# Tuning in to musical rhythms: Infants learn more readily than adults

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**Domain-general tuning processes may guide the acquisition of perceptual knowledge in infancy. Here, we demonstrate that 12-month-old infants show an adult-like, culture-specific pattern of responding to musical rhythms, in contrast to the culture-general responding that is evident at 6 months of age. Nevertheless, brief exposure to foreign music enables 12-month-olds, but not adults, to perceive rhythmic distinctions in foreign musical contexts. These findings may indicate a sensitive period early in life for acquiring rhythm in particular or socially and biologically important structures more generally.**

development | learning | perception

The ability to recognize and respond appropriately to species-specific information is essential for communication and survival. Experience-dependent tuning in the first year of life may facilitate the acquisition of perceptual skills in a range of socially meaningful domains. The domain of speech is a prominent example. Initially, infants discriminate speech sounds from languages they have never heard, but over the first year they become differentially responsive to a narrower range of speech distinctions that are relevant only in their native language-to-be (1, 2). A similar developmental course is evident in the domain of face perception. For example, 6-month-olds differentiate individual faces of non-human as well as human primates, but 9-month-olds are more like adults in differentiating human faces only (3). Here, we show comparable experience-dependent tuning in the domain of musical rhythm perception. We also demonstrate that culture-specific musical biases, once acquired, are more resistant to change in adulthood than in infancy.

Synchronized movement to music, such as clapping, tapping, dancing, singing, and ensemble performance, has been observed across all known cultures and historical periods, which implies universality of this aspect of human behavior (4). Such behavior is thought to depend on the ability to infer an underlying musical "beat" or meter and to integrate rhythmic information into that metrical framework.[§] In perception and production tasks, adults exhibit a powerful tendency to assimilate continuously varying rhythmic information into a familiar (i.e., culture-specific) metrical framework. Because Western listeners are accustomed to the temporally even or "isochronous" meters of Western music, they have considerable difficulty remembering or reproducing patterns that are not isochronous. Even when target patterns have noticeable deviations from isochrony, Western adults stretch or shrink the component rhythmic intervals toward an isochronous framework (5–9). Such culture-specific biases interfere with adults' differentiation of rhythmic variations of nonisochronous (foreign) tunes, even though such rhythms pose no difficulty for 6-month-old infants (10). Specifically, North American adults readily detect rhythmic variations that disrupt a familiar (Western), isochronous meter, but they fail to notice comparable disruptions of a foreign (Balkan), nonisochronous meter. By contrast, adults from Bulgaria and Macedonia, who receive exposure to both types of meter in childhood, and 6-month-old infants, who receive no such exposure, distinguish rhythmic variations in both isochronous and nonisochronous contexts. This finding implies culture-specific responding to musical rhythms by adult listeners but culture-general responding by 6-month-old listeners, which is consistent with findings in early speech and face processing (3, 11).

If musical rhythm perception undergoes a process of experience-dependent tuning that parallels that of speech and face perception, then the transition from culture-general to culture-specific responding could occur early in life. We investigated this possibility in experiment 1 by testing Western 12-month-old infants with the familiarization-preference procedure and stimuli used previously with Western 6-month-olds (10). Experiments 2 and 3 examined whether culture-specific biases in 12-month-olds and adults could be altered by brief, at-home exposure to foreign, nonisochronous music.

## Experiment 1

Infants were familiarized with a synthesized performance of a Balkan folk tune, followed immediately by two simplified variations of the folk tune: one containing a change that disrupted the meter of the original and the other containing a change that preserved the original meter. Infants were familiarized with a tune having either an isochronous meter that is common in both Western and Balkan music or a nonisochronous meter that is common in Balkan (Bulgarian and Macedonian) music but not in conventional Western music. Infants' looking times were examined for differential attention to structure-disrupting and structure-preserving test stimuli.

**Materials and Methods.** ***Participants.*** Participants were 52 infants who were 11–12 months of age (mean age = 349.5 days, SD = 17.5 days) at the time of testing. There were 26 girls and 26 boys. All participants were healthy, full-term infants who were free of colds on the test day and had no family history of hearing impairment. An additional 14 infants were excluded from the final sample because of fussing ($n = 12$) or parental interference ($n = 2$). Most infants lived in a monolingual, English-speaking environment, but some infants had a parent or grandparent who also spoke French ($n = 3$), German ($n = 1$), Korean ($n = 1$), Polish ($n = 3$), Portuguese ($n = 2$), or Tagalog ($n = 1$). Parents reported that neither they nor their infants had prior exposure to Balkan music.

