

Infants' overlapping vocalizations during maternal humming: Contributions to the synchronization of preterm dyads

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Abstract

Despite the neurological vulnerability of premature newborns, there is evidence that they are able to process temporal aspects of the maternal voice, as a previous study observed more overlapping vocalizations during maternal humming versus speech. However, there is a lack of knowledge about the markers of the infants' overlapping vocalizations. Our aim was to identify the location of overlapping vocalizations during the humming and the impacts of maternal antenatal and postnatal engagement of infant-directed singing on: (1) the features of humming and (2) the infants' overlapping vocalizations during humming. Preterm dyads ($N = 36$) were observed in silent, speech, and humming conditions. Microanalysis was performed using the Elan Program to identify the location of the overlapping vocalizations during the humming phrase. Infants' overlapping vocalizations were found predominantly at the ends of each humming phrase; almost half of the overlaps occurred on the final note. More overlapping vocalizations in the final notes were observed in female infants. Antenatal and postnatal experiences of ID singing are influenced by the mothers' nationality and contribute to maternal humming style. Preterm newborns synchronize with maternal humming, anticipating the end of musical phrases. The ability to synchronize seems to be phylogenetically associated with gender differences.

Keywords

preterm dyads, prenatal singing, maternal humming, infants' overlapping vocalizations, synchronization, gender differences

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Human newborns are attracted to human stimuli like faces, voices, and other non-verbal messages (Brazelton, 1973). Vocal interaction between mothers and newborns enables social contingency coordination and anticipation between partners (Dominguez, Devouche, Apter, & Gratier, 2016). Infants are responsive to the human voice, specifically to the maternal voice (DeCasper & Fifer, 1980; DeCasper & Spence, 1986). Newborns are ready for contingent vocal interaction (Pelaez, Ortega, & Gewirtz, 2011), synchronizing their overlapping vocalizations with their mothers' vocalizations (Rosenthal, 1982). Vocal turn-taking abilities seem to be the basis for establishing temporal reciprocity in early social interactions (Schaffer, 1999; Stern, Beebe, Jaffe, & Bennett, 1977). Maternal infant directed speech (ID speech) is modulated by infants' responsiveness (Smith & Trainor, 2008). In the neonatal period, during turn-taking mothers are prone to respond to infants' vocalizations within a temporal window of 1000 ms, and neonatal infants respond to their mothers at the same rate (Dominguez et al., 2016).

The learning of social contingency patterns involves the ability to predict events, which in turn induces pleasure and fun (Gergely & Watson, 1999). Newborns respond to interruptions and tempo changes (Clifton, 1974; Donohue & Berg, 1991; Stamps, 1977). In the first months of life, mothers' speech is predictable for infants and infants respond to mothers in a timely manner (Gratier, 2003; Gratier et al., 2015). Patterns of rhythmicity and maternal vocal repetitions help babies to anticipate the partners' forthcoming behavior (Brazelton, Koslowski, & Main, 1974; Bullowa, 1979).

Mother–infant vocal exchange is built around narratives that create a communicative musicality based on musical parameters such as pulse, pitch, timbre, intensity, and gesture (Malloch & Trevarthen, 2009). From birth, both modalities of ID speech and ID singing are always present. Music and language are considered to have common roots at the phylogenetic development of the human species (Arbib, 2005; Wray, 2002).

Longhi (2009) described “songese” as multimodal sensory information provided by maternal ID singing akin to the “motherese” that is used for speech. Infant-directed singing is an intuitive parental behavior with a particular rhythmic and temporal organization that affords a high degree of predictability for infants.

Mothers' ID singing may contribute to early forms of attunement. According to dynamic attending theory (Jones, 1976; Jones & Boltz, 1989), the listener's attention is driven by the metrical structure of a musical piece via a hierarchical procedure of rhythmic attunement (Drake, Jones, & Baruch, 2000). At the lowest structural levels, attunement supports analytical musical listening, providing cues to specific events in the musical piece. Based on the metrical structure of the listener's anticipation, Drake et al. (2000) stated that ID speech guides the infant through inter-onset intervals of approximately 600 ms. It is noteworthy that the beat in ID singing lasts between 300 and 700 ms (Trevarthen, 1999). Infant-directed singing probably plays a crucial role in the development of attention from birth as it stimulates the processing of sound at several levels of temporal hierarchy.

