Research Article

Metrical Categories in Infancy and Adulthood

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ABSTRACT—*Intrinsic perceptual biases for simple duration ratios are thought to constrain the organization of rhythmic patterns in music. We tested that hypothesis by exposing listeners to folk melodies differing in metrical structure (simple or complex duration ratios), then testing them on alterations that preserved or violated the original metrical structure. Simple meters predominate in North American music, but complex meters are common in many other musical cultures. In Experiment 1, North American adults rated structure-violating alterations as less similar to the original version than structure-preserving alterations for simple-meter patterns but not for complex-meter patterns. In Experiment 2, adults of Bulgarian or Macedonian origin provided differential ratings to structure-violating and structure-preserving alterations in complex- as well as simple-meter contexts. In Experiment 3, 6-month-old infants responded differentially to structure-violating and structure-preserving alterations in both metrical contexts. These findings imply that the metrical biases of North American adults reflect enculturation processes rather than processing predispositions for simple meters.*

The most important aspect of music may be its capacity to facilitate human movement coordination. All cultures have sound patterns with repetitive temporal structures, which facilitate synchronous dancing, clapping, instrument playing, marching, and chanting (Brown, 2003). These communal activities imply universal propensities to coordinate movement in time. On occasion, however, listeners are challenged by the rhythmic structures of foreign music. For example, North American adults have difficulty perceiving the rhythmic organization of classical Indian music despite the ease with which Indian audiences clap in time. Such phenomena implicate processes of musical enculturation in shaping perceptual abilities.

Many scholars have documented powerful biases in the perception and production of rhythmic patterns. Musical patterns contain a range of interonset-interval (IOI) durations, but Western adults often fail to respond differentially to small but perceptible duration differences. Instead, they seem biased to perceive and produce durations with simple ratios. For example, their spontaneous productions reveal long and short durations in a 2:1 ratio (Fraisse, 1982), and their reproductions of rhythmic patterns reveal durations stretched or reduced to fit simple ratios (Collier & Wright, 1995; Cummins & Port, 1998). Even musicians mistakenly assign simple duration ratios to rhythms characterized by complex ratios (Desain & Honing, 2003). Once listeners assign a specific duration ratio, they continue to interpret the unfolding pattern in terms of that ratio despite perceptible temporal changes (Clarke, 1987; Large, 2000). These findings are consistent with categorization of duration ratios and with assimilation of complex to simple duration ratios.

Biases for simple duration ratios are thought to arise from adults' categorization of durations according to the hierarchical temporal structure of the music, or the *meter*. On hearing a rhythmic musical pattern, listeners tend to infer a primary, underlying pulse of equally spaced (i.e., isochronous) events; faster levels of this underlying pulse result from binary or ternary subdivisions. Meter gives rise to the perception of alternating strong and weak beats, as in the waltz pattern of "*one* two three, *one* two three, . . . ," which results from the convergence of faster and slower isochronous levels in a 3:1 ratio (see Fig. 1). Theoretical accounts of meter assume that the durations of a specific rhythmic pattern are assimilated to an internal periodic clock (Povel, 1981; Povel & Essens, 1985) or system of oscillators (Large & Kolen, 1994). Rhythms containing simple duration ratios are thought to have greater coherence than rhythms containing complex duration ratios because they are readily assimilated to such isochronous, hierarchical structures (Jones & Boltz, 1989; Jones, Moynihan, MacKenzie, & Puente, 2002).

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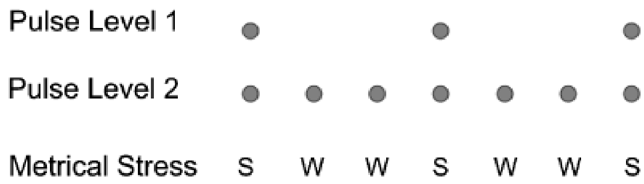

Fig. 1. Alternating strong (S) and weak (W) events in a metrical hierarchy of two isochronous pulse levels having a 3:1 ratio, typical of a waltz.

On the basis of the aforementioned findings, many scholars contend that intrinsic perceptual biases constrain the organization of rhythmic patterns. Specifically, "good" metrical structures are thought to consist of isochronous patterns at nested hierarchical levels that are related by simple integer ratios (Clarke, 1999; Povel & Essens, 1985). An alternative explanation is that the perceptual biases of Western listeners arise from the predominance of simple ratios in Western music. This possibility has not been evaluated experimentally despite the occurrence of metrical structures that violate isochronous structures and simple-integer ratios in many non-Western musical cultures.

