Ecological momentary assessment reveals causal effects of music enrichment on infant mood

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Music appears universally in human infancy with self-evident effects on infant psychophysiology: as many parents know intuitively, infants love to be sung to. The long-term effects of parental singing are unknown, however. In an offset-design exploratory 10-week randomized trial (N = 110 families of young infants, M_{age} = 3.67 months, 53% female, 73% White, retention rate = 92%), we manipulated the frequency of infant-directed singing via a singing intervention. The results, measured by smartphone-based ecological momentary assessment, show that infant-directed singing causes general post-intervention improvements to infant mood, but not to caregiver mood. The findings also show both the feasibility of longitudinal ecological momentary assessment of young infants and the potential of longer-term and higher-intensity singing interventions to improve health in infancy.

Keywords: music, infancy, parenting, infant-directed song, ecological momentary assessment, EMA

1 Introduction

Decades of research have demonstrated the profound impact of the quality of early life experiences on lifelong physical and mental health (Fries et al., 2005; Shonkoff et al., 2012). Building on Bowlby (1969)'s work on attachment, evidence from a wide variety of approaches and across diverse populations shows that consistent warmth, care, and responsiveness provided by caregivers is a key feature of healthy caregiving and positive infant-caregiver relationships (Schore, 2005; Stams et al., 2002).

For example, infants who experience emotionally available and responsive parenting have enhanced social and emotional skills (Feldman et al., 1999; Steele et al., 2008), have later advantages in school (NICHD Early Child Care Research Network, 2006; Pasco Fearon & Belsky, 2011), and are more likely to live a healthy life, both physically (Puig et al., 2013) and mentally (Shaw & Dallos, 2005). Conversely, when such nurturing environments are lacking, adverse consequences manifest, including altered neural circuit maturation (Wen et al., 2017), impaired cognitive development (Nelson et al., 2007), diminished social-emotional competence (Davis et al., 2004), and an increased risk of psychiatric symptoms that may persist through adulthood (Weissman et al., 2006). While genetic factors shared between parents and infants can partially explain such effects, they interact with environmental influences in complex ways; the foundational role of caregiver attention and care in healthy development remains evident.

Children face very different chances of receiving the benefits of a caring and nurturing infant-caregiver relationship, however. Factors related to risk and resilience, such as caregiver characteristics (e.g., age, sex, personality, marital status), cultural background, and socioeconomic circumstances, together mediated by differential access to resources and opportunities, interact to shape the variability in early life experiences

(Roubinov & Boyce, 2017). Socioeconomic status, for instance, influences the quantity and quality of speech directed towards infants (Fernald et al., 2013), shaping the development of the brain language system (Cheng, Roth, et al., 2023) and subsequent language and literacy skills (Hemmerechts et al., 2017). Moreover, contextual factors, such as poor marital relationship quality (Dennis & Ross, 2006) and inadequate social support (Reid & Taylor, 2015), are associated with increased risk of postpartum depression, affecting caregiver responsiveness and sensitivity towards infants (Feldman et al., 2009).

The high degree of variability in early home environments presents an opportunity to improve outcomes for young infants and their families. In particular, simple, low-cost, and low-tech interventions that involve only modest adjustments to infant care practices hold particular promise given their ease of uptake. For example, increasing early skin-to-skin contact (e.g., kangaroo care) has demonstrated numerous health benefits for both premature and full-term infants worldwide (Feldman et al., 2014; Moore et al., 2012). In this paper, we report an exploratory randomized trial of a high-potential but relatively unexplored type of enrichment: singing interventions for caregivers of young infants.

Caregivers universally sing to their infants in the course of child-rearing (Mehr et al., 2019; Singh & Mehr, 2023), throughout infancy (Yan et al., 2021), and regardless of family socioeconomic status (Mehr, 2014; Custodero et al., 2003; Fancourt & Perkins, 2018a). Such infant-directed singing has robust cross-cultural regularities (Hilton, Moser, et al., 2022; Yurdum et al., 2023; Mehr et al., 2019), including multimodal features that combine voice, touch, eye-contact, and movement, which infants may reciprocate via visual attention, cooing, smiling, and moving their hands and legs (Malloch & Trevarthen, 2009). These interactive behaviours may support a variety of communicative functions (Trehub & Gudmundsdottir, 2019; Mehr et al., 2021), including signaling social information (Mehr et al., 2016; Mehr & Spelke, 2017) or parental investment (Kotler et al., 2019; Mehr et al., 2017; Mehr & Spelke, 2017), enhancing social bonds (Fancourt & Perkins, 2018a), and promoting meaningful social interactions in families (Lense et al., 2022; Malloch, 1999).

It is unsurprising, therefore, that music and infant-directed singing have profound effects on infants. These have been studied in a variety of contexts. For example, infant-directed singing captures and sustains infant attention (Costa-Giomi & Ilari, 2014; Nakata & Trehub, 2004; Trehub et al., 2016) and regulates arousal and mood (Cirelli et al., 2020; Corbeil et al., 2016; Shenfield et al., 2003) on a short-term basis. In some cases, musical stimuli show stronger effects than infant-directed speech studies: after a still-face procedure, parent-produced familiar infant-directed songs reduced negative affect more strongly than infant-directed speech (Cirelli & Trehub, 2020), and in an open-ended listening task, infants become fussy after approximately twice as much time when hearing singing, relative to speech (Corbeil et al., 2016). Such effects do not depend fully on the familiarity of the music, however: even unfamiliar, foreign lullabies calm infants, as measured by heart rate, electrodermal activity, and pupillometry (Bainbridge, Bertolo, et al., 2021).

Moreover, the effects of infant-directed singing may extend beyond infants to caregivers themselves. For example, they may aid in the regulation of caregivers' own arousal levels (Cirelli & Trehub, 2020; Fancourt & Perkins, 2018b); reduce caregiving-related stress (Cho & Ilari, 2021); or enhance perceived well-being and affective connection with their infants (Fancourt & Perkins, 2017; Steinberg et al., 2021).

Singing therefore has substantial potential as an enrichment intervention, as all of the above short-term effects could in principle work cumulatively, leading to improved health outcomes in infants and caregivers. Curiously, this idea has largely gone untested, as most studies of health outcomes related to music in infancy focus on short-term effects of music interventions in hospital settings (e.g., Arnon et al., 2014; Filippa et al., 2013).

Here, we report an exploratory randomized trial of young infant-caregiver dyads, wherein we experimentally manipulated the frequency of infant-directed singing via a singing intervention. We measured outcomes primarily with smartphone-based ecological momentary assessment (EMA), a method that samples infant behavior naturalistically via many brief, repeated-measures surveys that caregivers complete daily at random intervals (e.g., Barbaro et al., 2023; Franchak, 2019).

Characteristic		n	% of sample
Country of residence	United States of America	59	54.00
	New Zealand	38	35.00
	Canada	10	9.00
	Singapore	1	1.00
	Sweden	1	1.00
Parent's country of birth	United States of America	52	48.00
	New Zealand	27	25.00
	Canada	7	6.00
	South Korea	7	6.00
	United Kingdom of Great Britain and Northern Ireland	3	3.00
	India	2	2.00
	Australia	1	1.00
	China	1	1.00
	El Salvador	1	1.00
	France	1	1.00
	Germany	1	1.00
	Hong Kong (S.A.R.)	1	1.00
	Iraq	1	1.00
	Malaysia	1	1.00
	Saudi Arabia	1	1.00
	Spain	1	1.00
	Zimbabwe	1	1.00
Parent race/ethnicity	White/European/New Zealand European	80	73.00
	Asian	20	18.00
	Black or African American	2	2.00
	Māori	1	1.00
	More than one race	5	5.00
	I'd prefer not to say	1	1.00
Parent's highest level of education	High school or equivalent	4	4.00
	Vocational/technical school (2 year)	2	2.00
	Some college/university	9	8.00
	College/university graduate	49	45.00
	Master's degree (MA or equivalent)	32	29.00
	Doctoral degree (PhD or equivalent)	4	4.00
	Professional degree (MD, JD, etc)	9	8.00
Current household income (USD)	Over $150,000	30	28.00
	$100,000 to $150,000	25	23.00
	$75,000 to $99,999	26	24.00
	$50,000 to $74,999	14	13.00
	Below $50,000	9	8.00
	I'd prefer not to say	5	5.00

Table 1 | Demographic characteristics of the sample.
Participants in New Zealand reported their household income in New Zealand dollars, so their responses have been converted to the approximate equivalent US-dollar category. The US-based and New Zealand-based versions of the demographics surveys included slightly different race labels, in line with local guidelines. For simplicity, we have combined the (US-based) category "White" and (New Zealand-based) category "European/New Zealand European".

2 Methods

2.1 Participants

All participants provided informed consent under a protocol approved by the Yale University Institutional Review Board (protocol #2000035858). We advertised the study via in-person visits to baby fairs, distribution of flyers at local daycare centers, preschools, and delivery hospitals, and a public radio advertisement in New Haven, Connecticut. Online recruitment efforts targeted social media groups for expecting and new parents, along with online communities related to early childhood education.

