

# Children infer the behavioral contexts of unfamiliar foreign songs

Courtney B. Hilton<sup>1,^,\*</sup>, Liam Crowley-de Thierry<sup>2,^,\*</sup>, Ran Yan<sup>1,3</sup>, Alia Martin<sup>2</sup>, & Samuel A. Mehr<sup>1,2,4,\*</sup>

<sup>1</sup>Department of Psychology, Harvard University, Cambridge, MA 02138, USA.

<sup>2</sup>School of Psychology, Victoria University of Wellington, Wellington 6012, New Zealand.

<sup>3</sup>Department of Psychology, Smith College, Northampton, MA 01063, USA.

<sup>4</sup>Data Science Initiative, Harvard University, Cambridge, MA 02138, USA.

<sup>^</sup>These authors contributed equally.

\*Corresponding author. Emails: [courtneyhilton@g.harvard.edu](mailto:courtneyhilton@g.harvard.edu), [crowleliam@myvuw.ac.nz](mailto:crowleliam@myvuw.ac.nz), [sam@wjh.harvard.edu](mailto:sam@wjh.harvard.edu)

**Author Note.** A reproducible version of this manuscript, including all analysis and visualization code and data, is available at <https://github.com/themusiclab/form-function-kids>. Audio excerpts from the *Natural History of Song Discography* are available at <https://osf.io/vcybz> and can be explored interactively at <https://themusiclab.org/nhsplots>; all other study data and materials are available at <https://osf.io/b9tnu>. The study was preregistered at <https://osf.io/56zne>. For assistance, please contact C.B.H., L.C-T., and S.A.M.

Music commonly appears in a variety of behavioral contexts in which it can be seen as playing a functional role, such as when a parent sings a song with the goal of soothing their child. Humans readily make inferences about such behavioral contexts based on sound alone. These inferences tend to be accurate, even if the songs are in foreign languages or unfamiliar musical idioms: upon hearing a Blackfoot lullaby, a Korean listener with no experience of Blackfoot music, language, or broader culture is far more likely to judge the music’s function as “to soothe a baby” than as “for dancing”. Are such inferences shaped by musical exposure or does the human mind naturally detect links between musical form and function? Children’s developing experiences with music provide a clear test of this question. We studied musical inferences in a large sample of children ( $N = 2,624$ ), who heard dance, lullaby, and healing songs from 70 world cultures and who were tasked with guessing the original behavioral context in which each was performed. We found little evidence for an effect of experience: children reliably inferred the original behavioral contexts with only minimal improvement in performance from the youngest (age 3 or younger) to the oldest (age 12). Children’s inferences tightly correlated with those of adults for the same songs, as collected from a similar massive online experiment ( $N = 85,068$ ). Moreover, the same musical/acoustical features were predictive of the inferences of both samples. These findings suggest that accurate inferences about the behavioral contexts of music, driven by universal links between form and function in music across cultures, do not require extensive musical experience.

1 Music is a ubiquitous part of human culture that plays a variety of functional roles in our day-to-day lives  
2 (Lomax, 1968; Mehr et al., 2019; Nettl, 2005; Trehub et al., 2015): We sing songs to entertain each other,  
3 to find spiritual connection, to tell stories, to regulate our emotions, or just to pass the time.

4 Whereas some musical contexts are idiosyncratic, like how complex geographical knowledge is culturally  
5 encoded in song by some groups of Indigenous Australians (Norris & Harney, 2014), others are recurrent  
6 across societies. These latter contexts tend to also be accompanied by recurrent sets of features. For  
7 example, in Western societies, lullabies tend to have slow tempos; smooth, minimally accented contours;  
8 and a narrow dynamic and pitch range (Bergeson & Trehub, 1999; Trehub, 1998; Trehub et al., 1993a), a  
9 pattern replicated in a globally representative sample of societies (Mehr et al., 2019). That music appears  
10 universally in conjunction with a given behavioral context (e.g., infant care), and that examples of music  
11 in that context share particular musical features (e.g., minimal accents), implies a link between form and  
12 function in music production.

13 Adults are sensitive to this link, in that they reliably distinguish song functions even when examples are  
14 unfamiliar and foreign. This has been demonstrated in experiments where naïve listeners are asked to identify  
15 the context in which a song was originally used, purely on the basis of the sounds it contains. Indeed, they  
16 successfully identify lullabies when paired with love songs as foils (Trehub et al., 1993b) and distinguish  
17 lullabies, dance songs, healing songs, and love songs from one another (Mehr et al., 2018, 2019).

How do adults come to be sensitive to these musical form-function links? Across the lifespan, musical experience is ubiquitous and rich, including through infancy (Mendoza & Fausey, 2021) and childhood (Bonneville-Roussy et al., 2013), so it’s plausible that a sensitivity to form and function in music is shaped by direct musical experience. This is especially so given people’s detailed long-term memories for music (Krumhansl, 2010; Levitin & Cook, 1996) and the importance of implicit associative learning in musical knowledge (Rohrmeier & Rebuschat, 2012).

Two forms of evidence point to an alternative explanation, however. First, systematic form-function pairings are found in vocalizations throughout the animal kingdom (Fitch et al., 2002; Morton, 1977), and likely reflect innate aspects of vocal signaling (Darwin, 1871; Mehr et al., 2020). Indeed, emotional vocalizations are not only cross-culturally intelligible within humans (Chronaki et al., 2018; Scherer et al., 2001; including in music: Balkwill & Thompson, 1999), but also between species (Filippi et al., 2017). Humans extend these emotional inferences to environmental sounds (Ma & Thompson, 2015) and even to abstract shapes (Sievers et al., 2019). Form-function inferences in music might borrow from and extend this repertoire of instinctive signaling mechanisms.

Second, despite their lesser degree of exposure to music, relative to adults, infants are affected by music in ways that are predictable from the behavioral functions of music. For example, infants relax more in response to unfamiliar foreign lullabies than non-lullabies (Bainbridge et al., 2021), and move rhythmically more in response to metrical music than speech (Zentner & Eerola, 2010). While neither implies that infants are aware of the function of a song, early-developing responses to music may eventually support form-function inferences when combined with precocial social inferences (Bohn & Frank, 2019; Mehr et al., 2016; Powell & Spelke, 2013); biases for socially meaningful stimuli (Frank et al., 2014); and functional intuitions about other socially embedded vocalizations, such as speech (Martin et al., 2012; Vouloumanos et al., 2014).

To test between these perspectives, we studied musical inferences across early and middle childhood, focusing on whether and how these inferences change as children’s musical experience grows. Children participated in a citizen-science experiment (readers can try it with their children at <https://themusiclab.org>) where they listened to examples of lullabies, dance songs, and healing songs from 70 mostly small-scale societies, drawn from the *Natural History of Song Discography* (Mehr et al., 2019), and were tasked with guessing the original behavioral context.

To examine the degree to which musical experience affected children’s inferences, we conducted a series of preregistered and exploratory analyses, asking (1) whether children are sensitive to form and function in music; (2) how their sensitivity changes over the course of childhood; (3) how children’s inferences compare to those of adults; and (4) whether and how children’s inferences are predictable from the acoustical features of the music.

## Methods

### Participants

Children visited the citizen science website <https://themusiclab.org> to participate. We posted links to the experiment on social media, which were spread via organic sharing, and we also advertised the experiment on <https://childrenhelpingscience.com>, a website disseminating information on web-based research for children (Sheskin et al., 2020). Recruitment was/is open-ended; at the time of analysis, we had complete data from 6,254 children with reported ages from “3 or under” to “17 or older.” Given our interest in early development, we chose to analyze only data from the youngest 10 age bands (ages “3 or under” to “12”). We excluded older children ( $n = 3,782$ ); children whose parents indicated that they had assisted their child during the experiment ( $n = 708$ ); children who indicated they had played the game previously ( $n = 543$ ); children with known hearing impairments ( $n = 388$ ); and children who were missing data from the test phase ( $n = 38$ ).

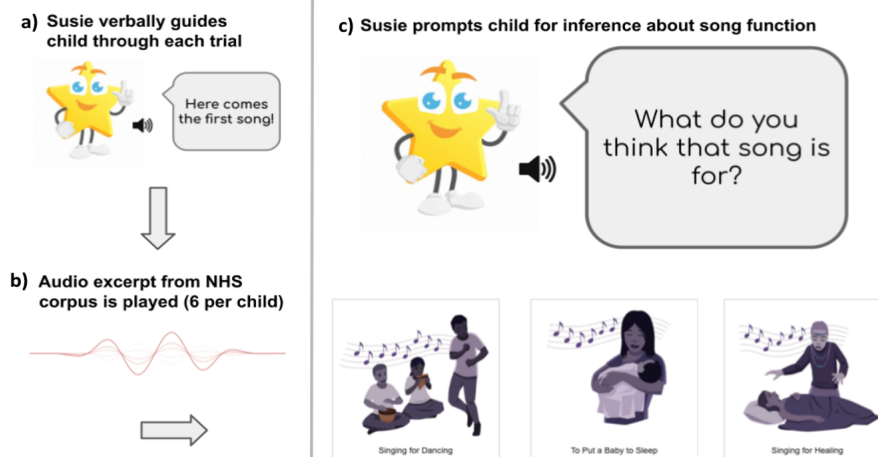
This left 2,624 participants for analysis (1,116 male, 1,396 female, 112 other; the cohort’s breakdown of age and gender, after exclusions, is in SI Figure 1) representing 108 native languages and 112 countries (SI Tables 1 and 2).

