Effects of Metrical Encoding on Melody Recognition
Author(s): Stefanie Acevedo, David Temperley and Peter Q. Pfordresher
Source: *Music Perception: An Interdisciplinary Journal*, Vol. 31, No. 4 (April 2014), pp. 372-386
Published by: University of California Press
Stable URL: http://www.jstor.org/stable/10.1525/mp.2014.31.4.372
Accessed: 09/04/2014 09:54

EFFECTS OF METRICAL ENCODING ON MELODY RECOGNITION

STEFANIE ACEVEDO
University at Buffalo, State University of New York & Yale University

DAVID TEMPERLEY
Eastman School of Music

PETER Q. PFORDRESHER
University at Buffalo, State University of New York

WE REPORT TWO EXPERIMENTS EXPLORING whether matched metrical and motivic structure facilitate the recognition of melodic patterns. Eight tonal melodies were composed from binary (four-note) or ternary (three-note) motivic patterns, and were each presented within a metrical context that either matched or mismatched the pattern. On each trial, participants heard patterns twice and performed a same-different task; in half the trials, one pitch in the second presentation was altered. Performance was analyzed using signal detection analyses of sensitivity and response bias. In Experiment 1, expert listeners showed greater sensitivity to pitch change when metrical context matched motivic pattern structure than when they conflicted (an effect of metrical encoding) and showed no response bias. Novice listeners, however, did not show an effect of metrical encoding, exhibiting lower sensitivity and a bias toward responding "same." In a second experiment using only novices, each trial contained five presentations of the standard followed by one presentation of the comparison. Sensitivity to changes improved relative to Experiment 1: evidence for metrical encoding – in the form of reduced response bias when meter and motive matched – was found. Results support the metrical encoding hypothesis and suggest that the use of metrical encoding may develop with expertise.

Received: October 6, 2012, accepted September 17, 2013.

Key words: Meter, Motivic Structure, Parallelism, Melody Recognition, Tonal Melody

NEAR THE END OF THEIR CLASSIC PAPER "THE Perception of Temporal Patterns," Povel and Essens (1985) observed a curious phenomenon:

> Suppose we ask a subject to listen to a double sequence consisting of the high-pitched sequence 3 1 1 1 2 1 3 [a sequence of interonset intervals, shown with upward stems in Figure 1A] together with a low-pitched isochronic sequence with a fixed interval of size 4 [shown with downward stems]. After several periods, the presentation is stopped and the subject is asked to compare the stimulus with the following one, which consists of the same sequence 3 1 1 1 2 1 3 but now combined with a low-pitched sequence with a fixed interval of size 3 [Figure 1B]. The second stimulus is also stopped after a few periods. The subject is then asked whether (s)he has recognized that the two stimuli contained the same rhythm or temporal pattern. Nine out of 10 times the answer will be negative (1985, p. 432).

Povel and Essens found this informal observation to be of great interest, and we agree. It suggests that the metrical context of a rhythmic pattern (provided in this case by the low-pitched isochronous pulse) can affect the pattern's mental representation: the same pattern in two different metrical contexts can be perceived as an entirely different pattern. A similar phenomenon was observed in a study by Sloboda (1983), in which pianists were instructed to perform short notated musical

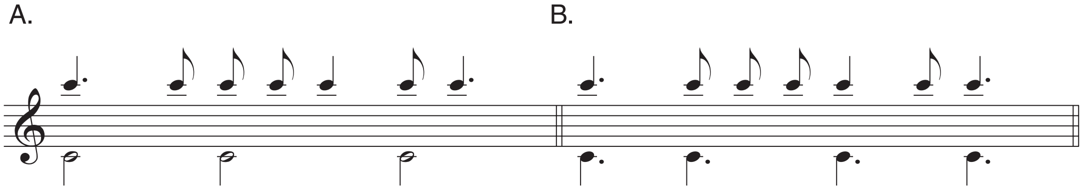

FIGURE 1. Altered perception of interonset intervals (top line) based on two different isochronous contexts (bottom line). From Povel and Essens (1985).

Music Perception, VOLUME 31, ISSUE 4, PP. 372–386, ISSN 0730-7829, ELECTRONIC ISSN 1533-8312. © 2014 BY THE REGENTS OF THE UNIVERSITY OF CALIFORNIA ALL RIGHTS RESERVED. PLEASE DIRECT ALL REQUESTS FOR PERMISSION TO PHOTOCOPY OR REPRODUCE ARTICLE CONTENT THROUGH THE UNIVERSITY OF CALIFORNIA PRESS'S RIGHTS AND PERMISSIONS WEBSITE, HTTP://WWW.UCPRESSJOURNALS.COM/REPRINTINFO.ASP. DOI: 10.1525/MP.2014.31.4.372

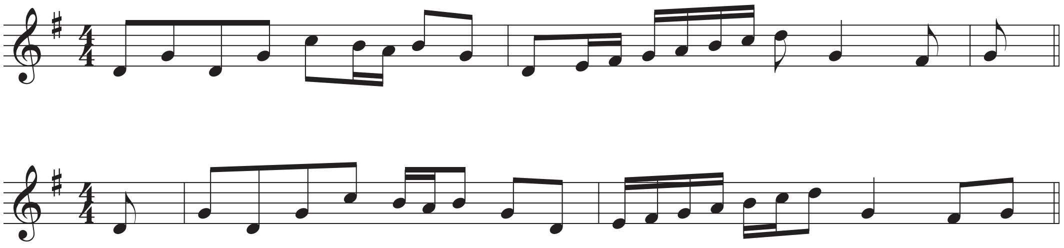

FIGURE 2. A melodic phrase in two different contexts, as used in Sloboda (1983).

passages. The passages included two melodic phrases containing the same pitches and rhythmic values, but in different metrical contexts (Figure 2). Though the two phrases were apparently seen and played within a few minutes of one another, Sloboda noted that not a single participant realized that they were identical. Here again, then, it appears that the metrical context in which a musical pattern is presented plays an important role in the way the pattern is mentally encoded; we will call this idea the *Metrical Encoding Hypothesis*.

The effect of metrical context on the identity of a melody has also been noted by several other authors, in studies of sensorimotor synchronization (Repp, 2007; Repp, Iversen, & Patel, 2008), subjective accentuation and attention (Repp, 2010), rhythmic expectation (Creel, 2011; Prince, Thompson, & Schmuckler, 2009a, 2009b), and the effect of motion on metrical perception (Phillips-Silver & Trainor, 2005). But in all of these studies, like those of Povel and Essens (1985) and Sloboda (1983), the phenomenon in question is not the main focus of the study and is observed only informally and anecdotally. One study that addresses the effect of meter on melodic encoding more directly is by Smith and Cuddy (1989). In this study, listeners learned melodies in either a 4/4 or 3/4 context (created by dynamically accenting every fourth or third note, respectively); the melodies were constructed so as to imply changes of harmony every 3 or 4 beats (matching or mismatching the metrical framework). After a melody familiarization period, listeners heard transposed comparison melodies and reported whether they matched the learned standards. Listeners responded more quickly to the changes in the 4/4 context than in the 3/4 context, regardless of matching or mismatching condition. This finding indicates an effect of meter on melodic encoding, suggesting a binary meter (4/4 and 2/4) advantage. Our study is similar to Smith and Cuddy's: like them, we investigate the interaction between meter and another musical dimension (in our case, intervallic pattern), observing whether compatibility between the two facilitates encoding. Our ultimate aim, however, is to explore the effect of meter on the identity of a melody: the fact that the same melody in different metrical contexts can seem quite different. We believe our study is the first to investigate this effect in a systematic way.