Much of the music from Eastern Europe, South Asia, the Middle East, and Africa has an underlying pulse of alternating long and short durations in a 3:2 ratio (Clayton, 2000). These complex meters, which are common in Bulgarian and Macedonian folk music, pose no apparent problems for adult and child singers and dancers from those countries (London, 1995; Rice, 1994). Prolonged exposure to specific metrical structures may enable listeners to distinguish structurally meaningful timing changes from changes (e.g., slowing down) associated with expressive performance (Desain & Honing, 2003). Instead of interpreting and reinterpreting unfolding sequences on the basis of small but detectable temporal deviations, listeners interpret these sequences within the framework of the meter (Clarke, 1999). Presumably, implicit knowledge of metrical structure, which undoubtedly varies across cultures, is central to the perception of rhythmic patterns.

Because infants have limited experience with music, they provide unique opportunities for examining intrinsic biases for metrical structure. In principle, comparisons between infant and adult listeners could reveal biases that stem from musical enculturation or from perceptual predispositions. In the speech domain, adults typically perceive native consonant contrasts more readily than foreign contrasts because of their tendency to assimilate foreign sounds to the perceptual categories of their native language (Best, McRoberts, & Sithole, 1988). By contrast, infants' perception of native and foreign consonant contrasts is equivalent until about 10 to 12 months of age, when native consonant categories begin to emerge (Werker & Lalonde, 1988). In the musical domain, analogous initial abilities and subsequent assimilation processes lead infants to exhibit comparable pitch discrimination skills in native and foreign melodic contexts and adults to exhibit superior skills in native compared with foreign melodic contexts (Lynch, Eilers, Oller, & Urbano, 1990; Trehub, Schellenberg, & Kamenetsky, 1999). The implication is that exposure to speech and music leads to culture-specific fine-tuning or perceptual reorganization.

If infants begin life with relatively flexible perceptions of meter, they should process simple and complex duration ratios equally well. By contrast, human predispositions for simple duration ratios, like those for simple frequency ratios (Schellenberg & Trehub, 1996), would lead infants to perceive simple duration ratios more efficiently than complex duration ratios. Regardless of the presence or absence of infant biases, adult attunement to the metrical categories of their musical culture should lead to enhanced processing of culturally typical duration ratios. In the present study, we compared North American adults, whose exposure was largely restricted to simple duration ratios; Bulgarian or Macedonian adults, whose exposure included both simple and complex duration ratios; and 6-month-old infants, whose limited musical exposure involved simple duration ratios. Specifically, we evaluated their perception of temporal changes in folk melodies with simple or complex metrical structure.

EXPERIMENT 1

After familiarization with multi-instrument performances of foreign folk melodies, North American adults were presented with altered versions that preserved or violated the original metrical structures. Listeners rated the consistency of the alterations with the rhythmic structures of the original performances.

Method

Participants

Participants were 50 college students (35 women, 15 men; 18–25 years) who had from 0 to 15 years of musical training ($M = 5.7$). Those with 7 or more years of music lessons were considered highly trained. Most participants had lived exclusively in North America, but 3 had lived in England, Russia, or the Dominican Republic for 6 to 10 years.

Apparatus and Stimuli

For the familiarization stimuli, four excerpts were taken from traditional folk-dance melodies of Serbia and Bulgaria (Geisler, 1989). All excerpts consisted of eight cycles, or measures; complex-meter excerpts had a maximum of seven notes per measure, and simple-meter excerpts had a maximum of eight. Each excerpt was arranged as a MIDI performance with four Quicktime MIDI instruments. The instrumentation consisted of a primary melodic instrument (acoustic fretless bass or tango accordion), a secondary melodic instrument (flute), an accompanying harmonic instrument (acoustic fretless bass or bright acoustic piano), and a percussion instrument (melodic tom, timpani, or kalimba). Two excerpts were from dances in simple meter (each eight-note measure subdivided into groups of 2 + 2 + 2 + 2), and two were from dances in complex meter (each seven-note measure subdivided into groups of 2 + 2 + 3 or 3 + 2 + 2, depending on the type of dance). Both primary melodic instruments were used in each meter.