No compensation was given, reducing the likelihood that adults were posing as children, but as an additional check, we examined participants' response times during the study. Consistent with prior work showing that response time in perceptual and cognitive tasks decreases over the course of childhood (Hale, 1990; Kiselev et al., 2009), response times during the task decreased reliably as a function of age ( $F(1, 2,622) = 216.96, p < .001, R^2 = 0.08$ ; SI Figure 2). More generally, there is growing evidence that online and lab-based data collection produce similar results, with limited evidence for reduced reliability in online cohorts (Germin et al., 2012; Hartshorne et al., 2019).

## Stimuli

Song excerpts were drawn from the *Natural History of Song Discography* (Mehr et al., 2019), a corpus of vocal music collected from 86 mostly small-scale societies, including hunter-gatherers, pastoralists, and subsistence farmers. Each song in the corpus was originally performed in one of four behavioral contexts: dance, healing, lullaby, and love. All recordings were selected on the basis of supporting ethnographic material, as opposed to the acoustic features of the songs (Mehr et al., 2018, see: 2019).

Because love songs were ambiguously detected in some prior work (Mehr et al., 2018), and given the difficulty of explaining this category to children, we omitted love songs from the experiment and studied only the remaining three contexts (dance, lullaby, and healing). This left 88 songs from 70 societies, sung in 30 languages (SI Table 3) and originating from locations corresponding to 46 countries (SI Figure 3).



**Figure 1 | Schematic of the test phase of the experiment.** Children participated in an online game, narrated by *Susie the Star*, whose instructions were spoken aloud and printed in speech bubbles on the screen. Parents helped their children get accustomed to the procedure, but were asked not to help during the test phase of the experiment. During testing (panels a-c) children listened to a series of songs; after each one, *Susie* asked them to guess its behavioral context.

## Procedure

Participants could use a computer, mobile phone, or tablet; they were encouraged to use a computer, however, for easier user interface navigation. A progress bar, displayed throughout the experiment, indicated the times when the child should be assisted by a parent and the times the child should not be assisted. A schematic of the procedure is in Figure 1.

Parents were instructed to begin the game without the child present, so that they could provide us with demographic information and become oriented to the interface. This information included whether the child had previously participated in the experiment; the child’s age, gender, country of residence, native language, any known hearing impairments; and whether or not the child was wearing headphones. We also asked about the frequency with which the child was exposed to parental singing or recorded music in the home.

Parents then turned the experiment over to their children, who were guided by an animated character, “Susie the Star.” Susie provided verbal encouragement to keep the children motivated; explained the task instructions, which were also presented visually (but the youngest children were likely unable to read them); and reminded the children of these instructions throughout the experiment. First, in a training phase, Susie played children a likely-to-be-familiar song (the “Happy Birthday” song) and asked them to identify what they thought it was used for, by selecting one of three choices: “singing for bath time,” “singing for school assembly” or “singing for celebrating a birthday.” Once children correctly identified the song’s behavioral context, Susie then presented the three song categories that children would be tested on in the experiment (lullaby, “for putting a baby to sleep”; healing, “to make a sick person feel better”; dance, “singing for dancing”). An illustration accompanied each song category’s description, to facilitate responses for children too young to read (see Figure 1).

Susie then played the children a counterbalanced set of six songs (two per song type) drawn randomly from the *Natural History of Song Discography* and presented in a random order. The excerpts were 14 seconds long and each played in its entirety before the child could advance. After each song, Susie asked “What do you think that song was for?” and children made a guess by clicking or tapping on a labeled illustration corresponding with the song type (see Figure 1). We also asked children to rate how much they liked the song, for use in a different study. Positive feedback was always given after each trial (e.g., “Good job!”), with an arbitrary number of “points” awarded (+20 points when correct and +15 points when incorrect).

Last, parents answered debriefing questions. The questions confirmed whether the child had worn headphones during the experiment (if, at the beginning of the study, the parent had stated the child would wear headphones), if the parent had assisted the child during the training portion of the experiment, and if the parent had assisted the child during the test questions.

## Pilot study and preregistration

We ran a pilot version of the experiment with 500 children (50 children in each age group, range 3-12; 221 male, 267 female, 12 other) to provide a dataset for exploratory analyses. Based on these data, and our broader theoretical interests motivated in the introduction section of this paper, we preregistered three confirmatory hypotheses to be tested in a larger sample (see the preregistration at <https://osf.io/56zne>): in the full cohort of children, accurate identification of behavioral contexts overall and in all three song types; a statistically significant but practically non-significant effect of age on accuracy ( $R^2 < .05$ ); small or null associations of musical exposure in the home on accuracy.

We also pre-specified four other hypotheses that were not investigated in the exploratory sample. Two of these are studied in this paper: predicted correlations between children’s intuitions about the songs and adults’ intuitions (with a sample expanded from our previous study in Mehr et al., 2019); and a prediction that the musical features of the songs that are predictive of children’s intuitions about them, within a given song type, will correspond with musical features previously identified as universally associated with that song type (from Mehr et al., 2019). We leave the remaining two hypotheses for future research.

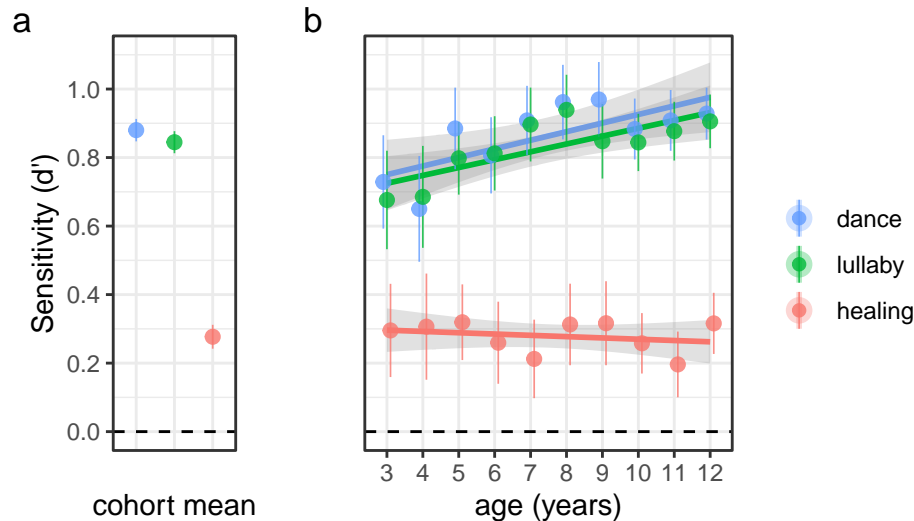
## Results

### Children’s musical inferences are accurate

Children accurately inferred the behavioral context of the songs they listened to at a rate significantly above chance level of 33.3% (Figure 2a;  $M = 52.2\%$ ,  $SD = 20.9\%$ ,  $d' = 0.81$ ), as they did in exploratory results,

and confirming the first preregistered hypothesis.

Notably, children did not use the three response options evenly: they guessed “dance” most frequently (42.6%), followed by “healing” (35.3%), and least often guessed “lullaby” (22.0%). As such, we computed  $d'$ -prime scores for each of the three song types for each of the participants, to assess discrimination independently from response bias. Dance songs were the most reliably discriminated ( $d' = 0.88$ , 95%  $CI$  [0.85, 0.91],  $t(2623) = 52.67$ ,  $p < .001$ , one-sample two-tailed  $t$ -test), followed closely by lullabies ( $d' = 0.84$ , 95%  $CI$  [0.81, 0.88],  $t(2623) = 51.45$ ,  $p < .001$ ). Healing songs were the least reliably discriminated but still robustly above chance ( $d' = 0.28$ , 95%  $CI$  [0.24, 0.31],  $t(2623) = 15.57$ ,  $p < .001$ ).



**Figure 2 | Accurate identification of all three song types, cohort-wide and as a function of age.** (a) Mean  $d'$ -prime scores across all children show above-chance identification of each song type, independent of their response bias. (b) Accuracy increases only modestly from the youngest to the oldest children, and only for lullabies and dance songs. In both panels, the circles indicate mean  $d'$ -prime scores and the error bars indicate the 95% confidence intervals. In panel b, the three thick lines depict a linear regression for each song type and the shaded regions represent the 95% confidence intervals from each regression.