***Stimuli.*** Familiarization and test stimuli consisted of two isochronous and two nonisochronous melodies used in Hannon and

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Abbreviation: CD, compact disc.

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§"Meter" is the underlying pattern of strong and weak beats inferred from the musical surface, as in the waltz pattern of "*one*, two, three, *one*, two, three. . . ." In Western music, meter consists of multiple hierarchical levels of evenly spaced (i.e., isochronous) periodic structure, with faster levels resulting from binary or ternary subdivisions. In some types of Balkan music, meter also consists of multiple levels, but some levels are not isochronous, consisting instead of alternating short and long temporal intervals. The term "rhythm" refers to the sequence of temporal intervals in a pattern, such as 500-500-250 ms. Because meter constrains the rhythmic structure of music, isochrony in Western meters gives rise to a greater frequency of simple ratios between temporal intervals, such as 1:1 or 2:1. By contrast, Balkan rhythms often contain long and short temporal intervals with more complex ratios, such as 3:2.

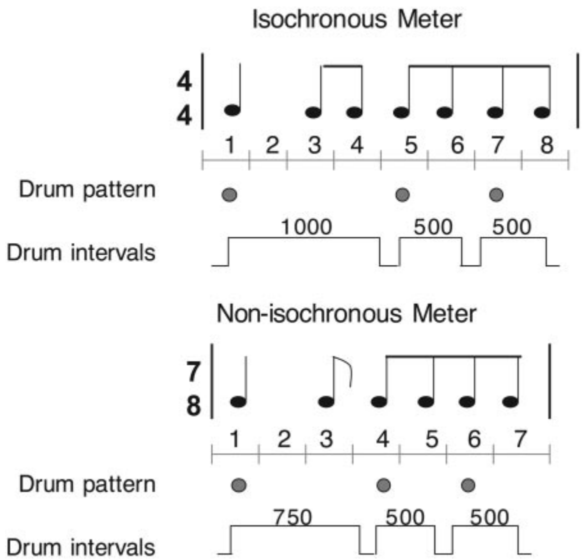


**Fig. 1.** One measure each of isochronous and nonisochronous meter familiarization excerpts with a long-short-short drum accompaniment, depicted in musical notation and graphical form. Each count of the measure is numbered to illustrate that isochronous meter excerpts consist of eight counts per measure, whereas nonisochronous meter excerpts contain seven counts per measure. The intervals in the isochronous meter drum pattern form a long-to-short ratio of 1,000:500 or 2:1; the intervals in the nonisochronous meter drum pattern form a long-to-short ratio of 750:500 or 3:2.

Trehub (10) (audio excerpts are available in QUICKTIME format as Audio Files 1–6, which are published as supporting information on the PNAS web site). All excerpts were selected from a collection of traditional folk-dance melodies from the Balkans (12). Fig. 1 illustrates the rhythmic structure for one cycle, or measure, of isochronous and nonisochronous meter excerpts. Excerpts in isochronous and nonisochronous meter consisted of eight measures in total, with each measure containing a maximum of eight 250-ms notes in isochronous meter and seven 250-ms notes in nonisochronous meter (Fig. 1). Most notes were 250 ms in duration, but longer notes (500, 750, and 1,000 ms) occurred occasionally in all excerpts. For all stimuli, each eight-measure excerpt was cycled repeatedly up to a maximum of ≈1 min (four repetitions).

For familiarization stimuli, each excerpt was computer-generated as a multi-instrument performance by using Musical Instrument Digital Interface (MIDI) format and four QUICKTIME synthesized instruments that played melody, harmony, or percussion. To highlight the meter unambiguously, a percussion instrument played a drum pattern that subdivided each measure into either a long-short-short or a short-short-long sequence of temporal intervals. For isochronous excerpts, long and short intervals in the drum pattern had a 2:1 ratio. For nonisochronous excerpts, long and short intervals had a 3:2 ratio (see Fig. 1).