Our methodology relies on a well-established psychological principle: If a pattern is constructed from repetitions or transformations of a smaller subpattern, this facilitates its encoding (Boltz & Jones, 1986; Deutsch 1980; Deutsch & Feroe, 1981; Povel & Collard, 1982; Restle, 1970). For example, the repeated four-note pattern in Figure 3 should allow the melody to be learned more easily than the same notes in a random order. If the Metrical Encoding Hypothesis is true, the perception of Figure 3 will depend on the metrical framework in which the pattern is heard (a framework that could be imposed by an accompaniment, a preceding context, or both). If it is heard with a compatible metrical structure such as A, then metrically strong beats coincide with the onset of each instance of the pattern (emphasizing half-note beats); thus all the instances of the pattern are metrically similar. (Here we represent musical meter in terms of metrical grids—a well-established convention; Lerdahl & Jackendoff, 1983; Liberman & Prince, 1977.) By contrast, if the metrical structure is *incompatible* with the melodic pattern (e.g., structure B), then the instances of the pattern are metrically different: strong beats fall on the first and fourth notes of the first instance, the third note of the second instance, and the second note of the third instance (emphasizing dotted-

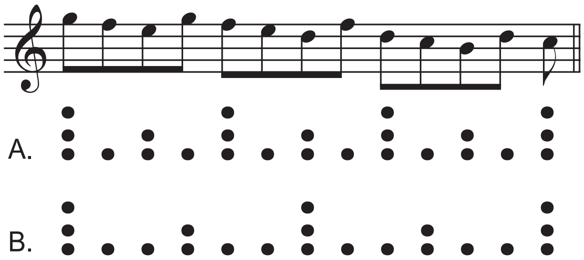

FIGURE 3. A melody with compatible (A) and incompatible (B) metrical structures.

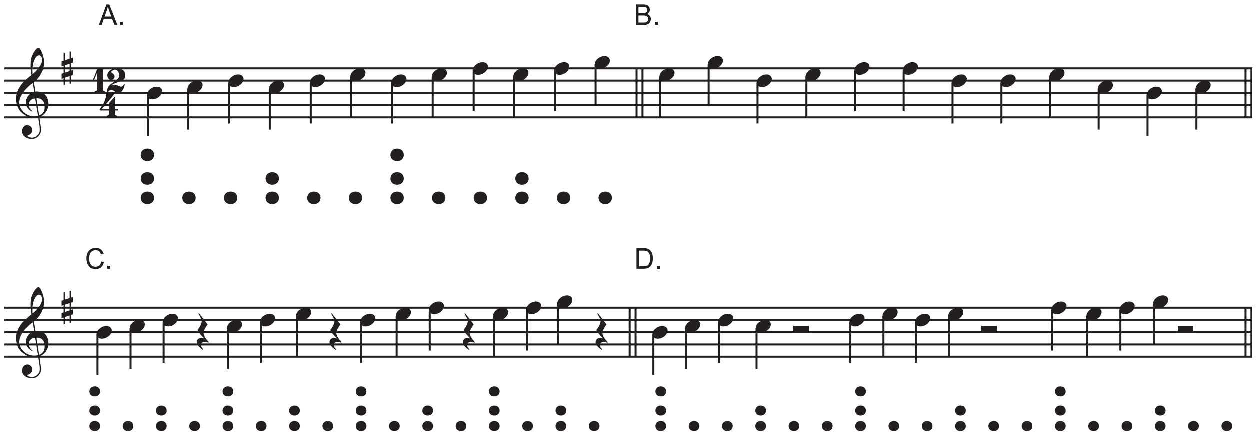

FIGURE 4. Melodies used in Deutsch (1980) with metrical grids added by the current authors. A and B show structured and unstructured melodies, respectively. C and D show temporal separations.

quarter beats). In this case, the Metrical Encoding Hypothesis predicts that the repeated pattern within the melody will not be easily recognized (just as the similarity between the two melodies in Figure 2 is not recognized), and encoding will be inefficient. The melody will therefore be more easily learned in the context of structure A than structure B.

An important precedent for our work is a study by Deutsch (1980; see also Boltz & Jones, 1986), in which listeners (trained musicians) heard 12-note melodic patterns and transcribed them in musical notation. Some of the patterns were *structured* patterns, constructed from repeated three-note motives, like Figure 4A; other *unstructured* patterns consisted of the same pitches in a random order, like Figure 4B (The metrical grids were added by us and will be explained below). Subjects learned the structured sequences more easily, notating them much more accurately than the unstructured ones. Deutsch's experiment establishes two important premises for our study. First, it shows that listeners (at least under some circumstances) are readily able to detect repeated patterns in a melody and can use them to encode the melody in an efficient way (this is a notable difference between Deutsch's and Smith & Cuddy's paradigms; the latter's melodies are mainly designed to instantiate a harmonic rhythm as opposed to any repeating pattern). Second, it shows that such efficient encoding is possible when the repetitions of the pattern are related only by *tonal transposition*, that is, by shifting along the diatonic scale: such shifting preserves the diatonic intervals but not the chromatic intervals. (In Figure 4A, for example, each instance of the pattern involves two ascending diatonic steps; in terms of chromatic intervals, each instance features a different combination of major and minor seconds.) Further research has suggested that the facilitating effect of repetitive structure on recall is not limited to transpositions, in that repeated structures based on patterns of melodic and rhythmic accents (e.g., contour pivots and lengthened tones), not related by exact or tonal transposition, can lead to similar facilitation (Boltz, 1991; Boltz & Jones, 1986; Boltz, Marshburn, Jones, & Johnson, 1985).

Deutsch (1980) also manipulated the temporal structure of her melodies. In some trials, the sequences were presented isochronously (as shown in Figure 4A), in some cases, temporal gaps were inserted between instances of the pattern (as in Figure 4C), and in some cases gaps occurred within pattern instances (as in Figure 4D). Participants notated the sequences most accurately when gaps occurred between pattern instances, less accurately in the isochronous condition, and worst when gaps occurred within pattern instances. Deutsch suggested that the effect of gaps in her experiment was due to temporal segmentation: a repeated pitch pattern can be recognized more easily when temporal gaps separate instances of the pattern, or at least do not interrupt instances of the pattern. No doubt this is part of the explanation; however, two other possible factors deserve consideration. One is rhythmic similarity. In both Figures 4A and C, every occurrence of the pitch pattern has the same rhythm; in Figure 4D, however, each occurrence of the pattern is rhythmically different. (Here, following convention, we define the length of each note as its interonset interval, making the notes followed by gaps equivalent to dotted-half-notes. Thus in Figure 4D, the rhythm of the first instance of the three-note pattern is quarter/quarter/quarter, the rhythm of the second is dotted-half/quarter/quarter, and so on.) Indeed, previous research has shown effects of rhythmic patterns (timing of tone onsets) on the recognition of pitch intervals (Kidd, Boltz, & Jones, 1984).

Therefore, it may be that the rhythmic similarity of pattern instances in Figures 4A and C facilitated encoding of the melodies, in contrast to Figure 4D. Yet another possible factor—which is of particular interest here—is metrical context. We assume that the metrical structures perceived for the melodies in Figure 4 were as shown below the score. Thus, in Figures 4A and C, the instances of the three-note pattern are not only rhythmically the same, but also occur at parallel metrical locations. (In Figure 4D, instances of the three-note pattern are not even rhythmically the same; there are rests within the second and third instances of the pattern, but none within the first and fourth instances. Since the pattern instances differ rhythmically, their alignment with the metrical structure differs as well.) According to the Metrical Encoding Hypothesis, the similarity of metrical context across pattern instances is crucial to the easy encoding of the melodies in Figures 4A and 4C. If these melodies were heard in incompatible metrical contexts, the hypothesis predicts that efficient encoding would be disrupted (compare with Figure 3 above). In part, the current study can be seen as an attempt to tease apart the factors that facilitated encoding in Deutsch's experiment.

If readers agree with our intuitions regarding the perceived metrical structures for the melodies in Figure 4, one might ask *why* these metrical structures are perceived. The melodies were not heard with any accompaniment, or with any immediately preceding context establishing a beat. This brings us to an important point: while meter affects the perception of repeated patterns, a repeated pattern can also affect metrical perception, favoring a metrical structure with the same pulse length as the pattern. In Lerdahl and Jackendoff's (1983) influential theory of meter, this principle—which they call the rule of *parallelism*—is the first of the *preference rules* stating the criteria involved in meter perception (see also Steedman, 1977; Temperley & Bartlette, 2002). Given melodies such as those shown in Figures 4A and C, then, there is strong pressure to hear meters aligned with the repeated pattern, leading to a dotted-half-note pulse in Figure 4A and a whole-note pulse in Figure 4C. (Figure 4D is somewhat more ambiguous, as it lacks the synchronized pitch-rhythm pattern of Figures A and C.) Previous studies have shown that meter perception is related to the regularity of repeating patterns (Ellis & Jones, 2009; Hannon, Snyder, Eerola, & Krumhansl, 2004). Parallelism is not always decisive; a meter that is incompatible with the repeated pattern in a melody may be perceived if it is strongly favored by other factors. This is crucial for our experiment; in some cases we impose a contextual meter on a melody that conflicts with the melody's motivic structure in an attempt to steer the listeners towards the contextual meter. But care must be taken to ensure that the contextual meter is indeed the one perceived.