## Musical inferences improve only slightly with age

To measure the degree to which these inferences change through development, we fit a simple linear regression predicting children’s average accuracy from age, finding a small but significant effect ( $F(1, 2,622) = 8.00$ ,  $p = 0.005$ ,  $R^2 = 0.003$ ), consistent with our exploratory analyses and preregistered hypothesis (i.e., a small, or practically non-significant increase in accuracy).

As a more rigorous test, which was not preregistered, we ran a mixed-effects model on participant-wise  $d'$ -prime scores, with random intercepts for participants and random intercepts and slopes for song types. In this model, the effect of age did not reach statistical significance ( $F(1, 117.47) = 2.33$ ,  $p = 0.13$ ).

## Musical inferences are unrelated to children’s home musical environment

We tested the relation between parent-child musical interactions and children’s musical inferences. Consistent with the preregistered hypothesis, we found no evidence for relations between  $d'$ -prime scores and the frequency of parental singing (SI Figure 4a;  $F(1, 2,620) = 0.02$ ,  $p = 0.89$ ), or the frequency of recorded music (SI Figure 4b;  $F(1, 2,620) = 0.03$ ,  $p = 0.87$ ).

## Musical inferences are highly similar between children and adults

With practically no change in accuracy from early childhood to early adolescence, might children’s musical inferences be similar to those of adults? We used all available data from the “World Music Quiz” on <https://themusiclab.org>, a similar experiment for adults. Data were available from 85,068 participants who were older than 18 years old (13,157 male, 6,643 female, 205 other, for 65,063 gender information was not available; mean age = 31.3, SD = 12.9, range: 18-99; n.b., a portion of these data were previously analyzed in Mehr et al. (2019), but not in relation to children’s performance on the task). For both adults and children, we computed the song-wise proportion of guesses for each song type (i.e., a measure of how strongly each song cued a given behavioral context) and then regressed these scores on each other.

In all cases, children’s inferences were highly predictive of adults’, with  $R^2$  values approaching 1 (Figure 3a-c; dance:  $F(1, 86) = 2,125.63$ ,  $R^2 = 0.96$ ; lullaby:  $F(1, 86) = 1,942.71$ ,  $R^2 = 0.96$ ; healing:  $F(1, 86) = 299.12$ ,  $R^2 = 0.78$ ; all  $p < .001$ ). This relationship was also robust when inferences were reduced from a continuous score to a discrete ranking of the songs by guessing percentage. We quantified the strength of this relationship using Kendall’s rank correlation coefficient  $\tau$ : a more conservative, non-parametric measure of correlation. Again, there was a strong positive correlation between children’s and adults’ inferences for all song types (dance:  $\tau = 0.884$ ; lullaby:  $\tau = 0.796$ ; healing:  $\tau = 0.706$ ; all  $p < .001$ ).

## Child and adult musical inferences are driven by the same musical features

To investigate what might drive children’s musical inferences, we analyzed which musical features were predictive of their guesses, within each song; and whether these musical features corresponded with those that were predictive of adults’ guesses. We began with the set of 36 musical features (expert annotations and transcription variables) previously studied in Mehr et al. (2019). To reduce overfitting, we selected variables via LASSO regularization (Friedman et al., 2016).

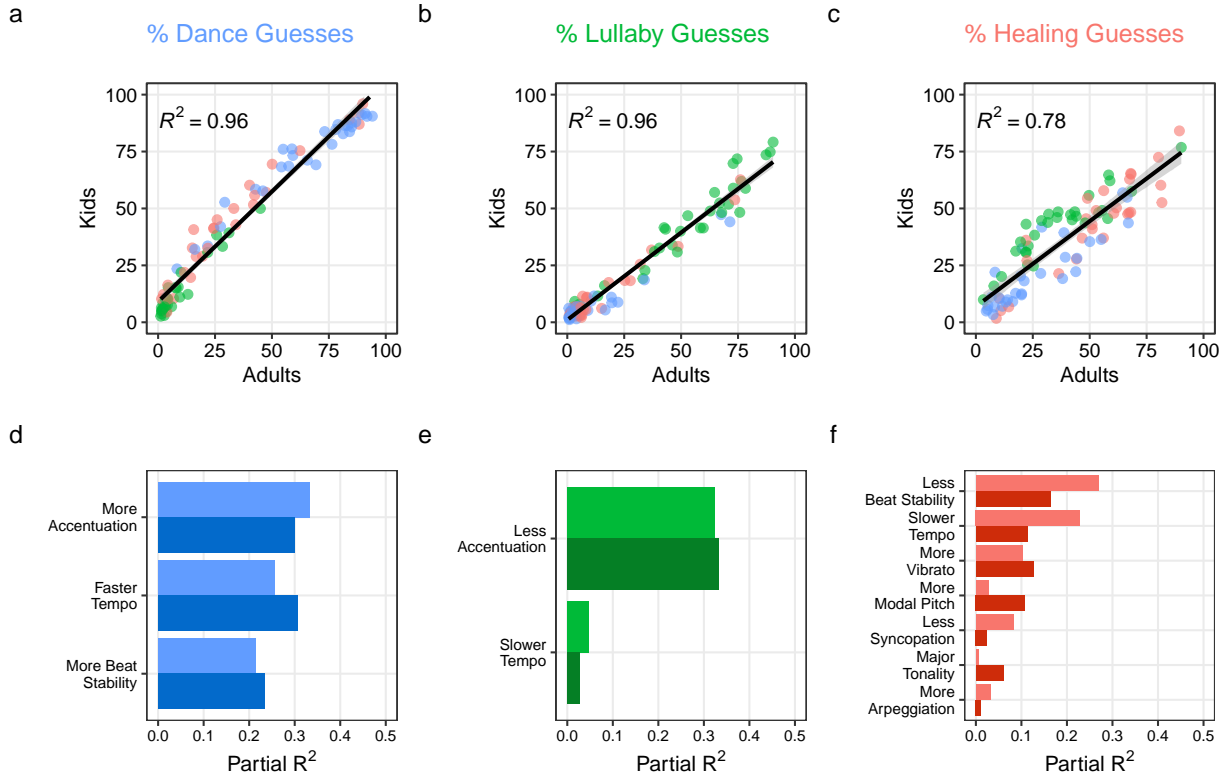
The model was trained to predict the child and adult inferences for each song on the basis of the 36 musical features. The key hyperparameter of the model (lambda), which determines how many features are selected, was chosen on the basis of a 10-fold cross-validation procedure across random subsets of the data, repeated 100 times for each song function to maximize robustness. The model mean squared error was averaged over these iterations, and we selected the highest lambda value whose model error was within one standard error of the minimum. This procedure yielded a small number of musical features predictive of each song-type guess; we then discarded those with coefficients below an arbitrary threshold of 0.01, as a form of secondary regularization (to err on the side of analyzing a smaller set of features).

We then built multiple regression models predicting the percentage of song-wise guesses in each category from the selected musical features. For all three song types, these features explained substantial variability in listener inferences (dance:  $F(1, 84) = 54.19$ ,  $p < .001$ ,  $R^2 = 0.66$ ; lullaby:  $F(1, 85) = 35.52$ ,  $p < .001$ ,  $R^2 = 0.46$ ; healing:  $F(1, 80) = 18.83$ ,  $p < .001$ ,  $R^2 = 0.62$ ). An analysis of the partial  $R^2$ s from the models showed that the musical features explained comparable degrees of variability in guessing behavior between children and adults (Figure 3d-f; full regression reporting is in SI Tables 4-6). To estimate the degree of similarity, we pooled song-wise guessing percentages and tested whether a model that could differentiate child/adult was statistically equivalent to one that could not, using a chi-square test. Only the model for dance inferences showed a statistical difference between children and adults (dance:  $\chi^2 = 5.89$ ,  $p = 0.005$ ; lullaby:  $\chi^2 = 6.46$ ,  $p = 0.07$ ; healing:  $\chi^2 = 3.32$ ,  $p = 0.23$ ).

## Discussion

We found that children make accurate inferences concerning the behavioral contexts of lullabies, dance songs, and healing songs. The songs were unfamiliar to the children, taken from a representative sample of vocal music from 70 human societies, yet their guessing patterns were well above chance and strikingly similar to those of adults. While older children guessed more accurately than younger children, on average, this





**Figure 3 | Children and adults make similar musical inferences that are driven by the same acoustical features.** The scatterplots (a-c) show the tight correlations between children's and adults' musical inferences. Each point represents average percent guesses that it was (a) “for dancing”; (b) “for putting a baby to sleep”; and (c) “to make a sick person feel better”; the songs’ *actual* behavioral contexts are color-coded, with dance songs in blue, lullabies in green, and healing songs in red. The lines depict simple linear regressions and the gray shaded areas show the 95% confidence intervals from each regression. The bar plots (d-f) show the similar amounts of variance (partial- $R^2$ ) in childrens’ (lighter bars) and adults’ (darker bars) guesses that is explained by musical features selected via LASSO regularization, for each of the three song types, computed from multiple regressions.

difference was very small, with the youngest children reaching near-adult levels of performance. Musical exposure in the home, from either recorded music or parental singing, was also unrelated to children’s performance. Together, these results suggest that the ability to infer musical function from acoustical forms, at least in the contexts studied here, develops early and seemingly independently from musical experience.

