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The Role of Melodic and Temporal Cues in Perceiving Musical Meter

Erin E. Hannon and Joel S. Snyder
Cornell University

Tuomas Eerola
University of Jyväskylä

Carol L. Krumhansl
Cornell University

A number of different cues allow listeners to perceive musical meter. Three experiments examined effects of melodic and temporal accents on perceived meter in excerpts from folk songs scored in 6/8 or 3/4 meter. Participants matched excerpts with 1 of 2 metrical drum accompaniments. Melodic accents included contour change, melodic leaps, registral extreme, melodic repetition, and harmonic rhythm. Two experiments with isochronous melodies showed that contour change and melodic repetition predicted judgments. For longer melodies in the 2nd experiment, variables predicted judgments best at the beginning of excerpts. The final experiment, with rhythmically varied melodies, showed that temporal accents, tempo, and contour change were the strongest predictors of meter. The authors' findings suggest that listeners combine multiple melodic and temporal features to perceive musical meter.

Music is an important stimulus for rhythmic movements, such as tapping, bouncing, swaying, clapping, and dancing. Most psychological and music-theoretical accounts define *meter* as a perceptual and conceptual organization of periodically alternating strong and weak beats that is superimposed on the musical surface (Dowling & Harwood, 1986; Lerdahl & Jackendoff, 1983; Povel & Essens, 1985). This metrical structure enables individuals in a group to move in synchrony with music and with each other. Meter is also thought to guide attention in a dynamic fashion, enhancing anticipation for when events are likely to occur (Jones, 1987). Aside from what is prescribed by the notated score, however, meter does not exist primarily as a physical parameter of the music but as an abstraction in the mind of the listener.

As in the case of other cognitive structures, such as linguistic grammar, significant questions remain about how listeners come to perceive meter in the course of development or while listening to a particular piece of music for the first time. Certainly, meter perception is constrained by basic aspects of behavior, such as the presence of superior time discrimination and production for time intervals of 300–1,200 ms (Engström, Kelso, & Holroyd, 1996; Fraisse, 1978; Friberg & Sundberg, 1995; Mates, Radil, Müller, & Pöppel, 1994; Peters, 1989). Beyond this, however, it is still unclear how the rich surface structure of music, with simultaneously unfolding patterns of pitch, duration, amplitude, spectrum, and expressive timing, gives rise to the perception of a simple periodic pattern of alternating strong and weak beats. The goal of the present study is to relate listeners' perceptions of metrical structure to various accent types that arise out of the melodic and temporal patterns in short melodies.

Meter perception is an instance of the general ability to use redundant and probabilistic information from multiple sources to organize and parse complex patterns in the environment. This strategy is evident in speech segmentation, in which adults (McQueen, 1998; van der Lugt, 2001) and infants (Mattys, Jusczyk, Luce, & Morgan, 1999) integrate multiple cues, such as sequential, phonotactic, or prosodic information, to locate word boundaries. In isolation, these cues only partially or inconsistently predict word segmentation, but in combination, they predict word boundaries reliably (Christiansen, Allen, & Seidenberg, 1998). Because complex sound patterns vary along many dimensions, and because listeners are able to combine multiple sources of perceptual information, a similar strategy is likely to be used in music perception. Even when individual accent types have a relatively weak impact on listeners' perceptions of metrical structure in music, the simultaneous presentation of multiple congruent accent types may create an emergent perceptual structure that affords dancing, tapping, singing, and many other forms of musical participation.

A periodic accent pattern is initially necessary for a listener to perceive meter. The term *accent* is defined as an increase in the perceptual salience of a musical event that results when that event differs in some way from surrounding events (Benjamin, 1984; Cambouropoulos, 1997; Cooper & Meyer, 1960). This broad definition encompasses a wide range of phenomena, but many studies, described below, have emphasized temporal accents, such as duration change, grouping position, and event onset, or dynamic

Erin E. Hannon, Joel S. Snyder, and Carol L. Krumhansl, Department of Psychology, Cornell University; Tuomas Eerola, Department of Music, University of Jyväskylä, Jyväskylä, Finland.

Joel S. Snyder is now at the Rotman Research Institute, Baycrest Centre for Geriatric Care, Toronto, Ontario, Canada.

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Correspondence concerning this article should be addressed to Erin E. Hannon, who is now at the Department of Psychology, University of Toronto at Mississauga, Mississauga, Ontario L5L 1C6, Canada. E-mail: eeh5@cornell.edu

accents, which result from intensity change. Accents arising from surface features should be distinguished from the alternating strong and weak beats felt once a metrical structure has been inferred. Perseveration or reinterpretation of an initially perceived metrical structure depends on a dynamic interplay between the metrical framework and the surface accents.

The literature on meter perception has tended to focus on temporal and dynamic accents. Various models have used these kinds of accents to recover scored meter in musical pieces and to predict synchronization behavior. Both symbolic computer models and autocorrelation-based computer models have used event onsets, interonset intervals (IOIs), and rhythmic repetition to successfully recover the scored meter in a number of musical works (Brown, 1993; Longuet-Higgins & Lee, 1982). Self-sustained oscillator models have used event onsets and intensity to predict tapping behavior (Large, 2000; Large & Kolen, 1994; Toiviainen, 1998). Other research has focused on temporal grouping accents. A temporal grouping accent arises when a tone is relatively isolated, the second of a two-tone cluster, or the initial or final tone of a cluster of three or more (Povel & Essens, 1985; Povel & Okkerman, 1981). In these studies, the degree to which temporal grouping accents occurred at regular temporal intervals determined rhythm reproduction accuracy (Povel & Essens, 1985) and gap detection in rhythms (Hébert & Cuddy, 2002), presumably because the regular placement of temporal grouping accents induced a metrical pulse.

Temporal and dynamic information plays an important role in how meter is conveyed in expressive musical performance. Pianists tend to emphasize events at strong metrical positions by making them longer, louder, or more legato (Drake & Palmer, 1993; Shaffer, 1981; Sloboda, 1983). These meter-related variations can aid listeners in perceiving the meter of an otherwise ambiguous musical excerpt (Palmer, Jungers, & Jusczyk, 2001; Sloboda, 1983). Performers also emphasize rhythmic grouping accents by increasing the intensity or duration of the final event in a group (Drake, 1993; Drake & Palmer, 1993; Repp, Windsor, & Desain, 2002). Intensity accents disambiguate the meter even in isochronous tone sequences (Windsor, 1993) or alter the perception of where a repeating pattern begins and ends (Zimba & Robin, 1998).

Temporal and dynamic accents are thus important cues to meter, but pitch patterns also create points of relative salience, termed *pitch accents.* Pitch accent is divided into two categories: interval accent and contour accent (Jones, 1993). *Interval accents* are created when a pitch is substantially higher or lower than those pitches preceding or following it. One example, sometimes called a *registral extreme accent,* is a note that is particularly high or low in pitch relative to surrounding pitches (Creston, 1961; Huron & Royal, 1996; Lerdahl & Jackendoff, 1983). A second type of interval accent results when a tone is preceded by a melodic leap that is larger than surrounding melodic intervals (Graybill, 1989; Lerdahl & Jackendoff, 1983). *Contour accents* result from changes in the direction of melodic contour. These *contour pivot points* are thought to generate salience because of their position at points of melodic change (Graybill, 1989; Huron & Royal, 1996; Jones, 1993). Interval and contour accents often overlap, because registral extremes almost always coincide with contour pivot points. Figure 1 provides examples of registral extreme, interval size, and contour pivot point accents.

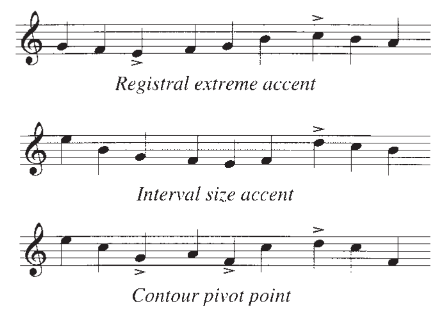

Figure 1. Three types of pitch accents. A registral extreme accent is a note in a particularly high or low register relative to surrounding notes, an interval size accent occurs when the interval between two notes is significantly larger than surrounding intervals, and a contour pivot point marks a change in the direction of the melody.

Contour pivot points can systematically affect listeners' judgments of metrical regularity in isochronous patterns. Thomassen (1982) created a metrical context by placing dynamic accents at periodic positions in an isochronous monotonic sequence. He then removed the dynamic accents, asking listeners to rate the metrical regularity of various three-note melodic patterns within the established metrical context. In general, listeners gave the highest regularity ratings to patterns with contour pivot points occurring at strong metrical positions, but this depended on whether the pivot was upward or downward and whether the subsequent pitch was repeated or not. Listeners' judgments were used to develop a predictive model of melodic accent based on the set of all possible three-note contour configurations. The predictions of Thomassen's model were found to correlate moderately with metrical position in musical scores (Huron & Royal, 1996).

A noted disadvantage of the Thomassen (1982) model is that it codes only local contour accent while ignoring interval size and global melodic shape, aspects of contour that could be important for accent (Huron & Royal, 1996). Music theorists have attempted to include global melodic shape in contour analysis (Marvin & Laprade, 1987; Morris, 1993). In such combinatorial models, each note of a pitch pattern is considered in relation to the entire pitch pattern (Quinn, 1999). For example, a later pivot point that is higher in pitch can override an earlier local pivot point. To quantify hierarchic contour relations, Morris (1993) created a contour reduction algorithm that prunes a complex melody down to its most salient pitches. Such an algorithm can be adapted for the purposes of studying contour accent by assigning a contour depth value to each note of a melody. Figure 2 provides an example of contour reduction for one melody.