Test stimuli were variations of the familiarization excerpts with reduced complexity, consisting of one melodic instrument and one percussion instrument. Test melodies were identical to familiarization melodies, with the exception of a change that either preserved or disrupted the original meter. A single 250-ms note, identical in pitch and location, was inserted in each measure of both structure-preserving and structure-disrupting variations. In structure-preserving variations, the durations of adjacent notes were modified to preserve the drum pattern and the number of counts per measure. In structure-disrupting variations, the additional note increased the duration of the longer interval in the drum pattern as well as the number of counts per measure (Fig. 2). Because the extra note was identical

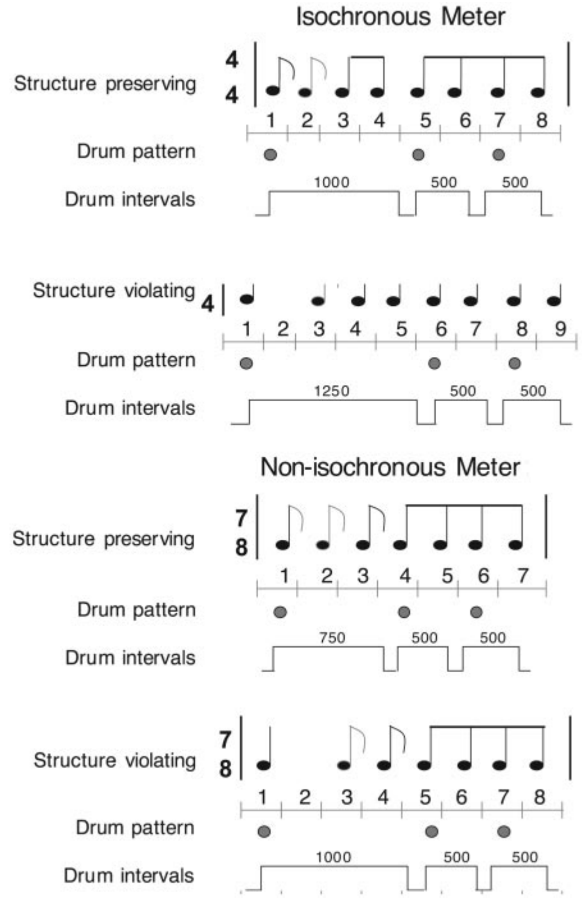


**Fig. 2.** One measure of structure-preserving and structure-violating variations on isochronous and nonisochronous excerpts. A single extra note (in gray) is inserted into each measure for both types of variations. In structure-preserving variations, the note preceding the change is shortened to maintain the meter and the duration of intervals in the drum pattern. In structure-violating variations, no existing note durations are modified, resulting in an increased long interval in the drum pattern and an extra count.

in pitch and location for both alteration types, structure-preserving and structure-disrupting test stimuli were identical except for the ratio between long and short intervals in the drum pattern and the number of counts per measure.

Half of the infants were randomly assigned to familiarization with one of the two isochronous meter excerpts; the other infants were familiarized with one of the two nonisochronous meter excerpts. All stimuli were prepared as QUICKTIME movies accompanied by identical visual (nonrhythmic) portions of a documentary film (13).

***Apparatus and procedure.*** We tested infants by means of a familiarization-preference procedure (10, 14). Infants sat on their parents' lap in a dimly lit testing room, with two monitors located ≈140 cm in front and to the right and left of the infant. An observer recorded infant looking times by pressing one of two buttons on the computer: one button for looking toward a monitor and the other for looking away. To attract infants' attention to the appropriate monitor, a flashing red screen on that monitor preceded each trial. Infants were first presented with 2 min of the familiarization stimulus, consisting of four 30-s repetitions alternating between monitors. After four familiarization trials, test stimuli were presented six times each, with the structure-preserving and structure-disrupting test stimuli alternating between monitors. Each test trial was terminated when the infant looked away for 2 s or when 60 s