Rhythmic perception is also affected by absolute tempo. Research has shown that the most preferred rate for the primary metrical level or *tactus*—the level at which one normally taps or conducts—is about 100 beats per minute, with preference decreasing gradually for higher and lower rates (London, 2004; Parncutt, 1994). In Figure 4C, for example, at a tempo of 120 quarters per minute, the preferred tactus level would most likely be the quarter note, whereas at 240 quarters per minute, it would probably be the half note. For present purposes, however, this issue is not of central importance. Repeated patterns occur in music, and seem perceptible, at a wide range of time scales; for example, the repeated pattern in Figure 4C seems readily perceptible at tempi of 60, 120, 240, or 480 quarter notes per minute, though the tactus may shift from one metrical level to another. In Lerdahl and Jackendoff's (1983) theory, parallelism operates at all metrical levels, not merely at the tactus level. Similarly, if metrical context affects the melodic patterns that are perceived—favoring patterns that are consistently aligned with beats at some metrical level—we see no reason to suppose that this is confined to the tactus level. The possible effects of absolute tempo should be borne in mind, however, and we will return to them later in the article.

In what follows, we present an experimental test of the Metrical Encoding Hypothesis. Twelve-note melodies were constructed with three-note or four-note motives, very similar to those used in Deutsch's (1980) experiment. Unlike in Deutsch's experiment, however, a strong metrical context was imposed, in the form of a chord progression preceding the melody and a simultaneous metronome. The metrical context could be compatible with the melody (with the same pulse length as the melodic motive) or incompatible with it. After each melody, an exact repetition or slightly differing melody followed in the same metrical context; participants had to identify it as the same or different. Our prediction—following the Metrical Encoding Hypothesis—was that the melodies would be more easily encoded when presented in a compatible metrical context than in an incompatible one, and that performance on the same-different task would therefore be better in the former condition.

Experiment 1

In Experiment 1, participants heard 12-note melodies based on either three- or four-note transposed motives, crossed with one of two distinct metrical contexts; the two metrical contexts, or structures, either matched or mismatched the motivic structures. Matching conditions featured a metrical beat coinciding with each instance of the motive. In mismatching conditions, motivic structures were paired with a metrical beat that conflicted with the motivic structure (e.g., a four-beat-inducing motivic structure paired with three-beat meter). Patterns were presented twice in a trial; recognition memory for motivic structure was tested by altering the pitch of one note during the second presentation. Recognition was measured using signal detection parameters that separate sensitivity (*d'*) from response bias (*c*). Our prediction was that matching motivic and metrical structures, as opposed to non-matching structures, would enhance listeners' sensitivity to pitch changes in repeated melodies (higher *d'*).

METHOD

Subjects. Participants were sampled from two populations: musical experts and novices. The novice subjects ($N = 12$) were undergraduate students from the University at Buffalo, SUNY community. Total music training past elementary school music education equaled 2.83 years on average (range = 0-8 years). The expert subjects ($N = 15$) were undergraduate students, graduate students, and faculty members from both the Eastman School of Music and the University at Buffalo School of Music (there were no significant differences in training between expert participants from the two universities). Total music training for the expert group was split into performance training on an instrument or voice ($M = 15.27$ years; range = 4-20 years) and ear-training experience in a class or individual setting ($M = 5.07$ years; range = 1-14 years). Three expert individuals reported having absolute pitch. Novice and expert participant groups differed significantly with respect to average training length ($p < .001$). Novice participants received class credit for participation; experts received no compensation.

We based classification of participants on multiple factors, not just years of reported music training. All musical experts, except for one, had more than 10 years of music training on an instrument. Among novices, the largest amount of any type of music training (in Experiment 1) was eight years, and only two subjects had more than five years. All musical experts had received a bachelor of music degree or higher in music except for one; this subject reported having 16 years of music training on an instrument and two years of ear training. One of the subjects in the expert group (with only four years of training on an instrument) reported having a graduate degree in music theory and a faculty position at the Eastman School of Music.

Design and conditions. Motivic parallelism (Lerdahl & Jackendoff, 1983) was used to create eight different twelve-note pitch patterns (or melodies; see Figure 5). Four of the patterns were created using parallel iterations of three-note motives (resulting in what we called ternary patterns), and four of the patterns were created using parallel iterations of four-note motives (binary patterns).[1] Each trial consisted of two presentations of a pattern: the second presentation was either an exact repetition of the first iteration (1/2 of all trials) or contained a single pitch change. Pitch changes occurred only on unaccented note positions for both metrical structures used (note positions 3, 6, and 8; see Figure 6) – this prevented simultaneity with metronome clicks used to imply metrical structure. Note positions 2 and 11, also unaccented, were not used in order to prevent recency effects. The recomposed version of each melody involved one diatonic, contour-preserving note change in one of the aforementioned note positions (producing 16 total melodic stimuli – eight with a note change in the second presentation of the pattern, eight with no note change), resulting in a note-change of no more than an intervallic distance of a second (major or minor, depending on tonality) from the original pitch.[2]

Each of the 16 melodic stimuli was paired with one of two metrical structures, creating what we called a "combined pattern." The metrical structure was established by an opening harmonic progression and an ongoing metronome click. The two metrical structures employed

---

[1] In some cases, alternate motivic patterns may be found within these melodies. We do not believe this is a serious problem. In every melody, the *most efficient* encoding of the melody—the only one that allows the entire melody to be encoded completely as a sequence of three four-note motives or four three-note motives—is the one we describe, in which the motive starts on the first note; so it seems reasonable to suppose that this was the one that participants would be drawn to most strongly (if they found any efficient encoding).

[2] We made every effort to balance the tonal stability of changes as well as their effect on melodic contour across change positions (cf. Dowling & Bartlett, 1981 regarding contour encoding of melody). However, given the complexity of the stimuli some variability was unavoidable. Specifically, there were a total of five downward pitch changes (three in note-position 8, two in note-position 6) and a total of three upward pitch changes (two in note-position 3, one in note-position 6)—a total of two changes in position 3, three changes in position 6, and three changes in position 8. Note that these differences do not confound the critical match/mismatch variable, which is independent of the type of pitch change.
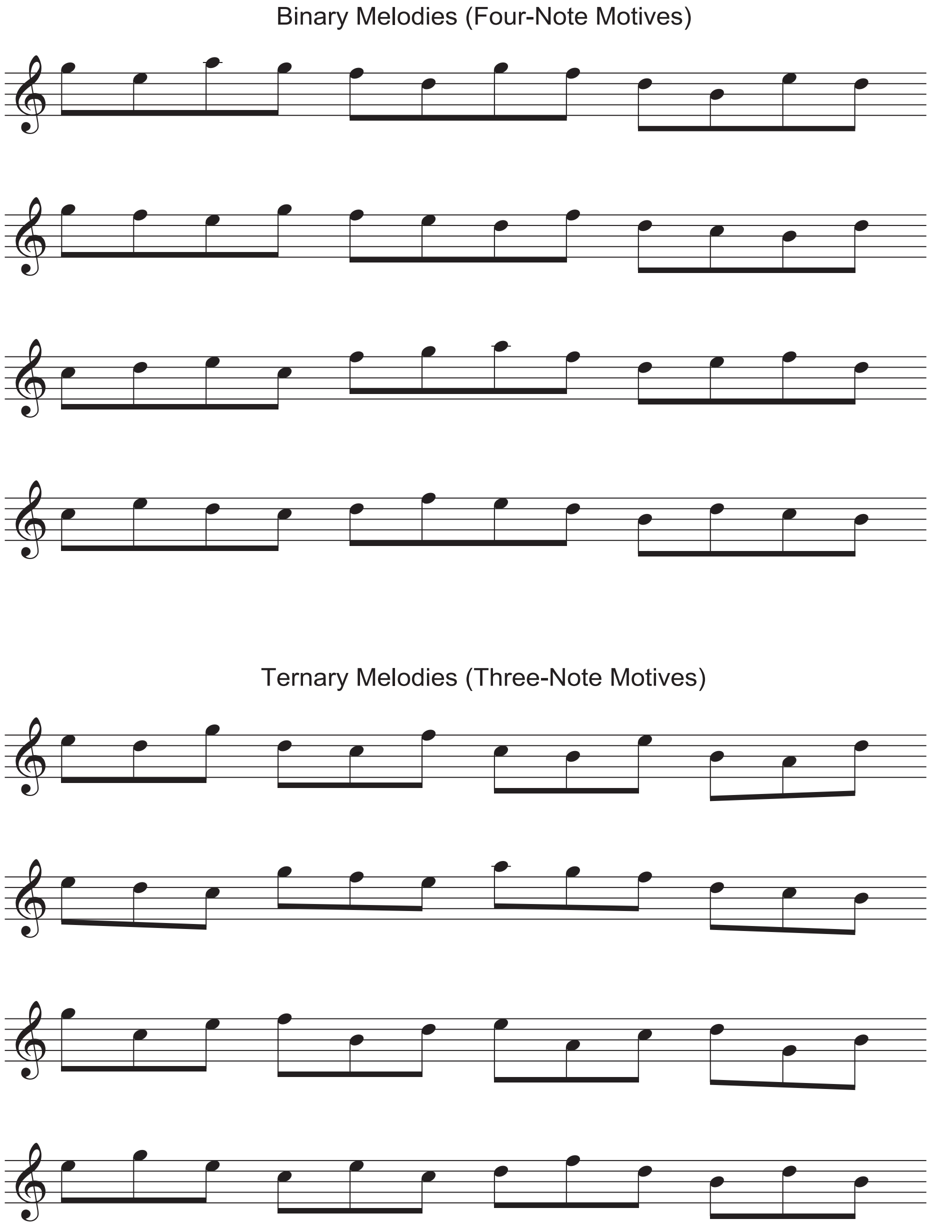
FIGURE 5. Motivic patterns used in Experiments 1 and 2. Binary melodies are based on parallel four-note groups, while ternary melodies are based on parallel three-note groups.