Despite efforts to quantify and predict pitch accent, many studies have failed to document reliable and consistent effects, especially in the presence of other accent types. In an early experiment, Woodrow (1911) reported that increases in loudness and duration, but not deviations in pitch, predicted the perceived starting position of a temporal group. When listeners were asked to tap to pitch-varied and monotonic versions of ragtime piano music, most tapping performance indexes did not differ for the two versions (Snyder & Krumhansl, 2001). Similarly, listeners' metrical stability ratings for melodies interrupted at various stopping positions revealed higher perceived stability following temporal accents but

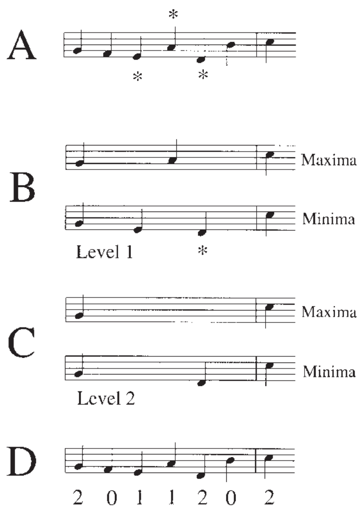

Figure 2. Illustration of Morris's (1993) contour reduction algorithm (with asterisks marking the local contour pivot points). A: A one-measure melody. At the first level of contour reduction, the local pivots plus the first and last notes of the melody, which are always included by definition, create subsets of maxima (high pivots) and minima (low pivots). B: Only the subset of local pivots from Panel A are reanalyzed for local pivots. C: Local pivots from Panel B create the final level, which cannot be reduced further. D: Final contour reduction values for each note correspond to the number of times an individual note was present at a reduced level.

not following melodic leaps or contour pivot point accents (Bigand, 1997). Even in expressive performance, pitch accents tend to be inconsistent and context-dependent (Drake & Palmer, 1993). Drake and Palmer (1993) found that pianists emphasized pitch accents by altering loudness, timing of IOIs, and articulation, but this depended on the type of melody and the type of pitch accent. For example, pianists increased the loudness of contour pivot points in isochronous melodies but not in rhythmically varied melodies, and melodic leaps were given dynamic stress only in a piece by Beethoven. Perception and production of pitch accents were thus highly dependent on the musical context and the presence or absence of temporal accents.

In contrast, other evidence suggests that pitch accent can alter how temporal and dynamic information is perceived. For example, listeners were unable to detect deviations from isochrony that occurred between two notes separated by a relatively large pitch interval (Drake, 1993). Listeners were also less sensitive to a decrease in intensity that coincided with a large melodic leap (Tekman, 1997, 1998). In addition, melodic accents may adversely affect tapping and reproduction when they conflict with temporal accents. Tapping variability was greater for patterns with conflicting pitch and temporal accents than for patterns in which they coincided (Jones & Pfordresher, 1997). Likewise, melodies containing concordant pitch and temporal accents were better remembered and reproduced than melodies containing conflicting pitch and temporal accents (Drake, Dowling, & Palmer, 1991; Monahan, Kendall, & Carterette, 1987). Thus, melodic and nonmelodic accents appear to interact.

Another type of melodic cue to meter is repetition or *parallelism* (Temperley, 2001). A note at the beginning of a repeated melodic pattern may be accented because it marks a periodic melodic structure (Lerdahl & Jackendoff, 1983; Steedman, 1977). Some models have used rhythmic and melodic repetition to recover the scored meter in musical works (Steedman, 1977; Temperley & Bartlette, 2002). Autocorrelation of the pitch time series, another index of melodic repetition, predicted the predominant period of synchronized tapping to music (Vos, van Dijk, & Schomaker, 1994). A second type of repetition accent may result when a note is immediately repeated, creating the impression of a longer duration (Creston, 1961). Figure 3 provides examples of *pattern repetition* and *note repetition* accents.

Accents might also arise from a change in harmony, called *harmonic rhythm* (Dawe, Platt, & Racine, 1993, 1994, 1995; Smith & Cuddy, 1989; Temperley, 2001). When listeners were asked to name the meter of melodies having triadic accompaniments, they perceived the points of harmonic change as metrical downbeats despite conflicting temporal accents (Dawe et al., 1993, 1994, 1995). Unaccompanied melodies can imply harmony sequentially, and this implied harmony could affect how listeners perceive meter. For example, listeners were slightly faster at detecting pitch deviants in unaccompanied melodies when implied harmonic changes were aligned with strong metrical positions, but only in some meters (Smith & Cuddy, 1989).

Some evidence suggests that harmonically prominent pitches are more likely to occur at strong metrical positions (Järvinen & Toiviainen, 2000). It is unclear, however, whether harmony and meter have interactive or independent effects on perception. One study obtained stability ratings for otherwise identical melodic excerpts that were taken from differing metrical or harmonic contexts and found that meter and harmony interacted for musicians (Bigand, 1993). A later study, however, did not replicate this interaction with a new set of stimulus materials (Bigand, 1997). Even if harmony and rhythm have independent effects, harmonic prominence may alter the salience of events and thus influence metrical processing. For example, nonadjacent notes that outline important harmonic units, such as triads, may be particularly salient and, thus, accented.

To summarize the literature on pitch accents, contour pivot points and melodic leaps appear to be relatively unreliable and context-dependent cues to meter. Pitch accents have been shown to affect expressive performance and perception of isochronous patterns, but the addition of temporal accents can override or obscure effects of pitch accent. Melodic structure may nevertheless have important effects on perception of meter when temporal information is lacking or ambiguous. Thus, to understand the role of pitch information in perceiving meter, it is necessary to manipulate the

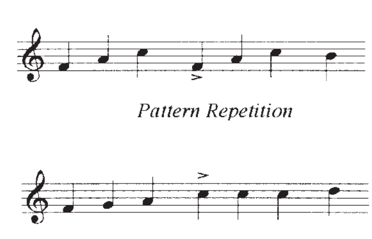

Figure 3. Two types of repetition accent. A note beginning a repeated melodic fragment is accented because of pattern repetition. A note that is immediately repeated is accented because of note repetition.

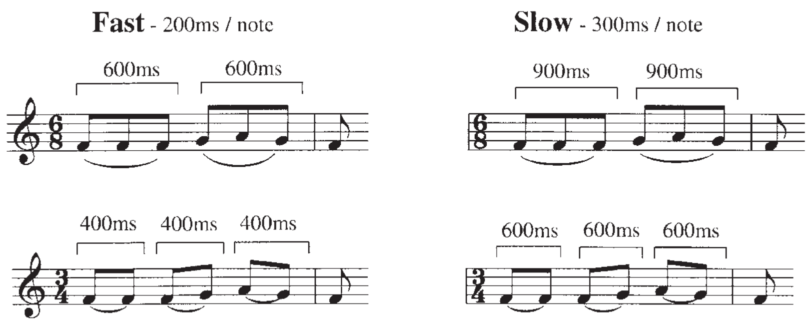

Figure 4. Four stimulus types used in the study. Each excerpt was presented in two different tempos with 200-ms and 300-ms interonset intervals and could be heard in two different meters, 3/4 (triple) and 6/8 (duple).

presence or absence of temporal cues. In addition, the studies that have examined pitch accent have typically been limited to a single type of contour or interval-size accent despite the fact that music contains a diversity of melodic features that may contribute to meter perception. These features include more complex aspects of contour accent that incorporate global melodic features, repetition of melodic patterns, repetition of individual notes, implied harmonic change, and triadic outlining at downbeat positions. The combination of different accent types may provide stronger metrical information than any one melodic accent type alone.

To test these ideas, the present experiments exploited the potential ambiguity of two familiar Western meters, *simple triple* (3/4) meter and *compound duple* (6/8) meter (Creston, 1961). In conventional metrical notation for a simple meter, the denominator specifies the relative duration of the beat, while the numerator specifies the number of beats per measure. Thus, 3/4 meter has three beats per measure, each a quarter note (or a binary subdivision into 2 eighth notes) in duration. In conventional notation for compound meter, the denominator specifies the duration of the beat's subdivision, while the numerator specifies the total number of such subdivision units per measure. The number of beats in a ternary meter can be determined by dividing the numerator by 3. Thus, 6/8 meter has 6 eighth notes and two beats per measure.

A measure of 6 eighth notes is metrically ambiguous because it can be interpreted as three beats consisting of 2 eighth notes (3/4) or two beats consisting of 3 eighth notes (6/8). In the absence of performance cues, such as variations in dynamics and note duration, this pattern can only be disambiguated by the presence or absence of accents at note positions within the measure. Specifically, accents on eighth notes in Positions 3 or 5 would reinforce three units of two, whereas an accent on Position 4 would reinforce two units of three.

The three present experiments used folk melodies scored in 3/4 and 6/8 meter. The participants were asked to judge which of two drum accompaniments, one in 3/4 and one in 6/8, best matched each melody. The first two experiments used isochronous sequences, in which all tones in the melody were of the same duration. The third experiment used melodies containing variations in the notated duration. All sequences were played in a mechanically regular fashion so that tone durations corresponded exactly to the notation. The melodies were analyzed for their melodic features, and predictor variables for each type of melodic accent were compared with listeners' judgments of the perceived meter.

Experiment 1

The first experiment used a set of isochronous, seven-note folk melodies that could be interpreted in either a triple (3/4) or duple (6/8) meter. Melodies were presented at two different tempos because of listeners' tendency to prefer interbeat intervals of about 600 ms (Fraisse, 1978). Listeners controlled the presentation of two drum accompaniments corresponding to the two different meters. For each melody, listeners indicated the perceived meter along a scale that was labeled with *strongly 6/8* at one end and *strongly 3/4* at the other. Intermediate positions were used to indicate more ambiguous perceptions of meter. Eleven predictor variables, derived from the empirical and theoretical literature reviewed above, coded different features of the stimuli. These variables were then used to predict responses.

Method

Participants. Twenty-three members (14 female, 9 male; ages 17–39 years) of the Cornell University community participated in the experiment. Some received course credit, and some received $5, for 1 hr of participation. Their average amount of formal musical training was 7 years (range: 0–25 years). None of the participants reported having perfect pitch or hearing problems.

Materials. Sixty-four short, isochronous excerpts were selected from the beginnings of European folk songs in the *Essen Folk Song Collection*, a database of approximately 6,000 melodies collected and transcribed to music notation from 1982 to 1994 under the supervision of Helmut Schaffrath (1995).[1] Half of the excerpts were scored in 3/4 meter, and half were scored in 6/8. Thus, excerpts could be perceived as either three beats subdivided into 2 eighth notes (3/4) or two beats subdivided into 3 eighth notes (6/8). Each excerpt consisted of one measure of 6 eighth notes plus the first note of the following measure (see Figure 4). For each trial, the seven-note excerpts were repeated for six cycles, with a five-note silence between repetitions. Practice trials consisted of three additional seven-note excerpts (also taken from the *Essen* database).

All excerpts were presented at a fast tempo of 200 ms per event and a slow tempo of 300 ms per event. The combination of tempo and meter resulted in potential interbeat intervals of 400 ms, 600 ms, or 900 ms. Figure 4 illustrates the four possible combinations of meter and tempo.