The inclusion criteria required participants to have a smartphone, to communicate and complete surveys in English, and to be a primary caregiver of the focal infant. Participants were primarily located in the United States and New Zealand (see Table 1), but as the study took place entirely online, there were no geographical constraints. At three points in the study, caregivers reported their level of involvement in caregiving on a daily basis. Most caregivers ($n = 103$) reported providing at least 50% of childcare at all three time points. Most participants had some degree of musical training; only 18 out of 110 participants reported having had no formal musical training (see Supplementary Table 1).

Of the 120 participants initially recruited, two withdrew from the study due to time constraints. Eight participants were excluded due to low completion rates, having responded to fewer than 50% of EMA pings either for two consecutive weeks during the study period or by the end of the study (an exclusion criterion determined before data collection began). This resulted in a final sample size of 109, indicating a retention rate of 92%.

We recruited the primary caregivers of infants a maximum of 9 months of age, but with a focus on younger infants. The participating infants were, on average, 3.66 months old at the start of the study (range: 0.17 - 8.93 months, interquartile range: 2.13 months; see Supplementary Figure 1 for a histogram of infant ages). Five infants were born pre-term (i.e., more than 3 weeks before their due date), and 57 of the infants were female. Caregivers were predominantly mothers (Mean age: 33.52 years; 103 female, 6 male), and were mostly White, highly educated, and socioeconomically advantaged (see Table 1 for demographics).

Participants incentives included digital gift cards, a baby songbook, and baby clothing (a total value of approximately US$70), distributed over the course the study. We also informed caregivers at the outset of the study that they would receive a personalized report summarizing their survey responses. This approach, inspired by gamified citizen science (e.g., Long et al., 2023; Liu, Hilton, et al., 2023), served as an additional motivation for study completion. An example report is in Supplementary Figure 2.

2.2 Study structure

We used an offset-randomised control trial design, with participants randomly assigned to either a manipulation ($n = 54$) or control group ($n = 56$). Study participation lasted for 10 weeks, with a 4-week singing intervention period (Figure 1). Assignment was fully random except for a few participants whose initial random assignment created an imbalance across the two groups. The manipulation group received the singing intervention during weeks 2–5 and the control group received the same intervention following the post-test period (weeks 7-10). As such, the first 6 weeks of the study comprised a pre-test, intervention, and post-test period, wherein the only difference between the groups was whether or not they had received the singing intervention.

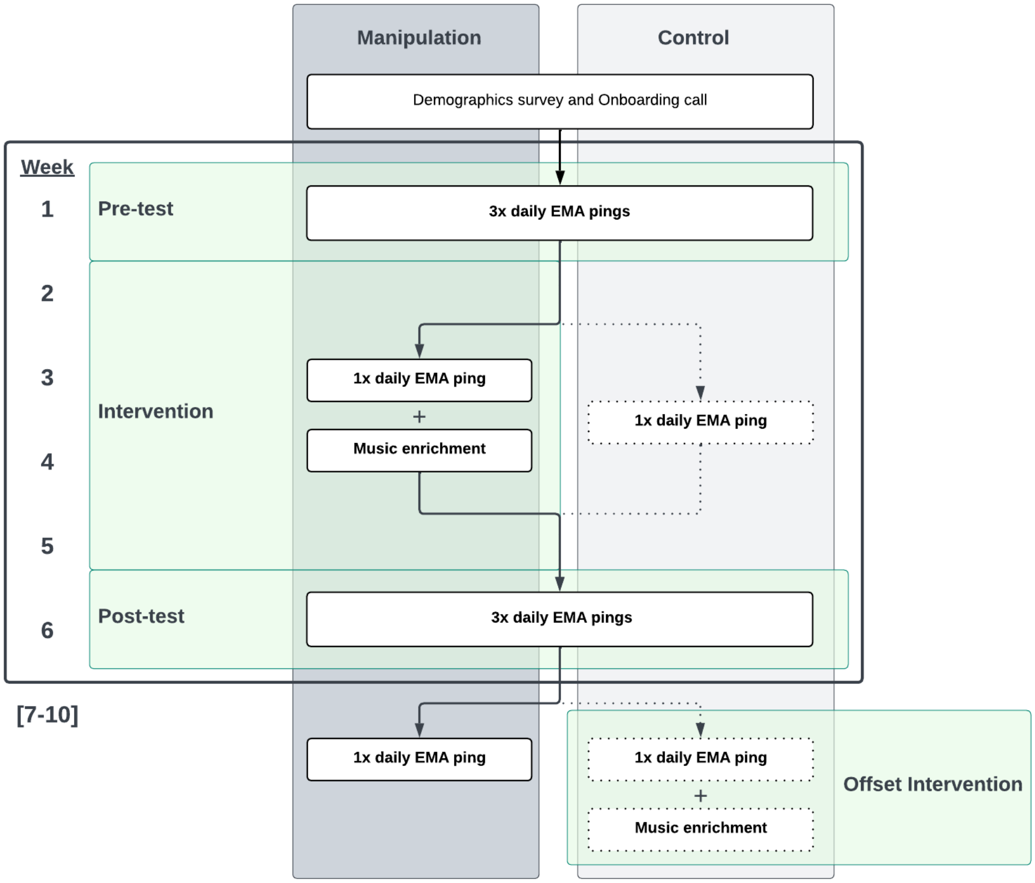

Figure 1 | Structure of the experiment. We conducted an offset-design randomized trial with a one-week pre-test, a four-week intervention, and a one-week post-test (see the areas highlighted in green). This main study period was followed by four further weeks of study participation, to accommodate the offset intervention period (for the control group). The left and right columns indicate the study flow for the manipulation and control groups, respectively. Both groups received the same number of EMA pings and followed identical procedures, except during the intervention period (weeks 2-5), during which the manipulation group participated in the music enrichment intervention along with their daily EMA pings, while the control group only completed the EMA pings and had no intervention.

Week 1 served as a pre-test, providing baseline EMA data for all families at high intensity (three pings per day). In Weeks 2-5, caregivers in the manipulation group underwent the intervention (see *Singing intervention*), while the control group received no intervention; during this period, EMA continued at a lower frequency of one ping per day for all families. Week 6 served as a post-test, with a high intensity EMA. Caregivers in the control group received the intervention during Weeks 7-10 while all families having the lower EMA frequency.

The study began with a one-on-one onboarding video call, where a designated researcher provided an overview of the study, guided participants in setting up to receive daily EMA notifications on their smartphones (see *Measures*), and answered any questions. Participants were required to be physically present with their infants during the onboarding session to safeguard against fraudulent participation, a common concern in online developmental studies (Perkel, 2020). The same researcher continued to serve as the participant's point of contact throughout the rest of the study.

2.3 Singing intervention

The goal of the intervention was to increase the frequency of infant-directed singing in daily life while also expanding caregivers' repertoire of songs. We aimed to do so by teaching participants new songs to sing at home and providing materials designed to encourage more singing, in general, in the course of their caregiving.

During the intervention, participants were given access to six instructional videos of unfamiliar songs presented in karaoke style, with lyrics synchronized to a bouncing ball indicating the rhythm (all videos are available at https://github.com/themusiclab/musical-babies). These videos were accessible either via The Person Project app or private YouTube links, depending on the type of EMA caregivers used (see Supplementary Text 1). Three videos were sent at the start of the intervention, with an additional three delivered halfway through. The songs were sourced from vintage songbooks and online archives of folk songs for children, then adapted for simplicity and ease of singing, especially for caregivers with limited music training. This process involved moderate rewriting and arranging. The songs were then recorded and produced by members of the research team who had extensive experience in early childhood music education (authors E.C., E.E., and S.A.M.).

Additionally, participants received an infant-friendly songbook of their choice from a provided list (i.e., the Ditty Bird Musical Book series, Cali's Books series), delivered to their homes at the outset of the intervention. These books featured pressable buttons to activate song playback, accompanied by vibrant illustrations and lyrics.

Last, to further motivate caregivers to sing more to their infants, we sent weekly email newsletters to participants in the manipulation group during the intervention. The newsletters introduced ideas to incorporate singing into daily caregiving routines; highlighted the significance of singing in infancy; and presented research findings relevant to the benefits of musical parenting, in an easy-to-understand format.

To sustain participants' engagement over the four-week intervention, the research team maintained regular communication with participants via text messages and/or emails, providing encouragement and promoting active involvement. Caregivers were not discouraged from singing outside of the intervention period; the intervention should be understood as supplementing existing levels of singing in the home, as opposed to suppressing such behaviors at non-intervention periods or in the control group.

2.4 Measures

The primary measures of infant and caregiver health were collected via EMA. We used a varied EMA schedule, with caregivers receiving one EMA survey per day throughout the study, at a random time during waking hours, except during two high-intensity weeks: Week 1 (pre-test) and Week 6 (post-test), where they received three EMA surveys a day (at random times in the morning, afternoon, and evening). In total, caregivers received 98 EMA surveys across the 10 weeks. EMA data collection was conducted either via The Person Project, a smartphone app developed by authors H.S. and D.T; or by Qualtrics surveys distributed by text message, via Inclivio (https://inclivio.com). Complete details about EMA distribution are in Supplementary Text 1.

