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The song, not the singer: Infants prefer to listen to familiar songs, regardless of singer identity

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Research Highlights

- Familiar songs recruited more infant attention, encouraged more rhythmic movement, and resulted in less sympathetic nervous system activation than unfamiliar songs
- Stranger's song renditions had comparable behavioral and electrodermal effects as mother's song renditions, even when they differed substantially in mean fundamental frequency and tempo
- Early and robust generalization of familiar songs across different singers is consistent with an account of songs as powerful signals for shared cultural identity

Abstract

Parent's infant-directed vocalizations are highly dynamic and emotive compared to their adult-directed counterparts, and correspondingly, more effectively capture infants' attention. Infant-directed singing is a specific type of vocalization that is common throughout the world. Parents tend to sing a small handful of songs in a stereotyped way, and a number of recent studies have highlighted the significance of familiar songs in young children's social behaviors and evaluations. To date, no studies have examined whether infants' responses to familiar vs. unfamiliar songs are modulated by singer identity (i.e., whether the singer is their own parent). In the present study, we investigated 9- to 12-month-old infants' (N = 29) behavioral and electrodermal responses to relatively familiar and unfamiliar songs sung by either their own mother or another infant's mother. Familiar songs recruited more attention and rhythmic movement, and lower electrodermal levels relative to unfamiliar songs. Moreover, these responses were robust regardless of whether the singer was their mother or a stranger, even when the stranger's rendition differed greatly from their mothers' in mean fundamental frequency and tempo. Results indicate that infants' interest in familiar songs is not limited to idiosyncratic characteristics of their parents' song renditions, and points to the potential for song as an effective early signifier of group membership.

Keywords: song, familiarity, vocal, head-turn preference, skin conductance

Introduction

Infants' environments are full of sounds with different features, sources, and meanings. Not all sounds, however, garner equal attention. Human vocalizations are particularly effective at capturing infant attention (Vouloumanos et al., 2010; Vouloumanos & Werker, 2007), especially if they are infant-directed and therefore more emotional, temporally regular, and dynamic in pitch than their adult-direct counterparts (Fernald, 1989; Nakata & Trehub, 2011; Trehub et al., 1994, 2016). Infant-directed singing is ubiquitous in parent-infant interactions, and parent-taught songs are socially meaningful (Cirelli & Trehub, 2018, 2020; Mehr et al., 2016; Mehr & Spelke, 2018). Here, we asked whether infants prefer listening to familiar songs, and whether their behavioral and electrodermal responses to familiar songs are modulated when the singer is their own parent.

Song is common during parent-infant interactions around the world (Mehr & Singh et al., 2018; Trehub & Gudmundsdottir, 2015). Parents report using song to capture infants' attention, soothe distress, engage them in play, and lull them to sleep (Custodero & Johnson-Green, 2003; Ilari, 2005; Trehub & Gudmundsdottir, 2015). Recent work points to the special significance of familiar songs. Cirelli and Trehub (2020) reported that infant distress was more effectively mitigated by parents singing familiar rather than unfamiliar songs. Five- to 14-month-olds also prefer to watch, accept toys from, and assist strangers who sing parent-taught songs (Cirelli & Trehub, 2018; Mehr et al., 2016; Mehr & Spelke, 2018). Songs learned from toys, however, did not affect social behavior. These social effects align with the observation that certain songs play a special role in parent-infant interactions. Self-reports and daylong recordings demonstrate that infants hear a small number of songs frequently (Bergeson & Trehub, 2002; Mendoza & Fausey, in press). Moreover, one study of 11 parents demonstrated that parents' song renditions are highly consistent across repetitions – renditions recorded a week apart were nearly identical in pitch and tempo (Bergeson & Trehub, 2002).

Parents' "signature" tunes in song and speech may facilitate infants' recognition of their mother's voice (Bergeson & Trehub, 2002, 2007). Prenatally, fetal heart rate increases in response to extrauterine recordings of own mother's speech compared to a female stranger's (Kisilevsky et al., 2003, 2009). Hours after birth, neonates recognize and prefer the spoken voice of their mother to a female stranger (DeCasper & Fifer, 1980; Fifer & Moon, 1995). By 7 months, infants selectively attend to their mother's speech when masked by the simultaneous presentation of a female stranger's speech (Barker & Newman, 2004). Despite robust preference for own-mother speaking voice, whether infants prefer their own mothers' singing has never been tested.

Song also signals group membership. Children select friends who know songs that they know (Soley & Spelke, 2016), and expect members of the same cultural group to know the same songs (Soley, 2019). For song to be a signal of in-group membership, listeners should recognize songs when sung with different voices, starting pitches, and tempos. Indeed, infants can recognize familiar tunes with modified key or tempo (Plantinga & Trainor, 2009; Trehub & Thorpe, 1989), and familiar songs sung by strangers (Cirelli & Trehub, 2018; Mehr et al., 2016; Mehr & Spelke, 2018). Whether they respond differently to their mother's unique renditions is unknown.

Here, we tested whether infants prefer listening to familiar songs and whether their responses are modulated by the identity of the singer (mother vs. stranger). In an initial lab visit, mothers sang well-known children's songs while "video chatting" with their infant, who was on the research assistant's lap in a neighboring room. Two months later, infants listened to recordings of their own mother and a stranger singing songs varying in familiarity in a head-turn preference procedure. Given the evidence for precocious preference for mothers' speaking voices and the social-emotional significance of familiar songs, we anticipated that both factors would influence listening times. Because both familiarity preferences and novelty preferences are common in the looking time literature (Hunter & Ames, 1988), we performed non-directional tests to investigate potential differences in either direction. We additionally explored how song familiarity and singer identity influenced skin conductance, positive affect, and rhythmic movements, given previous research demonstrating effects of song on infants' electrodermal activity and affect (Bainbridge & Bertolo et al., 2020; Cirelli et al., 2019).