Two percussive drum accompaniments were created for each tempo, corresponding to 3/4 meter and 6/8 meter. The accompaniment in 3/4

[1] All excerpts used in the present experiments are available in MIDI format at http://people.psych.cornell.edu/~eeh5/Stimuli.html.

presented a drumbeat on eighth notes in Positions 1, 3, and 5 of each measure (including silent sections), whereas the accompaniment in 6/8 presented a drumbeat on Positions 1 and 4. Three buttons on the interface, labeled *Triple, None,* and *Duple,* controlled a gate to each drum accompaniment so that the participant could choose to listen to either of the two accompaniments or silence.

All melodies were created in MIDI format and played with a grand piano timbre. A woodblock timbre was used for the drum accompaniment. The MIDI velocity, which determines loudness, was equivalent for all notes. The silent duration between the offset of a note and the onset of the following note was always 10 ms, resulting in a legato style of articulation.

Apparatus. The music was played under the control of a Macintosh G4 computer using MAX (Version 3.5.9–9) software. The MAX interface displayed instructions and response buttons to participants on a 17-in. (43.18-cm) Mitsubishi Diamond Plus 71 monitor. MAX played all stimuli by sending the MIDI information to Unity DS-1 (Version 1.2) software via Open Music System. Unity converts MIDI information into digital audio information. The output of Unity was then amplified by a Yamaha 1204 MC Series mixing console and presented to participants over AKG K 141 headphones.

Procedure. Participants were asked to compare each melody with both 3/4 and 6/8 drum accompaniments. Participants could start, stop, or change the drum accompaniments as frequently as they liked throughout the duration of a trial, but they were asked to try each accompaniment at least once. Because each melody was presented twice, the trial duration was limited to six cycles to prevent participants from memorizing metrical interpretations for individual melodies. This trial duration was sufficient for participants to try each drum accompaniment two or three times. Because the stimuli were ambiguous, we assessed listeners' perceptions of meter using a 6-point scale labeled *strongly 6/8* (1), *moderately 6/8* (2), *weakly 6/8* (3), *weakly 3/4* (4), *moderately 3/4* (5), and *strongly 3/4* (6). Participants were told to indicate at the end of the trial the point along the scale that corresponded to how they perceived the meter of the melody.

The experiment was divided into four blocks of 32 trials, preceded by a practice block of 6 trials. Each of the 128 experimental stimuli (64 melodies $\times$ 2 tempi) was randomly assigned to one of four experimental blocks (A, B, C, or D), with the constraint that a melody would never be repeated in a single block or in consecutive blocks. Each participant received a unique random ordering of the stimuli for each block. Consecutive trials always alternated between slow and fast tempi. Starting tempo was balanced across participants so that half started with a slow stimulus and half started with a fast stimulus. Additionally, four different block orders were balanced across participants (ABCD, BCDA, CDAB, and DABC) in a Latin square design. The practice trials consisted of three additional melodies (also taken from the *Essen* database; Schaffrath, 1995), which were each presented at two alternating tempi. Participants were allowed to repeat the practice trials until they felt comfortable with the task, but only 1 did so. The experiment lasted approximately 50 min. After the experiment, all participants were given a brief questionnaire about their musical background, which included questions about formal musical training.

Variable coding. To assess the relative importance of different types of melodic information, we created 11 predictor variables. These included 6 pitch accent variables, 2 repetition variables, 2 harmonic variables, and 1 tempo variable. A general summary of variable coding is given below, and detailed descriptions of all coding rules are presented in the Appendix. Figure 5 shows how accent variables were coded for each note of three excerpts used in the experiment.

Four variables, *Thomassen accent, local pivot, contour reduction,* and *global pivot,* were created to code pitch accent arising from contour change. Thomassen accents were calculated for each note, as specified in Thomassen (1982), using the Humdrum Toolkit (Huron, 1994). The local pivot variable was a simpler coding of contour change, assigning an accent to any note that was a contour pivot relative to its immediately adjacent notes. To address the possibility that global melodic information might affect perception of contour pivot points, we created two additional variables. The contour reduction variable was adapted from Morris (1993). Local pivot points in each melody were selected to create a subset of maxima and minima, from which local pivots were again selected to create a smaller subset, and so on until a final contour configuration remained. Each note was assigned a depth value corresponding to the number of times it was present at reduced hierarchical levels of the contour analysis. An example of contour reduction for one excerpt is presented in Figure 2. The global pivot variable was a simpler coding of local and global contour pivot points. This variable augmented the value of a local pivot by one point if it was the highest or lowest note in the melody.

Two pitch accent variables, *melodic leaps* and *distance from mean pitch,* quantified pitch accent resulting from interval size and registral extreme. Melodic leaps coded accent strength for notes preceded by large melodic leaps, depending on whether the size of the preceding leap was large (four or more semitones) or very large (seven or more semitones). The distance from mean pitch variable calculated each note's absolute distance from the mean pitch, divided by the melodic range of the excerpt to create a relative measure of pitch excursion within the melody.

Two variables, *pattern repetition* and *note repetition,* were created to predict accents resulting from melodic repetition. For pattern repetition, any note at the beginning of a repeated melodic fragment was given a value according to whether the repetition was exact or transposed and the number of times the fragment was repeated throughout the melody. For note repetition, notes were given points if they were immediately repeated, and they were incremented further when there were additional repeated notes in the excerpt. When a single note was repeated at nonadjacent positions, it was also incremented in value at each position, depending on the number of repetitions.

To correlate these variables with the judgments, we subsequently reduced accent values for individual positions to a single metrical prediction per excerpt. These predictions were calculated by taking the difference between the average accent values for Positions 3 and 5 and the accent value for Position 4. These positions in the melody were crucial for making the distinction between 3/4 and 6/8. Thus, if the averaged accent value for Positions 3 and 5 was greater than the accent value for Position 4, the prediction value was positive, indicating 3/4 meter. If the accent value for Position 4 was greater than the average accent value for Positions 3 and 5, the prediction value was negative, indicating 6/8. Because listeners were required to indicate the perceived meter of each excerpt on a scale of 1 (*strongly 6/8*) to 6 (*strongly 3/4*), a positive correlation between responses and a given variable indicated a match between that variable and listeners' perceptions.

Two harmonic variables, *triadic outlining* and *harmonic change,* quantified potential effects of implied harmony. To code triadic outlining, we assigned excerpts points if they contained nonadjacent alternating notes that outlined members of a triad. The number of points assigned depended on whether the triad was major or minor and whether the outlining was sequential or nonsequential. It was assumed that highly coherent triadic outlining, as in a sequentially outlined major triad, would be most salient, and the most points were assigned in this case. For harmonic change, the harmonic strength of note groups supporting 3/4 or 6/8 was coded according to whether those notes formed part or all of a triad. If two note groups in a given melody implied different harmonies, that melody was given a value based on the strength of both groups. An intermediate coding stage is illustrated in the center melody of Figure 5, showing individual note values for two different harmonic groups that imply 6/8. Coding methods for both harmonic variables ultimately specified single point values for entire excerpts and not for individual notes, as described in the Appendix.

Finally, *tempo* was included as a dichotomous variable (1 = *fast,* 2 = *slow*) to control for its effect on perceived meter. We anticipated that listeners would be biased toward larger subdivisions (6/8) in the fast tempo

Pitch	E	G	C	E	G	C	G		G	G	G	A	F	D	G		F	E	F	E	F	G	A
TA	1	.33	.56	.12	.09	.56	.17		1	0	0	.83	.09	.36	.29		1	.71	.24	.12	.09	.22	.67
LP	0	0	1	1	0	1	0		0	0	0	1	0	1	0		0	1	1	1	0	0	0
CR	2	0	2	1	0	1	2		3	2	1	3	0	3	3		2	2	1	2	0	0	2
GP	0	0	2	2	0	2	0		0	0	0	2	0	2	0		0	2	1	2	0	0	0
ML	0	0	1	2	0	1	2		0	0	0	0	1	0	1		0	0	0	0	0	0	0
DM	3.6	.57	4.4	3.6	.57	4.4	.57		.57	.57	.57	2.5	.43	4.4	.57		.57	1.6	.57	1.6	.57	1.4	3.4
PR	5	0	0	5	0	0	0		0	0	0	0	0	0	0		4	0	4	0	0	0	0
NR	0	0	0	0	0	0	0		2	0	1	1	0	0	2		2	0	2	-1	2	0	0
TO	2	2	2	2	2	2	2		0	0	0	0	0	0	0		0	0	0	0	0	0	0
HC	0	0	0	0	0	0	0		1	1	1	4	4	4	0		0	0	0	0	0	0	0

Figure 5. Sample coding of ten melodic accent types for three different excerpts in Experiment 1. The variables are Thomassen accent (TA), local pivot (LP), contour reduction (CR), global pivot (GP), melodic leaps (ML), distance from mean pitch (DM), pattern repetition (PR), note repetition (NR), triadic outlining (TO), and harmonic change (HC). Detailed descriptions of each accent type are given in the Appendix.

and smaller subdivisions (3/4) in the slow tempo because listeners tend to prefer an intermediate beat frequency at 600 ms (Fraisse, 1978; Parncutt, 1994).

Results and Discussion

Participants' responses along the scale from 1 (*strongly 6/8*) to 6 (*strongly 3/4*) were used as a dependent measure of perceived meter. Mean responses for both meters and tempos are presented in Figure 6. We first assessed the effects of tempo, scored meter, and formal musical training on perceived meter. Participants were categorized into groups with *high* (8 or more years) or *low* (less than 8 years) musical training. Responses for each participant were averaged across excerpts in each meter for each tempo and submitted to a three-way mixed-design analysis of variance (ANOVA) with tempo (fast vs. slow; within subject), scored meter (3/4 vs. 6/8; within subject), and musical training (low vs. high; between subjects) as variables. This analysis revealed significant main effects of tempo, $F(1, 21) = 7.16$, $p < .05$, and scored meter, $F(1, 21) = 11.95$, $p < .01$, but no main effect of musical training. There were no significant interactions. The lack of a main effect for musical training indicated that musicians were not better than nonmusicians at identifying the scored meter. Listeners tended to perceive slow excerpts as 3/4 and fast excerpts as 6/8. This result replicates previous findings showing that listeners tend to prefer moderately sized interbeat intervals of 600 ms, perceiving smaller subdivisions at slow tempos and larger subdivisions at fast tempos (Handel & Lawson, 1983; Parncutt, 1994).