The EMA surveys addressed various elements of infant and caregiver health within 2-3 hours of receiving an EMA ping, with 12 items on (1) *infant mood*, measured by self-assessed valence and arousal; (2) *infant distress and recovery*, assessed through a pictorial scale of infant fussiness (Adams et al., 2019), and details on soothing techniques and duration for recovery; (3) *caregiver mood and stress*, measured by self-assessed valence, impact, and rationality using the 3D Mind Model approach to mental state assessment (Thornton & Tamir, 2020), along with self-reported levels of caregiving-related stress; and (4) *musical behavior*, measured by the frequency of caregivers' engagement with focus behavior (i.e., singing, music listening). Three additional questions concerning the previous day were also included, such as the estimated frequency of infant-directed singing, the frequency of infant night waking, and the duration taken to fall back asleep. On high-density EMA weeks, these questions were only displayed in pings arriving before 11:30am (for participants who used The Person Project) and in the first ping of the day (for participants who used Inclivio).

We also collected data in four longer-form surveys spread throughout the study, for analysis in a different paper comparing EMA responses to retrospective surveys; they are not reported here. The full text of the EMA surveys is in Supplementary Text 2.

2.5 Compliance

On average, participants completed 72.44 of the 98 EMA surveys, for an overall response rate of 74%, with a higher rate during the low intensity weeks (1 EMA survey/day; 78.39%) than the high intensity weeks (3 EMA surveys/day; 68%). This compliance rate is comparable to those reported in other infant EMA studies, including one-week studies with intensive daily pings (Barbaro et al., 2023; Wenze et al., 2023; Franchak, 2019) and longitudinal studies lasting up to 16 weeks with less intensive pings (Allen et al., 2018; Franchak et al., 2024; Corpuz et al., 2023). Participants' response rates were unrelated to infant age at the start of the study ($\beta = 0.00017$; $p = 0.48$). The proportion of unanswered pings was slightly higher in the control group, although this difference did not reach significance at pre-test ($p = 0.27$), intervention ($p = 0.09$), or post-test ($p = 0.06$). Given the comparable levels of missingness in the two groups, we assume that nonresponse represents missing data at random and did not attempt to account for missingness in our analyses.

To assess responsiveness to EMA pings, we calculated response latency by subtracting the time of EMA notification from the time participants opened the survey on their smartphone. The median response latency was 20.48 mins minutes (high intensity weeks = 16.31 mins; low intensity weeks = 23.25 mins); this analysis was only available for participants whose pings were distributed by text message. Latency increased with infant age ($\beta = 0.09$, $SE = 0.04$, $p = 0.02$).

3 Results

3.1 Music enrichment increases the frequency of infant-directed singing

We began by asking whether the intervention worked; namely, whether we succeeded in increasing the frequency of infant-directed singing in the intervention group, relative to the control group. Two EMA items addressed this question, in different ways.

First, every EMA ping included an item asking caregivers whether they had sung to their infant in the preceding 2-3 hours (they could respond "Yes" or "No"). Only caregivers who reported having been with their infants in the last 2-3 hours responded. We dropped data where the caregiver indicated in the same EMA ping that their infant was sick. In all analyses comparing the behaviour of the intervention and control groups within a specific week, we use weekly scores that are calculated as averages of all responses to EMA pings during that week.

The intervention caused a clear increase in the frequency of infant-directed song (Figure 2, left panel), with no difference between groups at pre-test (proportion of "Yes" responses in manipulation group: M = 64%, SD = 24; in control group: M = 65%, SD = 22; t(103.69) = -0.08, $p = 0.93$, two-sample t-test), and a significant difference at post-test (proportion of "Yes" responses in manipulation group: M = 77%, SD = 20; in control group: M = 64%, SD = 24; t(98.88) = 3.11, $p = 0.002$, difference = 14, two-sample t-test). Note that during post-test, caregivers were no longer actively being encouraged to sing more to their infants: week 5 was the last week of the intervention. The significant difference between groups held despite this. A mixed-effects time-series model that accounted for autoregression across the 6 weeks of the study showed a significant interaction across group and time ($\beta = 0.26$, $SE = 0.12$, $p = 0.02$). In the manipulation group, each week of the intervention was associated with a 1.85 point increase in the proportion of times caregivers reported singing to their infants.

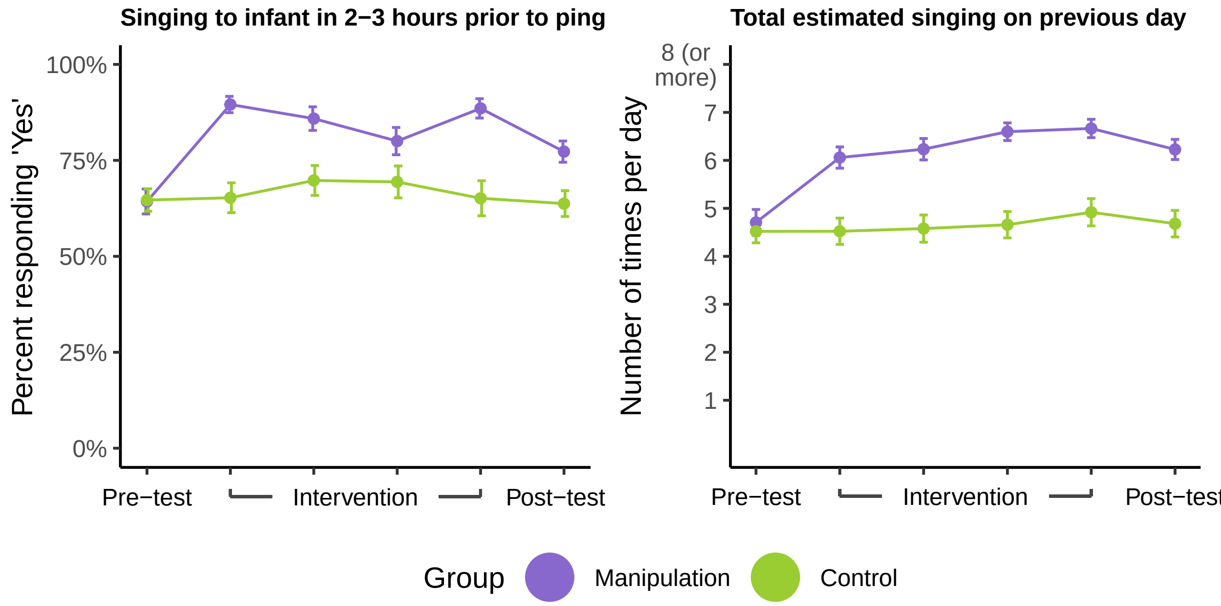

Figure 2 | Music enrichment increases the frequency of infant-directed singing. The plots depict responses to two items: "Did you sing to [baby] in the last 2-3 hours?" (left panel), asked up to three times per day with response options "Yes" or "No"; and "If you had to guess, how many times did you sing to [baby] yesterday?" (right panel), asked in the first notification of the day (delivered during morning hours between 9 and 11:30 am) with response options ranging from "1" to "8 or more times". There was a sharp increase in infant-directed singing for the manipulation group, but not the control group, as measured by both items; the increase persisted through the full intervention and was maintained in the post-test week. Tick marks indicate the study week; week 1 and 6 correspond to pre- and post-test, respectively, while weeks 2 through 5 span the intervention period. Points denote weekly averages, error bars indicate standard error of the mean.

These effects were specific to infant-directed singing, as we did not find comparable interaction effects for other music-related variables that were also reported in the same EMA surveys, such as playing recorded music for the infant (β = -0.16, SE = 0.12, p = 0.18); or caregivers' personal music listening (β = 0.00, SE = 0.12, p = 0.98) in the 2-3 hours preceding the EMA ping.

Notably, the absolute frequency of infant-directed singing was substantial in the manipulation group: by the final week of the intervention, 89% of the time, a caregiver had recently sung to their infant when they received an EMA ping (relative to 65% in the control group).

Second, morning EMA pings (i.e., those delivered before 11:30am) prompted caregivers to report how many times they had sung to their infant *on the previous day* ("If you had to guess, how many times did you sing to [baby] yesterday?") on an 8-point scale ranging from "1" to "8 or more times". Here too we found a clear effect of the intervention (Figure 2, right panel), with no group-level difference at pre-test (t(105.29) = 0.51, p = 0.61, two-sample t-test), a significant difference at post-test (t(101.22) = 4.45, p < .0001, two-sample t-test), and a significant group-by-timepoint interaction (β = 0.03, SE = 0.01, p < .0001) indicating an average of 0.28 more songs per week in the manipulation group (roughly 3% of the scale). While caregiver reports summarizing the previous day's singing with an integer may not be optimally precise, at the post-test period these effects represented a 1.48 unit increase in absolute daily estimates of singing behaviour (SD = 2.19).

Thus, convergent evidence demonstrates that the intervention succeeded at its primary goal, namely, to experimentally manipulate caregivers' infant-directed singing in daily life.