were derived from the two motivic structures: a matching metrical structure imposed a beat at the onset of each motive (creating half-note beats for the four-note motives and dotted-quarter-note beats for the three-note motives). Thus, the four-note motivic structure matched a 3/2 metrical structure (a simple meter, consisting of a half-note beat with a binary subdivision of four eighth notes) and the three-note motivic structure matched a 12/8 metrical structure (a compound meter, consisting of a dotted quarter-note beat with a ternary subdivision of three eighth notes). By crossing each motivic structure with each metrical structure, combined patterns were created that either matched or mismatched motivic and metrical structure.

Apparatus and stimulus generation. Stimuli were composed using Finale Songwriter and were converted into .WAV files using the built-in MIDI generator. The

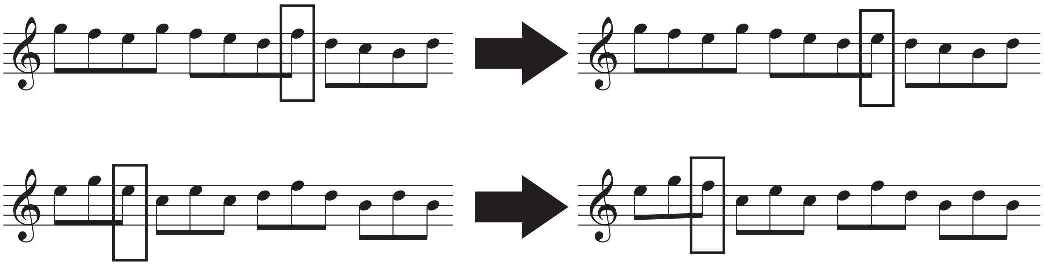

FIGURE 6. Sample melodies (binary and ternary) with note change. The top row shows an original binary pattern with its respective note change on position 8. The bottom row shows an original ternary pattern with its respective note change on position 3.

patches used were the "Snare Drum Click" patch for the metronome and the "Grand Piano" patch for the melody and harmonic progression. All stimuli were played at a tempo of eighth note = 250 ms (240 eighth notes per minute). Our assumption was that the tactus level would generally be heard as the dotted-quarter level (80 beats per minute) in the compound-meter trials and the half-note level (60 beats per minute) in the simple-meter ones; in the simple-meter trials, the quarter-note level might also be heard as the tactus. A MATLAB 7.13 script was used to run experimental trials and collect data. Instructions were presented via a computer screen, and sound stimuli were presented via headphones. Participants entered responses using the number pad on the computer keyboard (1 = *same*, 2 = *different*).

Procedure. The participants were exposed to two presentations of each combined pattern (64 trials: 32 with a change condition, 32 with a no-change condition). Each subject experienced one of two trial orders. No adjacent trials contained the same melody. Each trial consisted of two presentations of the meter/melody combination. The subject was told that the second performance of the melody may have a one-note difference; if so, the participant should say that the melody was different, otherwise the participant should report no change ("same" response). If unsure, the subject was told to guess. Each participant had a two-trial practice phase that used *Twinkle, Twinkle Little Star* as the melody (for familiarity and ease of recognition); the participant was given feedback on the practice trial and had a chance to ask for clarification before the experimental trials were begun. After the experimental trials, each participant was asked to fill out questionnaires about their music experience, along with a hearing sensitivity questionnaire (American Academy of Otolaryngology, 1989). Each experimental session lasted about 60 min.

Analysis. We analyzed recognition performance with respect to sensitivity and response bias, using the signal detection parameters d' (sensitivity) and c (response bias; MacMillan & Creelman, 2005). Recent research suggests that failure to adopt these distinctions in music perception tasks can distort the conclusions one makes about performance on perceptual tasks (Henry & McAuley, 2013). In particular, response bias simply reflects a participants' tendency to choose a given response independent of the correct response on a given target, and thus relates to the response criterion used more than to perceptual processing. All "different" responses for conditions with a changed pitch were coded as hits and all "different" responses for exact repetition trials were coded as false alarms. The proportion of hits and false alarms was computed for every participant and every condition based on crossing the factors motivic pattern type (binary, ternary) and meter type (simple, compound). Responses were aggregated across all change positions and melodic stimuli within a pattern type, based on preliminary results suggesting that these factors did not influence the critical relationship between meter and pattern. For these analyses, standard corrections were applied to individual hit rates and false-alarm rates [Correction for maximum values was 1-(½*N*) and correction for minimum values was 1/(2*N*)].

Signal detection parameters for each participant and condition were first analyzed using a 3-way mixed-model analysis of variance (ANOVA) with the between-subjects factor group (expert, novice) and within-subjects factors meter (simple, compound) and pattern (binary, ternary). We followed up this ANOVA with two subsequent analyses within each expertise group. For each group we performed a 2-way Meter × Pattern ANOVA, followed by planned comparisons designed to test the influence of metrical context within each pattern type (binary or ternary).

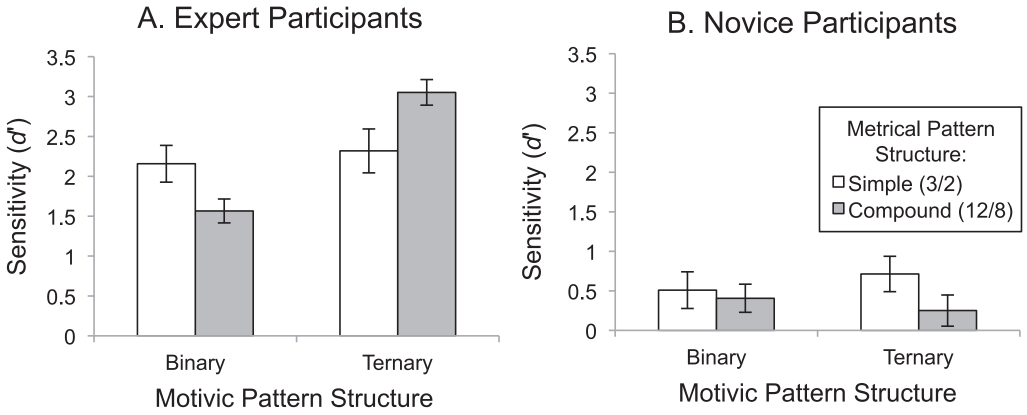

FIGURE 7. Mean sensitivity (*d′*) measures for expert participants (A) and novice participants (B) in Experiment 1 for each type of motivic and metrical structure condition. Error bars represent 1 standard error of the mean.