Method

Participants

Full-term infants were recruited from middle-class families in Mississauga, Canada. Parents were recruited while visiting the lab for a different study. All procedures were approved by the University of Toronto Research Ethics Board and informed consent was obtained.

Willing mothers (*N* = 51) stayed to record their singing. Of those, 37 returned to the lab with their infant. Two did not know a sufficient number of songs to be included, but returned as pilot participants. Six were excluded due to technical problems (*N* = 4) or fussiness (*N* = 2). The final sample included 29 infants (11 girls, 18 boys, Visit 1 *M* age = 8.48 months, SD = 0.39; Visit 2 *M* age = 10.55 months, *SD* = 0.85) at visit 2. On average, there were 63 days between the two visits (range = 20 - 107). None of the participants had known developmental delays or hearing/vision impairments. All parents reported singing to their child, most (27/29) multiple times per day.

Stimuli

Recording. Mothers were seated inside a sound-attenuating booth (Industrial Acoustic Corporation) with their infant on the experimenter's lap outside. The infant and mother were live-streamed to each other with audio muted to limit noise and restrict further song exposure. Mothers were provided lyrics to the first verse of ten children's songs well-known in Canada (e.g. *Twinkle, Twinkle, Little Star* and *Mary Had a Little Lamb*, see Supplemental Material) and were asked to sing the songs they knew to their infant as naturally as possible. They repeated each song until they achieved 30 seconds of uninterrupted singing for each. Recordings were obtained via Audacity 2.1.0 software with a Blue Yeti USB Microphone.

Afterward, mothers rated how frequently they sang each song to their child (1 - *never* to 6 - *multiple times per day*). The four most and four least frequent were selected as “mother” test stimuli for visit 2. The mean rating for “familiar” stimuli was 4.72, which corresponds to falling between responses “a few times per week” and “once per day”, and the mean rating for “unfamiliar” stimuli was 1.98, which corresponds to falling between responses “less frequently than once per week” and “never”. Assistants matched each mother with another mother (“stranger”) who sang the same 8 songs and whose singing was similar in accuracy.

Processing. The Noise Reduction function in Audacity was applied to each recording. Next, we selected the best version of the first verse (least noise/errors) and looped it for 30 seconds. Finally, each stimulus was RMS-normalized using a custom Python script (PyDub library; Robert, 2011).

Apparatus

Skin conductance was recorded using a wired BIOPAC MP160 System and *AcqKnowledge* 5.0 software on a Windows 10 computer. Data were recorded with a 100 Hz sampling rate and a 10Hz low-pass filter. Two pre-gelled, self-adhesive Ag-AgCl electrodes were connected to the BIOPAC amplifier via BN-EDA-LEAD 2 leads. Electrodes were placed on the plantar surface of the infant’s right foot and reinforced with paper medical tape and a cotton sock.

Skin conductance, also known as electrodermal activity, reflects changes in the sympathetic nervous system, and in emotion, cognition and attention (Critchley, 2002). In infants, skin conductance levels (SCL) increase in response to highly engaging or stressful events, and decrease when they are presented with relaxing stimuli such as lullabies (Bainbridge & Bertolo et al., 2020, Cirelli et al., 2019, Cirelli & Trehub, 2020, Ham & Tronick, 2006).

Procedure

During visit 2, infants sat on their parent's lap in a sound-attenuating booth. Parents wore sound-cancelling headphones presenting masking music. A research assistant attached the skin conductance sensors to the infant's foot while a second assistant entertained them.

The dyad sat in front of three monitors: one central screen, one 45 degrees to the right and one 45 degrees to the left, each roughly 4 feet from the infant. Two cameras (Sony Exmor R - one facing the infant below the center screen and one behind the infant's right shoulder) livestreamed the infants' behavior to an experimenter seated outside the sound booth, who was unaware of condition (no audio). This experimenter coded infant looking online using a custom-designed program (Realbasic) on a Windows XP workstation with SoundBlaster X-Fi Fatality sound card that controlled stimulus presentation based on infant response. The experimenter indicated when the infant was looking at the target screen/speaker with a button-press, and lifted the button when the infant looked away. Sounds were presented via an amplifier (Harmon/Kardon 3380) and loudspeakers (Audiological GSI) inside the booth, below each side monitor. Two training trials (right and left) playing piano music preceded the test trials.

Prior to every trial, the central screen flashed red to attract the infants' attention. When the infant looked forward, either the left or right screen flashed. When the infant looked toward the flash, a colourful static checkerboard replaced it and the stimuli played from the speaker below the screen. The trial ended when the infant looked away for >2 consecutive seconds. The maximum trial length was 30 seconds. Listening time was defined as the duration of time the stimulus played.

There were up to 16 trials (8 mother, 8 stranger) pseudo-randomized into two blocks. Each block contained both the mother's and stranger's versions of the same 4 songs (2 more familiar and 2 less familiar songs). The stimulus order was further pseudo-randomized to counter balanced singer identity, song familiarity, and side of presentation. This was done so that if a participant "fussed out", remaining trials would be approximately equally distributed across all four conditions. Most (25) infants participated in all 16 trials (the remaining 4 had 11-15 trials).