Participants were more likely to perceive an excerpt in the scored meter. However, the percentage of correct matches between perceived and scored meter was only 56% when responses on the scale were dichotomized into two metrical categories (1–3 = 6/8, 4–6 = 3/4). This relatively low percentage was not surprising given the ambiguous nature of the excerpts and the resulting difficulty of the task. We did not necessarily expect to find a match between scored and perceived meter for two primary reasons. First, because melodies in the *Essen* database (Schaffrath, 1995) were transcribed, scored meter reflects the metrical interpretation of the musicologist who created the transcription. Transcribed meter may have been influenced by factors present only in the original folk materials, such as the tempo, text, or expressive features of the original recording or performance. Second, even when the metrical structure of a piece is known (as in the case of a particular type of dance, such as a jig or reel), musicians and composers may intentionally include conflicting cues to meter as a means of creating metrical ambiguity or tension and, thus, provoking interest (Creston, 1961).

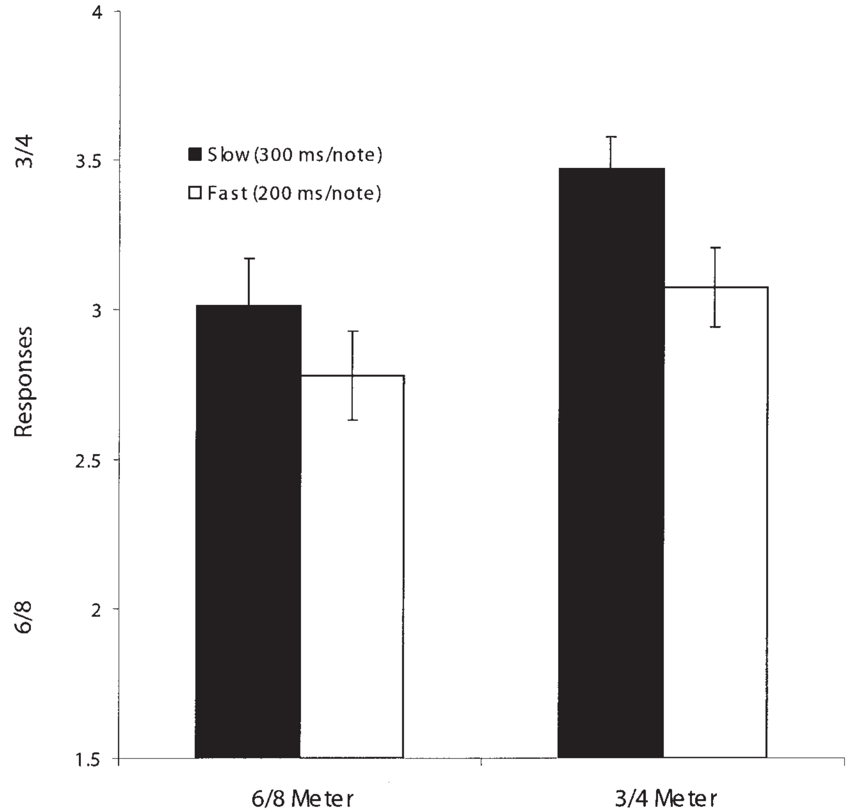

Figure 6. Mean meter judgments along the scale from 1 (*strongly 6/8*) to 6 (*strongly 3/4*) for slow versus fast excerpts that were scored in 6/8 or 3/4 meter in Experiment 1. Listeners were more likely to hear an excerpt in 3/4 when it was scored in 3/4 and more likely to hear an excerpt in 6/8 when it was scored in 6/8. When the tempo was fast, listeners were more likely to choose 6/8, and when it was slow, they were more likely to choose 3/4. Error bars represent standard errors of the mean.

The primary goal of the present study was to account for perceived meter using melodic accent features in these short excerpts, regardless of whether responses corresponded to the scored meter. To assess whether the combined melodic accents predicted listeners' responses, we regressed the predictions of 10 melodic accent variables and tempo onto the averaged responses along the judgment scale. The overall prediction level for the combined variables was high and significant, $R(11, 116) = .73$, $p < .01$. Because variables were expected to overlap, we assessed the unique contribution of each variable by calculating semipartial correlations. A semipartial correlation reflects the incremental contribution of an individual variable in predicting the dependent variable; it is equivalent to the amount by which the predictive strength of a model R drops when a given variable is removed from the regression (Darlington, 1990). When variables in a multiple regression are correlated, semipartial correlations can reveal the unique proportion of variance explained by a given variable, above and beyond the combination of all other variables.

Table 1 presents the semipartial correlations and the simple correlations for each variable. Note that simple correlations for many of the variables were significant but somewhat low. This suggests that in isolation, individual melodic accent types accounted for only a small proportion of the variance, but in combination they had a much greater predictive strength, as reflected

Table 1
Multiple Regression Results for All Variables in Experiment 1

Variable type	R	R^2	sr	r
All	.73**	.53**		
Pitch accent	.46**	.21**		
Thomassen accent			.00	.39**
Local pivot			.14**	.18*
Contour reduction			.03	.23**
Global pivot			.10†	.20*
Melodic leaps			.09	.33**
Distance from mean pitch			.03	.10
Repetition	.60**	.36**		
Pattern repetition			.23**	.43**
Note repetition			.24**	.52**
Harmonic	.25*	.06*		
Triadic outlining			.00	.11
Harmonic change			.07	.23**
Tempo			.19**	.23**

Note. A semipartial correlation (sr) reflects the incremental contribution of an individual variable in predicting the dependent variable; it is equivalent to the amount by which the predictive strength of a model R drops when a given variable is removed from the regression.
† $p = .06$. * $p < .05$. ** $p < .01$.

by the high multiple correlation. Variables with a significant unique contribution, as reflected by the semipartial correlation, were local pivots, pattern repetition, note repetition, and tempo. The semipartial correlation of global pivots approached significance ($p = .06$). Variables with significant simple correlations but low semipartial correlations did not make significant unique contributions because they correlated with one or more other variables that predicted responses equally well or better.

The simple coding of local contour pivot points outperformed the Thomassen (1982) model. This could have resulted from the presence of repetition variables in this model. As shown in Table 1, the simple correlation for Thomassen accent was higher than the simple correlation for local pivots. The note repetition variable may have overlapped with the predictions of the Thomassen model and thus taken some of its unique predictive strength.

Several observations suggest that it would be desirable to test the predictors with longer musical sequences. The nearly significant semipartial correlation of global pivots suggests that global melodic shape played a unique role in predicting perceived accent. In this experiment we used short, one-measure melodies, which left few instances in which global and local pivot values could conflict or make nonoverlapping predictions. Moreover, because of the short melody length, contour was inherently simple and lacked deep hierarchical structure. Examination of longer melodies may provide better information about the importance of contour reduction and global pivot points in predicting listeners' responses. Harmonic variables were not strong unique predictors of meter in this experiment, despite a significant simple correlation for harmonic change. Because unambiguous harmonic changes in these brief melodies were somewhat rare, these results do not necessarily suggest that harmonic change is not an important cue to meter in some cases. Longer melodies with more harmonic changes may reveal stronger effects of harmony.

Experiment 2

In Experiment 1, stimuli were short, one-measure excerpts, which may have biased results in favor of the more local coding strategies, such as local pivot points and the Thomassen (1982) accent. In addition, the short length may have obscured effects of implied harmony, because harmonic changes were infrequent in the brief excerpts. The second experiment attempted to address these possibilities using excerpts that were twice as long. Because these excerpts were also isochronous melodies, the second experiment allowed us to replicate and extend the findings of Experiment 1 with a different set of excerpts. In addition, we wanted to see if the importance of melodic cues might change over the course of a stimulus. To do this, we contrasted the predictions for the first measure with the predictions for the second measure to determine whether melodic cues to meter might change over the course of a melody and how this would affect metrical interpretations.

Method

Participants. Twenty members (7 female, 13 male; ages 18–40 years) of the Florida Atlantic University community participated in the experiment. All participants received course credit for their participation. Their average amount of formal musical training was 2.2 years (range: 0–30 years). None of the participants reported having perfect pitch or hearing problems.

Materials. Thirty isochronous, 13-note excerpts were selected from the *Essen* database (Schaffrath, 1995) and from a selection of European folk dances (Society for International Folk Dancing, 1966). Ten excerpts were scored in 6/8, and 20 were scored in 3/4. This imbalance arose because two-measure isochronous excerpts were more rare in 6/8 than in 3/4. Each excerpt consisted of two measures, with 6 eighth notes in each measure, plus the 1st note of the third measure. As in Experiment 1, each measure could be perceived as three beats subdivided into 2 eighth notes or two beats subdivided into 3 eighth notes. For each trial, the 13-note excerpts were repeated for six cycles, with a 5-note silence between cycles. All melodies were created in MIDI format and played with a grand piano timbre.

As in Experiment 1, each excerpt was presented at a fast tempo of 200 ms per note and a slow tempo of 300 ms per note. The combination of tempo and meter resulted in potential interbeat intervals of 400 ms, 600 ms, or 900 ms. Trials alternated between slow and fast tempi. The drum accompaniments were created exactly as in Experiment 1. Practice trials consisted of three additional 13-note excerpts, which were presented at slow and fast tempi.

Apparatus. The equipment and setup were identical to those in Experiment 1, with the following changes. The music was played under the control of a 450-MHz Macintosh G3 computer using MAX (Version 3.6.2) software. The MAX interface displayed instructions and played all stimuli by sending the MIDI information to a Kurzweil K2500RS sampling synthesizer. Stimuli were presented to participants over Sennheiser HD250 headphones.

Procedure. The task was identical to that of Experiment 1. The experiment was divided into two blocks of 30 trials, preceded by a practice block of 6 trials. The 60 experimental stimuli were randomly assigned to one of two experimental blocks, and fast and slow versions of each excerpt were presented in separate blocks. Each participant received a unique random ordering of the stimuli for each block. Starting tempo was balanced across participants so that half started with a slow stimulus and half started with a fast stimulus. The procedure of Experiment 2 was otherwise identical to that of Experiment 1, except that the experiment lasted 30 min instead of 50 min.

Variable coding. All variables were coded as in Experiment 1, with the following modifications. The repetition variables in Experiment 1 coded repetition that occurred throughout the entire seven-note excerpt. Because we did not know whether repetition accents would be salient to listeners over an entire two-measure excerpt, we coded repetition in two ways. Pattern repetition and note repetition variables only coded repeating note groups within each measure of the excerpt. We also created *holistic* versions of each repetition variable, which coded for repetition regardless of measure boundaries. The holistic coding can be likened to the global pivot and contour reduction variables because it assumes that listeners can integrate information over a larger span of time, in this case over the course of a two-measure melody. Descriptions of holistic pattern repetition and holistic note repetition are given in the Appendix.