The similarities in children’s and adults’ inferences were detectable even at the level of individual musical features of each song. For example, faster tempo, more stable beat structure, and more rhythmic accentuation, led listeners to guess that a song was used for dancing; less rhythmic accentuation and slower tempo cued listeners that a song was used as a lullaby; and songs with a slower tempo and less beat stability suggested that a song was used for healing. But across the board, these acoustical features were comparably predictive of both children’s and adults’ inferences, suggesting similar mechanisms.

What explains the associations between musical features and functional inferences? We speculate that they tie into the prototypical emotional and physiological content of songs’ behavioral contexts. Across cultures, dance songs typically aim to increase arousal (e.g., energizing groups of people to dance) whereas lullabies aim to decrease it (e.g., soothing an infant) (Mehr et al., 2019). This is mirrored in the arousal-mediating effects of both rhythmic accentuation (Ilie & Thompson, 2006; Schubert, 2004; Weninger et al., 2013) and tempo (Balch & Lewis, 1996; Holbrook & Anand, 1990; Husain et al., 2002; Yamamoto et al., 2007), consistent with the associations we observed here between functional inferences and musical features. Indeed, from a young age, infants are sensitive to arousal-mediating musical features (Bainbridge et al., 2021; Cirelli et al., 2019).

The degree of beat stability also was predictive of “used for dancing” inferences, which might be understood as relating to the sensorimotor coordination aspect of dancing: dancing involves the coordination of multiple bodies in time through sound (among other cues). A stable beat structure likely supports such coordination, supported by the psychological effects of “groove,” an impulse for rhythmic body movement in response to music with high beat stability, fast tempos, more rhythmic accentuation, and a moderate amount of rhythmic complexity (Janata et al., 2012; Witek et al., 2014). In both children and adults, we found that these features were all predictive of intuitions that a song was “used for dancing.”

The acoustic correlates of healing songs are more difficult to interpret. Their traditional behavioral context is characterized by formal and religious activity across cultures (Mehr et al., 2019), such as those found in shamanistic healing rituals (Singh, 2018). But these rituals often include dancing, and may thus constitute a fuzzier category than dance or lullaby; for example, among the children, the song most consistently categorized as a dance song (96% of the time) was, in fact, a healing song. Perhaps the wider variety of significant predictors of listener inferences, which include melodic arpeggiation and vibrato (but with generally lower partial  $R^2$  values than in the other song types), underscores this fuzziness. These correlates are less obviously related to behavioral function (which, admittedly, is more ambiguous in the case of “making a sick person feel better” than the more straightforward case of “putting a baby to sleep”), so while music is reliably used in the context of healing in traditional societies (Mehr et al., 2019), and has well-recognized potential in clinical settings (Cheever et al., 2018), the mechanisms and acoustical correlates of such effects are not yet clear.

Our findings suggest that at least some parts of higher-level music perception develop early, with only minimal musical experience, echoing the results of studies in infants, who show distinct physiological responses to lullabies, relative to non-lullabies (Bainbridge et al., 2021). Many music perception abilities appear to be precocial, including beat processing (Phillips-Silver, 2005; Winkler et al., 2009; Zentner & Eerola, 2010) that differ markedly from non-human primates (Honing et al., 2018); sensitivity to tonal structure in music (Lynch & Eilers, 1992); rich memories of musical stimuli (Granier-Deferre et al., 2011) that persist after long delays (Mehr et al., 2016); and early sensitivity to metrical (Hannon & Trehub, 2005) and tonal structures (Lynch et al., 1990) typical of infants’ native musical environment. The nature of human music perception — including high-level, communicative inferences about form and function — might therefore be similar to the perception of arousal signals in vocalizations across species (Filippi et al., 2017; Owren & Rendall, 2001), contrasting with abilities that require extensive direct experience, such as those involved with learning a specific language or fluency in performing a specific style of music.

This is not to say that experience does *not* shape listeners’ understanding of music: it obviously does, as



evidenced by common sense and a variety of studies showing modest differences in the interpretation of musical structure across cultures (e.g., Drake & Heni, 2003). But our results support the view that musical meaning may build on innate signalling mechanisms not unlike those found in nonhuman vocalizations [e.g., those found in the contexts of infant care and territorial signaling; Mehr et al. (2020)]. On this idea, foundations for musical understanding come from the combination of acoustic predispositions, shared with other species; social experience, which plays a key role in early learning (Baldwin et al., 1996; Kinzler et al., 2007; Liberman et al., 2017), including in music (Mehr et al., 2016; Mehr & Krasnow, 2017; Xiao et al., 2017); and their interaction with related modalities, such as movement and emotion (Sievers et al., 2013, 2019).

Thus, despite the variety of roles that music plays in our lives and the different meanings it can afford, shaped by culture and experience, the results reported here suggest that aspects of our musical intuitions are rooted in our biology. The psychology of music, like other acoustic predispositions, may develop as a natural component of the human mind.

## Context

This study builds on previous studies from our group (Mehr et al., 2018, 2019), demonstrating (a) cross-cultural regularities in the associations between acoustical forms of music and particular behavioral contexts in which music appears; and (b) the sensitivity of adults to these associations. Here, we explored how musical experience in childhood shapes that sensitivity, using the same stimuli as previous work. We also compared children’s intuitions about music to adults’ directly, and analyzed how these intuitions correlate with specific musical features (providing clues about the mechanisms underlying the main effects). The results complement those of another recent study (Bainbridge et al., 2021), where infants showed differential physiological responses to unfamiliar foreign lullabies, relative to non-lullabies; those early-appearing, implicit responses to different forms of music, may help to explain children’s high performance in identifying behavioral contexts for music. Together, these studies inform theories of the basic design features of a human psychology of music, including debates surrounding the biological foundations of music (Mehr et al., 2020) and its relation to more general aspects of cognition (Hilton et al., 2020).

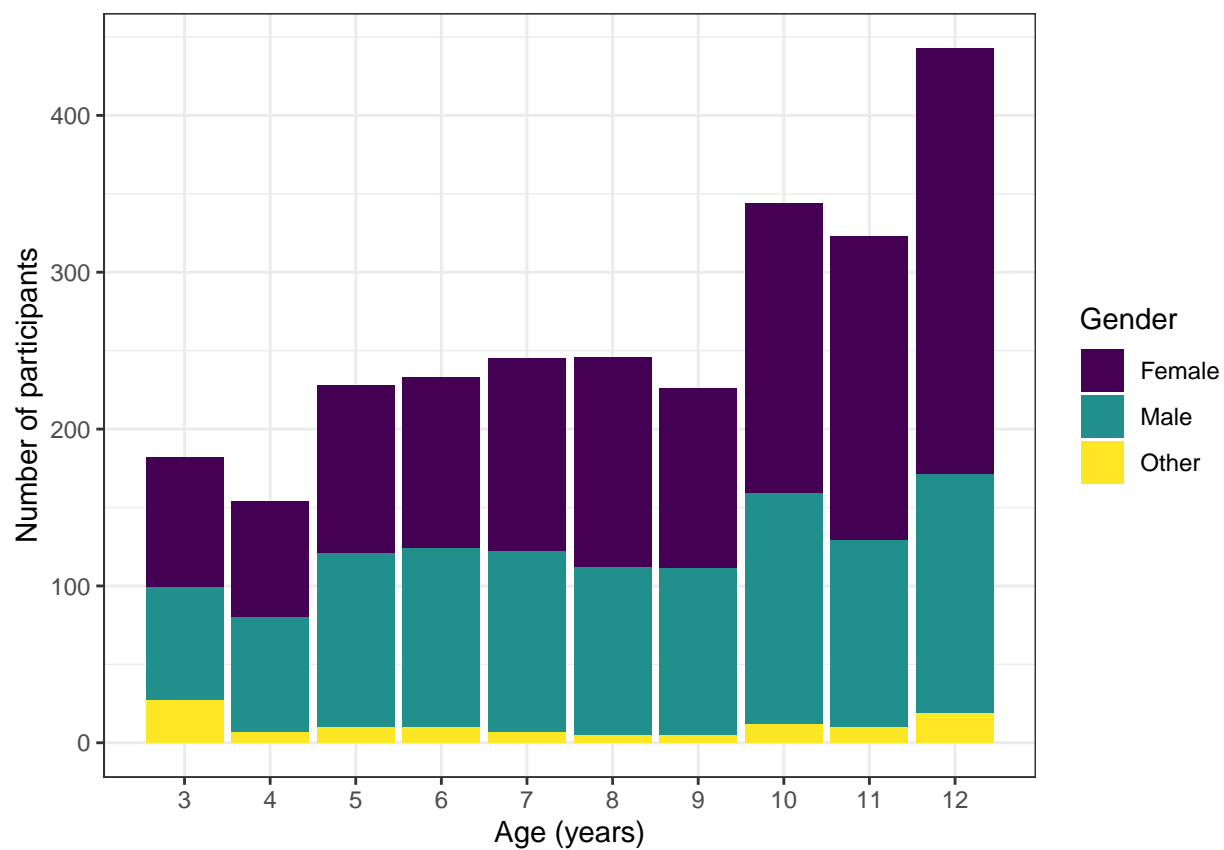
## Acknowledgments

We thank all the families who participated in this research; and C. Bainbridge, A. Bergson, M. Dresel, and J. Simson for assistance with designing and implementing the experiment; and L. Yurdom, who provided helpful comments on the manuscript.