Parents filled out the Music@Home-Infant questionnaire (Politimou et al., 2018), which measures parents' musical attitudes and behaviors in the home. In addition, parents rated song frequency a second time, because we thought it was possible that song frequency might have changed since their first visit (for instance, a mother who previously never sang "Hot Cross Buns" to her child might have incorporated into her repertoire of songs after singing it at her Time 1 lab visit).

Behavioural coding (positive affect, rhythmic movement)

Additional behavioral data were coded by trained assistants using ELAN (Slotjoes & Wittenburg, 2008). Coders indicated when the infant's face was visible, was displaying positive affect (smiling/laughing), and when they moved rhythmically. Rhythmic movements were defined as the same movement more than once in a row (clapping, swaying, etc). Coders could hear audio, but were not aware which songs were familiar, nor which singer was the mother. One assistant coded face visibility, positive affect, and rhythmic movement for all infants. A second coded four infants selected randomly from infants who demonstrated >1 instance of each behavior. Correlating durations of each behavior per trial (64 trials) indicated strong agreement (face visibility r = .99, positive affect r = .86. rhythmic movement r = .91).

Acoustic properties

We were interested in how acoustic properties (tempo and pitch) contributed to infant behavioural and electrodermal responses, and to quantify differences between own-mother and stranger renditions.

To operationalize pitch, we used MIRtoolbox 1.7 (Lartillot & Toiviainen, 2007) running on MATLAB 2016a to obtain fundamental frequency (*F*0) within each frame (50 ms half-overlapping bins), then removed values representing silence and *F*0 above 400Hz before calculating mean *F*0.

To operationalize tempo, two musically-trained assistants used a beats-per-minute (BPM) calculator (http://www.beatsperminuteonline.com/) to tap to each rendition. Agreement was high (Pearson's $r = 0.97$, $p < .001$), and mean BPM across raters was used in analyses. When ratings differed > 10 BPM, a third researcher provided a rating, and their rating was averaged with the closer of the first two (14% of stimuli).

Data processing

Skin conductance ("SC") data down-sampled to 10Hz were processed in Ledalab (V3) toolbox (Matlab 2016a). Data were visually inspected. Data from 3 infants were excluded due to extreme artifacts, excessive noise, or failed signals from poor sensor connections. Using Continuous Decomposition Analysis (Benedek & Kaernbach, 2010), we extracted tonic skin conductance level (SCL), which reflects general autonomic arousal (Dawson et al., 2016). SCL slope was calculated from the linear line of best fit from trial onset to trial end (see also Cirelli et al., 2020 and Kragness & Cirelli, 2020, for this data processing procedure).

Analyses

Our confirmatory analysis concerned the effects of song familiarity and singer identity on listening time. We used linear (LMEM) and generalized mixed-effects models (GLMM) (glmmTMB package, Brooks et al., 2017) in R (version 3.6.3) to evaluate the influence of song familiarity, singer identity, and acoustic properties (tempo and pitch) on listening time. Additional exploratory analyses were conducted to examine effects on electrodermal responses, positive affect, and rhythmic movement. In all models, participant was included as a random effect. The results of the exploratory analyses should be considered preliminary, and *p*-values should be treated with caution.

Results

Listening time

Listening times were log-transformed to account for positive skew common in looking-time data (e.g., ManyBabies Consortium et al., 2020). We conducted a LMEM with fixed effects singer (contrast-coded as “mother” = 1 and “stranger” = -1), age, trial number, average pitch, average tempo and parent-reported singing in the home (Music@Home Parent-Initiated Singing subscore; “MH.parent.singing”). The fixed effect *song familiarity* was coded two ways: binary (contrast-coded as “familiar” = 1 and “unfamiliar” = -1) or average parent-reported frequency at Time 1 and Time 2 (*1 = never* to *6 = multiple times per day*). A full model (random effect and slope) failed to converge, and elements were removed (Barr et al., 2013) until the model converged. Models including the random slope term resulted in a singular fit so it was removed to acquire the final model:

logListeningTime ~ singer * familiarity + mean.tempo + mean.*F*0 + trial.number + MH.parent.singing + age + (1|participantID)

For the binary coding of familiarity, trial number (β = -0.100, *SE* = 0.002, z = -5.310, $p < .001$) and song familiarity (β = 0.029, *SE* = .009, *z* = 3.180, $p = .001$) significantly affected listening time, such that listening time decreased over the course of the experiment and increased with familiarity (Figure 1). In other words, infants listened longer to familiar songs sung by both their mother (*M* familiar = 13.89 s, within-subjects 95% CI = ± 1.22; *M* unfamiliar = 11.71 s, *CI* = ± 1.25]) and a stranger (*M* familiar = 13.61 s, *CI* = ± 1.24, *M* unfamiliar = 11.80, *CI* = ± 1.24). No other effects nor the interaction term were significant. The same significant predictors were observed when average frequency rating was used as the dependent variable (trial number: $\beta = -0.010$, $SE = .019$, $z = -5.313$, $p < .001$; frequency: $\beta = .067$, $SE = .023$, $z = 2.930$, $p = .003$), as well as Time 1 and Time 2 frequency ratings alone (see Supplemental Material). Because average rated frequency offered the most fine-grained representation of this variable, it was used to represent familiarity in subsequent models.