Results and Discussion

Participants' judgments of the best fitting metrical accompaniment were used as a dependent measure of perceived meter. As in Experiment 1, formal musical training was categorized into high (8 years or more) and low (less than 8 years) groups. We first assessed the effects of scored meter, tempo, and formal musical training on perceived meter by performing a three-way mixed-design ANOVA with tempo (fast vs. slow; within subject), scored meter (3/4 vs. 6/8; within subject), and musical training (low vs. high; between subjects) as variables. This analysis revealed a significant main effect of scored meter, $F(1, 18) = 8.86$, $p < .01$, but no main effects of tempo or musical training. There were no significant interactions. Figure 7 illustrates that listeners again tended to perceive the meter that corresponded to the scored meter of the excerpt. When responses were dichotomized as either 3/4 or 6/8, the percentage of responses matching the scored meter was 70%. Although tempo did not have a strong effect on responses, the means indicate a trend in the same direction as in Experiment 1, at least for 3/4 melodies, with faster melodies decreasing the tendency for listeners to indicate 3/4.

The predictions of the 12 melodic accent variables and tempo were regressed onto the mean responses along the scale. As in Experiment 1, the combined variables predicted listeners' responses quite well, $R(13, 46) = .76$, $p < .01$. Table 2 presents the semipartial correlations and the simple correlations for each variable. As in Experiment 1, many of the individual variables had significant simple correlations, but the semipartial correlations indicate that only a subset made unique contributions to the fit of the model.

Contour change was again an important predictor of perceived meter. In contrast to Experiment 1, the Thomassen accent and contour reduction variables outperformed the local and global pivot variables. Importantly, global melodic shape uniquely predicted perceived meter, as reflected by the significant semipartial correlation for contour reduction. This finding is consistent with the idea that global melodic structure may become increasingly important as melody length increases and as the contour and hierarchical structure become more complex.

Listeners appeared to notice repetition regardless of measure boundaries, as reflected by significant semipartial correlations for both holistic pattern repetition and holistic note repetition. Both holistic repetition variables outperformed the local repetition variables, indicating that listeners remembered and noticed repetition over the entire melody, at least for two-measure excerpts. In general, the strong contributions of global pitch accent variables as well as holistic repetition variables suggest that listeners integrate information about melodic structure and accent over a wider temporal span than has commonly been assumed (e.g., Thomassen, 1982). Despite the increased melody length, however, neither of the harmonic variables contributed uniquely to the model, suggesting that implied harmonic change and triadic outlining did not predict perceived accent. It is also possible, however, that the present coding failed to capture the effects of harmonic information.

To assess whether melodic accents consistently supported metrical structures over the course of the entire excerpt, we compared first-measure predictions with second-measure predictions. Figure 8A presents intermeasure correlations, which are simple correlations between first- and second-measure predictions for each variable. Although all variables had positive intermeasure correlations, a number of them were nonsignificant. Therefore, such variables could have predicted responses poorly because they were poor predictors overall or because they only predicted responses in the first or second measure but not in both measures.

Simple correlations between responses and those variables with low intermeasure correlations were therefore examined separately for Measures 1 and 2. Figure 8B displays the simple correlations for the first and second measures of variables with low and nonsignificant intermeasure correlations. For all variables except contour reduction, first-measure predictions were better correlated

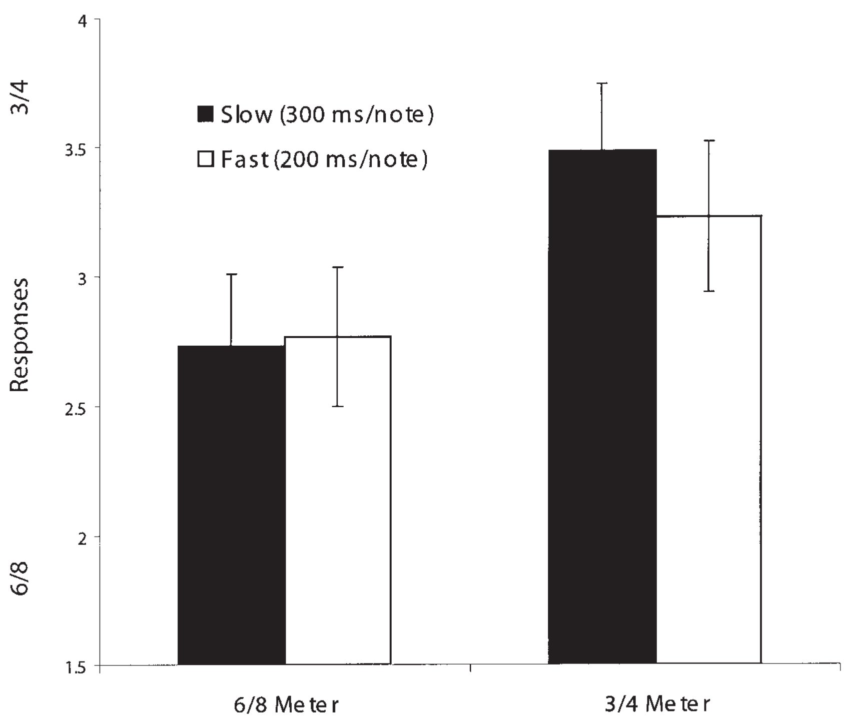

Figure 7. Mean meter judgments along the scale from 1 (*strongly 6/8*) to 6 (*strongly 3/4*) for slow versus fast excerpts that were scored in 6/8 or 3/4 meter in Experiment 2. There was a significant main effect of scored meter but not of tempo. Error bars represent standard errors of the mean.

Table 2
Multiple Regression Results for All Variables in Experiment 2

Variable type	R	R^2	sr	r
All	.76**	.58**		
Pitch accent	.69**	.47**		
Thomassen accent			.37**	.49**
Local pivot			.00	.13
Contour reduction			.22**	.38**
Global pivot			.13	.17
Melodic leaps			.05	.28*
Distance from mean pitch			.00	.18
Repetition	.47**	.22**		
Pattern repetition			.05	.30*
Holistic pattern repetition			.19*	.43**
Note repetition			.07	.35**
Holistic note repetition			.15*	.30*
Harmonic	.17	.03		
Triadic outlining			.07	−.01
Harmonic change			.00	.17
Tempo			.07	.09

Note. A semipartial correlation (sr) reflects the incremental contribution of an individual variable in predicting the dependent variable; it is equivalent to the amount by which the predictive strength of a model R drops when a given variable is removed from the regression.
* $p < .05$. ** $p < .01$.

with responses than were second-measure predictions. In addition, the Thomassen accent and melodic leaps variables had significant simple correlations in the first measure but not in the second. Thus, variables that are inconsistent over the course of an excerpt may contain segments, particularly at the beginning of the excerpt, that do predict listeners' responses, as in the case of melodic leaps. This might arise from a general strategy of listeners to attend to accent information at the beginning of a piece of music, making early decisions about meter. It might also reflect the tendency for melodies to begin with accent information that is maximally salient and thus predictive of perceived meter.

To summarize, Experiment 2 replicated several of the findings in Experiment 1 with a new set of melodies and a new set of participants. Results confirmed that contour change is an important melodic cue to meter. As predicted, increasing melody length improved the predictive strength of the contour reduction variable, perhaps as a result of the increased hierarchical complexity of contour structure in longer melodies. Similarly, holistic coding strategies for both types of repetition were more predictive than single-measure coding strategies. The short length of melodies in Experiment 1 was not, however, responsible for the weakness of the harmonic variables, because they also failed to contribute uniquely in Experiment 2. Finally, Experiment 2 sheds some light on the temporal course of meter induction, indicating that some melodic cues to meter may influence perceptions more at the beginning of a melody.

Experiment 3

Experiments 1 and 2 measured several important melodic cues to meter that had not been previously investigated. They confirmed, with melodic sequences that do not contain temporal cues, that listeners' judgments of meter can be predicted by melodic information alone. Most music, however, is not isochronous but contains tones of different durations. The pattern of varying duration may provide strong temporal cues to meter. Do melodic cues influence listeners' perception of meter only in the absence of temporal cues, or do melodic and temporal cues simultaneously and interactively determine perception? Experiment 3 addressed this question by presenting listeners with a new set of melodies that were nonisochronous. Listeners' responses were compared with the predictions of the strongest melodic accent variables from Experiments 1 and 2 as well as predictions of three temporal accent variables.

Method

Participants. The participants from Experiment 2 also participated in Experiment 3.

Materials. Thirty excerpts were selected from a collection of European folk dances (Society for International Folk Dancing, 1966). There were several criteria for selection. All excerpts consisted of two measures plus the 1st note of the third measure. Melodies contained 8 to 12 notes of three IOIs, corresponding to an eighth note, a quarter note, and a dotted quarter note. As in Experiments 1 and 2, articulation was legato, and there were no rests (silent durations) between notes. Fifteen excerpts were scored in 6/8, and fifteen were scored in 3/4. Similar to Experiments 1 and 2, excerpts could be perceived as containing two or three beats per measure. For each trial, the excerpts were repeated for six cycles, with a 5-note silence between cycles. The tempi, drum accompaniments, block structure, orders, and practice trials were created exactly as in Experiment 2.

Apparatus and procedure. The apparatus and procedure were identical to those in Experiment 2.

Variable coding. Only the variables from Experiments 1 and 2 with the strongest unique contributions were included in the melodic analysis for Experiment 3. These variables were Thomassen accent, local pivot, contour reduction, global pivot, holistic pattern repetition, holistic note repetition, and tempo.

In addition, three temporal variables, based on Povel and Essens (1985), were created to code effects of *note onset, temporal grouping,* and *note duration.* Every note onset was given one point. To code grouping position, notes were given a point if they were (a) the first or last of a group of three or more notes, (b) the second of a two-note group, or (c) isolated. Finally, note duration, which refers to the IOI between notes, was coded by assigning one point to any note duration greater than an eighth note. A detailed description of each temporal variable can be found in the Appendix.

Results and Discussion

We assessed the effects of tempo, scored meter, and formal musical training by performing a three-way mixed design ANOVA on the mean responses, with tempo (fast vs. slow; within subject), scored meter (3/4 vs. 6/8; within subject), and musical training (low vs. high; between subjects) as variables. This test revealed a significant main effect of scored meter, $F(1, 18) = 33.52$, $p = .01$, but no main effects of tempo or musical training. There were no significant interactions. The mean responses for each meter and tempo are shown in Figure 9. Listeners' responses matched scored meter on 77% of trials. Although there was not a significant main effect of tempo, the means resemble the trend observed in Experiments 1 and 2, with slower excerpts more frequently perceived as 3/4 and faster excerpts more frequently perceived as 6/8.