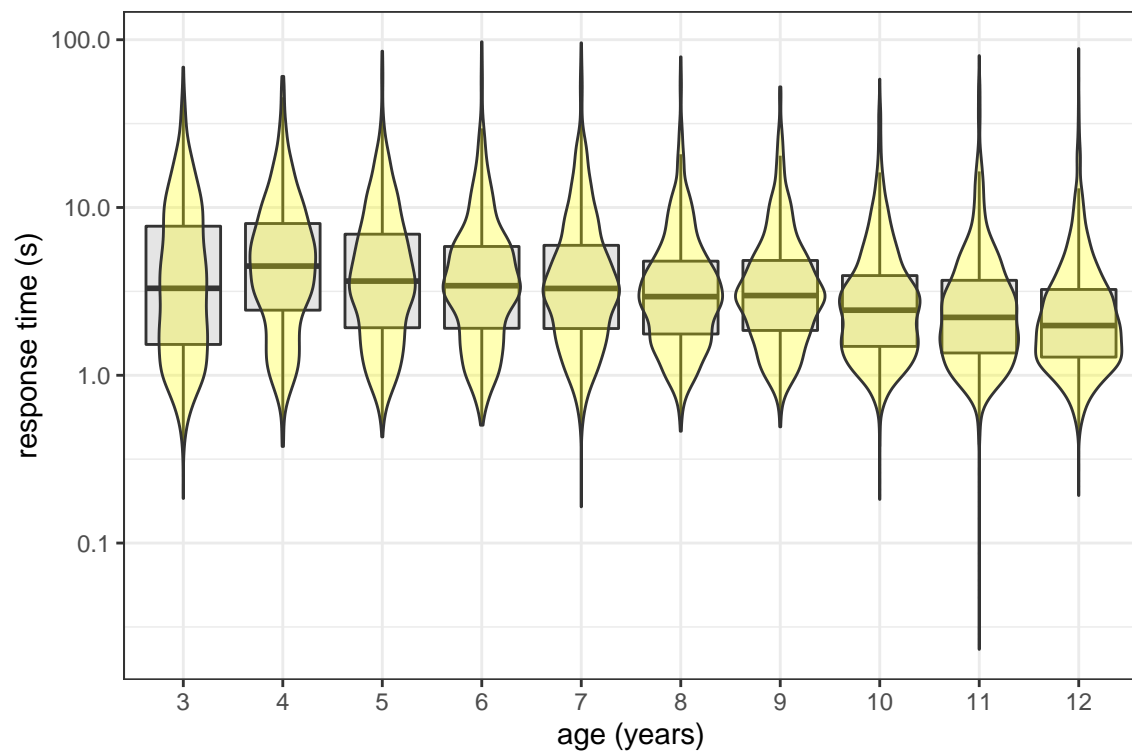
## Author contributions

L.C-T., A.M., and S.A.M. designed the research. L.C-T. wrote code to implement the experiment. L.C-T. and S.A.M. collected the data. C.B.H., L.C-T., and R.Y. analyzed the data, with supervision from S.A.M. and A.M. S.A.M. and A.M. provided funding and other resources. C.B.H., L.C-T., and S.A.M. led the writing of the manuscript and all authors edited and approved it.

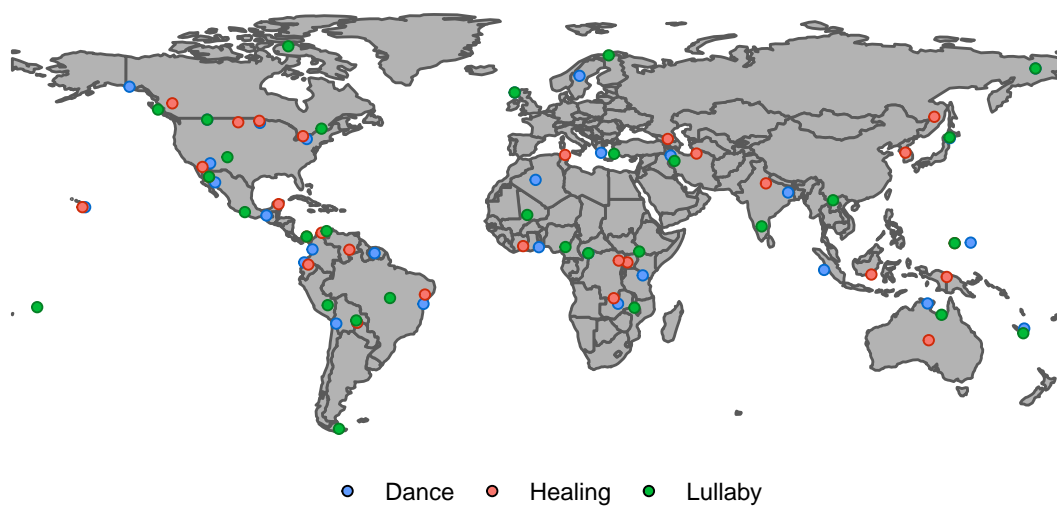
## Supplementary Figures



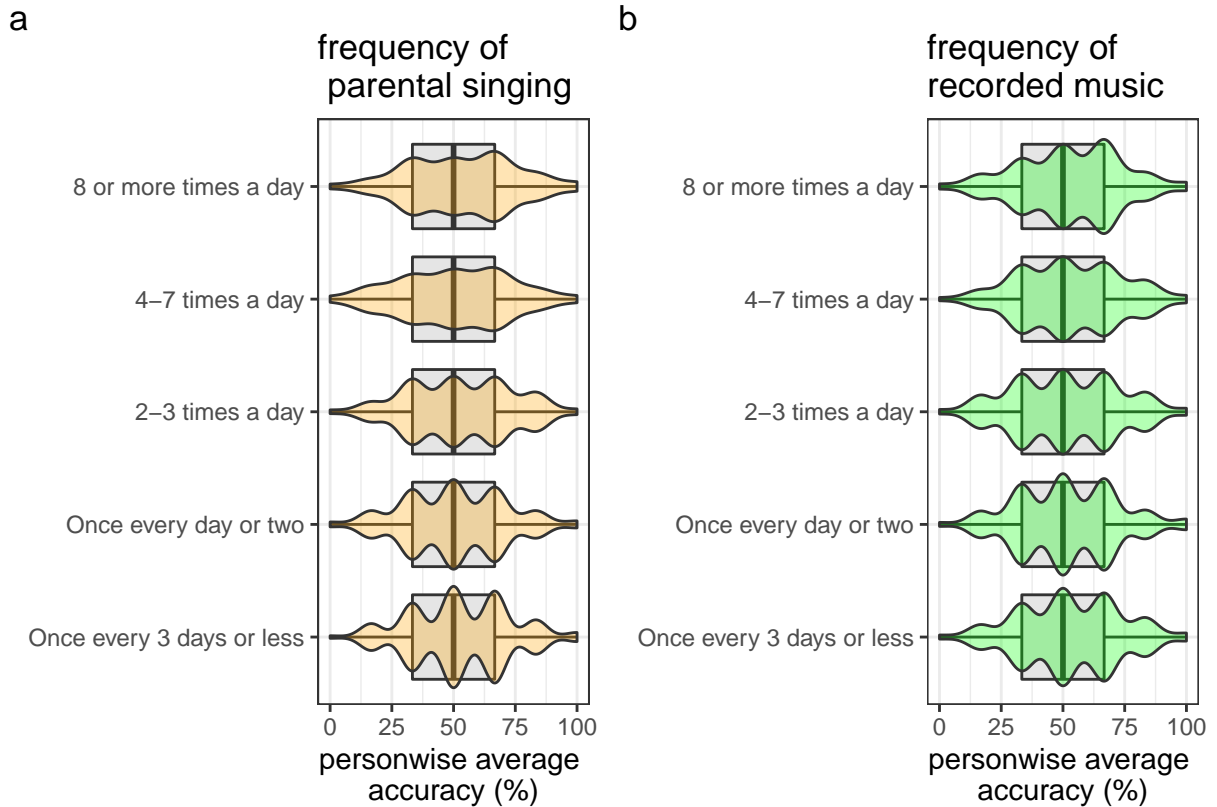
**Supplementary Figure 1.** The distributions of ages and genders of the participants.