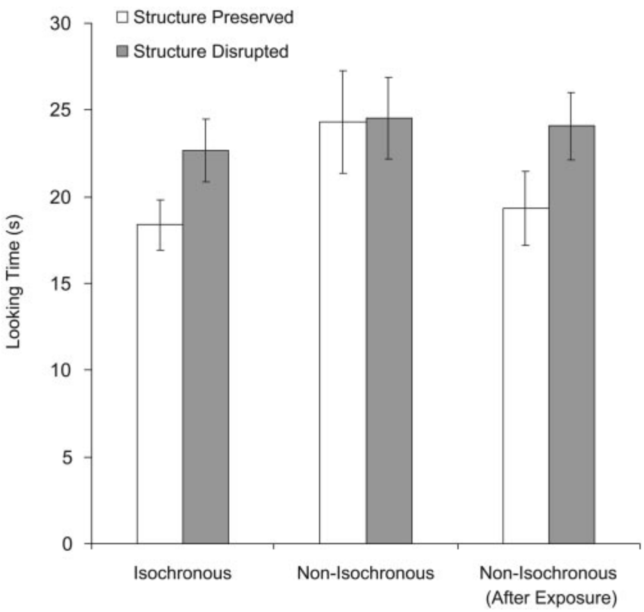


**Fig. 3.** Infants' looking times (in seconds) during presentation of structure-violating and structure-preserving variations of isochronous (familiar) and nonisochronous (foreign) folk tunes in experiments 1 and 2. Error bars represent SEs.

had elapsed. The order of the first monitor in the familiarization phase, the first monitor in the test phase, and the first test stimulus presented (structure-preserving vs. structure-disrupting) was counterbalanced.

**Results and Discussion.** Infant looking time, which corresponds to listening time because of the contingency between looking and sound presentation, was accumulated over successive presentations of structure-preserving and structure-disrupting test stimuli. In the isochronous familiarization condition (Fig. 3), looking (i.e., listening) times for the structure-disrupting variation (mean = 22.67 s, SE = 1.82) exceeded those for the structure-preserving variation (mean = 18.37 s, SE = 1.48) (paired, two-tailed $t$ test, $t = 3.50$, df = 25; $P < 0.01$), which is consistent with infants' typical preference for novel stimuli and replicates prior findings with 6-month-old infants (10). In the nonisochronous condition, however, looking times did not differ for structure-disrupting (mean = 24.54 s, SE = 2.35) and structure-preserving (mean = 24.3 s, SE = 2.98) variations (paired, two-tailed $t$ test, $t = 0.16$, df = 25; $P > 0.87$). This result contrasts with previous findings from 6-month-old listeners, who distinguished structure-disrupting from structure-preserving variations in the context of nonisochronous as well as isochronous meters (10). The present results are consistent with early developmental changes in speech and face perception. Infants' ability to differentiate foreign, nonisochronous rhythmic patterns declines by the end of the first year, but their sensitivity to comparable distinctions in culturally typical isochronous patterns remains unchanged.

If this developmental change arises from exposure to Western music during the first year of life, then exposure to music with foreign musical meters may prevent or reverse this apparent decline in sensitivity to foreign-meter variations. For example, after accumulating 5 h of interactive experience (distributed over a 1-month period) with a native speaker of Mandarin, American 12-month-olds show sensitivity to Mandarin speech contrasts comparable to that of 6-month-olds, unlike 12-month-olds who receive no such exposure (15). In experiment 2, we assessed 12-month-olds' ability to distinguish structure-disrupting from structure-preserving variations of foreign-meter tunes after brief, daily exposure to Balkan folk music.

## Experiment 2

The goal of experiment 2 was to assess whether brief, at-home exposure to nonisochronous meters in Balkan folk music could improve 12-month-olds' differentiation of structure-disrupting and structure-preserving variations in the foreign, nonisochronous context.

**Materials and Methods.** ***Participants.*** Participants were 26 infants who were 11–12 months of age (mean age = 350.6 days, SD = 16.4 days). There were 9 girls and 17 boys. All participants were healthy, full-term infants who were free of colds on the test day and had no family history of hearing impairment. Most infants lived in a monolingual, English-language environment, but a subset of infants had a parent who spoke French ($n = 1$), German ($n = 1$), Italian ($n = 1$), Japanese ($n = 1$), Chinese ($n = 1$), or Hungarian ($n = 1$) some of the time. No parent or infant had prior exposure to Balkan music. An additional 10 infants were excluded from the final sample due to fussing ($n = 9$) or prior exposure to Balkan music ($n = 1$).

***Stimuli.*** A compact disc (CD) was prepared for at-home listening. Each CD was ≈10 min in duration and contained five recordings of nonisochronous dance music from Macedonia, Bulgaria, or Bosnia (for a detailed description of selections on the audio CD, see Table 1, which is published as supporting information on the PNAS web site). The CD contained none of the tunes used during testing, so the metrical structure was the only feature common to melodies on the CD and those used during testing. Audio CDs, which were prepared by means of SOUNDEDIT and ITUNES, were burned onto CDs with a Macintosh computer. Familiarization and test stimuli were identical to those used in the complex meter condition of experiment 1.