The combined melodic and temporal variables predicted listeners' responses quite well. The nine variables and tempo were

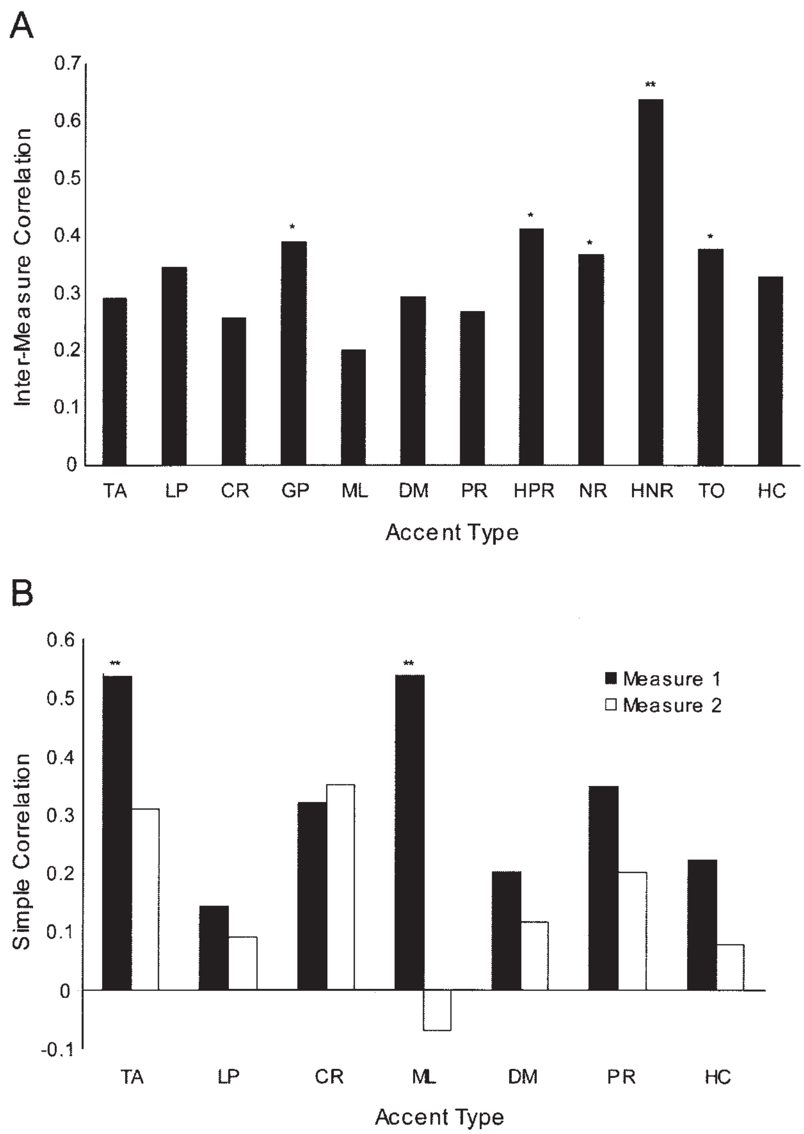

Figure 8. Comparisons of first- and second-measure predictions of all variables in Experiment 2. A: Inter-measure correlations for Thomassen accent (TA), local pivot (LP), contour reduction (CR), global pivot (GP), melodic leaps (ML), distance from mean pitch (DM), pattern repetition (PR), holistic pattern repetition (HPR), note repetition (NR), holistic note repetition (HNR), triadic outlining (TO), and harmonic change (HC). B: Simple correlations between responses and variable predictions, shown separately for each measure ($df = 28$). $^*p < .05$. $^{**}p < .01$.

regressed onto the average responses along the scale, yielding a high and significant prediction rate, $R(10, 49) = .86$, $p < .01$. The simple correlations and semipartial correlations for each variable are presented in Table 3. The semipartial correlations suggest that note duration and tempo were the strongest unique predictors of listeners' perceptions, replicating previous findings that duration and tempo influence perceived meter (Handel & Lawson, 1983; Parncutt, 1994; Povel & Essens, 1985). Moreover, the significant contribution of tempo shows that, despite the absence of a main effect of tempo in the above analysis, tempo did have an effect when other variables were controlled.

The most noteworthy finding is that melodic accent variables failed to make significant unique contributions in the presence of duration cues, despite strong unique contributions in the first two experiments. Table 4 displays simple correlations between all variables in Experiment 3, indicating that some melodic accent variables were significantly correlated with temporal accent variables. Note that both repetition variables had positive correlations with temporal variables, which suggests that their low semipartial correlations in the multiple regression may have been due to overlap with the temporal variables. Thus, although melodic repetition may have affected listeners' perceptions, it was redundant with the more dominant temporal variables, a result that is consistent with the idea that music contains multiple overlapping cues to meter. In contrast, pitch accent variables did not correlate with temporal variables, with the exception of contour reduction, which

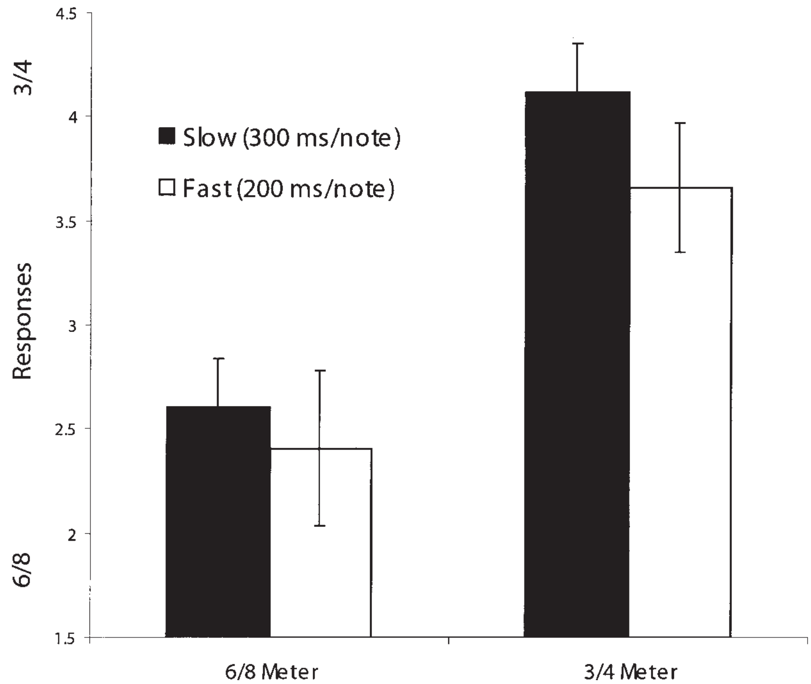

Figure 9. Mean meter judgments along the scale from 1 (*strongly 6/8*) to 6 (*strongly 3/4*) for slow versus fast excerpts that were scored in 6/8 or 3/4 meter in Experiment 3. There was a significant main effect of scored meter but not of tempo. Error bars represent standard errors of the mean.

correlated at a nearly significant level with only one temporal variable. This suggests that some pitch accent variables and temporal variables yielded different predictions for the excerpts and that listeners attended primarily to the temporal cues to meter.

It is possible that some pitch accent variables failed to predict responses not just because they differed from temporal variables but also because they were less consistent cues to meter overall. The intermeasure correlations for all variables are displayed in Figure 10A. In contrast to Experiment 2, the first- and second-measure predictions for all pitch accent variables were negatively correlated, suggesting that they made conflicting predictions. Figure 10B shows simple correlations between listeners' responses and accent variables with nonsignificant intermeasure correlations, revealing that, with the exception of contour reduction, pitch accent variables in either measure did not correlate significantly with responses. This contrasts with Experiment 2, in which first-measure predictions better predicted responses, even for variables that were weaker overall. The temporal variables did seem to predict better in the first measure, although both measures had significant simple correlations with responses.

Table 3
Multiple Regression Results for All Variables in Experiment 3

Variable type	R	R^2	sr	r
All	.86**	.75**		
Pitch accent	.36	.13		
Thomassen accent			.09	−.05
Local pivot			.09	.02
Contour reduction			.00	.27*
Global pivot			.10†	.02
Repetition	.51**	.26**		
Holistic pattern repetition			.07	.41**
Holistic note repetition			.04	.40**
Temporal	.82**	.68**		
Note onset			.07	.70**
Temporal grouping			.05	.72**
Note duration			.25**	.81**
Tempo			.11*	.15

Note. A semipartial correlation (sr) reflects the incremental contribution of an individual variable in predicting the dependent variable; it is equivalent to the amount by which the predictive strength of a model R drops when a given variable is removed from the regression.
† $p = .07$. * $p < .05$. ** $p < .01$.

One possibility to consider is that listeners assess which accent types are consistent or reliable cues to meter and then weigh them accordingly. This possibility is suggested by the finding that variables with conflicting predictions did not correlate with listeners' judgments. To test this possibility, we performed a second multiple regression analysis on a subset of 18 excerpts whose first- and second-measure pitch accent predictions did not conflict. We did this by taking the absolute difference between first- and second-measure pitch accent predictions and averaging these values across the four pitch accent variables for each excerpt. We then selected the excerpts with the lowest average differences. We thus excluded the excerpts with strongly conflicting first- and second-measure pitch accent predictions.

For this subset of excerpts, the overall prediction rate for the 10 variables was high and significant, $R(10, 25) = .92$, $p < .05$. The simple and semipartial correlations for each variable are presented in Table 5. It is important to note that contour reduction had a significant unique contribution. After contour reduction, the vari-

Table 4
Correlation Matrix for Variables in Experiment 3

Variable	TA	LP	CR	GP	HPR	HNR	NO	TG	ND
TA	—	.34†	.14	.32	−.12	.14	.04	−.06	.06
LP		—	.66**	.91**	−.07	.06	.17	.00	.00
CR			—	.68**	.21	.16	.34†	.16	.20
GP				—	−.20	.04	.11	−.01	−.07
HPR					—	.25	.28	.35†	.42*
HNR						—	.53**	.34†	.35†
NO							—	.77**	.76**
TG								—	.87**
ND									—

Note. TA = Thomassen accent; LP = local pivot; CR = contour reduction; GP = global pivot; HPR = holistic pattern repetition; HNR = holistic note repetition; NO = note onset; TG = temporal grouping; ND = note duration.
† $p < .07$. * $p < .05$. ** $p < .01$.

ables with the highest semipartial correlations were tempo, temporal grouping, and note duration. The absence of significant semipartial correlations for temporal variables, despite significant simple correlations, indicates that temporal variables were correlated with other variables in the regression. Thus, a high degree of overlap between temporal variables likely reduced their unique contributions, even though temporal variables were highly predictive as a group, $R(3, 32) = .88$, $p < .01$. The pitch accent variables as a group were much better predictors with this subset of excerpts, $R(4, 31) = .60$, $p < .01$, than with the entire set, $R(4, 55) = .36$, *ns.* Thus, the consistency of individual accent types may be important for predicting perceptions of meter, because the relative predictive strength of variables can be improved if instances in which those variables provide conflicting information are eliminated.