**Supplementary Figure 2.** Children's response times, aggregated across all trials, as a function of age. Note that the  $y$ -axis is on a log scale.



**Supplementary Figure 3.** Locations of societies in which the *Natural History of Song Discography* recordings used in the experiment were originally recorded.



**Supplementary Figure 4.** Children’s accuracy of identifying songs was not related to their in-home musical experiences: across different levels of **(a)** the frequency of parental singing and **(b)** the frequency of recorded music listening, person-wise accuracy did not change. The thick lines represent medians; the boxes represent interquartile ranges; the lines represent ranges; and the shaded areas depict kernel density estimates.

## Supplementary Tables

language	n
English	1620
Languages with < 20 participants	373
Spanish	177
Turkish	126
Chinese/Mandarin	75
German	63
French	45
Chinese/Cantonese/Yue	30
Indonesian	26
Polish	24
Dutch	22
Russian	22
Italian	20

**Supplementary Table 1**

Languages spoken by children

country	n
United States	1090
Countries with < 20 participants	409
Canada	212
United Kingdom	167
Turkey	122
Australia	97
Germany	61
Spain	53
Argentina	47
New Zealand	47
China	34
Singapore	34
Indonesia	33
Hong Kong	31
France	30
Malaysia	26
Philippines	25
Poland	23
India	21
Netherlands	21
Italy	20
Mexico	20

**Supplementary Table 2**

Countries of children



Song	Type	Culture	Modern-Day Country	Language
1	Lullaby	Lardil	Australia	Aranda
2	Healing	Anggor	Papua New Guinea	Anggor
3	Lullaby	Blackfoot	USA	Blackfoot
4	Healing	Uttar Pradesh	India	Andamans
5	Dance	Emberá	Colombia	Emberá
6	Healing	Akan	Côte d'Ivoire	Akan
7	Lullaby	Nahua	Mexico	Maya (Yucatan Peninsula)
8	Healing	Yapese	Federated States of Micronesia	Chuuk
9	Dance	Yolngu	Australia	Aranda
10	Dance	Aymara	Chile	Aymara
11	Dance	Blackfoot	USA	Blackfoot
12	Lullaby	Saami	Norway	Saami
13	Dance	Bahia Brazilians	Brazil	Bahia Brazilians
14	Healing	Seri	Mexico	Huichol
15	Healing	Ye'kuana	Venezuela	Javaé
16	Dance	Aka	Central African Republic	Aka
17	Healing	Lunda	Democratic Republic of the Congo	Bemba
18	Dance	Greeks	Greece	Georgia
19	Dance	Sweden	Sweden	Saami
20	Healing	Iroquois	Canada	Iroquois
21	Dance	Iroquois	New York	Iroquois
22	Healing	Maya (Yucatan Peninsula)	Mexico	Maya (Yucatan Peninsula)
23	Lullaby	Goajiro	Venezuela	Chachi
24	Dance	Gourara	Algeria	Gourara
25	Dance	Ojibwa	USA	Copper Inuit
26	Lullaby	Javaé	Brazil	Javaé
27	Healing	Bahia Brazilians	Brazil	Bahia Brazilians
28	Lullaby	Chewa	Malawi	Bemba
29	Lullaby	Aka	Central African Republic	Aka
30	Healing	Georgia	East Georgia	Georgia
31	Dance	Ainu	Japan	Ainu
32	Lullaby	Highland Scots	United Kingdom	Highland Scots
33	Lullaby	Seri	Mexico	Huichol
34	Dance	Garo	India	Andamans
35	Lullaby	Kurds	Iran	Kurds
36	Lullaby	Fut	Cameroon	Akan
37	Dance	Hawaiians	USA	Hawaiians
38	Lullaby	Samoans	Samoa	Hawaiians
39	Healing	Kuna	Panama	Emberá
40	Lullaby	Marathi	India	Andamans
41	Healing	Pawnee	USA	Blackfoot
42	Lullaby	Guarani	Bolivia	Bahia Brazilians
43	Healing	Meratus	Indonesia	Central Thai
44	Lullaby	Ainu	Japan	Ainu
45	Dance	Maasai	Tanzania	Amhara
46	Healing	Korea	South Korea	Ainu
47	Healing	Turkmen	Iran	Kurds
48	Lullaby	Chukchee	Russia	Chukchee
49	Dance	Lozi	Zambia	Bemba

(continued)

Song	Type	Culture	Modern-Day Country	Language
50	Lullaby	Kanaks	New Caledonia	Anggor
51	Lullaby	Greeks	Greece	Georgia
52	Dance	Tlingit	USA	Haida
53	Lullaby	Tuareg	Mali	Gourara
54	Healing	Kwakwaka'wakw	Canada	Haida
55	Lullaby	Nyangatom	Ethiopia	Amhara
56	Dance	Chachi	Ecuador	Chachi
57	Dance	Chuuk	Federated States of Micronesia	Chuuk
58	Healing	Quechan	USA	Hopi
59	Healing	Hawaiians	USA	Hawaiians
60	Dance	Kanaks	New Caledonia	Anggor
61	Healing	Tunisians	Tunisia	Gourara
62	Dance	Kurds	Iran	Kurds
63	Lullaby	Haida	Canada	Haida
64	Dance	Mataco	Argentina	Alacaluf
65	Dance	Saramaka	Suriname	Javaé
66	Dance	Mentawaians	Indonesia	Central Thai
67	Dance	Ewe	Ghana	Akan
68	Lullaby	Kuna	Panama	Emberá
69	Lullaby	Ona	Argentina	Alacaluf
70	Healing	Ojibwa	USA	Copper Inuit
71	Dance	Tzeltal	Mexico	Maya (Yucatan Peninsula)
72	Lullaby	Iglulik Inuit	Canada	Copper Inuit
73	Lullaby	Q'ero Quichua	Peru	Aymara
74	Lullaby	Iroquois	Canada	Iroquois
75	Healing	Nanai	Russia	Chukchee
76	Dance	Highland Scots	United Kingdom	Highland Scots
77	Dance	Chukchee	Russia	Chukchee
78	Healing	Mataco	Argentina	Alacaluf
79	Healing	Walbiri	Central and North-Central Australia	Aranda
80	Healing	Kogi	Colombia	Chachi
81	Dance	Hopi	USA	Hopi
82	Lullaby	Hopi	USA	Hopi
83	Healing	Otavalo Quichua	Ecuador	Aymara
84	Healing	Ganda	Uganda	Amhara
85	Lullaby	Yapese	Federated States of Micronesia	Chuuk
86	Dance	Yaqui	Mexico	Huichol
87	Healing	Mbuti	Congo	Aka
88	Lullaby	Phunoi	Laos	Central Thai

**Supplementary Table 3** Information about the song stimuli

Predictor	Kids				Adults			
	$\beta$	SE	t	p	$\beta$	SE	t	p
Intercept	-0.750	0.103	-7.287	<b>&lt;0.001</b>	-0.885	0.103	-8.590	<b>&lt;0.001</b>
Accent	0.746	0.115	6.484	<b>&lt;0.001</b>	0.690	0.115	5.982	<b>&lt;0.001</b>
Tempo	0.003	0.001	4.792	<b>&lt;0.001</b>	0.003	0.001	5.077	<b>&lt;0.001</b>
Macrometer stability	0.104	0.019	5.376	<b>&lt;0.001</b>	0.118	0.019	6.103	<b>&lt;0.001</b>

**Supplementary Table 4** Correlates of dance inferences

Predictor	Kids				Adults			
	$\beta$	SE	t	p	$\beta$	SE	t	p
Intercept	0.682	0.067	10.250	<b>&lt;0.001</b>	0.834	0.086	9.699	<b>&lt;0.001</b>
Accent	-0.661	0.103	-6.392	<b>&lt;0.001</b>	-0.867	0.133	-6.497	<b>&lt;0.001</b>
Tempo	-0.001	0.001	-2.073	<b>0.041</b>	-0.001	0.001	-1.576	0.119

