Rhythm and meter are fundamental components of music that are universal yet also culture specific. Although simple, isochronous meters are preferred and more readily discriminated than highly complex, nonisochronous meters, moderately complex nonisochronous meters do not pose a problem for listeners who are exposed to them from a young age. The present work uses a behavioral task to examine the ease with which listeners of various ages acquire knowledge of unfamiliar metrical structures from passive exposure. We examined perception of familiar (Western) rhythms with an isochronous meter and unfamiliar (Balkan) rhythms with a nonisochronous meter. We compared discrimination by American children (5 to 11 years) and adults before and after a 2-week period of at-home listening to nonisochronous meter music from Bulgaria. During the first session, listeners of all ages exhibited superior discrimination of isochronous than in nonisochronous melodies. Across sessions, this asymmetry declined for young children but not for older children and adults.

Keywords: perceptual learning; rhythm perception; development; enculturation

Introduction
Rhythm and meter are essential, universal components of music that vary across cultures. Just as a child must learn his or her native language without formal instruction, so too must listeners acquire implicit knowledge of the rules that govern the music of their culture, including rules about musical temporal structure.\textsuperscript{1,2} Recent studies suggest that newborns and young infants are sensitive to beat and rhythm,\textsuperscript{3–6} yet culture-specific perceptual experience clearly plays a crucial role in shaping rhythm and meter perception and production.\textsuperscript{2,7–12} Despite evidence of cultural influence, relatively little is currently known about the developmental trajectory of culture-specific musical rhythm and meter processing.

A widely held assumption by educators, policymakers, and parents is that when it comes to learning music, earlier is better. Early experience has profound effects on human development,\textsuperscript{13,14} and age-related declines in learning have been observed in language and other domains,\textsuperscript{15–17} yet surprisingly few studies have directly addressed the question of whether younger learners have an advantage over older learners in the context of acquiring musical knowledge. Most studies address this question in the context of formal music training. For example, beginning music lessons prior to the age of 7 is thought to be essential for acquiring absolute pitch, the ability to name a pitch class in the absence of a reference.\textsuperscript{18,19} Likewise, anatomical and functional brain enhancements observed among musicians are negatively correlated with the age at which musicians began taking music lessons.\textsuperscript{20–23} One problem with interpreting such findings, however, is that onset of music training is usually confounded with total amount of training (in years) because individuals who began music lessons at a young age tend to have more years of music training overall than those who began later, particularly among college-age samples. However, recent evidence suggests that even when total amount of music training is controlled, performance on rhythm perception and synchronization is better among musicians who began lessons prior to the age of 7 than those who began after that age.\textsuperscript{24,25}
The above findings have potentially important implications, because they suggest that, like language, there may be an advantage to acquiring musical expertise early in development. However, even if individuals have the same amount of formal training in years, other factors may contribute to age-related learning differences. For example, music lessons for young children may differ in content, structure, and appeal when compared with lessons for older children. Practice patterns may also differ across younger and older learners. Thus, given the complexity and diversity of music training experiences, it is nearly impossible for researchers to ensure that all participants in a study receive the same amount and type of formal training. Even if we observe age-related decline in the capacity to learn to play an instrument, this does not necessarily imply that the same decline characterizes informal learning in the context of everyday music listening and enculturation. As an informal, implicit process, the latter type of learning is perhaps more comparable to language acquisition, yet little is known about age-of-acquisition effects in the context of musical enculturation.

The present experiment examines how passive exposure to music from a foreign culture influences perception of rhythm and meter at different ages. Although young listeners can infer the underlying beat from a rhythmic pattern,4–6 they nevertheless appear to acquire hierarchical metrical representations or categories that influence beat induction in a top–down fashion.26 Metrical structures vary cross-culturally, and Western music in particular tends to contain isochronous beats at multiple levels and durations that stand in simple 2:1 or 1:1 ratios. It is perhaps for this reason that Western listeners have difficulty perceiving, remembering, and producing rhythms that contain complex duration ratios and fail to conform to an isochronous beat.7,26–31 By contrast, music from various regions of the world (the Balkans, South Asia, Africa, South America) can contain nonisochronous meter with alternating long and short durations having 3:2 ratios.32 Accordingly, listeners from these cultures perceive isochronous and nonisochronous meters similarly as long as the structures are culturally familiar (S. Ullal, E.E. Hannon & J.S. Snyder, in prep.).7,33–34

