However, there are a few inherent weaknesses both in the priming methodology and in the current study. First, the data indicated a ceiling effect for accuracy, as is indicated in Figure 7. While Margulis' model is highly variable in predicting the expectedness of events in the A condition, the accuracy data for the A condition provided by the experiment was nearly always 100%. This finding indicates that the response time method does not accurately detect expectations after a certain threshold of expectedness.

Second, the experiment did not attempt to isolate specific

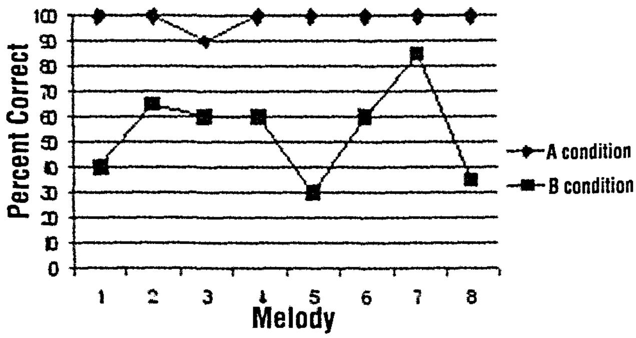

Figure 7: Comparing Accuracies between A and B Conditions.

musical events. Instead, it simplistically grouped events as either expected or unexpected, rather than producing a larger number of groups to determine how accurate the Margulis model predicts listener expectations. However, as Figure 8 indicates, RT data provides accurate data at the level of the individual melody. Future studies could arrange individual melodies into several groups and staircase those groups according to their expectedness ratings, as RT data should provide a reliable indication of whether the predicted staircase effect is consistent with listener expectations.

However, the primary goal of the present study was to

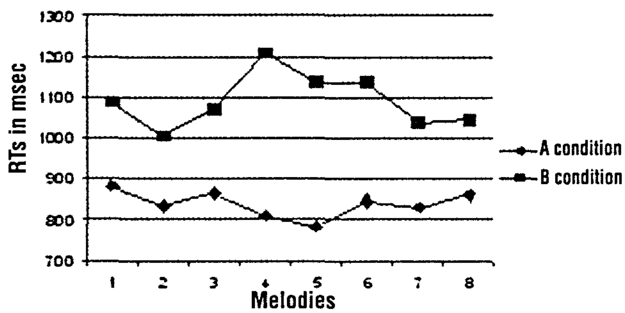

Figure 8: Comparing RT's between A and B Conditions.

develop an on-line method that could permit the study of real-time processing decisions according to listener expectations, using an approach that does not terminate musical processing. This study suggests that listeners without formal musical training can detect events with varying degrees of expectedness at an automatic, nearly unconscious level. Untrained listeners therefore possess a tacit knowledge of the musical idiom, in this case common practice western harmony. That knowledge generates automatic expectations during the listening experience, which ultimately leads to the kind of physiological, affective response in listeners we call surprise.

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Mentor Comments

Professor Elizabeth Margulis speaks glowingly about the quality of David Sears' work, describing it as equivalent to doctoral level research and emphasizing its uniqueness in drawing from three diverse disciplines.

In five classes across five years, David Sears has proven himself to be an exceptional thinker – perhaps the most creative, probing intellect I've encountered in nearly a decade of teaching. I first noticed David's rare abilities in a basic music theory course, when he regularly scribbled questions and comments into the margins of homework assignments. These questions examined the intellectual foundation of the discipline, anticipated future topics, and resonated with current concerns in the field. Throughout his undergraduate years, he has pursued a fascinating agenda of original research. I am unsurprised that he graduates this semester with a degree in Music on top of his degree in English, the author of a publishable piece of research that has won him fellowships to McGill University in Montreal and University of Pennsylvania in Philadelphia, as well as an invitation to present the paper at a conference at the University of Calgary.

This project began two years ago, when David and I started meeting regularly to discuss his interest in music cognition. It started to take clearer shape as a semester project for my Fall 2007 Honors Colloquium on Music and Mind. David zeroed in on expectation as a mechanism shared by music and language processing. He sought to investigate empirically the way that tonal surprises can create tension in melodies. This pursuit is original and important; no researcher has yet made systematic connections between expectation and affect in a laboratory setting.

David conducted an enormous literature review for this study. He probably knows more about expectation in music than all but perhaps a handful of scholars. I guided him in certain directions, on occasion, but the initiative and the review was all his. Although David made use of my work in his article, he conceived of his research question, designed his study, composed the stimuli (a huge task on *its own, consisting of the writing and programming of 32 musical excerpts fulfilling stringent requirements), ran all the subjects, analyzed the data, and wrote the paper. I offered suggestions along the way, but the work was entirely David's.*

David deserves this award because he has produced Ph.D. thesis-level work as an undergraduate, teaching me about what students are capable of, and encouraging me to bring more students into my lab. I have been inspired by David to get more undergraduates involved in research. But I know that it will be a while before I see another David. He represents the absolute best in undergraduate research. He made connections between the English, Music, and Psychology Departments to complete an interdisciplinary project that offers a substantial contribution to the literature. The amount of creativity, dedication, initiative, and expertise in multiple fields required to accomplish this study defies description. I feel fortunate to have had the opportunity to work with such a gifted student.