To summarize, our findings suggest that temporal accents have a primary role in predicting perceived meter. However, melodic cues that are consistent over the course of a melody may contribute uniquely even in the presence of temporal information. The analysis of the excerpts suggests that pitch accent variables may have failed to make unique predictions because they were inconsistent. Additionally, temporal variables may have outperformed melodic repetition variables due to overlapping predictions. We have provided some evidence that listeners were capable of assessing the reliability of accent types to the extent that they were more likely to ignore variables that gave conflicting information over the course of a melody.

General Discussion

Music presents the listener with rapidly changing information. Nonetheless, listeners can abstract from the rich and complex musical surface a coherent, abstract metrical structure that allows them to organize incoming information and anticipate future events in a dynamic fashion. In the present study, we have attempted to quantify and measure the effects of several types of simultaneous information that listeners may use to solve the problem of meter induction. Our findings indicate that a combination of multiple melodic accent types can reliably predict listeners' perceptions of meter. This conclusion is supported by experiments measuring listeners' perceptions of meter in one- and two-measure isochronous melodies as well as temporally varied two-measure melodies.

Contour change and melodic repetition appeared to be important cues to meter in isochronous melodies. For longer isochronous melodies, listeners integrated melodic information over the course of the entire excerpt, as indicated by the dominance of variables that coded the melodic sequences holistically (ignoring measure boundaries). Note that duration dominated perception of meter in the rhythmically varied melodies, although several melodic variables did correlate with listeners' responses. Moreover, when excerpts with conflicting pitch accent cues were eliminated from the analysis, pitch accent variables improved in predictive strength, and temporal variables continued to predict responses for this subset. Overall, our results indicate that listeners are able to combine information from various musical structures to perceive meter and that they are sensitive to the reliability of such information over the course of an excerpt.

Past research has suggested that melodic cues are unreliable predictors of meter (Drake & Palmer, 1993; Snyder & Krumhansl, 2001; Woodrow, 1911). These studies have usually either focused on a single type of melodic accent or studied melodic accents only in the context of strong temporal cues to meter. By measuring the effects of several simultaneous melodic accent types in the presence and absence of temporal variation, however, we found that melodic cues can predict listeners' perceptions and should therefore be incorporated into theoretical accounts of meter perception. Our approach of quantifying melodic accent types may benefit models of meter induction, which currently rely almost exclusively on temporal and intensity information (Large, 2000; Longuet-Higgins & Lee, 1982; Povel & Essens, 1985; Todd, O'Boyle, & Lee, 1999).

An important feature of the present approach is our assumption that listeners efficiently combine melodic cues in a probabilistic manner, processing several types of information simultaneously. We did not expect that listeners would rely on any one type of accent to perceive meter but, rather, that they would rely on a combination of accent types. This account parallels approaches to speech segmentation that use multiple prosodic cues to reliably identify word boundaries where individual prosodic cues fail (Christiansen et al., 1998). Because music provides varied sources

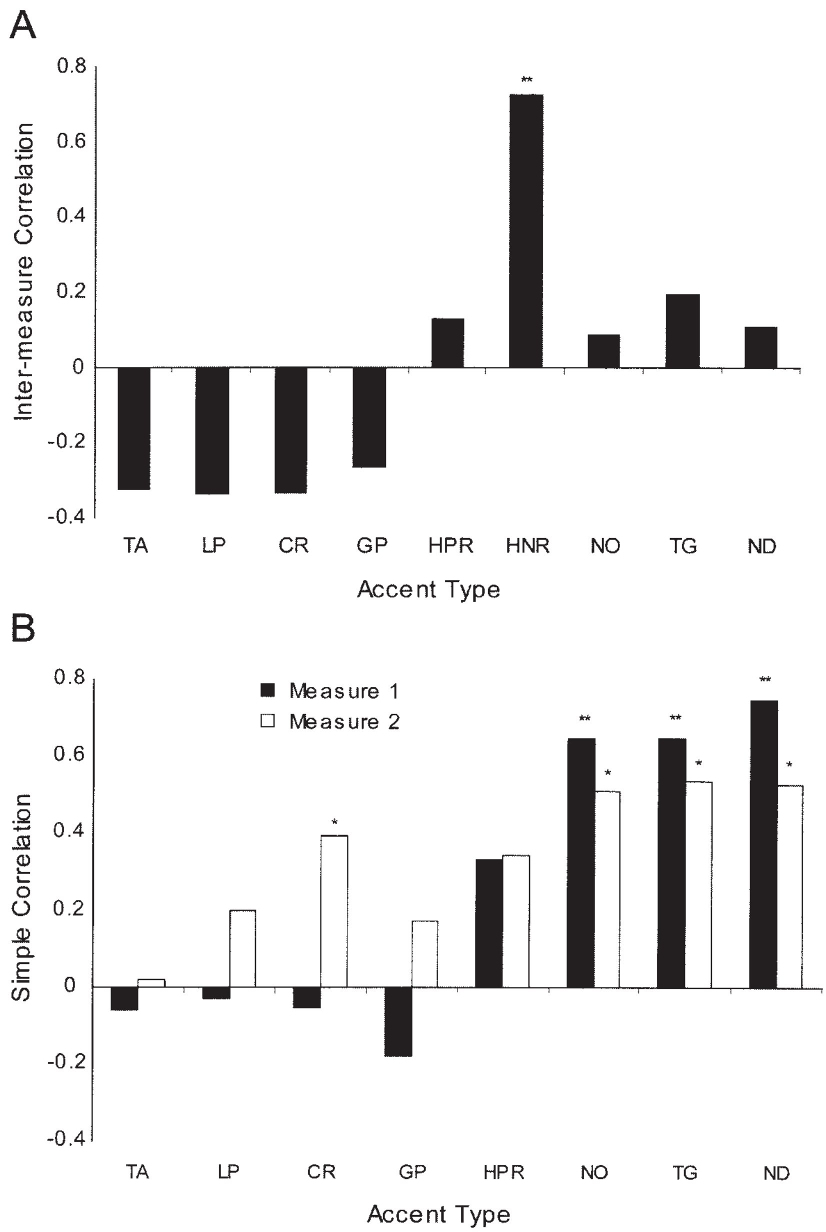

Figure 10. Comparisons of first- and second-measure predictions of all variables in Experiment 3. A: Intermeasure correlations for Thomassen accent (TA), local pivot (LP), contour reduction (CR), global pivot (GP), holistic pattern repetition (HPR), holistic note repetition (HNR), note onset (NO), temporal grouping (TG), and note duration (ND). B: Simple correlations between responses and variable predictions, shown separately for each measure ($df = 28$). $*p < .05$. $**p < .01$.

of information in both temporal structure and pitch structure, an effective perceptual system would identify which stimulus dimensions reliably convey the meter and dynamically adapt to the quality of information during processing. We have provided evidence for this by showing that listeners were more likely to ignore cues when these provided conflicting information over the course of a stimulus. Our findings suggest that individual cues will be more or less predictive depending on their reliability over time and the reliability and covariation of other simultaneous accent types.

There has been a long-standing tradition of theorizing about pitch and rhythm as separate and independent dimensions of music (for a review, see Krumhansl, 2000). Behavioral data from adults with and without brain damage support the idea that melodic and rhythmic information is processed separately (Palmer & Krumhansl, 1987; Peretz & Kolinsky, 1993). It is perhaps because of such evidence that theories of meter have not generally incorporated pitch and melodic structure. Our results indicate that when temporal information is available, it dominates over melodic cues,

Table 5
Multiple Regression Results for All Variables in the Excerpt Subset of Experiment 3

Variable type	R	R^2	sr	r
All	.92**	.84**		
Pitch accent	.60**	.36**		
Thomassen accent			.10	.00
Local pivot			.03	.00
Contour reduction			.12*	.28
Global pivot			.03	−.13
Repetition	.65**	.43**		
Holistic pattern repetition			.00	.65**
Holistic note repetition			.05	.35*
Temporal	.88**	.77**		
Note onset			.03	.70**
Temporal grouping			.10	.80**
Note duration			.09	.87**
Tempo			.10†	.14

Note. A semipartial correlation (sr) reflects the incremental contribution of an individual variable in predicting the dependent variable; it is equivalent to the amount by which the predictive strength of a model R drops when a given variable is removed from the regression.
† $p = .09$. * $p < .05$. ** $p < .01$.

a result that replicates previous findings (Bigand, 1997; Snyder & Krumhansl, 2001; Woodrow, 1911). This might be expected if pitch and rhythm are processed separately, because listeners appear to bypass melodic information when temporal cues are present. However, it is also possible that listeners attend more to the cues that are most reliable, regardless of whether those cues are temporal or melodic. Thus, listeners may process both melodic and temporal cues simultaneously but attend more to duration information, which would obscure effects of covarying melodic accents.

Listeners' tendency to rely on note duration could result from experience with music in which note duration is a more reliable cue to meter than melodic accent. Pitch patterns may be governed by any number of constraints, such as harmonic, grouping, or motivic structure, but note duration may most consistently mark the metrical structure. This suggestion is supported by Huron and Royal (1996), who found that note duration was the best predictor of scored meter in Western folk melodies. Our own searches of the *Essen Folk Song Collection* (Schaffrath, 1995) and the *Finnish Folk Song Collection* (Eerola & Toiviainen, 2004) revealed that melodies rarely begin with isochronous passages: Approximately 7.6% of melodies in 3/4 and 6/8 begin with one measure of 6 isochronous notes, and only 1.0% of melodies begin with two measures of 12 isochronous notes. Variation in note duration is usually present at the beginning of melodies, where it would be important for meter induction, thus diminishing the importance of melodic accents. This could explain why pitch accents were least consistent for the rhythmically varied stimuli in our last experiment. Perhaps temporal cues to meter provide a strong metrical framework that allows pitch to vary independently of meter.