**Supplementary Table 5** Correlates of lullaby inferences

Predictor	Kids				Adults			
	$\beta$	SE	t	p	$\beta$	SE	t	p
Intercept	0.871	0.089	9.777	<b>&lt;0.001</b>	0.740	0.112	6.613	<b>&lt;0.001</b>
Macrometer stability	-0.079	0.014	-5.439	<b>&lt;0.001</b>	-0.072	0.018	-3.965	<b>&lt;0.001</b>
Tempo	-0.002	0.000	-4.870	<b>&lt;0.001</b>	-0.002	0.001	-3.205	<b>0.002</b>
Maj(-)/min(+) tonality	-0.088	0.029	-3.012	<b>0.003</b>	-0.125	0.037	-3.399	<b>0.001</b>
Arpeggiation	0.194	0.072	2.678	<b>0.009</b>	0.129	0.091	1.419	0.160
Syncopation	-0.130	0.079	-1.647	0.104	-0.095	0.099	-0.958	0.341
Vibrato	0.072	0.048	1.499	0.138	0.187	0.060	3.107	<b>0.003</b>
Modal Pitch Class	0.065	0.100	0.651	0.517	0.284	0.126	2.263	<b>0.026</b>

**Supplementary Table 6** Correlates of healing inferences

## References

- Bainbridge, C. M., Bertolo, M., Youngers, J., Atwood, S., Yurdum, L., Simson, J., Lopez, K., Xing, F., Martin, A., & Mehr, S. A. (2021). Infants relax in response to unfamiliar foreign lullabies. *Nature Human Behaviour*. <https://doi.org/10.1038/s41562-020-00963-z>
- Balch, W. R., & Lewis, B. S. (1996). Music-Dependent Memory: The Roles of Tempo Change and Mood Mediation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 10.
- Baldwin, D. A., Markman, E. M., Bill, B., Desjardins, R. N., Irwin, J. M., & Tidball, G. (1996). Infants' Reliance on a Social Criterion for Establishing Word-Object Relations. *Child Development*, 20.
- Balkwill, L.-L., & Thompson, W. F. (1999). A cross-cultural investigation of the perception of emotion in music: Psychophysical and cultural cues. *Music Perception*, 17(1), 43–64. <https://doi.org/10.2307/40285811>
- Bergeson, T., & Trehub, S. (1999). Mothers' singing to infants and preschool children. *Infant Behavior and Development*, 22(1).
- Bohn, M., & Frank, M. C. (2019). The Pervasive Role of Pragmatics in Early Language. *Annual Review of Developmental Psychology*, 29.
- Bonneville-Roussy, A., Rentfrow, P. J., Xu, M. K., & Potter, J. (2013). Music through the ages: Trends in musical engagement and preferences from adolescence through middle adulthood. *Journal of Personality and Social Psychology*, 105(4), 703–717. <https://doi.org/10.1037/a0033770>
- Cheever, T., Taylor, A., Finkelstein, R., Edwards, E., Thomas, L., Bradt, J., Holochwest, S. J., Johnson, J. K., Limb, C., Patel, A. D., Tottenham, N., Iyengar, S., Rutter, D., Fleming, R., & Collins, F. S. (2018). NIH/Kennedy Center workshop on music and the brain: Finding harmony. *Neuron*, 97(6), 1214–1218. <https://doi.org/10.1016/j.neuron.2018.02.004>
- Chronaki, G., Wigelsworth, M., Pell, M. D., & Kotz, S. A. (2018). The development of cross-cultural recognition of vocal emotion during childhood and adolescence. *Scientific Reports*, 8(1), 8659. <https://doi.org/10.1038/s41598-018-26889-1>
- Cirelli, L. K., Jurewicz, Z. B., & Trehub, S. E. (2019). Effects of maternal singing style on mother–infant arousal and behavior. *Journal of Cognitive Neuroscience*. [https://doi.org/10.1162/jocn\\_a\\_01402](https://doi.org/10.1162/jocn_a_01402)
- Darwin, C. (1871). *The descent of man*. Watts & Co.
- Drake, C., & Heni, J. B. E. (2003). Synchronizing with Music: Intercultural Differences. *Annals of the New York Academy of Sciences*, 999(1), 429–437. <https://doi.org/10.1196/annals.1284.053>
- Filippi, P., Congdon, J. V., Hoang, J., Bowling, D. L., Reber, S. A., Pašukonis, A., Hoeschele, M., Ocklenburg, S., Boer, B. de, Sturdy, C. B., Newen, A., & Güntürkün, O. (2017). Humans recognize emotional arousal in vocalizations across all classes of terrestrial vertebrates: Evidence for acoustic universals. *Proceedings of the Royal Society B: Biological Sciences*, 284(1859). <https://doi.org/10.1098/osf.io/rspb.2017.0990>
- Fitch, W. T., Neubauer, J., & Herzel, H. (2002). Calls out of chaos: The adaptive significance of nonlinear phenomena in mammalian vocal production. *Animal Behaviour*, 63(3), 407–418. <https://doi.org/10.1006/anbe.2001.1912>
- Frank, M. C., Amso, D., & Johnson, S. P. (2014). Visual search and attention to faces during early infancy. *Journal of Experimental Child Psychology*, 118, 13–26. <https://doi.org/10.1016/j.jecp.2013.08.012>
- Friedman, J., Hastie, T., & Tibshirani, R. (2016). *Lasso and elastic-net regularized generalized linear models. Rpackage version 2.0-5*.
- Germine, L., Nakayama, K., Duchaine, B. C., Chabris, C. F., Chatterjee, G., & Wilmer, J. B. (2012). Is the Web as good as the lab? Comparable performance from Web and lab in cognitive/perceptual experiments. *Psychonomic Bulletin & Review*, 19(5), 847–857. <https://doi.org/10.3758/s13423-012-0296-9>

- Granier-Deferre, C., Bassereau, S., Ribeiro, A., Jacquet, A.-Y., & DeCasper, A. J. (2011). A melodic contour repeatedly experienced by human near-term fetuses elicits a profound cardiac reaction one month after birth. *PLoS ONE*, 6(2). <https://doi.org/10.1371/journal.pone.0017304>
- Hale, S. (1990). A Global Developmental Trend in Cognitive Processing Speed. *Child Development*, 61(3), 653–663.
- Hannon, E. E., & Trehub, S. E. (2005). Metrical categories in infancy and adulthood. *Psychological Science*, 16(1), 48–55. <http://pss.sagepub.com/content/16/1/48.short>
- Hartshorne, J. K., Leeuw, J. de, Goodman, N., Jennings, M., & O'Donnell, T. J. (2019). A thousand studies for the price of one: Accelerating psychological science with Pushkin. *Behavior Research Methods*, 51, 1782–1803. <https://doi.org/https://doi.org/10.3758/s13428-018-1155-z>
- Hilton, C. B., Asano, R., & Boeckx, C. A. (2020). Why musical hierarchies? *Behavioral and Brain Sciences*.
- Holbrook, M. B., & Anand, P. (1990). Effects of Tempo and Situational Arousal on the Listener's Perceptual and Affective Responses to Music. *Psychology of Music*, 18(2), 150–162. <https://doi.org/10.1177/0305735690182004>
- Honing, H., Bouwer, F. L., Prado, L., & Merchant, H. (2018). Rhesus monkeys (*Macaca mulatta*) sense isochrony in rhythm, but not the beat: Additional support for the gradual audiomotor evolution hypothesis. *Frontiers in Neuroscience*, 12. <https://doi.org/10.3389/fnins.2018.00475>
- Husain, G., Thompson, W. F., & Schellenberg, E. G. (2002). Effects of Musical Tempo and Mode on Arousal, Mood, and Spatial Abilities. *Music Perception*, 20(2), 151–171. <https://doi.org/10.1525/mp.2002.20.2.151>
- Ilie, G., & Thompson, W. F. (2006). A Comparison of Acoustic Cues in Music and Speech for Three Dimensions of Affect. *Music Perception*, 23(4), 319–330. <https://doi.org/10.1525/mp.2006.23.4.319>
- Janata, P., Tomic, S. T., & Haberman, J. M. (2012). Sensorimotor coupling in music and the psychology of the groove. *Journal of Experimental Psychology: General*, 141(1), 54–75. <https://doi.org/10.1037/a0024208>
- Kinzler, K. D., Dupoux, E., & Spelke, E. S. (2007). The native language of social cognition. *Proceedings of the National Academy of Sciences*, 104(30), 12577–12580. <http://www.pnas.org/content/104/30/12577.short>
- Kiselev, S., Espy, K. A., & Sheffield, T. (2009). Age-related differences in reaction time task performance in young children. *Journal of Experimental Child Psychology*, 102(2), 150–166. <https://doi.org/10.1016/j.jecp.2008.02.002>
- Krumhansl, C. L. (2010). Plink: "Thin Slices" of Music. *Music Perception*, 27(5), 337–354. <https://doi.org/10.1525/mp.2010.27.5.337>
- Levitin, D. J., & Cook, P. R. (1996). Memory for musical tempo: Additional evidence that auditory memory is absolute. *Perception & Psychophysics*, 58(6), 927–935. <https://doi.org/10.3758/BF03205494>
- Liberman, Z., Woodward, A. L., & Kinzler, K. D. (2017). The Origins of Social Categorization. *Trends in Cognitive Sciences*, 21(7), 556–568. <https://doi.org/10.1016/j.tics.2017.04.004>
- Lomax, A. (1968). *Folk song style and culture*. American Association for the Advancement of Science.
- Lynch, M. P., & Eilers, R. E. (1992). A study of perceptual development for musical tuning. *Perception & Psychophysics*, 52(6), 599–608. <https://doi.org/10.3758/BF03211696>
- Lynch, M. P., Eilers, R. E., Oller, D. K., & Urbano, R. C. (1990). Innateness, Experience, and Music Perception. *Psychological Science*, 1(4), 272–276. <https://doi.org/10.1111/j.1467-9280.1990.tb00213.x>
- Ma, W., & Thompson, W. F. (2015). Human emotions track changes in the acoustic environment. *Proceedings of the National Academy of Sciences*, 112(47), 14563–14568. <https://doi.org/10.1073/pnas.1515087112>