Among Western listeners, biases toward isochronous meter appear to emerge during infancy, as shown by the finding that American infants readily distinguish folk melodies with either type of meter at 6 months of age, but by 12 months they only discriminate melodies with isochronous meter.7,8 Interestingly, this developmental decline in perception of nonisochronous meter can be prevented if 12-month-olds are given 2 weeks of at-home exposure to nonisochronous Balkan folk music for 10 min per day, after which they show robust discrimination of nonisochronous melodies.8 By contrast, the same amount of exposure has minimal effect on the performance of adults, who continue to exhibit a strong bias toward isochronous meters and simple rhythmic ratios even after exposure.8 Thus, the capacity to learn from everyday music exposure appears to change between infancy and adulthood, perhaps in tandem with musical enculturation. As culture-specific musical knowledge develops, listeners may acquire increasingly robust representations that are decreasingly susceptible to modification.2 The present study therefore adapted the at-home exposure paradigm described previously8 to examine how readily children of different ages and adults learn from passive exposure to unfamiliar (Balkan) nonisochronous meters. Listeners between the ages of five and adulthood participated in a perceptual judgment task with both isochronous and nonisochronous folk melodies before and after at-home exposure to recordings of nonisochronous, Balkan folk music. This allowed us to directly and precisely manipulate informal exposure to music to examine potential age-of-acquisition effects in music learning.

Methods

Participants

Five groups of participants were approximately of ages 5, 7, 9, 11, or 18+ years. There were 24 5-year-olds (11 female; M_age = 5.2, age range: 4.5–5.8), 23 7-year-olds (8 female; M_age = 6.99, age range: 6–7.8), 24 9-year-olds (11 female; M_age = 8.92, age range: 8–9.8), 26 11-year-olds (15 female; M_age = 11.3, age range: 10–13), and 23 adults (14 female; M_age = 21.3, age range: 18–36). Families of child participants volunteered in response to letters distributed in the community and received a toy after each testing session, and adult participants received course credit for their participation. All participants had normal hearing, no history of hearing problems, did not suffer from a cold or illness on the
day of testing, and spoke English fluently. Some participants were fluent in a second language but were bilingual from infancy \((n = 10)\) or acquired English prior to age five \((n = 10)\). Forty-one participants \((30\) children) reported having had some formal music training, which ranged from zero to 11 years \((M = 0.80)\). An additional 25 participants \((24\) children) reported having had formal dance training, which ranged from zero to 7 years \((M = 0.43)\). No participants had ever visited the Balkan peninsula, and none reported being familiar with music, dances, or languages from that region.

Only the participants who tested in both sessions were included in the final sample. An additional 13 participants were run but excluded from the final sample because of equipment failure \((n = 5\) children), insufficient exposure period \((n = 1\) child), or because the participant gave the same response throughout the entire experiment \((n = 7\) children, 1 adult). We also established an inclusion threshold to exclude children who clearly did not understand the task and/or failed to follow instructions. We reasoned that if children understood the task, they should have little difficulty correctly distinguishing perfectly accurate from highly disrupted renditions of a previously presented melody. The final sample therefore excluded participants who gave higher similarity ratings to the severely disrupted test stimulus than to the unaltered test stimulus in the isochronous conditions of the initial session \(see Fig. 2\) and stimulus description in the next section). This led to the exclusion of 33 children \((12 5\)-year-olds, 10 7\)-year-olds, 4 9\)-year-olds, and 7 11\)-year-olds), roughly 21% of the total sample.

**Stimuli**

The similarity judgment task was identical across the two test sessions. Two blocks of each meter were presented, for a total of four blocks per session. All stimuli were generated using a MIDI sequencer (Digital Performer) and converted to AIFF using the Apple QuickTime synthesizer (Apple, Inc., Cupertino, CA). Each block began with a familiarization stimulus followed by four test stimuli \(identical to those used previously, Refs. 7 and 8\). Four traditional Balkan folk songs, each eight measures in duration, were used as familiarization stimuli, two originally scored in 4/4 isochronous meter and the other two in 7/8 nonisochronous meter. Each familiarization stimulus had two melodic instruments playing in unison or thirds, a harmonic instrument, and a fourth percussion instrument presenting a repeating long–short–short or short–short–long pattern. Drum patterns with isochronous meter alternated between 1,000 msec and 500 msec intervals, yielding a 2:1 ratio, whereas nonisochronous meter drum patterns alternated between 750 msec and 500 msec, yielding a 3:2 ratio \(see “unaltered” stimuli in Fig. 1\). All familiarization stimuli were accompanied by a dynamic cartoon display of a tiger holding a guitar and swaying back and forth.