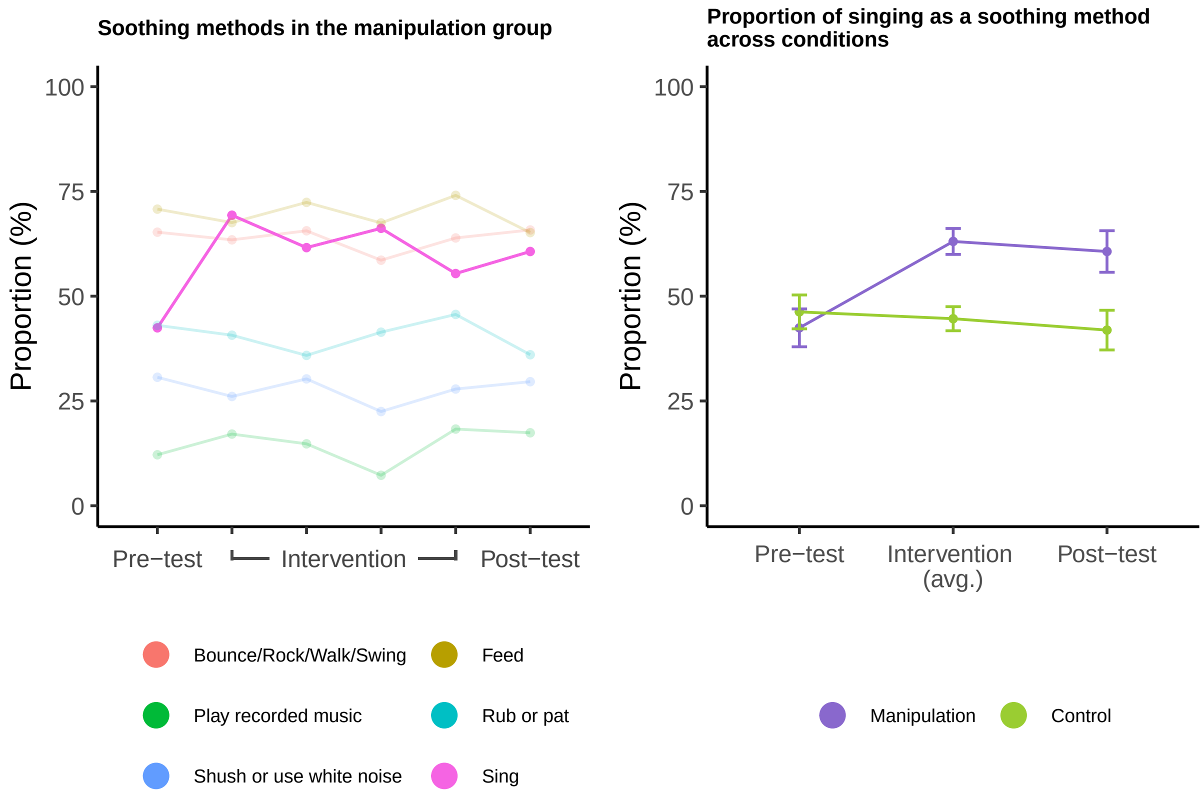

Figure 3 | Music enrichment alters parent responses to infant fussiness. In each EMA ping, we asked the parent if their infant was fussy in the previous 2-3 hours; if they answered 'Yes', then we asked how they attempted to soothe the infant. The left panel illustrates the proportion of responses in the manipulation group for six soothing techniques (of 12 available options; see Supplementary Text 2). Tick marks indicate the study week; week 1 and 6 correspond to pre- and post-test, respectively, whereas weeks 2 through 5 span the intervention period. Singing in response to fussiness was the only soothing technique out of 12 that showed an increase in usage from pre- to post-test. This increase was specific to the manipulation group, as shown in the right panel, which rescales the data as a proportion of all responses and averages across the four intervention weeks (weeks 2-5) for simplicity. In the manipulation group, parents used singing in response to fussiness more than half of the time. The points indicate mean scores across the given week(s) and error bars denote standard errors of the mean.

3.2 Music enrichment increases the use of singing specifically in the context of soothing infants

Given the well-known role of music in soothing or calming infants (e.g., Bainbridge, Bertolo, et al., 2021), we wondered whether the singing intervention had not only general effects on the use of infant-directed singing, but also specific effects, increasing its use in soothing contexts.

It did. In each EMA survey, we asked participants if their infant was fussy in the last 2-3 hours. If so, they indicated all soothing techniques they used in response, from a list of 12 different techniques (e.g., feeding, changing a diaper, shushing, playing recorded music, singing; the full list is in Supplementary Text 2).

While the use of non-musical soothing techniques remained more-or-less constant over the course of the study, in the manipulation group there was a large increase in the proportion of time caregivers used singing in response to fussy infants (Figure 3, left panel; pre-test: M = 0.44, SD = 0.31; average across intervention: M = 0.53, SD = 0.41; post-test: M = 0.51, SD = 0.35). While singing was the third most frequently used soothing technique among the 12 different techniques (both at pre-test and overall), following picking-up/bouncing/rocking/swinging and feeding, singing was the only technique with increased caregiver use as a result of the intervention, an increase of 18 percentage points from pre-test to post-test (t(98.72) = 2.71, $p = 0.008$).

No such increase was observed in the control group, however, where the singing response stayed comparably flat (t(96.97) = -0.70, $p = 0.49$; Figure 3, right panel). The cross-group difference at post-test was statistically significant (t(97.78) = 2.74, $p = 0.007$). Notably, we did not observe a group-level difference at post-test in the frequency of playing recorded music to infants, indicating that the effect wasn't a general increase in the use of music to soothe infants (t(88.07) = 0.94, $p = 0.35$).

Thus, the singing intervention not only increased the overall use of infant-directed singing in daily life, but specifically changed how caregivers responded to infant fussiness. We note here that no part of the intervention specifically instructed caregivers to use music in the context of soothing; the decision to use music in the context of soothing infants is apparently an intuitive one.

3.3 Infant-directed singing improves infant mood but not caregiver mood

As music has been shown to affect a variety of affect- and arousal-related variables in infants, in the short-term (e.g., Bainbridge, Bertolo, et al., 2021; Cirelli & Trehub, 2020; Cirelli et al., 2019; Corbeil et al., 2016), a key question for this randomized trial is whether such effects are cumulative. Does music enrichment produce lasting effects on infant affect?

To study this question, we focused primarily on caregiver evaluations of infant mood, reported using a sliding scale from Negative (0) to Positive (100). In each EMA survey, caregivers rated their infant's mood during the last 2-3 hours. Caregivers only responded if they had been with their infant during that time. Importantly, this item does *not* measure caregivers' perceptions of infants' mood in response to singing. Rather, the item measures perceptions of infant mood *in general*.

To account for participant variability in scale usage, we z-scored mood ratings within participants. We then computed a weekly average score for each infant. Consistent with prior results showing improvements in mood as infants grow older (Barr, 1990), all infants, on average, showed improvements in mood from pre- to post-test (mean difference = 0.25, $t(102.00) = 4.99$, $p < .0001$). These improvements were moderated by manipulation group, however (Figure 4, left panel).

At pre-test the two groups did not differ (manipulation group: M = -0.10, SD = 0.41; control group: M = -0.11, SD = 0.30, $t(95.76) = 0.18$, $p = 0.86$), but at post-test, the singing intervention had caused a significant difference in infant mood, with the manipulation group approximately 0.34 standard deviations higher (manipulation group: M = 0.24, SD = 0.32; control group: M = 0.06, SD = 0.32; $t(102.78) = 2.94$, $p = 0.002$, one-sided t-test).

A mixed-effects time-series model (using untransformed data) that accounted for autoregression showed a significant interaction term across group and time ($\beta = 0.18$, $SE = 0.05$, $< .001$). In the manipulation group, each week of intervention was associated with a 1.56 unit increase in the 100-point mood scale for infants in the manipulation group ($p < .001$), or roughly one tenth of a SD increase per week of intervention.

Last, given the exploratory nature of these analyses, we tested whether the main mood result repeated across both subsets of the main sample: a first cohort, recruited mainly in the United States from February to June 2023; and a second cohort, recruited mainly in New Zealand from June to December 2023. Mixed-effects time-series models revealed the same expected group-by-time interaction in both the first ($\beta = 0.12$, $SE = 0.06$, $= 0.04$) and second cohorts ($\beta = 0.32$, $SE = 0.10$, $= 0.001$), although not every subtest replicated (e.g., the difference in mood scores at post-test was statistically significant in the first cohort, $t(54.20) = 2.49$, $p = 0.008$, one-sided t-test; but did not reach significance in the second cohort, $t(15.05) = 1.31$, $p = 0.1$, one-sided t-test. The significant group-by-time interactions indicate a successful internal replication, but the smaller effect size in the second cohort suggests a need for replication.