RESULTS

Sensitivity (d′). Mean d' measures are shown in Figure 7 for expert participants (Figure 7A, left panel) and novice subjects (Figure 7B, right panel) as a function of pattern structure and meter. Patterns in which meter and motivic pattern structure match are the external bars (positioned to the far left and far right), whereas internal bars are mismatching conditions. These measures reflect differences in the underlying response distributions associated with internal responses to different trial types (here, trials that have a changed pitch or do not), and are scaled in z-score units. Thus, a d' score of 1 suggests response distributions with central tendencies separated by 1 standard deviation. As can be seen, the experts exhibited superior performance within a pattern type when the metrical structure complemented the temporal structure of the motivic pattern (i.e., matching conditions): d' scores were higher for binary patterns when the meter was simple (3/2) as opposed to compound (12/8), whereas the reverse held for performance on ternary patterns. By contrast the novices exhibited very low sensitivity, and were not influenced either by pattern structure or by meter.

These observations were borne out in the three-way ANOVA, which yielded a main effect of Group, $F(1, 25) = 85.81$, $p < .01$, $\eta^2_p = 0.77$, reflecting overall better performance by experts ($M = 2.27$, $SE = 0.20$) than novices ($M = 0.47$, $SE = 0.21$); a main effect of Pattern, $F(1, 25) = 7.08$, $p < .05$, $\eta^2_p = 0.22$, reflecting better performance on ternary patterns ($M = 1.68$, $SE = 0.19$) than binary patterns ($M = 1.22$, $SE = 0.14$); and a significant Group × Pattern × Meter interaction, $F(1, 25) = 12.60$, $p < .01$, $\eta^2_p = 0.34$, as described above. The critical Meter × Pattern interaction approached but did not reach significance, $p = .053$, $\eta^2_p = 0.14$, likely due to the fact that novices were apparently not influenced by this interaction.

The effect of the meter-pattern match within expert subjects was further assessed via a two-way ANOVA that yielded a main effect of Pattern, $F(1, 14) = 16.54$, $p < .01$, $\eta^2_p = 0.54$, and a significant Pattern × Meter interaction, $F(1, 14) = 14.06$, $p < .01$, $\eta^2_p = 0.50$. Planned comparisons between meter conditions within each motivic structure (conducted as one-tailed t-tests) yielded significant differences between metrical context conditions for both binary, $t(14) = 2.12$, $p < .05$, and ternary, $t(14) = -3.43$, $p < .01$, pattern structures. By contrast, the ANOVA on novice participants yielded no significant effects, and planned contrasts were likewise nonsignificant. The lack of significant effects among novice participants could be due to a floor effect given low values of d', although it should be noted that mean performance among novice participants was significantly greater than chance, $t(11) = 2.26$, $p < .05$, which would yield $d' = 0$.

Bias (c). Response bias reflects the tendency for a participant to respond "different" or "same" (here, labeling a trial as having or not having a changed pitch), irrespective of the trial type, and thus does not reflect the ability to distinguish different trial types. Ideal responding has no response bias, and leads to a c-score of 0. By contrast, $c > 1$ indicates a tendency to favor "same" (no change) over "different" responses (a "conservative" response bias). Overall accuracy generally deteriorates as the absolute value of c increases from zero (Henry & McAuley, 2013). Mean values of c, shown in Figure 8, showed negligible effects of meter and pattern structure for either group, with a stronger conservative bias for novice ($M = 0.49$, $SE = 0.16$) as opposed to expert

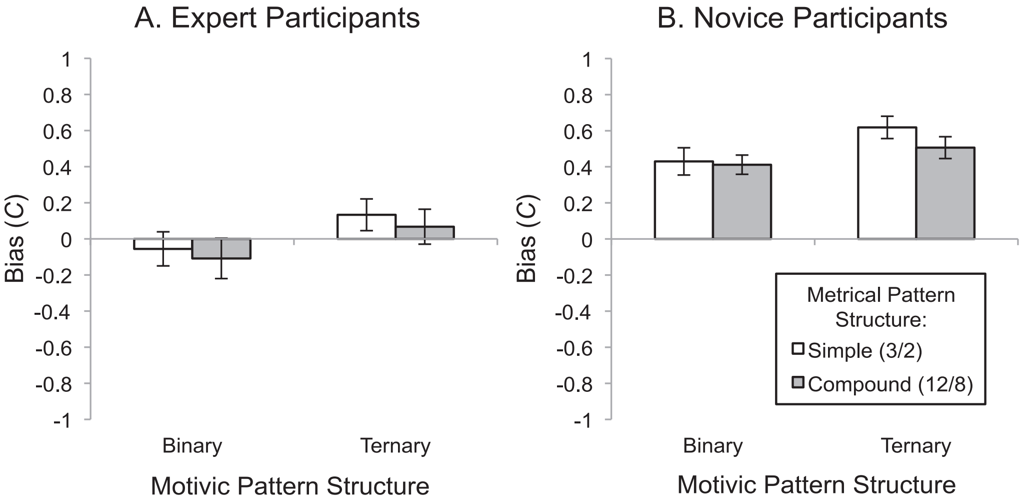

FIGURE 8. Mean bias (*c*) measures for expert participants (A) and novice participants (B) in Experiment 1 for each type of motivic and metrical structure condition. Error bars represent 1 standard error of the mean.

subjects (who showed effectively no response bias, $M = 0.01$, $SE = 0.10$). These observations were borne out in the three-way ANOVA, which yielded a main effect of group, $F(1, 25) = 18.03$, $p < .01$, $\eta^2_p = 0.42$, but no other significant effects. Likewise, follow-up ANOVAs and planned comparisons within each group were nonsignificant.

DISCUSSION

Results from Experiment 1 suggest a greater tendency for expert listeners to use metrical encoding than novice listeners: whereas recognition memory among experts was influenced by the match between meter and motivic pattern structure, novices showed no such effect. This use of metrical encoding appears to work to the advantage of expert listeners, given their overall greater sensitivity (with lower response bias) to changed pitches than novices. These results accord with other claims of qualitative differences among expert and novice listeners (e.g., Smith, 1997). It is important to note that the role of metrical encoding in our task is implicit; that is, we did not ask listeners to respond consciously to the match between meter and motivic pattern structure. Thus, results of Experiment 1 run counter to the hypothesis that effects of music expertise only appear in tasks that require an explicit response to musical structure (Bigand & Poulin-Charronnat, 2006).

However, we should be cautious in drawing conclusions about metrical encoding among novice listeners from Experiment 1. Though novices were able to discriminate change from no change trials at a rate that was significantly better than chance in statistical terms, performance was low enough that we were concerned about the possibility that many novice performers may have been guessing. Thus, the lack of a metrical encoding effect among novices may simply have resulted from the fact that the task was too hard to elicit any experimental effect in this group. We ran a second experiment that was designed to increase performance in another novice group.

Experiment 2

Experiment 2 was designed to facilitate memorization in novices through repetition. We did so in order to increase overall accuracy on the task; it is possible that the novice group's low sensitivity in the first experiment prevented any effects of the Meter × Pattern interaction. An effect should arise when overall novice performance improves. Results from pilot studies suggested that five iterations of the standard might be sufficient to enhance performance in this way.

METHOD

Subjects. Seventeen undergraduate subjects were recruited from the University at Buffalo, SUNY ($M_{age} = 19.65$ years, $SE = 0.44$). Total music training past elementary school music education equaled 2.00 years on average (range = 0-8 years). A Student's *t*-test showed no significant differences in either age ($p = .72$) or music training ($p = .43$) between novice subject groups in experiments one and two.