For each familiarization stimulus, four test renditions were created, two that preserved the original meter and drum pattern of the familiarization stimulus, and two that disrupted its meter and drum pattern \(see Fig. 1\). Test stimuli contained only the drum pattern and one melodic instrument \(piano\). Thus, even the unaltered test stimulus had novel instrument timbre and texture.
relative to familiarization, though it preserved the exact pitch and rhythm of the original. Both “structure-preserving” and “structure-disrupting” test stimuli contained an extra 250-msec eighth note inserted into every measure. Structure-preserving stimuli reduced adjacent note durations to maintain the original metrical structure and drum pattern, whereas structure-disrupting stimuli left adjacent durations unchanged, which lengthened a drum interval and therefore disrupted the meter. The severely disrupted stimulus contained many extra notes that were 250–500 msec in duration, inserted pseudorandomly one to three times per measure. Test stimuli thus presented both obvious disruptions as well as more subtle disruptions. All auditory test stimuli were randomly paired with a video of one of five animated sheep. Each sheep was paired with each test stimulus, creating four possible sheep–stimulus pairings per stimulus. For use in a brief practice block preceding testing, an additional set of familiarization and test stimuli were created from the song “Mary Had a Little Lamb,” with familiarization and test renditions created as described previously.

For the at-home listening phase of the study, a compact disc (CD) was created that contained five recordings of nonisochronous dance music from Macedonia, Bulgaria, or Bosnia used in prior work. The CD was 10 min long and contained none of the folk songs used during test sessions. Audio CDs were burned using iTunes on a Macintosh computer (Apple, Inc., Cupertino, CA).

For the second test session, a brief recognition test was prepared to determine whether participants followed the at-home CD listening instructions. Fifteen 20-sec excerpts were presented in random order. Five were targets (clips from the take-home CD), five were nontargets drawn from the same Balkan artists with nonisochronous meters, and five were nontargets drawn from folk music recordings from other regions of the world. Thus, nontargets were highly confusable with targets, making it difficult for participants to succeed on the recognition test without listening at home to the audio CD.

**Apparatus and procedure**

Each testing session included four blocks (one per familiarization song), plus a practice block at the beginning of the session. Within each block, participants first heard a familiarization stimulus for 2 minutes, followed by four “test” renditions of the same song. Participants rated how similar each test stimulus was to the original familiarization stimulus on a scale of 1 (very similar) to 5 (very different). Sheep–stimulus pairings, block order, and test stimulus order were counterbalanced between subjects.

Participants were tested alone on a Mac Mini computer (Apple, Inc., Cupertino, CA) running PsyScope and equipped with an ioLab USB response box and two desktop computer speakers. Responses were collected using a rectangular game board with a row of six colored squares, the leftmost of which contained a picture of the tiger which accompanied the familiarization song. Five laminated game pieces were created (e.g., rocket, star, flower), which participants placed on the game board to indicate their rating. The game board thus served as a tangible representation of the five-point similarity rating scale with maximal similarity on the left (near the tiger) and dissimilarity on the right (far away from the tiger). The experimenter gave each participant verbal instructions based on the following: “A tiger will play you the first song. Listen carefully! His song is the best song. His friends are each going to try to play the same song, but they can’t all play it like the tiger. Use the scale to show how close each animal gets to the tiger’s song. If the animal’s version is very close to the tiger’s, put your game piece next to the tiger. If the animal’s version is wrong, put your game piece far away from the tiger.” For any given trial, the child placed his or her game piece on the game board and the experimenter entered the child’s response using the response box.

Each test session was preceded by a brief practice block, during which participants were given practice using the rating scale. During the test phase of the practice block, each test stimulus was presented twice—first with explicit feedback about the similarity of each stimulus relative to familiarization and a second time without feedback. Participants could repeat the familiarization block until they felt comfortable with the task.

Participants were asked to return for a second test session 12–15 days later. During the interim, they were asked to listen at home twice daily to the audio CD using a provided log sheet to indicate listening days and times. At the end of the second test session, participants were given the recognition test by means of PsyScope, which presented targets and nontargets in random order. Participants...
indicated whether each excerpt had or had not been on the take-home audio CD. During the final test session participants completed a questionnaire assessing their musical and cultural background.

Results

Similarity ratings
Accurate performance in the similarity judgment task entailed giving higher dissimilarity ratings to structure-disrupting than to structure-preserving test stimuli, so difference scores were calculated as a measure of accuracy. For each block we subtracted ratings of test stimuli that preserved the meter (the mean of unaltered and structure-preserving ratings) from ratings of test stimuli that disrupted the meter (mean of structure-disrupting and severely disrupted ratings). We combined ratings of both subtle and more obvious disruptions because we wanted to ensure the task was easy enough for the younger age groups. We expected overall accuracy to increase with age regardless of meter.

Session 1
As shown in Figure 2A, older participants were generally more accurate than younger participants, consistent with our prediction that younger children would find the task more challenging. Moreover, all groups exhibited higher accuracy in isochronous rather than nonisochronous conditions, consistent with prior work. These trends were confirmed by a two-way mixed design analysis of variance (ANOVA) with factors of meter (within subjects) and age group (between subjects), which revealed a main effect of age group, $F(4,115) = 8.322$, $P < 0.001$, meter, $F(1,115) = 37.037$, $P < 0.001$, and a significant interaction between meter and age group, $F(4,115) = 2.76$, $P < 0.05$. Bonferroni-corrected $t$-tests revealed that accuracy was higher in isochronous than in nonisochronous conditions for 5-year-olds, $t(23) = 3.807$, $P < 0.001$, 7-year-olds, $t(22) = 2.59$, $P < 0.05$, and adults, $t(23) = 3.029$, $P < 0.01$, and marginally significant for 9-year-olds, $t(23) = 1.892$, $P = 0.07$, and 11-year-olds, $t(23) = 1.681$, $P = 0.10$ (see Fig. 2A).