***Apparatus and procedure.*** Two weeks before a laboratory visit, we mailed parents an audio CD, instructions, and a log sheet. Parents were instructed to play the CD at an audible level once every morning and afternoon when the infant was alert and contented. They were asked to maintain the infants' regular routines, without drawing attention to the music. Parents kept track of music-listening sessions by using the log sheet. After the 2-week listening period, infants participated in a laboratory test session (nonisochronous condition). The apparatus and procedure during test sessions was identical to experiment 1.

**Results and Discussion.** Infants looked significantly longer during the structure-disrupting variation (mean = 24.07 s, SE = 1.95) than during the structure-preserving variation (mean = 19.31 s, SE = 2.14) (Fig. 3) (paired, two-tailed $t$ test, $t = 2.97$, df = 25; $P < 0.01$). A comparison of looking times in experiment 2 and in the nonisochronous condition of experiment 1 revealed a significant interaction between variation type (structure-disrupting vs. structure-preserving) and condition (exposure vs. no exposure) (mixed design analysis of variance, $F = 4.19$, df = 1, 50; $P < 0.05$), indicating that 12-month-olds in experiment 2 distinguished rhythmic variations in the foreign metrical context, unlike their peers in experiment 1 who had no prior exposure to foreign-meter music. Moreover, preference scores (proportion of total looking time during the structure-disrupting variation) did not differ between the nonisochronous condition of experiment 2 and the isochronous condition of experiment 1 (two-tailed, independent-samples $t$ test, $t = 0.56$, df = 50; $P > 0.57$), suggesting that exposure led to comparable performance in familiar and foreign contexts. In short, 2 weeks of passive, at-home exposure facilitated infants' differentiation of rhythmic patterns in a foreign musical context.

PSYCHOLOGY

## Experiment 3

The goal of experiment 3 was to determine whether comparable exposure to foreign music in adulthood could lead to comparable rapidity of learning. Adults were tested by means of a similarity judgment task. In this task, adults heard the same sequence of familiarization and test stimuli as did infants, but they responded by rating each variation on the basis of its similarity to the original familiarization stimulus. This task paralleled the infant procedure by permitting graded responses to each variation on the basis of its dissimilarity or novelty relative to the original stimulus. Adults were randomly assigned to an experimental or control group. Adults in the experimental group participated in two test sessions separated by 1 or 2 weeks, and they listened daily to an audio CD of Balkan folk music between the two test sessions. They could earn a modest monetary reward for accurately recognizing tunes from the CD in a recognition test after the second test session. Adults in the control group participated in two test sessions 1 or 2 weeks apart, with no exposure to nonisochronous music during the intervening period.

**Methods.** ***Participants.*** Participants were 40 college students (25 women and 15 men who were 18–35 years old) whose musical training ranged from 0 to 15 years (mean = 3.21). The level of musical training was comparable across participants in the control condition (mean = 3.38) and the experimental condition (mean = 3.05). Most participants had grown up in North America, but some individuals had lived in Ireland (2 years), Sri Lanka (2 years), United Arab Emirates (1 year), Ukraine (10 years), Poland (3 years), or Pakistan (10 years). Individuals who had lived outside of North America were divided evenly between control and experimental groups. No participants reported prior exposure to Balkan music. An additional six participants were tested but not included in the final sample because they scored <75% on the recognition test.

***Stimuli.*** Familiarization and test stimuli were identical to those used in experiments 1 and 2. During the test phase, two additional test stimuli served as foils. One of these foils was an unaltered version of the primary melody from the familiarization stimulus (highly similar). The other was disrupted by the pseudorandom insertion of extra notes twice per measure (highly dissimilar). Foils were included to encourage participants to use the full range of the similarity judgment scale.

A brief set of practice trials preceded testing at the first session. For practice, we generated one familiarization stimulus and four test stimuli based on a children's tune ("Mary Had a Little Lamb"). Two structure-preserving test stimuli presented an identical rendition of the original or contained extra notes that preserved the meter. Two structure-violating variations contained extra notes or pauses inserted several times per measure, resulting in salient disruptions of the metrical structure.