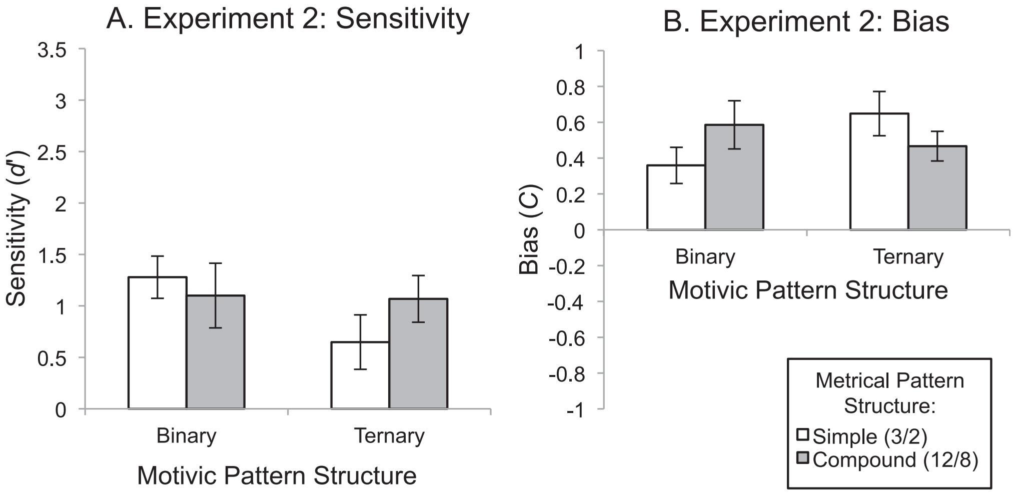

FIGURE 9. Mean sensitivity (*d'*, panel A) and bias (*c*, panel B) measures for novices in Experiment 2 for each type of motivic and metrical structure condition. Error bars represent 1 standard error of the mean.

Apparatus and stimulus generation. All stimuli were generated and presented in the same manner as in Experiment 1.

Design and conditions. All conditions were the same as in Experiment 1, except for one parameter: In order to familiarize the subject with the stimulus melody, four repetitions of the original melody were given before the target, with a harmonic progression in between each presentation. Melodic changes for Experiment 2 were still diatonic, contour preserving, and in the same note positions as in Experiment 1.

Procedure. All procedures were the same as in Experiment 1.

RESULTS

Similar analyses were employed as in Experiment 1. Because only one group was used in Experiment 2, data were analyzed using two-way within-subjects ANOVAs. Figure 9 shows mean data reflecting sensitivity (*d'*, left panel) and response bias (*c*, right panel). Sensitivity was significantly higher in Experiment 2 ($M = 1.02$, $SE = 0.26$) than in Experiment 1, reflected in a two-sample *t*-test (one-tailed, given the prediction of increased sensitivity with repetitions of the standard), $t(27) = 2.15$, $p < .05$, $r^2 = 0.15$. Likewise, differences across means were nominally consistent with the metrical encoding hypothesis (cf. Figure 7A), with sensitivity higher for matching conditions (exterior bars) than mismatching conditions (interior bars). The ANOVA, however, did not yield any statistically significant results: main effect of meter, $F(1, 16) = 0.42$, $p = .53$, $\eta^2_p = 0.03$; main effect of pattern, $F(1, 16) = 2.38$, $p = .14$, $\eta^2_p = 0.13$; interaction, $F(1, 16) = 2.92$, $p = .15$. The critical Meter × Pattern interaction yielded a modest effect size, $\eta^2_p = 0.15$. Planned contrasts were also nonsignificant, $p > .15$ (for each case).

Results for response bias are shown in the right panel of Figure 9. Contrary to sensitivity measures, the comparison of overall response bias across Experiments 1 and 2 was not significant. However, the 2-way ANOVA did yield a significant Meter × Pattern interaction, $F(1, 16) = 5.85$, $p < .05$, $\eta^2_p = 0.27$, with no significant individual main effects. This interaction reflected a tendency for the conservative response bias found for novice participants to be reduced for conditions in which metrical structure matched the motivic pattern structure (the inverse of the effect for *d'*, in which higher values indicate better responding). This effect was subtler than that seen in the sensitivity data of expert participants in Experiment 1 (where $\eta^2_p = 0.50$), however, and neither of the planned contrasts within pattern types reached significance. Nevertheless, response bias measures do suggest that novice listeners are influenced by the match between meter and pattern structure (exterior bars versus interior bars), though this influence is manifested in a different characteristic of performance than exhibited by experts.

DISCUSSION

In Experiment 2, repeated presentations of the combined meter/motive pattern increased overall sensitivity to changes among novice listeners, relative to Experiment 1, and led to results that suggested an effect of metrical encoding in the reduction of response biases that typically interfere with optimal performance. Thus, the lack of metrical encoding effects across novice listeners in Experiment 1 may have partly been due to the difficulty of the task for this group. However, the fact that significant effects of metrical encoding still failed to appear in measures of sensitivity suggests that it was not the efficacy of encoding, per se, that was influenced, but instead a more balanced overall strategy in choosing responses. We reflect on possible implications of this result in the next section.

General Discussion

It has been noted informally that the same melody presented in two different metrical contexts can sound quite different (Povel & Essens, 1985; Sloboda, 1983). This suggests that meter plays an important role in the way melodies are encoded—what we have called the Metrical Encoding Hypothesis. The first aim of the current study was to directly examine the effect of meter on the identity of a melodic pattern. Our study relies on the well-established fact that a melody can be more easily encoded if it contains a repeated motive (Boltz & Jones, 1986; Deutsch 1980). If metrical context plays a role in the encoding of melodic segments, then short-term memory for a melody should be facilitated when the metrical context matches periodic recurrences of repeated motives within that melody.

In our first experiment, musical experts were more accurate in identifying whether a change had occurred in the melody when it occurred in a compatible metrical context; this suggests that they found the melody easier to encode in such a context, and therefore, that they more readily identified the motive in that condition, supporting the Metrical Encoding Hypothesis. By contrast, musical novices in our first experiment showed no such effect; they had difficulty with the task, performing only slightly (though significantly) above chance. A second experiment facilitated the task by playing the standard melody five times before the comparison was heard; in this case, novice listeners improved overall with respect to sensitivity, and were influenced by the match between meter and pattern structures. This influence, however, was manifested in response bias rather than in sensitivity (which yielded nonsignificant effects), and suggests a different kind of metrical encoding effect among novices than we found for expert listeners.

Overall, our study provides strong support for the Metrical Encoding Hypothesis with regard to expert listeners; for such listeners, the metrical context of melodic segments appears to affect their perceived similarity and thus seems to play a role in how they are encoded. For novice listeners, the picture is less clear. In the context of signal detection analyses used here, effects of metrical encoding among novice listeners in Experiment 2 have to do with the kind of decision criterion these listeners use, rather than sensitivity (*d'*). This is a theoretically significant result, given the possible sources of each measure. Sensitivity is typically considered to be the preferred measure for purely perceptual processes (cf. Henry & McAuley, 2013) given that *d'* is presumed to reflect differences in the "average neural responses" to different kinds of trials (MacMillan & Creelman, 2005, p. 260, but see Pastore, Crawley, Berens, & Skelly, 2003 for a more cautious interpretation). By contrast, response bias simply measures how popular one response or the other is, irrespective of the actual correct answer on a given trial. Moreover, response bias may reflect individual response heuristics such as subjective probabilities, which occur post-perceptually (Wickens, 1992). Given such results, a possible source of the conservative bias among novice listeners (i.e., a tendency to report no pitch change in the comparison pattern) in the present experiments may be a response strategy based on the impression that changed pitches (which are difficult to detect) are rare. The reduction in this tendency (for matches between meter and pattern structure in Experiment 2) may therefore reflect a correction in the estimation of probabilities across all trials.

One might wonder if the results of our study were affected by a general processing advantage for either simple or compound meters, or for binary or ternary motivic patterns. A related point is that the absolute length of patterns (i.e. the time interval between the onset of one pattern instance and the onset of the next) systematically differed between binary and ternary patterns (1 s for binary patterns versus 750 ms for ternary patterns); likewise, the rate of the predicted tactus level differed between simple meter (1 s) and compound meter (750 ms) trials. We did not expect any of these factors to affect the results of our experiments greatly, and overall, our results suggest that they did not. Among the expert listeners in Experiment 1, accuracy was higher for ternary patterns (89% versus 80%); this may be due to the fact that the period of repetition in the ternary patterns (80 bpm) was closer than that of the binary patterns (60 bpm) to the "optimal" pulse period of about 100 bpm (London, 2004; Parncutt, 1994). However, no such effect was found for the novices in either experiment. In Experiment 1, the novices showed higher accuracy for simple meter over compound meter trials, though the difference was small (59% to 55%). Aside from these two effects, there were no main effects of pattern or meter for any of the three groups (experts and novices in Experiment 1 and novices in Experiment 2). While there may be small preferences for binary or ternary motivic patterns, for compound or simple meters, or for metrical levels or repeated patterns at certain absolute time scales, these factors do not appear to have had a major impact in our experiments.