Session 2
Performance in session 2 differed markedly from session 1, particularly for the younger groups. The two-way meter by age group ANOVA revealed a main effect of age group, $F(4,115) = 16.058$, $P < 0.001$, but only a marginally significant main effect of meter, $F(1,115) = 3.42$, $P = 0.07$, and a significant interaction between meter and age group, $F(4,115) = 4.245$, $P < 0.01$. Unlike during session 1, where an advantage for isochronous-meter stimuli was apparent at all ages, during session 2, this advantage was evident only among adult participants, $t(23) = 3.79$, $P < 0.01$, and to an extent among 11-year-olds, although the advantage was not significant in this group, $t(25) = 1.602$, $P = 0.12$. Seven- and 9-year-olds performed comparably in isochronous and nonisochronous conditions during session 2, $t(23) < 0.30$, $P > 0.76$, and 5-year-olds performed more accurately in the nonisochronous condition, although this trend was not significant, $t(23) = 1.27$, $P = 0.217$ (see Fig. 2B).

Changes across sessions
An overall three-way mixed-design ANOVA with factors of meter, session, and age group confirmed that there was a significant three-way interaction,
Enculturation scores (percent correct) were above chance (M_{age5} = 0.79, SD = 0.14; M_{age7} = 0.86, SD = 0.17; M_{age9} = 0.85, SD = 0.14; M_{age11} = 0.84, SD = 0.15; M_{adult} = 0.84, SD = 0.14), and a one-way ANOVA revealed that recognition accuracy did not vary by age, F(4,112) = 0.843, P > 0.50. It was therefore unlikely that younger children listened
more or were more compliant than older children or adults.

Conclusions
The present findings suggest that incidental exposure to music with foreign, nonisochronous meters has different effects on younger than older listeners. Specifically, passive at-home exposure to Balkan folk music with nonisochronous meter gave rise to dramatic changes in the perception of nonisochronous and isochronous meter among 5-year-olds and to some extent among 7-year-olds, but minimal effects among 11-year-olds and adults. It was also shown that at-home exposure eliminated a previously observed bias toward isochronous meters among children of age 9 and below that. By contrast, 11-year-olds and adults consistently performed more accurately in the isochronous than in the nonisochronous conditions across sessions, regardless of exposure. Thus, greater susceptibility to perceptual experience, previously documented among 12-month-old infants, appears to extend to the first 5 years of childhood, and culture-specific representations may continue to undergo development up until age 11.

It is important to acknowledge limitations that should be addressed in future work. By providing all participants with the same CD, the present experiment manipulated musical experience in a much more controlled fashion than has been possible in prior work. However, it was impossible to ensure that all subjects received the same amount and quality of exposure to the CD. The recognition test provided an important index of listening quality, but future work, perhaps in a laboratory setting, could attempt to more closely monitor exposure to ensure maximal compliance.

A second limitation arose from using the same task with all participants. Younger children were at a disadvantage relative to older children and adults who presumably have more developed working memory, cognitive control, attention span, and superior task comprehension. We felt that using the same task across ages was a more conservative approach than reducing task difficulty for younger groups, given the possibility that younger learners might outperform older learners. The fact that the youngest children showed the greatest gains in performance despite their overall poorer performance provides strong support for the claim that they learn more readily. It would nevertheless be helpful in future work to equate task difficulty across groups to ensure that it does not interact with learning outcomes.

Finally, the study could be improved by including a control group of listeners who receive no at-home listening experience. Because exposure to isochronous music remained constant across sessions, we expected no change in performance in the isochronous condition and thus considered it a within-subjects control. However, we found that 5- and 7-year-olds’ performance in the isochronous condition diminished over the two sessions. This outcome might be expected if young children have weak representations of isochronous meter that are readily reorganized through exposure to nonisochronous meter. It is thus essential to determine whether declines in performance arose due to exposure or due to repeated testing.

In conclusion, the present work provides an initial glimpse into the fundamental question of how and when culture-specific musical knowledge is acquired over the course of child development. Such research is essential for understanding musical development and the mechanisms underlying music learning. The work also adds to a growing body of evidence suggesting that age-of-acquisition effects characterize music learning just as they do language learning, and that such effects arise in the context of formal music training as well as informal musical enculturation.

Conflicts of interest
The authors declare no conflicts of interest.

References