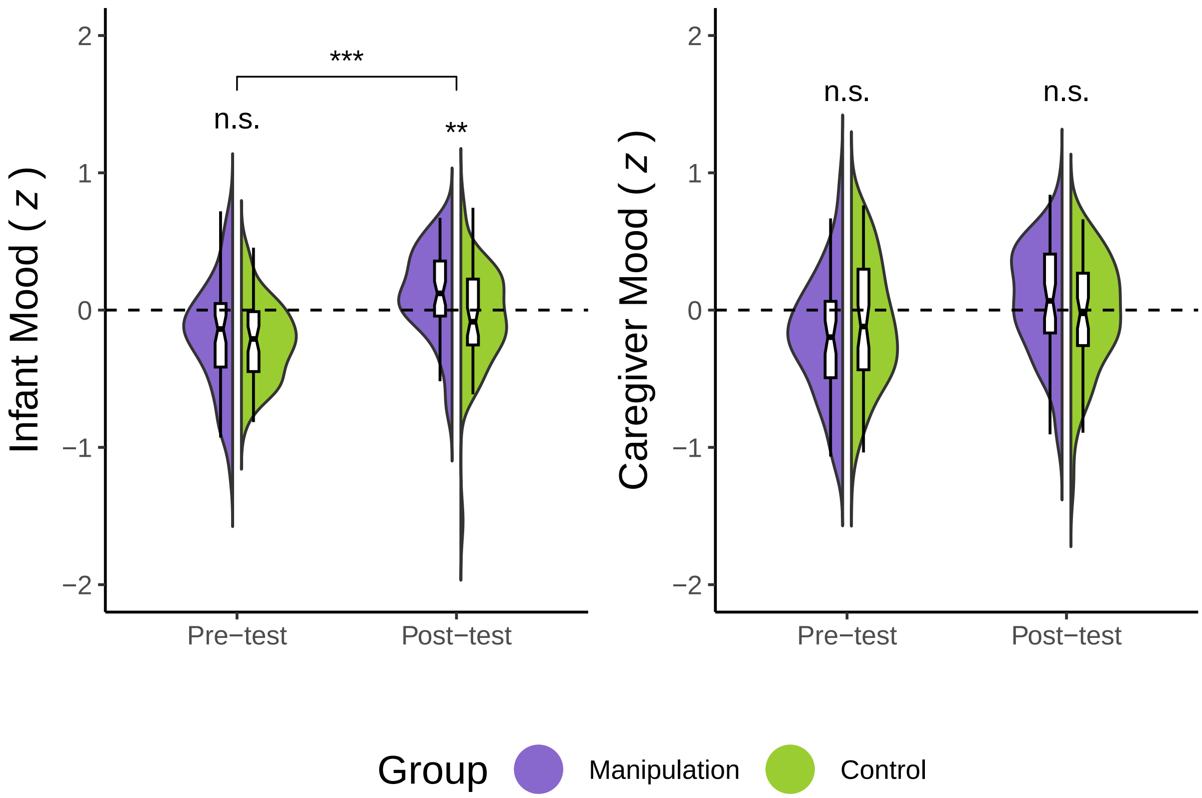

Figure 4 | Music enrichment improves infant mood but not caregiver mood. In each EMA ping, caregivers were asked to report their infant's mood and their own mood at the moment they received the ping, both on a 100-point slider (anchored at "Very negative" and "Very positive"). We normalized responses within participants to account for individual differences in scale use. While average mood of infants in the two groups did not differ at pre-test, it did at post-test, with significantly more positive mood reports in the manipulation group (left panel). We did not observe the same pattern for caregiver mood (right panel). The half-violins depict the distributions of weekly mean mood ratings from each of the two groups, weighted by participant. The shaded area in the half-violins represent kernel density estimates; the vertical boxplots denote the median (horizontal line), 95% confidence interval (notches), and interquartile range (edges of the boxes). The significance stars above the violins denote the between-groups comparison at a given time point. The horizontal bar denotes the significant group-by-time interaction in the time-series model. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Caregivers also rated how energetic their infants were in the previous 2-3 hours, using a comparable scale to the mood item; we found no comparable effects on this measure, suggesting the effects of the singing intervention are specific to infant mood and do not generalize to infant arousal.

We proceeded by analyzing data concerning caregiver mood, for two reasons. First, improvements to infant mood might well translate to improvements in caregiver mood, since happier infants are easier to look after than fussier ones. Second, a potential concern with the infant mood result is the potential for contamination in caregiver self-reports: they might erroneously report happier infants when they themselves felt happier; because this trial relies on caregiver EMA data, we are unable to directly assess infant mood in isolation from the caregiver.

We addressed these issues with several analyses of caregivers' responses to ratings of their own mood, completed in the same EMA surveys and using the same (z-transformed) scale as the infant mood item. In contrast to infant mood, we found no differences between groups at pre-test (manipulation group: M = -0.15, SD = 0.46; control group: M = -0.02, SD = 0.48, $t(104.90) = -1.42$, $p = 0.16$) or post-test (manipulation group: M = 0.14, SD = 0.43; control group: M = 0.03, SD = 0.48, $t(101.71) = 1.21$, $p = 0.12$). This absence of effect suggests that the effect of music enrichment on caregiver self-reports of infant mood does not erroneously represent an effect on caregiver mood.

Infant mood and caregiver mood were moderately and positively correlated, however (Spearman's rank correlation; $r = 0.39$, $p < .0001$); adding caregiver mood as a predictor to the mixed model regressing condition and day number on infant mood weakened the time-by-group interaction enough that it no longer reached statistical significance ($p = 0.09$). We found no evidence for a difference in correlation across the manipulation and control groups ($\beta = 0.01$, $p = 0.59$), indicating that any potential reporting biases were not due to the intervention.

To further assess the degree of potential confounding between infant and caregiver mood reports, we tested whether each of the infant and caregiver mood self-reports correlated with third measures that we expected to be more strongly linked to caregiver mood than infant mood. Two variables in the daily EMA surveys met this criterion: a measure of how socially connected caregivers felt (from "Very lonely" to "Very connected") and a measure of the perceived stress of caregiving ("How stressful have you found parenting in the last 2-3 hours?"). Both items should, in principle, be more strongly associated with caregiver mood than infant mood, assuming the two mood items are indeed measuring different real-world constructs.

They were. The association of social connection and caregiver mood ($\beta = 0.44$, $p < .0001$) was both stronger and in the opposite direction of the association between social connection and infant mood ($\beta =$ -0.08, $p =$ 0.02; interaction: $\beta = 0.002$, $p < .0001$, autoregressive time series model with untransformed mood data). Similarly, while both infant ($\beta =$ -0.02, $p < .0001$) and caregiver mood ($\beta =$ -0.02, $p < .0001$) predicted how stressful caregivers found parenting, the interaction between the two mood variables was statistically significant ($\beta = 0.0001$, $p < .0001$). These results suggest that our measures of infant mood and caregiver mood tapped into substantively different mood phenomena in the study population.

In sum, we found a causal effect of the singing intervention on infant mood, but not caregiver mood, despite the two mood measures being correlated with one another. It is possible that increasing the frequency of infant-directed singing may improve *both* infants' and caregivers' moods, whether directly (e.g., singing makes caregivers feel positive) or indirectly (e.g., having a happier infant makes caregivers feel positive). If so, putative effects on caregiver mood are small enough that they could not be reliably detected in this brief intervention study.

4 Discussion

We report evidence that a brief singing intervention increases the frequency of infant-directed singing, that caregivers intuitively extend this musical behavior specifically to the context of soothing their infants, and that these changes in the home musical environment cause improvements to infant mood in general. This suggests that the immediate effects of music on infants (e.g., Bainbridge, Bertolo, et al., 2021; Cirelli et al., 2019) may be cumulative, leading to longer-term effects on infants.

Importantly, the main effect of the singing intervention on infant mood was found in EMA pings that occurred *regardless of whether the caregiver had recently sung to the infant* (i.e., as opposed to items asking about infants' mood responses to singing in particular). This implies that infant-directed singing improved infant mood *in general*, in a one-week post-test period that followed the intervention (at which time caregivers were no longer explicitly instructed to sing to their infants). The present findings therefore substantiate a causal relationship between an enriched musical environment and general improvements in infant mood.

Moreover, while this result is supported only by caregiver-observational data, several considerations suggest that the findings reflect robust changes in infant affect. First, the data were collected with ecological momentary assessment, instead of retrospective surveys, and therefore are unlikely to be contaminated by recall bias (Stone & Shiffman, 2002; Reis, 2012). Second, the results largely replicated internally, in two separate samples recruited in two different countries, and therefore are unlikely to reflect the caregiving practices of only one community. Third, we found no corresponding effect of the intervention on caregiver mood, suggesting that caregivers' self-reports of infant mood did not simply reflect caregivers' own mood, as they might in the presence of a reporting bias (see Results). Fourth, the modest correlation between caregiver reports of infant mood and their own mood was of a comparable size in both the manipulation and control groups, suggesting that an expectancy effect (e.g., where only parents who had experienced the music intervention reported erroneously high infant or caregiver mood) did not account for the main effects. Future studies can further support the veracity of infant mood assessment via EMA by supplementing the method with direct lab-based or home-based observations of infant mood and behavior, psychophysiological measures of infant arousal, and so on.