When compared to ID speech, the repetition of mothers' ID singing may ensure moderate arousal levels (Shenfield, Trehub, & Nakata, 2003) maintaining positive affect (Stern, 1974; Stern et al., 1977). We still know very little about the musical and behavioral parameters of vocal contingency in ID singing. Studies that investigated how infants pay attention during ID singing compared to ID speech are not consistent. Costa-Giomi and Ilari (2014) found no significant differences between the two conditions in 11-month-old infants, whereas Nakata and Trehub (2004) observed in 6-month-old infants a greater reduction of movements and a longer cumulative visual fixation on the maternal face during singing. This suggests a higher level of attention to singing than to speech. These differences are probably due to the age difference between infants in the two samples, as we know that ID singing changes according to the age

of the infant. Methodological issues like which sung/spoken renditions were used and the habituation paradigm may also be responsible for different results.

Emotional coordination in mother–infant interactions may be facilitated by the pulse regularity of singing. Nakata and Trehub (2011) studied variations of the beat and of lengthening the final notes of a phrase and concluded that expressive time cues are enhanced in ID singing compared to adult-directed singing. This suggests that the temporal structure (meter and rhythm) of maternal singing may be underscored by its temporal regularity. Maternal ID speech and maternal ID singing are expressed through hierarchical temporal organization at multiple timescales from hundreds of milliseconds to tens of seconds (S. Falk & Kello, 2017). For these authors, the hierarchical temporal structure is related to the temporal perception of sound clusters with multiple timescales. The pulse is the primary ingredient of the rhythm and, in music, constitutes a fundamental unit of duration (Iyer, 2002). Also it is the beat of the mother's song that ensures the hierarchical structure of the song (Longhi, 2009). This is important for the way newborns develop expectations relative to the rhythmic cycles within mother–infant communication (Winkler, Gábor, Hádena, István, & Henkjan, 2009).

The final lengthening of the ends of musical phrases is a key feature of the hierarchical structure (Repp, 1998) as it helps infants to perceive units such as vocal phrases and phrase groupings (S. Falk & Kello, 2017; Gratier, 2003; Trainor & Adams, 2000). The lengthening of the end of a musical phrase is a subtle feature of expressive timing in musical performance and if it is curtailed, listeners will experience the last notes as shorter than the preceding ones (Iyer, 2002).

Several temporal expressive features of parental singing have been identified: (1) the slowing of tempo at structural endings (*ritardando*) and a variable tempo (*rubato*; Trehub, Hill, & Kamenetsky, 1997; Trehub, Unyk, et al., 1997) and (2) a greater emphasis on the phrasing structure of songs (Trainor, Clark, Huntley, & Adams, 1997). When singing a playful song, mothers tend to lengthen the last syllables of the musical phrase as well as the inter-phrase pauses, whereas when singing a lullaby, they only lengthen the pauses (Trainor et al., 1997). In a longitudinal study, final-note lengthening was present and tempo slowed for infants aged 3 and 6 months, but the lengthening in ID singing was more salient for older infants (Delavenne, Gratier, & Devouche, 2013). The lengthening of the final phrase was more pronounced in mothers' singing to female infants.

Despite the fetus and the newborn being acquainted with the maternal voice (Carvalho, Justo, Gratier, & Rodrigues, 2019), we still know little about the impact of the maternal antenatal and neonatal engagement of ID singing upon the development of preterm dyads' vocal interactions.

In a previous study, we focused on the temporal structure of maternal speech and humming during Kangaroo mother care in a neonatal intensive care unit (NICU). Kangaroo care consists of having the preterm newborn in skin-to-skin contact with his or her mother to stabilize the infant's physiological parameters and behavior; using temporal microanalysis of maternal and infant vocalizations, we showed an increase in the frequency of infants' overlapping vocalizations during maternal humming when compared with speech (Carvalho, Justo, Gratier, Tomé, Pereira & Rodrigues, 2019). Furthermore, overlapping vocalizations were more frequently observed for mother–female infant dyads than for mother–male infant dyads in the context of ID humming. However, the temporal and acoustic characteristics of maternal humming that encourage an increase in the infant's overlapping vocalizations are still unknown. It is also important to clarify the role of the infants' overlapping vocalizations for the synchrony and attunement of dyads.