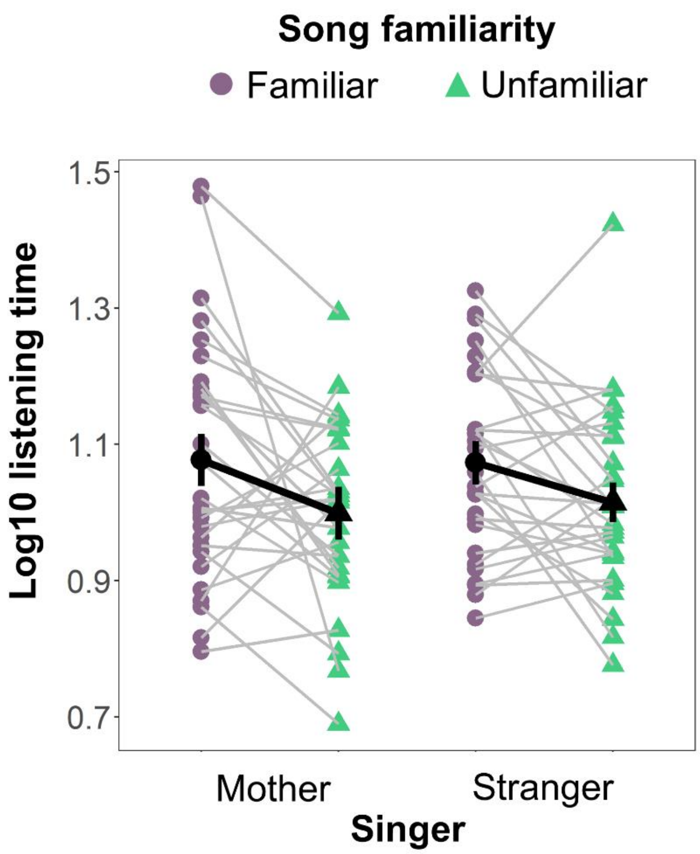

Figure 1. Depicts log listening times to familiar and unfamiliar songs sung by infants' own mother or a female stranger. Each point represents one infant, and observations from the same infant in each "singer" condition are connected with a line. Error bars indicate within-subjects 95% confidence intervals.

To examine whether effects were driven by songs heard with extremely high frequency, we excluded songs with average frequency ≥ 5.0, which would include songs that were sung most frequently (“multiple times per day” and “once per day”). After this, 332 of 451 (73.61%) observations remained and the same significant effect of familiarity was observed (β = 0.078, *SE* = 0.028, z = 2.787, p = .005).

Differences in renditions. We found no evidence to suggest that infants preferred their own mother’s renditions, which begged the question: how different were the renditions? We compared all mother-stranger pairs of the same song presented to infants in the same session, operationalizing differences as *percent* difference (difference divided by the average), which corresponds with the equivalent perceptual difference pairs of pitches sung in different octaves (for example, the percent difference between C4/D4 and C5/D5 is the same, but the absolute difference measured in Hz is smaller for the former pair). For tempo, on average, pairs differed by 15.91% (minimum = 0%, maximum = 71.88%). For *F*0, on average, pairs differed by 14.68% (minimum = 0%, identical, maximum = 49.87%, nearly an octave difference). There was therefore wide variation between pairs, with some pairs very similar and others very different.

We next examined listening time to mother’s vs. stranger’s version of the same song (mother minus stranger). We excluded songs that were *never* heard at home (average frequency rating = 1.0), since we would not expect infants to prefer a particular rendition for these songs. After exclusions, 195 pairs of renditions remained. We included the fixed effects difference in tempo (absolute value, square-root to account for positive skew), difference in pitch (absolute value, square-root to account for positive skew), age, song frequency, and parent-initiated singing. We also fit the interaction between tempo, pitch, and song frequency, expecting differences in renditions to matter more for songs heard more often. Finally, we included participant as a random effect, yielding the model:

```
pref.for.mom ~ tempo.percent.difference * F0.percent.difference * avg_song_frequency +
        MH.parent.singing + age + (1|participantID)
```

No significant effects or interactions were observed (p's > .443) suggesting that the preference for familiar songs was robust regardless of differences between renditions (see Supplemental Table 2).

Skin Conductance Level

We used the same predictors as for listening time, adding listening time to the current model since infant SCL has been shown to increase over a trial when listening to recorded song (Bainbridge & Bertolo et al., 2020):

```
SCL.slope ~ singer * avg_song_frequency + mean.tempo + mean.F0 + listening.time + trial.number +
        MH.parent.singing + age + (1|participantID)
```

In general, infants' skin conductance levels increased over each trial. This activation was less pronounced when listening to familiar songs (β = -0.228, SE = .115, z = -1.976, p = .048); see Figure 2A and Supplemental Table 3) and songs with a higher mean $F0$ (β = -1.368, SE = 0.410, z = -3.336, p = .001). In addition, results indicated SCL slopes were less positive over longer trials (β = -0.254, SE = 0.103, z = -2.472, p = .013). We obtained convergent results when using only the first 7 seconds of trials to ensure the effect of familiarity was not an artefact of listening time (see Figure 2B and Supplemental Material).