Infant mood is an important issue for caregivers as it is closely linked to parenting stress (Oddi et al., 2013), caregiver-infant bonding and attachment (Nolvi et al., 2016; Takács et al., 2020), and subsequently the infants' social and emotional development (Steele et al., 2008; Shaw & Dallos, 2005). Such associations raise the possibility that general improvements in infant mood, caused by altering the home music environment in young families, could subsequently cause other positive health-related outcomes. While we did not observe any such effects here (such as an improvement in caregiver mood), we note that this study had only a brief (4-week), low-intensity, self-directed intervention. A longer-term, higher-intensity intervention, perhaps with direct music instruction from a qualified teacher, may well uncover more widespread effects. These could potentially generalize to other health domains that are tightly related to caregivers' well-being, such as the frequency of infant night waking, the duration of crying bouts, the ease with which caregivers can calm their infants when upset, or levels of caregiver stress.

Infant-directed singing is a multifaceted mode of communication and interaction, including a variety of distinct musical attributes, such as exaggerated melodic contours, high pitch variability, repetitive rhythmic patterns (e.g., Malloch & Trevarthen, 2009; Hilton, Moser, et al., 2022); in conjunction with other caregiving behaviors, such as increased physical proximity, infant-directed attention, touch, rocking, infant-directed speech (Mehr & Krasnow, 2017; Mehr et al., 2021; Fancourt & Perkins, 2018a; Trehub & Gudmundsdottir, 2019). We cannot yet know which of these specific characteristics or behaviors are the ones that caused improvements in infant mood, as the intervention likely altered all of them. Future randomized trials that include active control groups may determine the degree to which *singing* specifically alters infant temperament, over and above the many positive caregiving behaviors that are associated with singing (but not uniquely so).

On a methodological note, these findings demonstrate the feasibility of long-term EMA studies in young infants and their caregivers. We observed that consistent engagement with over a 10-week period, while learning from a singing intervention and integrating that learning into caregivers' daily routines with young infants, was manageable, given the low level of attrition and high level of adherence. EMA is commonly used in studies of adults but is relatively underused by developmentalists; when used, studies are typically short, spanning less than 2 weeks (e.g., Barbaro et al., 2023; Franchak, 2019; Wenze et al., 2023). While latency to ping response did vary in our data, including an increase in response time as infants grew older, very few families dropped out of the study (i.e., a retention rate of 92%), despite our asking caregivers to respond to nearly 100 surveys in 10 weeks. These findings suggest that EMA may be a promising method to adopt in studies of other naturalistic behaviors, especially those that are amenable to longitudinal study.

Last, we note that the primary caregivers of young infants studied here were quite happy to engage with a multi-week singing intervention, despite having relatively little music training, on average; and despite being presumably quite busy, stressed-out primary caregivers of young infants. At the end of the study, the vast majority of caregivers reported that they would continue singing to their infants after the study (90.3%), and self-reported their overall experience in the study as positive, particularly appreciating the opportunities to actively incorporate music in to their daily lives and experience the positive impacts singing had on their infants as well as themselves (see Supplementary Text 3 for further information and results from the exit survey). These findings, combined the ease of carrying out the intervention, its very low cost, and its other reported effects, suggest a strong potential for music interventions to improve infant and caregiver health.

End notes

Data, code, and materials availability

A fully reproducible manuscript; data; analysis and visualization code; and other materials are available at github.com/themusiclab/musical-babies. This repository will be permanently archived on Zenodo at the time of publication.

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Author contributions

- S.A.M. conceived of the research, provided funding, supervised students, and coordinated all project activities.
- D.I.T. provided funding for the Person Project data collection platform.
- E.C., L.Y., E.E., B.M., and S.A.M. contributed to study design, materials development, including the music enrichment intervention, and data collection.
- E.L., M.B., P.B., and B.M. provided research assistance.
- C.B.H. led implementation of the study on the Person Project data collection platform, with additional contributions from H.S., S.A.M., and D.I.T.
- E.L. and S.A.M. implemented the study on the Inclivio data collection platform.
- E.C., L.Y., E.E., and E.L. collected data and managed all communication with participants.
- L.Y. wrote analysis code, with additional contributions from E.C., C.B.H., and S.A.M.
- L.Y., E.C., and S.A.M. designed the figures.
- E.C., L.Y., and S.A.M. wrote the manuscript and all authors edited or approved it.

Online Supplementary Information

Supplementary Text 1: EMA distribution

We used two different methods for EMA distribution. The methods had minor differences in terms of user experience, in that one was a standalone smartphone app that participants installed on their phones while the other distributed EMA surveys by text message, but distributed the same survey content. The use of one method or the other should have little appreciable effect on scientific outcomes of this work, as comparable numbers of participants in the manipulation and control groups used each EMA method; the method was simply determined chronologically, in that the first cohort of participants (recruited mainly in the United States) used the Person Project, while the second cohort of participants (recruited mainly in New Zealand) used Inclivio.

During high intensity weeks, caregivers received three pings a day, spaced at least 2 hours apart, in the morning (9:00am-11:30am), afternoon (1:30pm-4:00pm) and evening (6:00pm-8:30pm). In low-intensity weeks, participants received one daily EMA survey ping between 8:30am-8:30pm on the Person Project, and between 9:00am-8:30pm on Inclivio. Each survey took approximately two minutes to complete. Participants were encouraged to complete the survey promptly upon the arrival of the ping.

Details of the two distribution methods follow.

The Person Project

In this EMA distribution method, participants completed surveys in a smartphone app built on the React programming library for iOS and Android. This app presented survey items in javascript; participants were prompted to complete them via push notifications; and securely stored their responses in a PostgreSQL database, implemented via Ruby on Rails on Amazon Web Services. Upon an arrival of a ping, participants accessed the surveys by tapping the notification. If participants could not complete the survey immediately, they could still access it through their notification history on the smartphone.

Inclivio

In this EMA distribution method, participants received text messages that each contained a URL leading to a Qualtrics survey. Inclivio facilitated participant enrollment, distributed the text messages, and transmitted participant identifiers and other relevant data (e.g., time indicators, custom values to pipe into our survey questions) to Qualtrics, as in previous EMA studies using the platform (Kuczynski, Piccirillo, et al., 2023; Dora, Kuczynski, et al., 2024). EMA pings expired after 4 hours.

Supplementary Text 2: EMA survey content

This section reproduces the text of all items in the EMA surveys; the same content was presented across the two EMA distribution methods, with minor differences in the appearance of each item. The text "BABY" was replaced with the infant's first name.

1. Please report how YOU have been feeling in the last 2-3 hours on the following scales.

a. How positive have you been feeling? [slider] Very negative — Very positive
b. How energetic have you been feeling? [slider] Very lethargic — Very energetic
c. How socially connected have you been feeling? [slider] Very lonely — Very connected
d. Have you been spending more time thinking or feeling? [slider] Thinking — Feeling

2. How stressful have you found parenting in the last 2-3 hours?

a. Not stressful at all
b. A bit stressful
c. Somewhat stressful
d. Very stressful

3. Last night, how many times did BABY wake up after s/he fell asleep? [*This item was only included in the first ping of the day.*]

a. Slept through the whole night
b. Woke up once
c. Woke up twice
d. Woke up three or more times

[*If baby woke up*] **3.1 When BABY woke up during the night, how long did it take for him/her to fall back asleep?**

a. Less than 2 minutes
b. 3-8 minutes
c. 9-15 minutes
d. More than 15 minutes

4. If you had to guess, how many times did you sing to BABY yesterday? [*This item was only included in the first ping of the day.*]

[slider] 1 — 8 or more times

5. Were you with BABY in the last 2-3 hours?

a. Yes
b. No

[***If parents answered "No" to this question, the survey ended***]

6. Do you think BABY is feeling sick today?

1. Yes
2. No

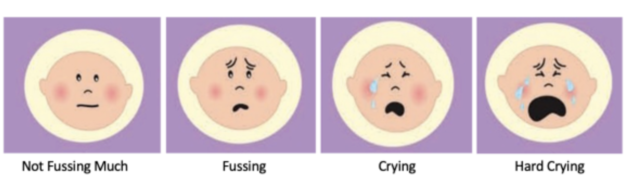
7. How would you describe BABY's mood in the last 2-3 hours?

a. Very negative — Very positive [continuous scale]
b. Very passive/calm — Very aroused/active [continuous scale]

8. In the last 2-3 hours, was BABY at all distressed or fussy?

a. Yes
b. No

9.1. [*If baby was fussy*] **How distressed or fussy was BABY?** (Scale adapted from Adams et al. (2019).)