To the extent that our study shows an effect of metrical context on melodic encoding (at least for expert listeners), it relates to previous work in several ways. Earlier we discussed Deutsch's (1980) study, in which listeners (musicians) heard melodies constructed from repeated motives and had to write them down; the insertion of temporal gaps degraded accuracy when the gaps occurred within instances of the motive, but not when they occurred between instances. Our study suggests that the superior performance in the latter condition may be due not only to temporal segmentation or to the rhythmic similarity of the melodic segments, but also to the fact that they were similar in metrical context; if the melodies had been presented in a metrical context incompatible with the motive, we suspect that this effect would have been greatly reduced.

Our study also sheds new light on the complex relationship between meter and motivic structure. Numerous studies—experimental, theoretical, and computational—suggest that listeners favor a meter that is compatible with repeated patterns (Hannon et al., 2004; Lerdahl & Jackendoff, 1983; Steedman, 1977; Temperley & Bartlette, 2002). What our study shows is that this causal relationship also goes in the opposite direction: The metrical context in which a melody is heard can affect whether a repeated pattern is perceived in the first place. Meter and motivic structure thus influence one another in a complex interactive relationship.

As discussed earlier, the effect of motivic structure on meter is consequential for our study. Repeated melodic motives, such as those used in our melodies, can cause listeners to infer a compatible meter. In a pilot version of our study (not reported above), we used similar stimuli to those presented here but without the metronome click accompanying the melody, so that the meter was conveyed only by the preceding harmonic progression; we found no effect of metrical context. We suspect that, once listeners were presented with the melody, they inferred the meter implied by the motivic structure rather than that implied by the harmonic progression. It is possible that the same thing occurred, at least to some extent, with the experiments reported here: Even after hearing the harmonic progression, listeners may sometimes have "tuned out" the persistent metronome click, and derived the meter from the motivic structure. In that case, metrical context would obviously have no effect. It would be of interest to redo the study in a way that eliminated this problem, by somehow ensuring that listeners were entraining to the desired metrical framework—for example, by having them tap along with it.

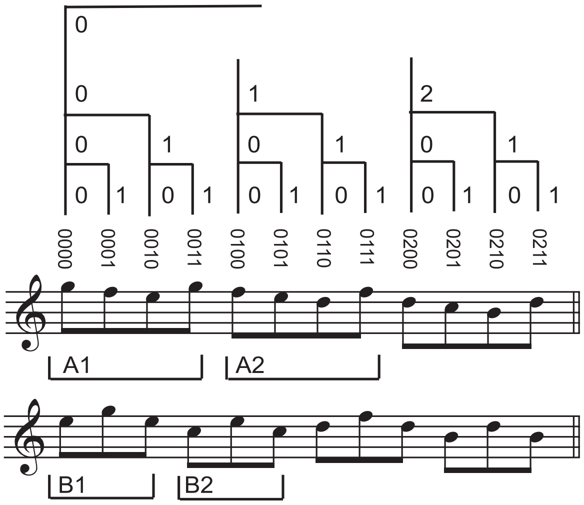

FIGURE 10. Illustration of sample melodies and tree schema used to determine metrical parallelism.

If meter does indeed play a central role in the encoding of melody (at least for expert listeners), how might this work? One proposal has been offered by Temperley (1995, 2001). Under this proposal, a metrical grid is represented in the form of a tree (see Figure 10; here a 3/2 metrical framework is assumed). Branches of the tree are either binary or ternary—following the usual constraints on meter in Western music—and branches are numbered accordingly, 0 or 1 for binary branches and 0, 1, or 2 for ternary branches. Every timepoint has an "address" that can be read by listing the numbers of the branches that lead to it; the addresses of each timepoint are shown below the tree. We may then define two segments as *metrically parallel* if they are equal in length and span similar addresses. Let us say for the moment that two addresses are "similar" if they are identical up to the level of the tactus (the half-note level, in this case). By this definition, the two segments marked A1 and A2 contain similar addresses; both contain four branches whose addresses end in 00-01-10-11. The segments are therefore metrically parallel. By contrast, segments B1 and B2 are not metrically parallel. The claim is then that, in searching for motivic similarities between melodic segments—either within a melody or between two different melodies—we only compare segments that are metrically parallel. For two segments to actually be motivically related, of course, they must not only be parallel in meter but also similar in rhythm and intervallic pattern; but if they are not metrically parallel, they will not be compared, so any similarities in pitch or rhythm will not be noticed. This framework could explain why, in our experiments, binary patterns were more easily encoded in a simple metrical context. In this context, the motivic segments were metrically parallel; they were therefore compared and their similarity (in intervallic pattern) was recognized. By contrast, compound patterns featured segments such as B1 and B2, which were not metrically parallel in a simple metrical context, though they were parallel in a compound metrical context and therefore recognized as similar in that context.

Another interpretation of the present results extends from the *joint accent structure* construct proposed by Jones (1987; See also Jones, Boltz, & Kidd, 1982; Large & Jones, 1999). According to this view, listeners track periodicities formed by recurring accents along different auditory dimensions or auditory streams. Patterns in which these periods complement each other should be tracked more effectively, thus facilitating selective attention, encoding, and recognition, whereas patterns with conflicting information (e.g., a four-beat melodic accent period paired with a three-beat temporal accent period) will lead to less effective processing. Past research has supported this prediction in patterns that combine melodic accents with accents formed by lengthened interonset intervals (e.g., Boltz, 1991; Ellis & Jones, 2009; Jones & Pfordresher, 1997; Jones & Ralston, 1991; Pfordresher, 2003). An accent structure perspective would interpret the metronome used to sustain the metrical context as a pattern of accents in one auditory stream that may conflict with or complement accents that occur within the combined pitch patterns. Such an interpretation is plausible; although we did not create pitch patterns in order to generate explicit accent periods, the use of parallelism is inevitably correlated with the regularity of melodic accents (Jones, 1981). However, in a certain respect this interpretation is not substantially different from the Metrical Encoding Hypothesis proposed above. In both cases, the critical point is that the encoding of pitch patterns is subject to the influence of a prevailing temporal frame in which the pitch pattern appears. Such a prevailing context may be the result of using meter as a memory frame (cf. Palmer & Krumhansl, 1990; Palmer & Pfordresher, 2003), or as a result of temporal markers on events associated with accents (as in joint accent structure). Such issues are ultimately of great importance, but are beyond the scope of the present paper.

While we have described the effect of a metrical context on melodic encoding as one of facilitation, it is also possible that it is an effect of interference. With regard to our experiments, one might ask: Does a compatible metrical context enhance the encoding of a melodic pattern, or does an incompatible metrical context degrade it? The situation would be clarified if a third condition were added in which melodies were heard with no metrical structure at all. If performance in the "no-meter" condition was equal to that in the "incompatible-meter" condition but worse than in the "compatible-meter" condition, we could conclude that the compatible meter was creating a facilitative effect; if performance in the "no-meter" condition were equal to the "compatible-meter" condition but better than the "incompatible-meter" condition, we could conclude that the incompatible meter was creating an interference effect. The problem is that it would be difficult, if not impossible, to create a "no-meter" condition. Listeners have a strong tendency to impose a metrical structure on any musical pattern, even a completely undifferentiated sequence of pulses (Woodrow, 1909); given melodies such as those used in our experiments, it seems likely that they would infer a meter compatible with the motivic pattern.

We have argued here that motivic structure has a complex interactive relationship with meter, both influencing it and being influenced by it. This kind of interactive relationship is also seen elsewhere in music cognition. As an example, meter affects harmonic structure, in that we tend to infer changes of harmony at strong beats; but harmony also affects meter, in that we tend to infer strong beats at obvious points of harmonic change (Smith & Cuddy, 1989; Temperley, 2001). Meter and grouping have a similar interactive relationship: We tend to hear strong beats at the beginnings of phrases, but we tend also tend to hear phrase beginnings at strong beats (Lerdahl & Jackendoff, 1983). Such interactions illustrate the complexity of music cognition. From a modeling point of view, they suggest that attempts to model individual components of music perception in a piecemeal fashion—e.g., models of meter perception or motivic perception—may ultimately fall short, since they fail to capture the interdependent nature of these components. A more holistic approach—in which meter, motivic structure, harmony, and grouping are all inferred in parallel—may be required, though this presents a daunting computational challenge.