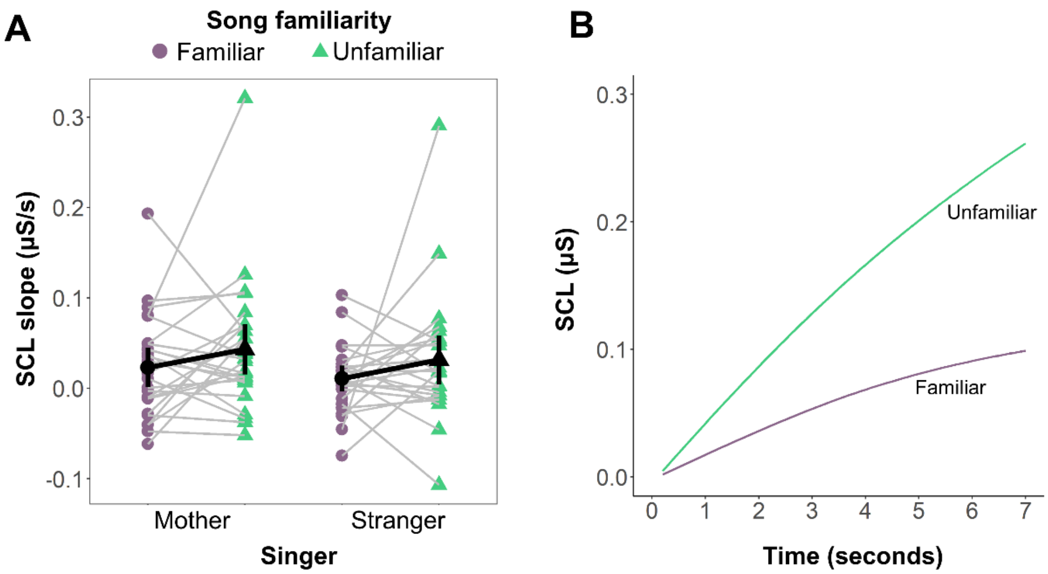

Figure 2. (A) Depicts SCL slope over a trial while listening to familiar and unfamiliar songs sung by infants' own mother or a female stranger. Each point represents one infant, and observations from the same infant in each "singer" condition are connected with a line. Error bars indicate within-subjects 95% confidence intervals. (B) Depicts mean SCL over the first 7 seconds of familiar and unfamiliar trials, including only trials >= 7 seconds.

Positive affect

Positive affect was relatively rare, only occurring on 46 of 451 trials (10.21%) across all participants. We used a generalized linear model with a binomial outcome indicating whether a smile occurred on a trial:

positive.affect ~ singer * avg_song_frequency + mean.tempo + mean.F0 + trial.length + trial.number + MH.parent.singing + age + (1|participantID)

Neither singer identity nor song familiarity affected whether positive affect was displayed (see Supplemental Table 4). Interestingly, faster tempo songs were more likely to elicit positive affect (β = 2.258, *SE* = 0.939, *z* = 2.404, *p* = .016). No other effects or interactions were significant. Twelve infants never smiled during a trial. Analyses with the 17 participants who smiled at least once revealed the same significant effect of tempo (β = 2.002, *SE* = 0.932, *z* = 2.149, *p* = .032). Among these participants, songs that elicited smiles were faster (*M* = 121 BPM) than songs that did not (*M* = 110 BPM).

Rhythmic movements

Though not as rare as smiles, rhythmic movements occurred in only 103 of 451 trials (22.84%). We first evaluated a model with *proportion of time moving rhythmically* as the dependent variable:

```
proportion.time.rhythmically ~ singer * avg_song_frequency + mean.tempo + mean.F0 + trial.number +
                              MH.parent.singing + age + (1|participantID)
```

A greater proportion of time was spent moving rhythmically during trials with more familiar songs (β = 0.217, *SE* = 0.085, *z* = 2.548, *p* = .011; Supplemental Table 5) and on later trials (β = 0.224, *SE* = 0.069, *z* = 3.231, *p* = .001). The same significant effects were observed with a binomial outcome representing whether movement occurred on a trial, and in an analysis excluding 9 infants who *never* moved rhythmically (see Supplemental Material). In a final exploratory analysis, we found a positive association between trial-level proportion of time smiling and proportion of time moving rhythmically on trials that contained both (see Supplemental Materials).

Discussion

Song is a ubiquitous infant-directed vocalization. Familiar songs are particularly effective at regulating infant emotion and guiding social affiliation. Here, we tested whether singer identity (mother or female stranger) modifies infant interest in familiar songs. Familiar songs encouraged longer listening times, less sympathetic nervous system activation, and more rhythmic movements than less familiar songs. Notably, attention was not only modulated by *highly* familiar songs: familiarity remained predictive when excluding songs sung "every day" and "multiple times per day". This familiarity preference was not influenced by singer identity, even when strangers' renditions differed substantially from the mother's. While some have speculated that the remarkable consistency in parents' song renditions facilitates infant recognition of their mother's voice (Bergeson & Trehub, 2002), our results suggest generalizability, rather than specificity, better describes infants' song recognition, even for frequently-heard songs. This finding is consistent with an account of songs as highly effective signifiers for in-group membership (Soley & Spelke, 2016).

Infants readily recognized song renditions that were highly dissimilar to their mothers', extending previous studies on infants' music perception abilities. On average, tempo and pitch were shifted by about 15%, well above detectable levels for infants younger than those tested here (Baruch & Drake, 1997; Trainor & Trehub, 1992). Notably, no own-mother preferences were observed even in the most extreme cases, in which pitch or tempo differences exceeded a factor of two. Adult-like tune recognition relies primarily on *relative* rather than *absolute* pitch and rhythm sequences – that is, the specific pitch and timing of a song is less important than the relationships between adjacent notes. *Happy Birthday*, for instance, is recognizable when sung quickly or slowly, and in various musical keys. Infants can also recognize melodies transposed to different keys (Plantinga & Trainor, 2009) and rhythms played at different tempos (Trehub & Thorpe, 1989). The case could conceivably be different, however, in the context of parents' frequently-sung infant-directed songs, which are reportedly highly consistent in pitch and tempo across renditions (Bergeson & Trehub, 2002). Nevertheless, infants clearly recognized even highly disparate renditions.