Most durations, or IOIs, in the primary melodic line were 250 ms, but longer IOIs (500, 750, and 1,000 ms) occurred in all excerpts, primarily at strong metrical positions. To highlight the primary metrical pulse, we increased note amplitude (MIDI velocity) at strong metrical positions (velocities of 120–127 for these notes and 90 for all other notes). Note onsets from the drum accompaniment and harmonic instruments also occurred more frequently at strong than at weak metrical positions. Thus, these familiarization stimuli provided a variety of cues that are considered important for inferring the meter of a sequence. For both simple- and complex-meter stimuli, the drum accompaniment consisted of long-short-short or short-short-long patterns that were repeated in every measure.

For each primary familiarization melody, we created two test stimuli that had the identical melody but were altered by the addition of a single 250-ms note in each measure. In the *structure-preserving version*, the duration of an adjacent note was modified to preserve the original metrical structure; in the *structure-violating version*, the same note was inserted in the same location, but the durations of adjacent notes were not changed. The test stimuli were presented at uniform amplitude (MIDI velocity of 90) and were simplified by the use of one melodic instrument (acoustic grand piano) and one drum accompaniment (woodblock). Examples of familiarization, structure-preserving, and structure-violating stimuli for simple and complex meters are depicted musically and graphically in Figure 2. (Audio excerpts are available on the Web at http://people.psych.cornell.edu/∼eeh5/MCstimuli.html.)

The location of extra notes within the test stimuli varied across measures, but the notes always occurred during the long duration of the drum accompaniment. In the structure-preserving alterations, the duration of the note preceding the insertion was reduced from 500 to 250 ms, which preserved the overall duration of the measure and the pattern of durations in the drum accompaniment. The drum accompaniment in these versions consisted of long and short durations of 1,000 and 500 ms for the simple meter and 750 and 500 ms for the complex meter. Structure-violating alterations had no adjustment to adjacent notes, so the insertion led to an increase in the long duration of the drum pattern and in the overall duration of the measure. Thus, structure-violating drum accompaniments consisted of long and short durations of 1,250 and 500 ms for the simple meter and 1,000 and 500 ms for the complex meter. Note that structure-violating alterations of the simple meter resulted in a complex meter and structure-violating alterations of the complex meter resulted in a simple meter.

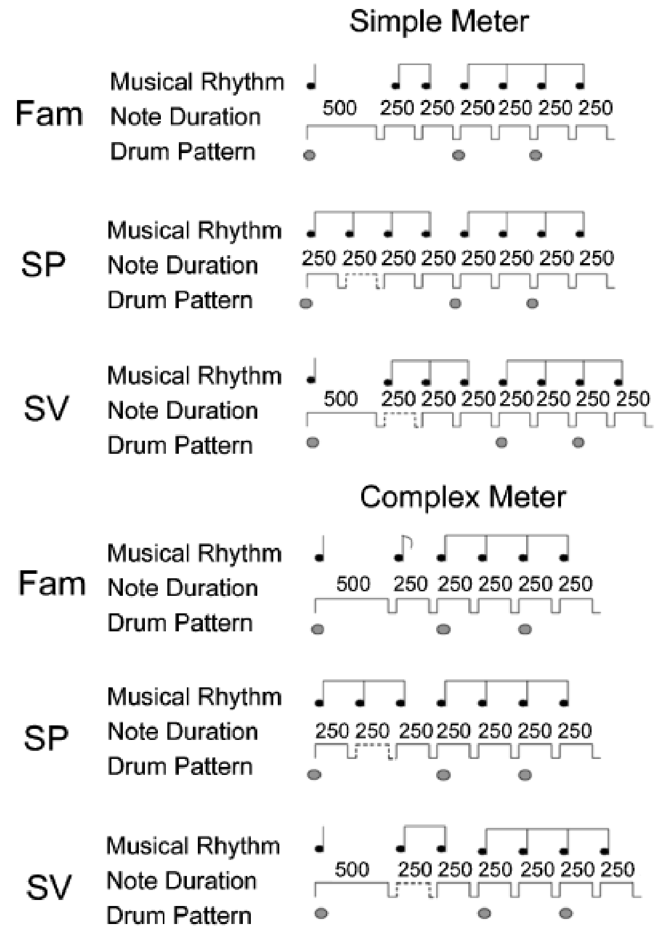

Fig. 2. One-measure examples of a typical familiarization stimulus (Fam), its structure-preserving alteration (SP), and its structure-violating alteration (SV), for both simple meter (top) and complex meter (bottom). Each example is shown in both musical notation and graphical form. The drum accompaniment is indicated by the gray dots. For the alterations (test stimuli), the added note is indicated by a dashed line.