The audio CD for adult home listening was identical to the audio CD from experiment 2, with the exception of one adult tune that replaced a children's tune (see Table 1). The audio CD was ≈12 min in duration.

A recognition test was prepared for participants in the experimental condition. This test consisted of 20-s excerpts, 5 targets (taken from the audio CD) and 15 nontargets, 12 of which were drawn from the same Balkan artists. Thus, the voices, instruments, and style of most nontarget excerpts were similar to target excerpts, precluding success on the recognition test without the requisite listening experience. The other three excerpts consisted of folk music and jazz and were included as obvious nontargets.

***Apparatus and procedure.*** Adults, who were tested alone or in pairs, listened to the stimuli over headphones at individual computer stations. PSYSCOPE software presented stimuli and instructions and collected responses (16). Trials were presented in blocks consisting of one isochronous or nonisochronous 2-min familiarization stimulus followed by four test stimuli: two structure-preserving and two structure-disrupting variations of the familiarization stimulus, ordered randomly. Participants rated how well the four test stimuli matched the rhythmic structure of the familiarization stimulus (from 1 to 6, with 1 corresponding to very similar and 6 corresponding to very dissimilar). Each block was repeated three times per session, resulting in three sets of judgments per stimulus per session. Block order was counterbalanced across participants.

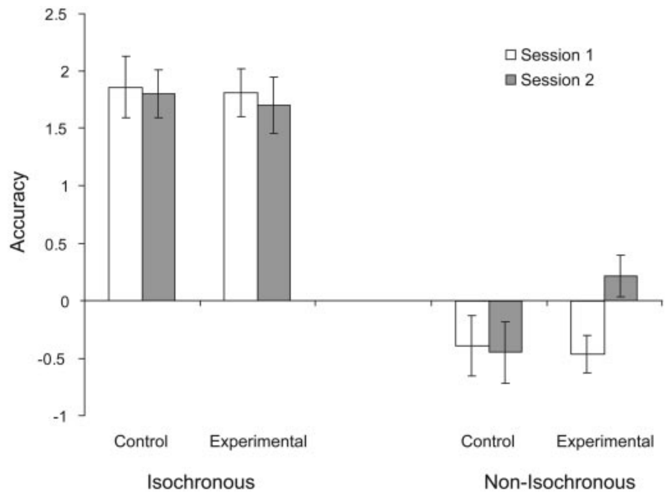


**Fig. 4.** Mean accuracy scores (rating for structure-disrupting version minus rating for structure-preserving version) across sessions in the context of isochronous and nonisochronous meters. The accuracy of participants in only the experimental group improved from session 1 to session 2 in the nonisochronous meter condition. Error bars represent SEs.

Each participant was randomly assigned to the control or experimental group. Participants in both groups were asked to return for a second session at the same time 1 ($n$ = 22) or 2 ($n$ = 18) weeks later. Participants in the experimental group were instructed to listen at home twice daily to the audio CD during the interim in preparation for a subsequent recognition test. After completing the similarity judgment task, participants in the experimental condition took the recognition test, presented by means of PSYSCOPE (16). They listened to a series of randomly ordered excerpts (targets and nontargets) and indicated whether each excerpt had or had not been present on the audio CD. Participants in the experimental condition could earn up to $10 for accurate recognition scores (percentage of hits and correct rejections).

After the last session, participants completed a questionnaire assessing musical and cultural background and, for participants in the experimental condition, the number of times they listened to the CD and the types of activities carried out while listening.

**Results and Discussion.** Higher dissimilarity ratings for structure-disrupting than for structure-preserving variations reflected accurate performance, so difference scores provided a measure of accuracy on the similarity judgment task. Consistent with prior work (10), adults performed more accurately overall in the isochronous, Western conditions (mean = 1.79, SE = .23) than in the nonisochronous, Balkan conditions (mean = −.27, SE = .22) (mixed design analysis of variance, $F$ = 74.61, df = 1, 35; $P$ < 0.001) (Fig. 4). Note that accuracy scores in the nonisochronous conditions were generally <0 (Fig. 4), indicating that adults did not merely confuse the two variations but were systematically incorrect. In the nonisochronous condition, adults tended to rate the structure-disrupting variations as more similar to the original stimulus than the structure-preserving variations. Because the structure-disrupting variation is consistent with Western meter, this pattern of performance implies that adults assimilated the original nonisochronous rhythms into a Western, or isochronous, metrical framework.