Songs produced by mothers and strangers were comparably effective at capturing infant attention, generating rhythmic movement, and altering sympathic nervous system activation. This could suggest that infants of this age do not recognize their mother's singing voice, or if such an effect exists, that it is too small for our design to detect (and smaller than the observed effect of song familiarity). This would be surprising, given that infants this age and younger (4 to 5 months) can readily discriminate between speakers (Fecher & Johnson 2018) and given the ubiquity of parent singing in their daily lives. In general, singer identity is more difficult to discriminate than speakers (Bartholomeus, 1974), likely because singing constrains the idiosyncratic melodies and rhythms that aid speaker recognition (Van Lancker & Kempler, 1987), and because song is less frequent than speech. Nevertheless, speech and song have sufficient acoustic overlap such that adults can identify singers from speech tokens (Peynircioğlu, 2016). One infant participant delightedly exclaimed “Mama!” and turned to look at their mother upon hearing her recorded rendition of “If You’re Happy and You Know It”, a highly familiar song. Future studies could employ habituation/dishabituation procedures to directly test whether infants are capable of discriminating their mother’s singing voice from a stranger’s.

On the other hand, infants’ preference for their mother’s voice may be modulated by age or context. Most studies documenting this preference focus on newborns (DeCasper & Fifer, 1980). Reflexively orienting to the primary caregiver’s voice at this age,when auditory perception is more mature than visual perception, may scaffold early mother-infant bonding. Four-month-old infants show no preference for their father’s voice, despite successfully discriminating male voices (Ward & Cooper, 1999). Likewise, older infants and toddlers recognize familiar words equally well regardless of whether the speaker is a parent or stranger (Bergelson & Swingley, 2017; Cooper et al., 2018; van Heugten & Johnson, 2012). Future research is needed to better understand the developmental trajectory of vocal recognition and preferences. In any case, the present results suggest that at this age, song familiarity plays a comparatively stronger role in recruiting infant attention to singing.

Exploratory analyses of infants’ electrodermal responses to pitch and tempo revealed unexpected patterns. In adults, both higher-pitched and faster music is associated with higher arousal, even in response to culturally-unfamiliar music (e.g., Egermann et al., 2015; McAdams et al., 2017). Similarly, infant arousal decreases as mothers sing “Twinkle, Twinkle” as a lullaby (sung slowly and in a low pitch) rather than as a playsong (Cirelli et al., 2019). Unexpectedly, here, higher pitch was associated with *less* sympathetic nervous system activation, and tempo was associated with affect (smiling) rather than arousal.

To quantify song familiarity, we relied on parents' reports. Promisingly, our results were robust to different codings of "familiarity". However, the extent to which parents can accurately report their singing is an open question. Daylong recordings from 35 American families with infants report between 1.2 and 33 minutes of singing per day (Mendoza & Fausey, in press), notably lower than what a sample of Canadian parents reported in surveys (Cirelli et al., 2020). This discrepancy may be due to parents overestimating their use of song on surveys, reluctance to sing in the presence of an audio recorder, differences between samples, or other factors. Future research combining different methods of measurement, ranging from daylong recordings to hourly logs, will provide a fuller picture of parent singing in the home.

The present study underscores infants' remarkable flexibility to generalize across different renditions of familiar songs. To our knowledge, this is the first study to compare song renditions such a wide variation in pitch, tempo, and vocal timbre. Infants not only preferentially attended to familiar songs, but these songs also generated more rhythmic movements and reduced sympathetic nervous system activity. Early and robust generalization of familiar songs across different singers is consistent with an account of songs as powerful signals for group membership and cultural identity.

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Supplemental Material

Selected children's songs

Twinkle, Twinkle, Little Star	*London Bridge*
The Itsy Bitsy (Eensy Weensy) Spider	*Hot Cross Buns*
You Are My Sunshine	*Mary Had a Little Lamb*
If You're Happy and You Know It	*I'm a Little Teapot*
Row, Row, Row Your Boat	*The Ants Go Marching*

Note: Two parents also sang "ABC", which notably has the same melody and rhythmic structure to *Twinkle, Twinkle, Little Star*.

Supplemental Table 1
Effects of singer identity, acoustic properties, demographic characteristics, and song familiarity coded four different ways on listening time.