9.2.[*If baby was fussy*] **What did you do to calm BABY down? [check all that apply]**

a. Feed
b. Rub or pat
c. Swaddle
d. Pick up/Bounce/rock/swing
e. Shush/white noise
f. Play TV/tablet/video/etc
g. Play recorded music
h. Sing
i. Give pacifier / teether
j. Put in bed
k. Change diaper
l. Waited for them to calm down
m. Other

9.3. [*If baby was fussy*] **How long did it take BABY to calm down?**

a. Less than 1 minute
b. 1-2 minutes
c. 3-5 minutes
d. 6-10 minutes
e. 11-20 minutes
f. 20+ minutes (or still fussing)

10. Did you sing to BABY in the last 2-3 hours?

a. Yes
b. No

11. Have you played recorded music for BABY in the last 2-3 hours?

a. Yes
b. No

12. Have you made or listened to music for your own enjoyment in the last 2-3 hours?

a. Yes
b. No

Supplementary Text 3: Results from caregiver exit survey

At the end of the study, caregivers were invited to complete an optional exit survey to share their overall experiences during the 10-week study period. Fifty-eight caregivers (52.7%) chose to do so. Summary information from the survey is presented here.

Positive experiences in the study

The majority of respondents (89.7%) described their experience positively, typically mentioning opportunities to actively integrate music into their daily lives, which they felt led to positive experiences:

We had a lot of fun singing songs... there was one particular road trip that was challenging [and] I was inspired by the study to sing a lot on to help get us through.

... She would smile when we sang if she would start to get fussy or be ready for bed. I think it cued her body that she was going to sleep or help soothe her. Really loved the experience! I also felt like the singing bonded us even more!

I could definitely see that singing to my baby helped soothe him. I really enjoyed the experiment and will keep singing to my baby everyday.

This study really brought more singing and song-play into my relationship with my son.

[Baby] responded so well to the signing and would get really excited especially when you're really animated and do actions. It was also helpful when she was unsettled and would calm her quickly.

[Baby] just loves songs and [it's] part of our daily routine – I'm not sure if we would have sung as much if we didn't do the study. She laughs and giggles and particularly loves songs with actions.

For my own mental health, singing calmed me down and refreshed me almost whilst with my baby it definitely put a smile on her face.

Views on the music enrichment intervention varied

Consistent with EMA results, most respondents (94.8%) reported that they were able to increase singing during the intervention period. However, while many found the singing intervention materials helpful for incorporating more singing into their daily routines, their reactions to the types of material varied.

For example, less than half of the respondents (43.1%) regularly used the original songs we produced to broaden caregivers' repertoire for singing to their infants. Some comments hinted at caregivers' preference for singing familiar songs rather than learning new songs (e.g., "I would have preferred more common children's songs... even if they were in other languages"; "I had plenty of my own songs"; "Just not my favorite, not very familiar").

On the other hand, a large number of respondents liked (77.6%) and actively used the infant-friendly board book that was sent to participants, which contained widely popular songs for infants (e.g., The Wheels on the Bus, Head Shoulders Knees & Toes, Twinkle Twinkle Little Star). The easy accessibility of this physical book (i.e., there was no need to open and navigate their phone to access songs) also seemed not only to add convenience for caregivers but also to attract older siblings of their infants:

My 2yo loved getting involved with singing the songs in the board book!

My older children enjoyed the board book and began to sing the songs to their sibling too.

My older child loves the book and frequently uses it to sing with the baby.

Caregivers' ability to complete EMA surveys varied

Some participants found it challenging to respond promptly upon receiving an EMA ping (34.5%). When asked to suggest the ideal time for EMA surveys, 19 respondents recommended when their infants are asleep (e.g., naptime, nighttime), although, of course, this would be scientifically counterproductive, in that responses would be retrospective.

Some parents also noted that due to the complexity of daily life with young infants, caregivers sometimes had to delay completing surveys until they had spare moments to complete, even if they noticed the EMA ping at the moment. There were also instances when caregivers found the EMA ping had expired at the time when they found a moment to fill out the survey:

Generally, I responded within 2-4 hrs, as I couldn't guarantee 2 minutes un-interrupted until then.

Unfortunately the time lapsed on some and was just too busy and would forget to go back to it.

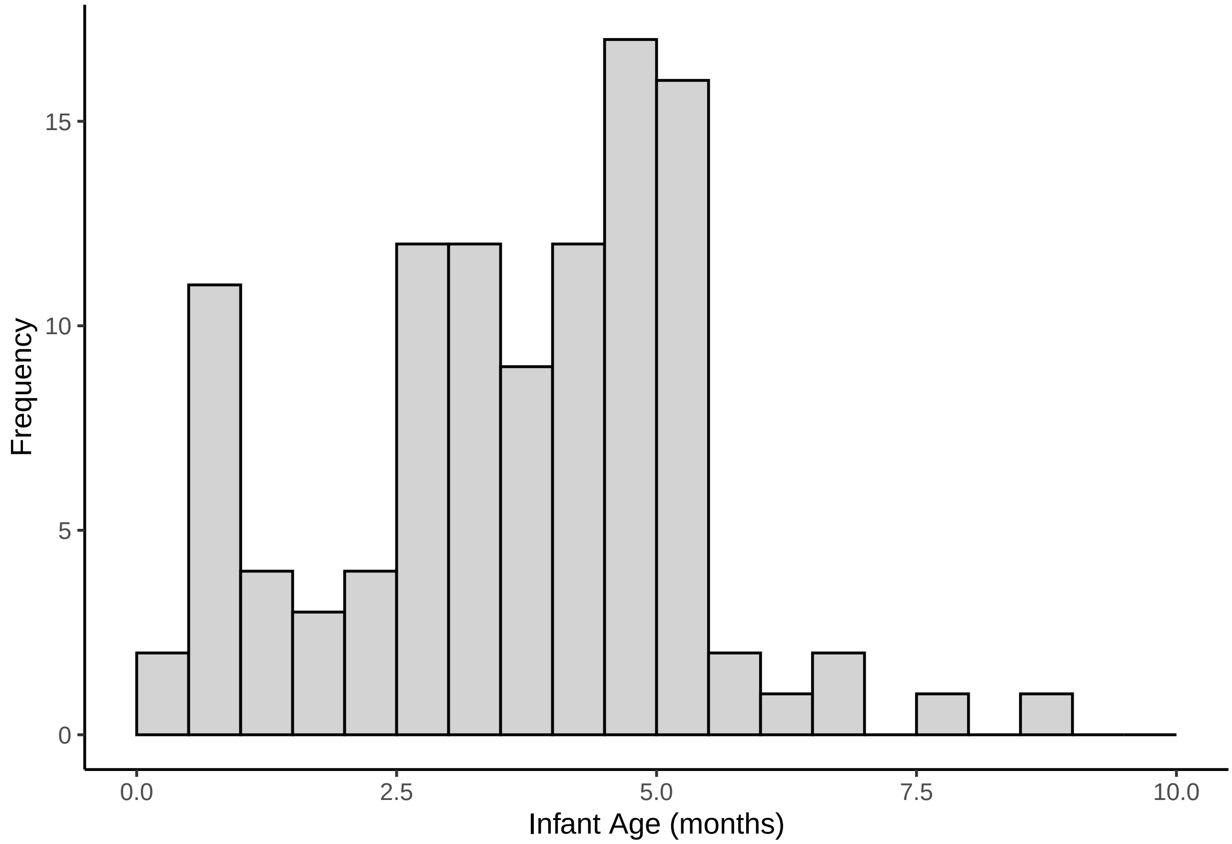
Difficult juggling baby so sometimes forgot to return once started.

I didn't notice the notifications until it was too late and the survey had expired. I wish there was a bigger time window or to notify more prominently.

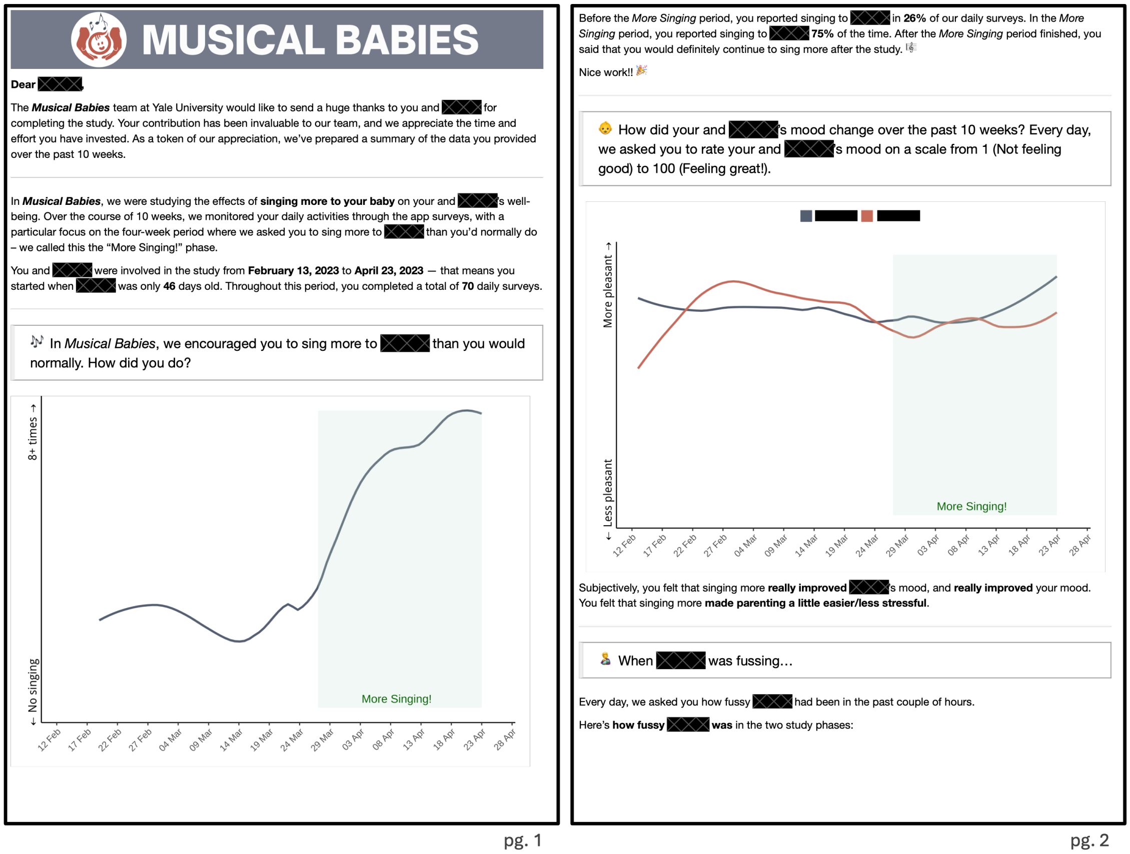
It would be good to have more than 4 hours before the survey expired as I wasn't always to complete the survey in that timeframe.