Author Note

Stefanie Acevedo is now at the Department of Music, Yale University.

This work represents a portion of Stefanie Acevedo's master's thesis from the University at Buffalo, completed in the summer of 2012. This research was supported in part by NSF grant BCS-0642592. We are grateful to Mari Riess Jones for helpful discussions regarding this project and to J. David Smith for helpful comments on an earlier version of this paper, as well as other fellow members of the Auditory Perception and Action Lab at the University at Buffalo.

Correspondence concerning this article should be addressed to Stefanie Acevedo, 51 Clark Street, Apt. 1, New Haven, CT 06511. E-mail: stefanie.acevedo@yale.edu

References

AMERICAN ACADEMY OF OTOLARYNGOLOGY (1989). *Five minute hearing test.* Retrieved in 2004 from http://www.etnet.org/healthinfo/hearing/hearing_test.cfm (Current as of 2013 from http://www.entnet.org/HealthInformation/Hearing-Loss.cfm)

BIGAND, E., & POULIN-CHARRONNAT, B. (2006). Are we "experienced listeners"? A review of the musical capacities that do not depend on formal musical training. *Cognition, 100*, 100-130.

BOLTZ, M. G. (1991). Some structural determinants of melody recall. *Memory and Cognition, 19*, 239-251.

BOLTZ, M. G., & JONES, M. R. (1986). Does rule recursion make melodies easier to reproduce? If not, what does? *Cognitive Psychology, 18*, 389-431.

BOLTZ, M. G., MARSHBURN, E., JONES, M. R., & JOHNSON, W. W. (1985). Serial-pattern structure and temporal-order recognition. *Perception and Psychophysics, 37*, 209-217.

CREEL, S. C. (2011). Specific previous experience affects perception of harmony and meter. *Journal of Experimental Psychology: Human Perception and Performance, 37*, 1512-1526.

DEUTSCH, D. (1980). The processing of structured and unstructured tonal sequences. *Perception and Psychophysics, 28*, 381-389.

DEUTSCH, D., & FEROE, J. (1981). The internal representation of pitch sequences in tonal music. *Psychological Review, 88*, 503-522.

DOWLING, W. J., & BARTLETT, J. C. (1981). The importance of interval information in long-term memory for melodies. *Psychomusicology, 1*, 30-49.

ELLIS, R. J., & JONES, M. R. (2009). The role of accent salience and joint accent structure in meter perception. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 264-280.

HANNON, E. E., SNYDER, J. S., EEROLA, T., & KRUMHANSL, C. L. (2004). The role of melodic and temporal cues in perceiving musical meter. *Journal of Experimental Psychology: Human Perception and Performance, 30*, 956-974.

HENRY, M. J., & MCAULEY, J. D. (2013). Failure to apply signal detection theory to the Montreal Battery of Evaluation of Amusia may misdiagnose amusia. *Music Perception, 30*, 480-496.

JONES, M. R. (1981). A tutorial on some issues and methods in serial pattern research. *Perception and Psychophysics, 30*, 492-504.

JONES, M. R. (1987). Dynamic pattern structure in music: Recent theory and research. *Perception and Psychophysics, 41*, 621-634.

JONES, M. R., BOLTZ, M., & KIDD, G. (1982). Controlled attending as a function of melodic and temporal context. *Perception and Psychophysics, 32*, 211-218.

JONES, M. R., & PFORDRESHER, P. Q. (1997). Tracking musical patterns using joint accent structure. *Canadian Journal of Experimental Psychology, 51*, 271-291.

JONES, M. R., & RALSTON, J. T. (1991). Some influences of accent structure on melody recognition. *Memory and Cognition, 19*, 8-20.

KIDD, G., BOLTZ, M. G., & JONES, M. R. (1984). Some effects of rhythmic context on melody recognition. *The American Journal of Psychology, 97*, 153-173.

LARGE, E. W., & JONES, M. R. (1999). The dynamics of attending: How people track time-varying events. *Psychological Review, 106*, 119-159.

LERDAHL, F., & JACKENDOFF, R. (1983). *A generative theory of tonal music.* Cambridge, MA: MIT Press.

LIBERMAN, M., & PRINCE, A. (1977). On stress and linguistic rhythm. *Linguistic Inquiry, 8*, 249-336.

LONDON, J. (2004). *Hearing in time: Psychological aspects of musical meter.* New York: Oxford University Press.

MACMILLAN, N. M., & CREELMAN, C. D. (2005). *Detection theory: A user's guide.* Mahwah, NJ: Lawrence Earlbaum Associates.

PALMER, C., & KRUMHANSL, C. L. (1990). Mental representations for musical meter. *Journal of Experimental Psychology: Human Perception and Performance, 16*, 728-741.

PALMER, C., & PFORDRESHER, P. Q. (2003). Incremental planning in sequence production. *Psychological Review, 110*, 683-712.

PARNCUTT, R. (1994). A perceptual model of pulse salience and metrical accent in musical rhythms. *Music Perception, 11*, 409-464.

PASTORE, R. E., CRAWLEY, E. J., BERENS, M. S., & SKELLY, M. (2003). "Nonparametric" A' and other modern misconceptions about signal detection theory. *Psychonomic Bulletin and Review, 10*, 556-569.

PFORDRESHER, P. Q. (2003). The role of melodic and rhythmic accents in musical structure. *Music Perception, 20*, 431-464.

Phillips-Silver, J., & Trainor, L. J. (2005). Feeling the beat: Movement influences infants' rhythm perception. *Science*, *308*, 1430.

Povel, D. J., & Collard, R. (1982). Structural factors in patterned finger tapping. *Acta Psychologica, 52*, 107-123.

Povel, D. J., & Essens, P. (1985). Perception of temporal patterns. *Music Perception*, *2*, 411-440.

Prince, J. B., Thompson, W. F., & Schmuckler, M. A. (2009a). Pitch and time, tonality and meter: How do musical dimensions combine? *Journal of Experimental Psychology: Human Perception and Performance, 35*, 1598-1617.

Prince, J. B., Thompson, W. F., & Schmuckler, M. A. (2009b). The effect of task and pitch structure on pitch-time interactions in music. *Memory and Cognition, 37*, 368-381.

Repp, B. H. (2007). Hearing a melody in different ways: Multistability of metrical interpretation, reflected in rate limits of sensorimotor synchronization. *Cognition*, *102*, 434-454.

Repp, B. H. (2010). Do metrical accents create illusory phenomenal accents? *Attention, Perception, and Psychophysics*, *72*, 1390-1403.

Repp, B. H., Iversen, J. R., & Patel, A. D. (2008). Tracking an imposed beat within a metrical grid. *Music Perception*, *26*, 1-18.

Restle, F. (1970). Theory of serial pattern learning: Structural trees. *Psychological Review*, *77*, 481-495.

Sloboda, J. A. (1983). The communication of musical metre in piano performance. *The Quarterly Journal of Experimental Psychology Section A*, *35*, 377-396.

Smith, J. D. (1997). The place of novices in music science. *Music Perception, 14*, 227-262.

Smith, K. C., & Cuddy, L.L. (1989). Effects of metric and harmonic rhythm on the detection of pitch alterations in melodic sequences. *Journal of Experimental Psychology: Human Perception and Performance*, *15*, 457-471.

Steedman, M. J. (1977). The perception of musical rhythm and metre. *Perception*, *6*, 555-569.

Temperley, D. (1995). Motivic perception and modularity. *Music Perception*, *13*, 141–169.

Temperley, D. (2001). *The cognition of basic musical structures*. Cambridge, MA: MIT Press.

Temperley, D., & Bartlette, C. (2002). Parallelism as a factor in metrical analysis. *Music Perception*, *20*, 117-149.

Wickens, C. D. (1992). *Engineering psychology and human performance.* New York: Harper Collins Publishers.

Woodrow, H. H. (1909). A quantitative study of rhythm. *Archives of Psychology, 18*, 1-66.