	Binary (familiar, unfamiliar)			*Time 1 frequency*			*Time 2 frequency*			*Average frequency rating*		
Effect	*β* (*SE*)	*z*	*p*	*β* (*SE*)	*z*	*p*	*β* (*SE*)	*z*	*p*	*β* (*SE*)	*z*	*p*
Familiarity	0.0289 (*.0091*)	3.180	.001	0.0435 (*.0207*)	2.099	.036	0.0749 (*.0220*)	3.406	.0007	0.0667 (*.0228*)	2.930	.003
Singer identity (mother, stranger)	-0.0013 (*.0091*)	-0.146	.883	-0.0282 (*.0192*)	-1.466	.143	-0.0152 (*.0199*)	-0.763	.446	-0.0249 (*.0207*)	-1.200	.230
Tempo (beats per minute)	0.0390 (*.0490*)	0.789	.425	0.0435 (*.0207*)	1.037	.300	0.0371 (*.0488*)	0.760	.448	0.0476 (*.0488*)	0.975	.330
*F*0 (average fundamental frequency)	-0.0030 (*.0880*)	-0.034	.973	0.0014 (*.0886*)	0.016	.987	-0.0282 (*.0890*)	-0.317	.751	-0.0181 (*.0885*)	-0.204	.838
Trial number	-0.1001 (*.0019*)	-5.310	< .0001	-0.0996 (*.0190*)	-5.252	< .0001	-0.1011 (*.0189*)	-5.344	< .0001	-0.1002 (*.0189*)	-5.313	< .0001
Music@Home parent singing subscore	-0.0054 (*.1142*)	-0.047	.962	-0.0191 (*.1148*)	-0.166	.868	-0.0361 (*.1149*)	-0.314	.753	-0.0284 (*.1140*)	-0.249	.803
Age (days)	0.2730 (*.2450*)	1.123	.261	0.2655 (*.2445*)	1.086	.277	0.2464 (*.2442*)	1.009	.313	0.2408 (*.24233*)	0.994	.320
Familiarity * singer	0.0029 (*.0090*)	0.321	.748	0.0296 (*.0192*)	1.540	.124	0.0135 (*.0199*)	0.676	.499	0.0261 (*.0207*)	1.261	.207

Supplemental Table 2

Effects of acoustic properties and demographic differences in infants' listening times to own-mother vs. stranger renditions of the same song.

Effect	*β* (*SE*)	*z*	*p*
Average frequency rating	-0.068 (*1.178*)	-0.057	.954
Tempo difference	0.493 (*1.059*)	0.466	.642
*F*0 difference	0.651 (*1.205*)	0.540	.589
Music@Home parent-initiated singing	0.263 (*0.468*)	0.562	.574
Age (days)	0.506 (*0.939*)	0.539	.590
Tempo difference * *F*0 difference	-0.795 (*1.193*)	-0.666	.505
Tempo difference * Average frequency rating	-0.320 (*1.187*)	-0.270	.788
*F*0 difference * Average frequency rating	-0.501 (*1.220*)	-0.411	.681
Tempo difference * *F*0 difference * Average frequency rating	0.925 (*1.206*)	0.767	.443

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Supplemental Table 3

Effects of singer identity, song familiarity, acoustic properties, and demographic characteristics on SCL slope (µS per second).

Effect	β (*SE*)	*z*	*p*
Average frequency rating	-0.2280 (*.1154*)	-1.976	.048
Singer identity (mother, stranger)	0.0011 (*.1081*)	0.010	.992
Listening time	-0.2539 (*.1027*)	-2.472	.013
Tempo	-0.359 (*.2400*)	-1.441	.149
*F*0	-1.3382 (*.4101*)	-3.336	.001
Trial number	0.0665 (*.0989*)	0.673	.501
Music@Home Parent Singing subscore	-0.2751 (*.3081*)	-0.893	.372
Age (days)	1.1412 (*.6971*)	1.637	.102
Singer identity * Avg frequency rating	0.0567 (*.1084*)	0.523	.601

Supplemental Table 4

Effects of singer identity, song familiarity, acoustic properties, and demographic characteristics on positive affect (binary).

Effect	β (*SE*)	*z*	*p*
Average frequency rating	0.3271 (*.4391*)	0.745	.456
Singer identity (mother, stranger)	-0.0994 (*.4170*)	-0.238	.812
Listening time	0.3947 (*.3782*)	1.043	.297
Tempo	2.2581 (*.9392*)	2.404	.016
*F*0	0.3286 (*1.569*)	0.209	.834
Trial number	0.2613 (*.3601*)	0.726	.468
Music@Home Parent Singing subscore	-1.1426 (*1.790*)	-0.638	.523
Age (days)	-0.9753 (*4.312*)	-0.226	.820
Singer identity * Avg frequency rating	0.2583 (*.4116*)	0.628	.530

Supplemental Table 5

Effects of singer identity, song familiairity, acoustic properties and demographic characteristics on rhythmic movement.

	Proportion of time moving rhythmically			*Rhythmic movement (yes/no)*		
Effect	*β* (*SE*)	*z*	*p*	*β* (*SE*)	*z*	*p*
Average frequency	0.2170 (*.0852*)	2.548	.011	0.8395 (*.3764*)	2.230	.026
Singer identity (mother, stranger)	0.0158 (*.0763*)	0.207	.836	0.3106 (*.3353*)	0.926	.354
Listening time	NA	NA	NA	0.1609 (*.3711*)	0.433	.665
Tempo (beats per minute)	0.1516 (*.1813*)	0.836	.403	1.1870 (*.8089*)	1.467	.142
*F*0 (average frequency)	-0.2834 (*.3336*)	-0.850	.395	-1.3979 (1.4518)	-0.963	.336
Trial number	0.2242 (*.0694*)	3.231	.001	1.0007 (*.3123*)	3.204	.001
Music@Home parent singing subscore	-0.1184 (*.6567*)	-0.180	.857	-0.1257 (*2.5533*)	-0.049	.961
Age (days)	-1.5392 (1.3947)	-1.104	.270	-5.1443 (5.4396)	-0.946	.344
Familiarity * singer	-.0290 (*.0764*)	-0.380	.704	-0.2062 (*.3373*)	-0.611	.541

Supplementary Analyses

Supplemental analysis of listening time with different codings of familiarity.