These responses highlight the challenges caregivers face in promptly responding to EMA pings while caring for their infants, suggesting the need for careful consideration in determining EMA schedules. Nonetheless, the high compliance rate found in the current study, despite the study asking caregivers to respond to nearly 100 surveys in 10 weeks, suggests that EMA may be a promising method to adopt in studies of other naturalistic behaviors, especially those amenable to longitudinal study.

Supplementary Figures



Supplementary Figure 1 | Histogram of infant ages at the start of the study.



MUSICAL BABIES

Dear [redacted],

The *Musical Babies* team at Yale University would like to send a huge thanks to you and [redacted] for completing the study. Your contribution has been invaluable to our team, and we appreciate the time and effort you have invested. As a token of our appreciation, we've prepared a summary of the data you provided over the past 10 weeks.

In *Musical Babies*, we were studying the effects of **singing more to your baby** on your and [redacted]'s well-being. Over the course of 10 weeks, we monitored your daily activities through the app surveys, with a particular focus on the four-week period where we asked you to sing more to [redacted] than you'd normally do – we called this the "More Singing!" phase.

You and [redacted] were involved in the study from **February 13, 2023** to **April 23, 2023** — that means you started when [redacted] was only **46** days old. Throughout this period, you completed a total of **70** daily surveys.

In *Musical Babies*, we encouraged you to sing more to [redacted] than you would normally. How did you do?

pg. 1

Before the *More Singing* period, you reported singing to [redacted] in **26%** of our daily surveys. In the *More Singing* period, you reported singing to [redacted] **75%** of the time. After the *More Singing* period finished, you said that you would definitely continue to sing more after the study.

Nice work!!

How did your and [redacted]'s mood change over the past 10 weeks? Every day, we asked you to rate your and [redacted]'s mood on a scale from 1 (Not feeling good) to 100 (Feeling great!).

Subjectively, you felt that singing more **really improved** [redacted]'s mood, and **really improved** your mood. You felt that singing more **made parenting a little easier/less stressful.**

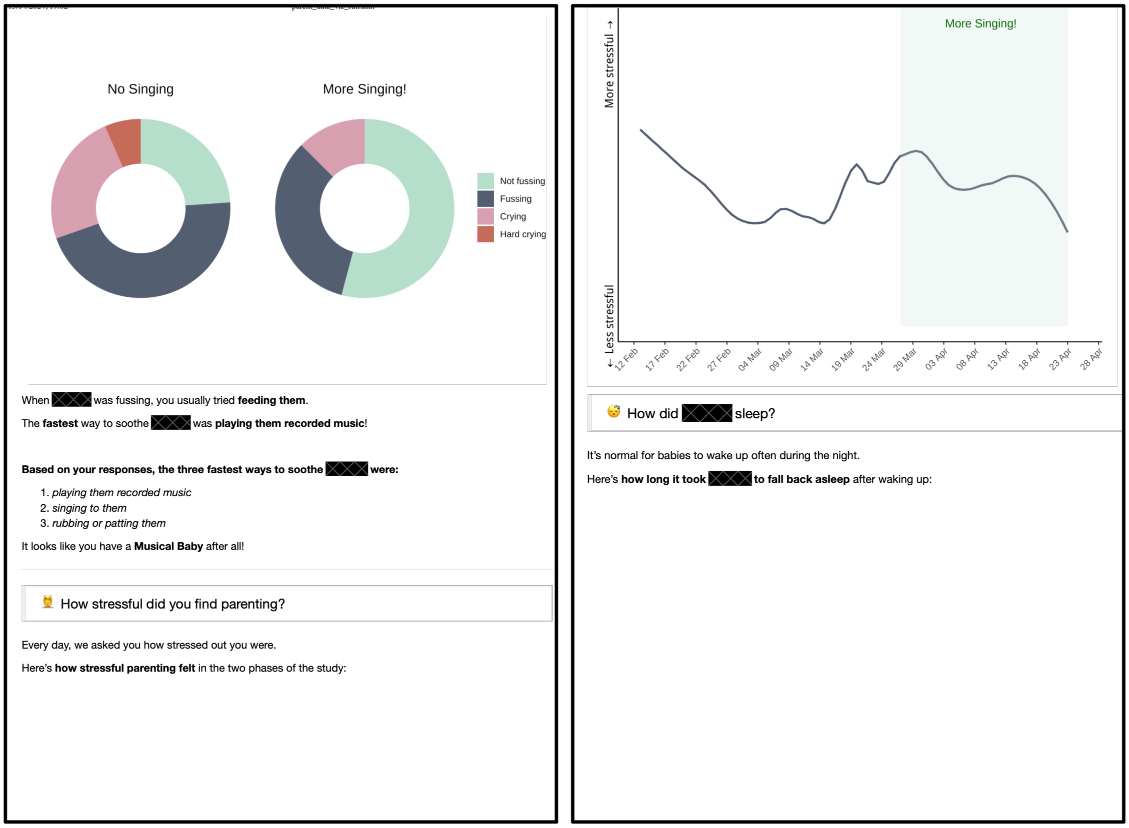
When [redacted] was fussing…

Every day, we asked you how fussy [redacted] had been in the past couple of hours.

Here's **how fussy [redacted] was** in the two study phases:

pg. 2

Supplementary Figure 2 | Example report for participants. At the end of the study, we sent participants a report summarizing data they provided over the course of the study, as an incentive.



When [redacted] was fussing, you usually tried **feeding them**.

The **fastest** way to soothe [redacted] was **playing them recorded music**!

Based on your responses, the three fastest ways to soothe [redacted] were:

1. *playing them recorded music*
2. *singing to them*
3. *rubbing or patting them*

It looks like you have a **Musical Baby** after all!

😫 How stressful did you find parenting?

Every day, we asked you how stressed out you were.

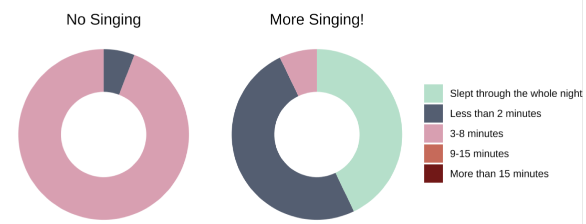
Here's **how stressful parenting felt** in the two phases of the study:

😴 How did [redacted] sleep?

It's normal for babies to wake up often during the night.

Here's **how long it took [redacted] to fall back asleep** after waking up:

Supplementary Figure 2 (cont.) | Example report for participants.



Once again, we'd like to say a huge thank you for your participation in the study. We hope you enjoyed your time with us and that the techniques and strategies learned during the study will continue to be a source of joy and well-being for both of you.

Best regards,

Ekanem, Eun, and Lidya

The Musical Babies Team

MUSICAL BABIES

Please note that the above information is not medical advice, and is simply a summary of the data you provided while participating in *Musical Babies*.

If you have any questions or concerns, feel free to contact us at musiclab@yale.edu (mailto:musiclab@yale.edu).

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Supplementary Figure 2 (cont.) | Example report for participants.

Supplementary Tables

Level of music training	n	% of sample
Advanced	14	13.00
Intermediate	15	14.00
Some	62	56.00
None	18	16.00

Supplementary Table 1 | Participants' musical backgrounds.
We measured participants' level of musical training with the question "How would you describe your music training experience?". Participants could select any of the following types of musical training: no formal musical training, lessons or classes (either before or during elementary school years, during middle and high school years, or in adulthood), participation in community-based music groups (e.g., church choir, community ensembles), majoring in music, and a free-text option. Partipants who reported either majoring or minoring in music, or working in music professionally were coded as having an "advanced" background in music. We then counted the number of other responses (excluding "no formal musical training") selected by each participant, and coded participants as having either "some" ($<$ 2 categories selected) or "intermediate" ($<$ 4 categories selected) training in music.

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