- Martin, A., Onishi, K. H., & Vouloumanos, A. (2012). Understanding the abstract role of speech in communication at 12months. *Cognition*, 123(1), 50–60. <https://doi.org/10.1016/j.cognition.2011.12.003>
- Mehr, S. A., & Krasnow, M. M. (2017). Parent-offspring conflict and the evolution of infant-directed song. *Evolution and Human Behavior*, 38(5), 674–684. <https://doi.org/10.1016/j.evolhumbehav.2016.12.005>
- Mehr, S. A., Krasnow, M. M., Bryant, G. A., & Hagen, E. H. (2020). Origins of music in credible signaling. *Behavioral and Brain Sciences*, 1–41. <https://doi.org/10.1017/S0140525X20000345>
- Mehr, S. A., Singh, M., Knox, D., Ketter, D. M., Pickens-Jones, D., Atwood, S., Lucas, C., Jacoby, N., Egner, A. A., Hopkins, E. J., Howard, R. M., Hartshorne, J. K., Jennings, M. V., Simson, J., Bainbridge, C. M., Pinker, S., O'Donnell, T. J., Krasnow, M. M., & Glowacki, L. (2019). Universality and diversity in human song. *Science*, 366(6468), 957–970. <https://doi.org/10.31234/osf.io/emq8r>
- Mehr, S. A., Singh, M., York, H., Glowacki, L., & Krasnow, M. M. (2018). Form and function in human song. *Current Biology*, 28(3), 356–368. <https://doi.org/10.1016/j.cub.2017.12.042>
- Mehr, S. A., Song, L. A., & Spelke, E. S. (2016). For 5-month-old infants, melodies are social. *Psychological Science*, 27(4), 486–501. <https://doi.org/10.1177/0956797615626691>
- Mendoza, J. K., & Fausey, C. M. (2021). Everyday music in infancy. *Developmental Science*. <https://doi.org/10.31234/osf.io/sqatb>
- Morton, E. S. (1977). On the occurrence and significance of motivation-structural rules in some bird and mammal sounds. *The American Naturalist*, 111(981), 855–869. <http://www.jstor.org.ezp-prod1.hul.harvard.edu/stable/2460385>
- Nettl, B. (2005). *The Study of Ethnomusicology* (2nd Edition). University of Illinois Press.
- Norris, R. P., & Harney, B. Y. (2014). Songlines and Navigation in Wardaman and other Australian Aboriginal Cultures. *Journal of Astronomical History and Heritage*, 17(2), 15.
- Owren, M. J., & Rendall, D. (2001). Sound on the rebound: Bringing form and function back to the forefront in understanding nonhuman primate vocal signaling. *Evolutionary Anthropology*, 10(2), 58–71. <https://doi.org/10.1002/evan.1014>
- Phillips-Silver, J. (2005). Feeling the Beat: Movement Influences Infant Rhythm Perception. *Science*, 308(5727), 1430–1430. <https://doi.org/10.1126/science.1110922>
- Powell, L. J., & Spelke, E. S. (2013). Preverbal infants expect members of social groups to act alike. *Proceedings of the National Academy of Sciences*, 110(41), E3965–E3972. <https://doi.org/10.1073/pnas.1304326110>
- Rohrmeier, M., & Rebuschat, P. (2012). Implicit Learning and Acquisition of Music. *Topics in Cognitive Science*, 4(4), 525–553. <https://doi.org/10.1111/j.1756-8765.2012.01223.x>
- Scherer, K. R., Banse, R., & Wallbott, H. G. (2001). Emotion Inferences from Vocal Expression Correlate Across Languages and Cultures. *Journal of Cross-Cultural Psychology*, 32(1), 76–92. <https://doi.org/10.1177/0022022101032001009>
- Schubert, E. (2004). Modeling Perceived Emotion With Continuous Musical Features. *Music Perception*, 21(4), 561–585. <https://doi.org/10.1525/mp.2004.21.4.561>
- Sheskin, M., Scott, K., Mills, C. M., Bergelson, E., Bonawitz, E., Spelke, E. S., Fei-Fei, L., Keil, F. C., Gweon, H., Tenenbaum, J. B., Jara-Ettinger, J., Adolph, K. E., Rhodes, M., Frank, M. C., Mehr, S. A., & Schulz, L. (2020). Online developmental science to foster innovation, access, and impact. *Trends in Cognitive Sciences*. <https://doi.org/10.1016/j.tics.2020.06.004>
- Sievers, B., Lee, C., Haslett, W., & Wheatley, T. (2019). A multi-sensory code for emotional arousal. *Proceedings of the Royal Society B*, 286(1906). <https://royalsocietypublishing.org/doi/abs/10.1098/rspb.2019.0513>



- Sievers, B., Polansky, L., Casey, M., & Wheatley, T. (2013). Music and movement share a dynamic structure that supports universal expressions of emotion. *Proceedings of the National Academy of Sciences*, 110(1), 70–75. <https://doi.org/10.1073/pnas.1209023110>
- Singh, M. (2018). The cultural evolution of shamanism. *Behavioral and Brain Sciences*, 41, 1–62. [https://www.cambridge.org/core/product/identifier/S0140525X17001893/type/journal\\_article](https://www.cambridge.org/core/product/identifier/S0140525X17001893/type/journal_article)
- Trehub, S. (1998). Music as a window on infant audition. *Current Topics in Acoustical Research*.
- Trehub, S. E., Ghazban, N., & Corbeil, M. (2015). Musical affect regulation in infancy. *Annals of the New York Academy of Sciences*, 1337(1), 186–192. <https://doi.org/10.1111/nyas.12622>
- Trehub, S. E., Unyk, A. M., & Trainor, L. J. (1993a). Adults identify infant-directed music across cultures. *Infant Behavior and Development*, 16(2), 193–211. [https://doi.org/10.1016/0163-6383\(93\)80017-3](https://doi.org/10.1016/0163-6383(93)80017-3)
- Trehub, S. E., Unyk, A. M., & Trainor, L. J. (1993b). Maternal singing in cross-cultural perspective. *Infant Behavior and Development*, 16(3), 285–295. <http://www.sciencedirect.com/science/article/pii/0163638393800368>
- Vouloumanos, A., Martin, A., & Onishi, K. H. (2014). Do 6-month-olds understand that speech can communicate? *Developmental Science*, 17(6), 872–879. <https://doi.org/10.1111/desc.12170>
- Weninger, F., Eyben, F., Schuller, B. W., Mortillaro, M., & Scherer, K. R. (2013). On the Acoustics of Emotion in Audio: What Speech, Music, and Sound have in Common. *Frontiers in Psychology*, 4. <https://doi.org/10.3389/fpsyg.2013.00292>
- Winkler, I., Háden, G. P., Ladinig, O., Sziller, I., & Honing, H. (2009). Newborn infants detect the beat in music. *Proceedings of the National Academy of Sciences*, 106(7), 2468–2471. <https://doi.org/10.1073/pnas.0809035106>
- Witek, M. A. G., Clarke, E. F., Wallentin, M., Kringelbach, M. L., & Vuust, P. (2014). Syncopation, Body-Movement and Pleasure in Groove Music. *PLoS ONE*, 9(4). <https://doi.org/10.1371/journal.pone.0094446>
- Xiao, N. G., Quinn, P. C., Liu, S., Ge, L., Pascalis, O., & Lee, K. (2017). Older but not younger infants associate own-race faces with happy music and other-race faces with sad music. *Developmental Science*. <https://doi.org/10.1111/desc.12537>
- Yamamoto, M., Naga, S., & Shimizu, J. (2007). Positive musical effects on two types of negative stressful conditions. *Psychology of Music*, 35(2), 249–275. <https://doi.org/10.1177/0305735607070375>
- Zentner, M., & Eerola, T. (2010). Rhythmic engagement with music in infancy. *Proceedings of the National Academy of Sciences*, 107(13), 5768–5773. <https://doi.org/10.1073/pnas.1000121107>