The binary coding of familiarity (familiar/unfamiliar) did not account for the fact that there was significant variation in parent-reported frequency between the two categories. Average parent-reported frequency ratings between familiar and unfamiliar songs within a single participant differed by as little as 1 point (16.7% of the full scale) to as many as 4.5 points (75% of the full scale). To ensure that this result was robust to different codings of familiarity, we re-ran the model with familiarity coded in three other ways: (1) parent-reported frequency at Time 1, (2) parent-reported frequency at Time 2, and (3). The same significant effects were observed for all four models (Supplemental Table 1).

Supplemental analysis of skin conductance in the first 7 seconds.

To ensure the effect of familiarity on SCL slope was not an artefact of listening time, we conducted a post-hoc analysis of slope *over the first 7 seconds*, only including trials that lasted at least 7 seconds. This was thought to be long enough for SCL to change but short enough to retain as many trials as possible. Out of 403 trials, 315 were retained for analysis. A paired *t*-test comparing mean SCL slope for “familiar” and “unfamiliar” (binary-coded) trials supported the results of the full analysis ($t(25) = -2.535$, $p = .018$, Cohen’s $d_Z = .497$), such that the SCL increase was smaller for familiar songs than unfamiliar songs.

Supplementary analyses of rhythmic movement

Because many trials had no rhythmic movements we reran the analysis with a generalized linear model and a binomial outcome representing whether movement occurred on a trial or not, adding listening time as a fixed effect since longer trials would afford more opportunities to move. The same significant effects were observed (familiarity: β = 0.840, *SE* = 0.376, *z* = 2.230, *p* = .026; trial number: β = 1.001, *SE* = 0.312, *z* = 3.204, *p* = .001). Finally, nine infants *never* moved rhythmically and were removed from the analysis and the same significant effects were observed (familiarity: β = 0.830, *SE* = 0.362, *z* = 2.295, *p* = .022; trial number: β = 0.956, *SE* = 0.312, *z* = 3.067, *p* = .002).

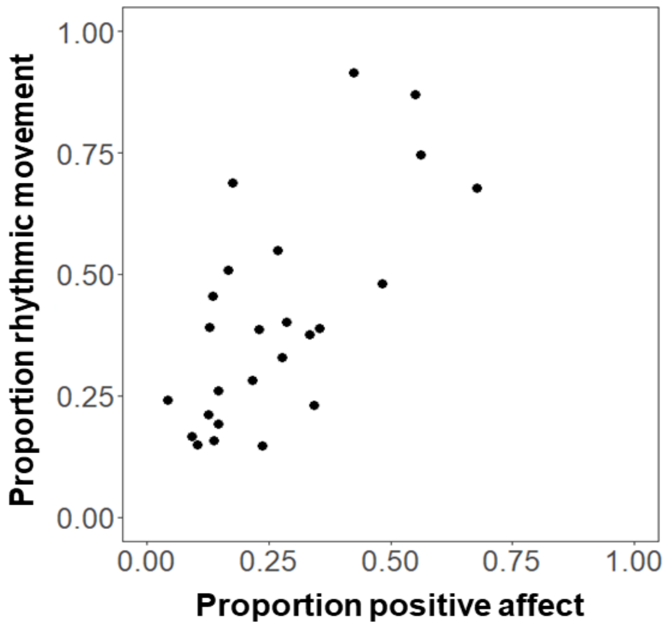
Exploratory analysis of positive affect and rhythmic movement

Previous studies demonstrated that rhythmic movements and positive affect often co-occur in infants' responses to music (Cirelli & Trehub, 2019; Zentner & Eerola, 2010). As an exploratory analysis, we examined whether these behaviours were correlated in trials that contained both. Only 25 trials contained both, which were contributed to by 13 participants. In those trials only, we examined whether the proportion of positive affect and rhythmic movement in each trial were correlated:

```
prop.rhythmic.movement ~ prop.positive.affect + (1|participantID)
```

The behaviors were highly correlated (β = 0.631, *SE* = 0.133, *z* = 4.742, *p* < .0001; see Supplemental Figure 1).

Rhythmic movements were fairly common. Two-thirds of the infants moved rhythmically at least once, and rhythmic movement was observed in over 20% of trials. Among infants who smiled *and* moved rhythmically on the same trial, the proportion of time spent smiling and moving was positively correlated. These results align with previous work reporting links between musical movements and joy in infants and toddlers (Cirelli & Trehub, 2019; Zentner & Eerola, 2010). Future work is needed to explore how these early musical movements develop into the complex auditory-motor synchronization behaviours that emerge in preschool years and become further refined throughout childhood (Drake et al., 2000; McAuley et al., 2006).



Supplemental Figure 1. Depicts the association between rhythmic movements and positive affect. Each point represents a single trial on which both rhythmic movements and positive affect were present (25 trials).

Supplementary analyses of mothers' singing

Based on reviewer suggestion, we explored whether the acoustic features of mothers' singing were influenced by how frequently they reported singing it to their child. Posthoc analyses suggested that song familiarity was associated with mother's mean *F*0 (β = 2.623, *SE* = 0.678, *z* = 3.870, $p < .001$), but not their tempo (β = 0.776, *SE* = 0.845, *z* = 0.918, *p* = .358). Parents therefore tended to sing more "familiar" songs with a higher pitch. However, infant listening time was not affected by mean *F*0 (*p* = .400), so the acoustic properties of their rendition do not seem to have been driving longer listening times to familiar songs.