Each inserted note had the same pitch as the preceding or following note, to minimize the salience of the melodic change caused by the insertion. Because the pitch and location of the inserted note were identical in the structure-preserving and structure-violating test stimuli, these stimuli were identical except for the change in the ratio of the short and long durations of the drum pattern and the overall duration of each measure.

Aside from the structure-preserving and structure-violating stimuli, two additional test stimuli served as foils. One was an unaltered version of the primary familiarization melody, and the other was the familiarization melody disrupted by the pseudorandom insertion of two notes in each measure. These foils were included to promote a wide range of ratings.

For the practice trials that preceded testing, the familiarization stimulus was a well-known children's tune ("Mary Had a Little Lamb"). It was followed by four test stimuli. Two preserved the rhythmic structure, one being identical to the familiarization stimulus, and the other having extra notes that preserved the rhythm. The other two test stimuli had obvious violations of rhythmic structure resulting from the addition of two or three notes or pauses per measure. All participants rated these structure-violating test stimuli as inconsistent with the familiarization stimulus.

Procedure

Participants, who were tested in groups of 1 to 5, listened to the stimuli over headphones at individual computer stations. All musical excerpts and instructions were controlled by means of PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Trials were presented in blocks consisting of one familiarization stimulus followed by four test stimuli: the structure-preserving and structure-violating versions of the familiarization stimulus, plus the two foils. Each familiarization stimulus was presented for 2 min, allowing for seven repetitions of simple-meter excerpts and eight repetitions of complex-meter excerpts. Participants rated how well the four test stimuli matched the rhythmic structure of the familiarization stimulus (on a scale from 1, *very well*, to 6, *very poorly*). Each block was repeated three times, resulting in three sets of judgments per familiarization stimulus. Order of blocks and order of test stimuli were counterbalanced across participants.

Results and Discussion

A three-way mixed-design analysis of variance (ANOVA) with within-subjects factors of familiarization meter (simple vs. complex) and alteration type (structure preserving vs. structure violating) and a between-subjects factor of musical training (high vs. low) revealed significant main effects of meter, $F(1, 48) = 18.18$, $p < .001$, $\eta^2 = .28$, and alteration type, $F(1, 48) = 88.59$, $p < .001$, $\eta^2 = .65$, and a significant interaction between meter and alteration type, $F(1, 48) = 117.12$, $p < .001$, $\eta^2 = .71$. Inspection of the top panel of Figure 3 shows that much higher ratings (i.e., greater dissimilarity) were given to structure-violating than to structure-preserving alterations for simple-meter excerpts, but not for complex-meter excerpts. The interaction between musical training, meter, and alteration type was not significant, $F(1, 48) = 2.06$, $p = .16$, $\eta^2 = .04$, but there were indications that musical training affected response accuracy. Accuracy scores were calculated by subtracting ratings of structure-preserving alterations from ratings of structure-violating alterations. Accuracy scores and years of musical training were correlated for simple-meter stimuli, $r(48) = .43$, $p < .01$, but not for complex-meter stimuli, $r(48) = .18$, $p = .21$. In other words, more extensive musical training was associated with more differentiated responding to structure-violating and structure-preserving stimuli only in the context of familiar metrical structure.

In summary, the metrical structure of musical patterns had a dramatic effect on the perception of those patterns. For simple metrical structures, adults' ratings of alterations that disrupted