Overall, adults in exposure and nonexposure groups performed similarly across the two sessions in the isochronous condition, but the exposure group performed more accurately in the nonisochronous condition of the second session, as shown by a three-way interaction among meter, session, and group (mixed design analysis of variance, $F = 4.50$, df = 1, 35; $P < 0.05$). At-home exposure thus generated some improvement, but accuracy remained at chance levels (mean = .22, SE = .18) in the second session (two-tailed, one-sample $t$ test, $t = 1.192$, df = 19; $P > 0.25$). In short, adults failed to attain native-like performance after exposure to foreign musical structures, in contrast with 12-month-old infants, whose postexposure performance in the foreign musical context was equivalent to their preexposure performance in the familiar musical context.

In principle, differences in the duration of exposure between sessions could account for greater learning in 12-month-olds than in adults. Although adults in experiment 3 were instructed to listen to the CD twice daily, their self-reports indicated that, on average, they listened once daily (mean = 11.3 min, SD = 5.16). Duration of exposure, however, did not predict accuracy scores. There was no correlation between self-reported duration of daily listening and improvement ($r = -0.11$, df = 20, $P > 0.64$), nor was there a difference in the 1- vs. 2-week exposure groups (two-tailed, independent-samples $t$ test, $t = 0.1$, df = 18; $P > 0.97$). Because adults had monetary incentives for identifying tunes from the CD, they may have listened in an active, deliberate manner, which should have given them an advantage over infants, for whom the music played in the background during other activities. It is therefore likely that differences between adults and 12-month-olds in post-exposure performance arose not from differences between the two learning contexts but from age-related changes in the ability to learn foreign musical structures from simple exposure.

## General Discussion

Taken together, experiments 2 and 3 indicate that adults do not learn about foreign metrical structures as readily as do infants. Adults also have difficulty differentiating nonnative speech sounds (17, 18) and faces from unfamiliar racial groups (19, 20) even after extensive experience with foreign speech and faces. Our findings may indicate that age-related constraints influence the nature and extent of learning from perceptual experience across multiple domains.

The results of experiments 2 and 3 support two claims. First, passive exposure to the music of a particular culture can lead to the emergence of culture-specific responsiveness during infancy, presumably because infants learn rapidly from statistical regularities in the input, whether that input is linguistic or musical (21–23). Second, perceptual experience may have a greater impact on musical rhythm perception during infancy than it does during adulthood. In principle, the adult-like responses of 12-month-olds in experiment 1 could arise from adult-like representations. Our findings from experiments 2 and 3 indicate, however, that adults' and infants' representations differ in fundamental ways. A lifetime of exposure to Western music may entail greater perceptual "commitment" to Western metrical structures, which results in foreign patterns being assimilated into stable and entrenched representations of familiar structures, one consequence of which is slower learning (17, 22, 24). By contrast, infants' representations of musical meter may be considerably less robust and, consequently, more susceptible to modification.¶ This interpretation is consistent with the notion that infant and child behaviors arise from representations that emerge gradually and grow in strength over the course of development as a result of increasing experience and neural complexity (27).

We documented the emergence of culture-specific biases for the perception of musical rhythm in infancy, and we showed that a limited amount of passive exposure could eliminate these biases in infants but not in adults. In combination with prior work on speech and face perception, our results support the notion that domain-general tuning fosters the acquisition of perceptual knowledge about socially meaningful stimuli in the environment, such as sights and sounds associated with important persons or events. Simple learning mechanisms may underlie this perceptual tuning process, but our findings are consistent with the view that infants in particular have a heightened capacity for perceptual learning. Experience-related changes in the strength of representations may give rise to the appearance of "sensitive" periods during development, when learning is particularly rapid and behavior is modified easily. Our findings indicate that such processes are not specific to language or to faces but extend to other domains such as music. Early learning about faces and voices is often viewed as evidence of their social and biological significance. Music must be added to the list of socially and biologically significant stimuli, or it must be acknowledged that the phenomenon of rapid perceptual attunement coupled with early flexibility is more widespread than is currently believed.

¶Although infants' metrical representations may be immature, it is unlikely that infants and adults used fundamentally different temporal processing strategies in the present study. Recent evidence that young infants can infer and remember the meter of simple rhythmic patterns (24, 25) supports the interpretation that infants' performance in the present task arises from their grasp of basic aspects of musical meter.

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