The present experiments, which obtained only one response per melody, did not track possible changes in metrical interpretation over time. Changes could arise from variations in either the prevalence of various cue types or the perceptual salience of cues. We found that the first and second measures of the excerpts differed in both the metrical cues that were present and the predictive strength of some of the accent variables. However, our method did not allow us to track possible changes in the perceived meter over time. Using other measures, such as tapping (Snyder & Krumhansl, 2001; Toiviainen & Snyder, 2003) and event-related potentials (Brochard, Abecasis, Potter, Ragot, & Drake, 2003; Snyder & Large, 2004; Snyder, Zanto, Large, & Kelso, 2003), may provide more dynamic measures of the relative strength of melodic accent types over the course of longer musical passages. Obtaining multiple responses with such methods could enable documentation of multiple metrical interpretations for a single excerpt, such as when strong surface accents result in a metrical reinterpretation part way through an excerpt.

The present findings have important implications for how listeners perceive meter in music, a topic that has been the subject of music-theoretical, perceptual, and computational interest (for a review, see Clarke, 1999). Although temporal accents are well-documented cues to metrical structure, the effects of individual melodic cues have been difficult to assess because of their limited predictive strength in isolation. We have shown that by combining multiple types of melodic information, it is possible to predict how listeners perceive the meter of short melodic excerpts in the presence and in the absence of temporal accents. Our results provide evidence that listeners exploit the rich surface structure of music in order to perceive meter, dynamically adapting their listening strategies depending on the availability, past reliability, and current strength of both melodic and temporal cues.

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Appendix

Coding of Accent Variables

The variables described below attempt to quantify features of melodies that give rise to accent. In many cases, the coding of features corresponded to findings in the empirical and theoretical literature, and in some cases coding details were guided by our intuitions. A lack of predictive strength for a given variable may suggest that the particular accent type does not influence listeners' judgments of meter, or it may suggest that the variable was not quantified in a way that was optimal.

For most variables, an accent value was assigned to each note in each excerpt. The distribution of accents on Positions 3, 4, and 5 of the measure was essential for perceiving the meter in the task. Accents on Positions 3 and 5 supported 3/4, whereas accents on Position 4 supported 6/8. Predictions for all pitch accent, repetition, and temporal variables were therefore based on accent values for those note positions. For each excerpt, the value of Note 4 was subtracted from the value of Note 3, the value of Note 4 was subtracted from the value of Note 5, and then these differences were averaged. The two harmonic variables had a different way of quantifying predictions for each excerpt, as described in detail below. With the exception of holistic repetition variables, all variables yielded one prediction per measure. For the longer excerpts, single predictions were calculated by taking the average prediction for the two measures of the excerpt.

Pitch Accent Variables

Thomassen Accents

The Thomassen (1982) model specifies a set of accent values for any three-note contour configuration. These configurations include contour pivots as well as repetition and continuous contour trajectories. To predict accent in complex melodies, the model uses a moving window of three notes that go through a melody note by note. This results in three different accent values for all but the first and last notes of the melody, corresponding to the note's value in Positions 3, 2, and 1 of successive contour configuration windows. Following the methods of Thomassen, we multiplied these values to yield accent predictions for each note.

Local Pivot

This variable assigned a value of 1 to any note that was higher or lower than both of its immediately adjacent notes. All other notes received a value of 0. By default, the first and last notes of a melody received a value of 0.

Contour Reduction

This variable was adapted from Morris (1993). Melodies were first analyzed by flagging the local *maxima* and local *minima,* as well as the first and last notes of the melody. Maxima were defined as notes higher than or equal to immediately adjacent notes, and minima were defined as notes lower than or equal to immediately adjacent notes. Flagged notes were then analyzed as subsets of maxima and minima. Subsets of maxima were subsequently analyzed for their local contour maxima, and subsets of minima were analyzed for their local contour minima. The process was repeated until the contour could not be reduced further. Each note of the melody was then assigned a depth value according to the number of times it was present at reduced hierarchical levels of the contour analysis. Thus, any note that remained until the final level received the highest value (see Figure 2 for an example).

Global Pivot

This variable assigned a value of 1 to any note that was higher or lower than both of its immediately adjacent notes. If any of these pivots also happened to be the highest or lowest note in the entire melody, they were given a value of 2. All other notes received a value of 0. By default, the first and last notes of a melody received a value of 0.

Melodic Leaps

This variable coded accent strength for notes preceded by upward or downward melodic leaps. Instead of coding interval size continuously, we categorized leaps into two categories of *large* or *small* to emphasize the relative size of a leap instead of the magnitude. A note preceded by a small leap of four or more semitones received a value of 1. A note preceded by a large leap of seven or more semitones received a value of 2. All other notes received a value of 0. The assignment of intervals to large and small categories followed from previous research on melodic expectation (Krumhansl, 2000).

Distance From Mean Pitch

This variable calculated the relative distance between each note of the melody and the mean pitch of the melody. Pitches were assigned semitone values centered at middle C (C4 = 0, C4# = 1, etc.). The mean semitone value was calculated for each melody. The absolute difference between the melody's mean and each individual note was then calculated and divided by the range of the excerpt.

Repetition Variables

Pattern Repetition

This variable assigned accent values to notes on potential downbeat positions in both meters (Positions 1, 3, and 5 in 3/4 and Positions 1 and

4 in 6/8). The assigned values varied depending on whether the repeated fragment was transposed or exactly repeated. Although repetition occurred in many different positions, the following rules applied only to melodic patterns that occurred at downbeat positions in 3/4 and 6/8.

Transposed pattern repetition. The following points were assigned to the first note in every repeated but transposed melodic fragment. For these repeated fragments, the relative semitone relationships between all notes had to be exactly repeated at another pitch level.

1. First notes of repeated but transposed two-note patterns = 1 point.

2. Three repeated but transposed two-note patterns = 2 points.

3. Two repeated but transposed three-note patterns = 3 points.

4. If there were two or more transposed groups in the melody, additional points were added for every group (for *n* additional groups of repeated notes, *n* points were added to the first note of every group).

Exact pattern repetition. The following points were assigned to the first note in every exactly repeated melodic fragment.

5. First notes of two exactly repeated two-note patterns = 4 points.

6. (a) First notes of two exactly repeated three-note patterns = 5 points.

   (b) First notes of three exactly repeated two-note patterns = 5 points.

7. If there were two or more exactly repeated groups in the melody, additional points were added for every group (for *n* additional groups of repeated notes, *n* points were added to the first note of every group).

Holistic Pattern Repetition

This variable was applied only to the two-measure excerpts in Experiments 2 and 3. Coding was identical to that for pattern repetition except that points were added to notes beginning repeated patterns within and across the two measures, not just those beginning repeated patterns within the measure.

Note Repetition

This variable coded repetition of individual notes that were adjacent as well as individual notes that were repeated at nonadjacent positions. It also coded for accents that resulted from a note's proximity to a group of immediately repeated notes or for the weakening of a repeated note's accent value as a result of its previous presence on a weak beat. The following rules apply only to notes occurring at potential downbeat positions.

Adjacent repetition.

1. First note in a series of two adjacent repeated notes = 1 point.

2. A note that immediately followed a group of three or more adjacent and repeating notes = 2 points.

3. If there were two or more groups in the measure, additional points were added for every group (for *n* additional groups of repeated notes, *n* points were added to the first note of every group).

Nonadjacent repetition.

4. A note that was repeated at successive downbeat positions was incremented at each position by the number of times it was repeated (for *n* repetitions of a note, *n* points were added to that note at each repeated position).

Weakening nonadjacent repetition.

5. Within the measure, if a note initially presented on Position 2 was repeated on a strong beat that was not adjacent, 1 point was subtracted from the repeated note.

Holistic Note Repetition

This variable was applied only to the two-measure excerpts in Experiments 2 and 3. Coding was identical to that for note repetition, but values for adjacent and nonadjacent repetition were incremented further for groups that were repeated across measures.

Harmonic Variables

Triadic Outlining

This variable assigned points to excerpts if they contained notes at Positions 1, 3, and 5 in 3/4 that were members of a major or minor triad. Such outlining could occur sequentially, in order of lowest to highest pitch in a triad, or nonsequentially, in any order. If the downbeat of the following measure was not a member of the triad outlined in the previous measure, a point was subtracted from the total score. Numbers of points were assigned to each excerpt, with triadic outlining as described below. The Roman numerals represent scale degrees, with uppercase numerals representing major degrees and lowercase numerals representing minor degrees in the diatonic scale. Each excerpt was given the following number of points depending on the structure of the triad:

1. Major triad, outlined sequentially (I–iii–V or V–iii–I) = 4 points.

2. Minor triad, outlined sequentially (i–III–V or V–III–i) = 3 points.

3. Major triad outlined nonsequentially (no particular order) = 2 points.

4. Minor triad outlined nonsequentially = 1 point.

5. No triadic outlining = 0 points.

Harmonic Change

This variable coded implied harmonic change. Harmonic strength can be defined as the degree to which certain combinations of pitches are conventional in a given key. We used a simple hierarchy of four types of interval combinations (listed below). Harmonic strength was coded for 2-, 3-, or 4-note groups within the measure, and then a prediction was assigned

(*Appendix continues*)

if those groups implied different harmonies. This prediction was based on the strength of both groups. A value was calculated for a note group only if all tones were part or all of a triad. Therefore, note groups could consist of a unison; two members of a tonal interval, such as perfect fourth (P4), perfect fifth (P5), major or minor third (M3/m3), or major or minor sixth (M6/m6); or all three members of a triad. Notes in a melody could be broken up into 4 + 2 notes, supporting 3/4, or 3 + 3 notes, supporting 6/8. In both cases, the first group in the measure was called *Group A* and the second group was called *Group B.*

Points were assigned for each group to measure the harmonic strength of note groups:

1. Notes were three members of a triad = 4 points.
2. Notes were members of a P5 or P4 interval = 3 points.
3. Notes were members of an M3/m3 or M6/m6 interval = 2 points.
4. Notes were one repeated unison = 1 point.

If Groups A and B belonged to different triadic structures, harmonic change for the entire excerpt was calculated by taking the average score for Groups A and B. Two separate sets of scores were created for each excerpt, corresponding to the two meters (a 4 + 2 grouping structure or a 3 + 3 grouping structure). For each excerpt, the final prediction was calculated by subtracting the score in 6/8 from the score in 3/4, yielding a variable that ranged from −4 to 4 and could be directly entered into a regression with mean responses.

Temporal Variables

Note Onset

A position with an event onset was given a value of 1, and any position without a note onset was given a value of 0.

Temporal Grouping

Events were given a point if they were (a) the first or last of a group of three or more notes, (b) the second of a two-note group, or (c) isolated.

Note Duration

Note durations corresponded to the interonset interval of each event in a pattern. Any note having a duration greater than an eighth note received a point. All other events received a 0.

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