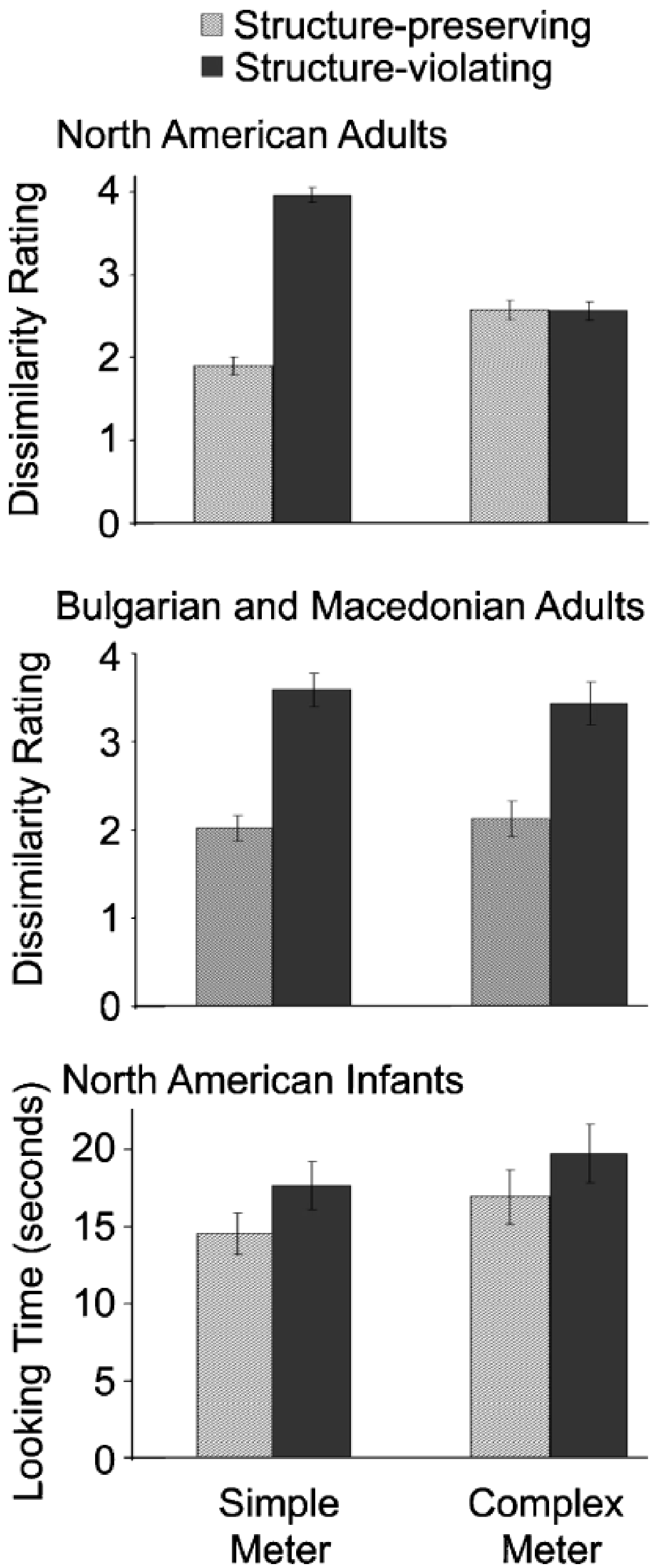

Fig. 3. Mean dissimilarity judgments of North American adults in Experiment 1 (top panel) and Bulgarian and Macedonian adults in Experiment 2 (middle panel) and infants' mean looking times in Experiment 3 (bottom panel). Results for structure-preserving and structure-violating alterations are shown separately for simple- and complex-meter patterns. Error bars indicate standard errors.

simple duration ratios and underlying isochronous structure were significantly different from their ratings of alterations that preserved the structure. No such differentiation was evident in the context of complex metrical structure. In effect, adults noticed alterations from typical to atypical metrical structures but not alterations from atypical to typical metrical structures. Such asymmetric performance parallels adults' greater ease of detecting changes from conventional to unconventional pitch and rhythmic patterns than detecting changes from unconventional to conventional patterns (Bharucha & Pryor, 1986; Schellenberg, 2002). Encoding difficulties with unconventional sequences may arise from the inappropriate assimilation of atypical sequences to familiar musical categories.

EXPERIMENT 2

Participants' difficulty with complex metrical structures in Experiment 1 was consistent with musical enculturation processes. Nevertheless, it remained to be determined whether listeners exposed to both simple and complex ratios, such as adults from Bulgaria or Macedonia (Rice, 1994), would exhibit comparable ease of processing complex and simple duration ratios. Experiment 2 was a replication of Experiment 1 with adults of Bulgarian or Macedonian origin.

Method

Participants

Participants were 17 first- or second-generation immigrants (12 women, 5 men; 18–38 years) from Bulgaria ($n = 13$) or Macedonia ($n = 4$) who had from 0 to 14 years ($M = 3.4$) of music lessons (primarily involving Western music). All of them had participated in traditional cultural activities in childhood or adulthood, either in their home country or in the host country.

Apparatus and Procedure

The apparatus, stimuli, and procedure were the same as in Experiment 1.

Results and Discussion

A three-way mixed-design ANOVA with within-subjects factors of familiarization meter (simple vs. complex) and alteration type (structure preserving vs. structure violating) and a between-subjects factor of musical training (high vs. low) revealed a significant main effect of alteration type, $F(1, 15) = 49.33$, $p < .001$, $\eta^2 = .77$, and a significant interaction between alteration type and musical training, $F(1, 15) = 11.69$, $p < .01$, $\eta^2 = .44$. There was no main effect of familiarization meter and no other significant interactions. Inspection of the middle panel of Figure 3 reveals higher ratings (greater dissimilarity) of structure-violating than structure-preserving alterations for both simple- and complex-meter excerpts. Accuracy scores, calculated as in Experiment 1, were significantly correlated with years of musical training for simple-meter stimuli, $r(15) = .55$, $p < .05$, and for complex-meter stimuli, $r(15) = .60$, $p < .05$. Unlike adults of North American origin, those of Bulgarian and Macedonian origin had experienced long-term exposure to both simple and complex metrical structures, which enabled them to differentiate structure-violating alterations from structure-preserving alterations in both metrical contexts.

EXPERIMENT 3

Although the findings of Experiments 1 and 2 were consistent with enculturation processes, they did not rule out inherent biases for simple metrical structures. We investigated 6-month-old infants' perception of the simple- and complex-meter stimuli of Experiments 1 and 2 by means of a familiarization-preference procedure.

Method

Participants

Participants were 64 infants who were 6 to 7 months of age ($M = 6.9$ months; 28 girls, 36 boys). All infants were free of colds on the test day and had no family history of hearing impairment. An additional 21 infants were excluded from the final sample because of fussing ($n = 18$), sleeping ($n = 1$), or technical failure ($n = 2$).

Apparatus and Stimuli

Familiarization and test stimuli consisted of the four sets of simple- and complex-meter stimuli from Experiment 1. Half of the infants received one of the two simple-meter stimuli; the other half received one of the two complex-meter stimuli. All stimuli were prepared as Quicktime movies accompanied by identical visual (nonrhythmic) portions of a documentary film (Attenborough, 1991).

A Macintosh G4 computer controlled (a) the presentation of auditory stimuli through a centrally located but out-of-view loudspeaker (Altec Lansing AC 522), (b) the presentation of visual stimuli on two 17-in. color monitors (Sony) separated by approximately 91 cm, and (c) the recording of infants' responses. The experimenter, who observed each infant through a small hole in a partition separating the infant from the experimenter and the control equipment, recorded all changes in the infant's direction of gaze. The infant's visual fixations were also visible from the monitor of a digital video camera that focused on the infant's face. The experimenter and mother wore headsets playing music to mask the auditory stimuli presented to the infants.

Procedure

We tested the infants by means of a familiarization-preference procedure. Each infant sat on a parent's lap in a dimly lit testing room. The two monitors were approximately 140 cm in front and to the right and left of the seated infant. The observer recorded the infant's looking times by pressing two buttons on the computer, one button when the infant looked toward a monitor and the other when the infant looked away. The infant was first presented with 2 min of the familiarization stimulus, split into four 30-s segments that alternated between monitors. To attract infants' attention to the appropriate monitor at the beginning of each such sequence, the monitor on which the stimulus would first be presented flashed a red screen. When the infant looked at the monitor, the familiarization stimulus was presented. After the four 30-s repeated segments of the familiarization stimulus, test stimuli were presented six times each, with the structure-preserving and structure-violating test stimuli alternating between monitors. Each test trial was terminated when the infant looked away for 2 s or when 60 s had elapsed.

Each infant was randomly assigned to one of the two familiarization excerpts in simple or complex meter. The order of the first monitor in the familiarization phase, the first monitor in the test phase, and the first test stimulus (structure preserving vs. structure violating) was counterbalanced.

Results and Discussion

Looking times were analyzed for differential attention to structure-preserving and structure-violating alterations in the simple- and complex-meter contexts. A two-way, mixed-design ANOVA with familiarization meter (simple vs. complex) as a between-subjects variable and alteration type (structure preserving vs. structure violating) as a within-subjects variable revealed a significant main effect of alteration type, $F(1, 62) = 16.445$, $p < .001$, $\eta^2 = .21$. There was no significant interaction between familiarization meter and alteration type. The bottom panel of Figure 3 presents mean looking times for structure-preserving and structure-violating test stimuli in the simple- and complex-meter conditions. In the context of both simple and complex meters, infants looked significantly longer for structure-violating alterations than for structure-preserving alterations. Greater looking time to structure-violating alterations is interpretable as a novelty preference, which implies that infants perceived structure-violating alterations to be less similar to the familiarization stimulus than were structure-preserving alterations. Unlike North American adults, who differentiated structure-violating from structure-preserving changes only in the context of simple-meter excerpts, infants differentiated those changes in complex- as well as simple-meter contexts.

GENERAL DISCUSSION

North American infants were more similar to Bulgarian and Macedonian adults than to North American adults in that they differentiated alterations that violated the metrical structure of musical patterns from those that preserved the metrical structure both when the original pattern had simple meter and when it had complex meter. These findings imply that the temporal perception and production biases of North American adults arise from extended exposure to the simple metrical structures that predominate in Western music. Human listeners may begin with flexible processing of metrical structure, which facilitates perception of temporal nuances in various kinds of music. Months, perhaps years, of exposure to the dominant metrical categories of a specific musical culture may prompt perceptual reorganization or narrowing of the metrical frameworks that can be handled with ease.

It is possible, although unlikely, that the absence of infant biases for simple ratios reflects different mechanisms for processing temporal structures in infancy and adulthood (Collier & Wright, 1995). For example, infants could perceive temporal patterns in a serial manner, without the hierarchical and anticipatory aspects of adult metrical processing. However, several lines of evidence are consistent with rich metrical processing in infancy. Infants have a number of prerequisite skills for perceiving meter, including the ability to detect subtle changes in duration (Morrongiello & Trehub, 1987) and tempo (Baruch & Drake, 1997), to detect minuscule (12-ms) gaps in brief tones (Trehub, Schneider, & Henderson, 1995), to discriminate isochronous from nonisochronous tone patterns (Demany, McKenzie, & Vurpillot, 1977), and to generalize auditory patterns on the basis of rhythmic structure (Trehub & Thorpe, 1989). Infants can discriminate musical excerpts on the basis of rhythmic changes (Chang & Trehub, 1977) and on the basis of subtle performance cues (e.g., intensity and duration changes) associated with metrical structure (Palmer, Jungers, & Jusczyk, 2001). These cues are correlated with metrical structure in infant-directed singing (Trainor, Clark, Huntley, & Adams, 1997). Moreover, infants' ability to detect small timing changes depends on the strength of implied metrical structure (Bergeson, 2002). Finally, 7-month-old infants can categorize unique rhythms on the basis of implied metrical structure (Hannon & Johnson, in press). In view of this evidence, it is likely that meter is fundamental to the organization of auditory-temporal input in infancy. Greater flexibility in that organization may be possible earlier in life, before listeners become attuned to the musical input in their environment.

Our findings imply that adult biases in temporal pattern processing result from category-learning processes that are part of musical enculturation, not from intrinsic perceptual biases for simple temporal structures. Implicit knowledge of musically relevant categories is critical for the appreciation of music in any culture. Listeners must discern the metrical structure of a piece in the face of temporal fluctuations that reflect the performer's expressive intentions (Desain & Honing, 2003). Comparable category learning enables listeners to discern words and meaningful prosodic changes in the speech stream despite enormous variability within and across speakers.

Abilities that are part of the initial state of auditory pattern processing are likely to undergo reorganization when young listeners discover which distinctions are common or meaningful in their culture and which are not. For some segmental and suprasegmental aspects of speech, perceptual reorganization occurs in infancy (Nazzi, Jusczyk, & Johnson, 2000; Werker & Lalonde, 1988). Comparable changes in music processing may have a more protracted course of development. For example, culture-specific changes in the perception of musical harmony do not occur until the early school years (Krumhansl & Keil, 1982; Trainor & Trehub, 1994). Our findings provide the first demonstration of reorganization in temporal pattern processing, presumably as a result of exposure to music. One challenge for the future is to document the developmental course of that reorganization.

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