The aim of this study is to identify the location of the infants' overlapping vocalizations during the humming phrases hoping to determine the temporal markers of these overlapping

vocalizations. We also intend to analyze the influence of maternal prenatal and postnatal experiences of ID singing upon the development of maternal humming and also on the infants' overlapping vocalizations during humming.

Method

Design

Following the approval of the Ethical Committee of the Central Lisbon Hospital Center (267/2015), mothers of preterm infants being cared in the NICU of Maternidade Dr. Alfredo da Costa hospital were invited to participate in a study dedicated to the observation of vocal interaction during skin-to-skin care (Kangaroo method). All participants signed informed consent and agreed to be videotaped.

During the observation of vocal interaction, mothers and infants were in skin-to-skin contact, using the method of Kangaroo supported diagonal flexion positioning (Buil et al., 2016). Preterm infants were in a state of quiet alertness or drowsiness (Brazelton & Nugent, 2011, pp. 49–51) at the beginning of the observation. Mothers were asked to hum or to speak to their infants according to a 15-min protocol. The protocol was comprised of 5 consecutive periods, each lasting for 3 min: baseline—speech or humming—silence—humming or speech—silence. In the humming condition, mothers were asked to hum for their infants by improvising a melody without words (for details, see Carvalho, Justo, Gratier, Tomé, Pereira & Rodrigues, 2019).

After the observation of the dyads' vocal interactions, mothers were interviewed using a Sociodemographic and Clinical Questionnaire. To enquire about maternal antenatal and postnatal sound experiences a questionnaire titled Questionnaire about Sound-Music Experiences Before and After Birth (QSMEBAB) was also used. This questionnaire was specifically created for this study (Carvalho, Justo, & Rodrigues, 2018). Among its 41 items, 20 were about pregnancy (e.g.: "*... I sang frequently to my baby before birth*") and 21 were about after the birth (e.g.: "*... I sing to my baby in Kangaroo care*"). Answers were recorded in Likert-type scales varying from 0 (*I completely disagree*) to 5 (*I completely agree*).

Participants were excluded from the study based on the following criteria: (1) mother being younger than 19 years old, (2) difficulties understanding and speaking the Portuguese language, (3) auditory deficit in infant or mother, (4) gestation without medical supervision, (5) previous psychiatric pathology or current diagnosis of depressive pathology, and (6) addictive behaviors. Dyads were also excluded if, during observation, babies had any of the following conditions: (1) a post-menstrual age lower than 32 weeks or higher than 37 weeks, (2) unstable vital parameters, (3) Continuous Positive Airway Pressure support, (4) intraventricular hemorrhages, (5) congenital neurological anomalies of the auditory cortex, (6) a nasogastric tube, and (7) breathing supports. Dyads were also excluded if skin-to-skin Kangaroo care had not been practiced at least once.

Sample

Fifty dyads were initially recruited. Due to hospital routines and personal issues, 10 dyads were not able to participate in the study. Due to sound interference during the recording process, four dyads were excluded. The final sample included 36 dyads. Mothers ($N = 36$) were mostly of Portuguese nationality ($n = 26$) and the remaining participants ($n = 10$) were African or Brazilian nationals living in Portugal for more than 7 years. Ages ranged from 21 to 48 years ($M = 34$, $SD = 5.63$), education was of University level (number of years of education:

$M = 15.33$, $SD = 3.69$), socioeconomic status was of medium-high level, most of the mothers were married ($n = 23$), and most of them had previous children ($n = 22$). No mother reported having musical training or being a professional musician. The infants' gender ratio (20 males vs. 16 females) reflected the vulnerability of male infants regarding prematurity. Gestational age at birth was around 30 weeks ($M = 212.78$ days, $SD = 17.11$, $min. = 178$, $max. = 241$) and birth weight was 1,265.47 g on average ($SD = 308.20$, $min. = 590$ g and $max. = 2,017$ g). At observation infants' chronological age was 26.5 days on average ($SD = 19.99$, $min. = 4$, $max. = 81$) and weight was 1,538.05 g ($SD = 237.72$, $min. = 1,060$ g, $max. = 2,185$ g). Pregnancies were mostly of the single kind ($n = 26$) while 7 cases were pregnancies with 2 fetuses and 3 cases were pregnancies with 3 fetuses.

Coding of vocal behavior

A video recording (MP4) and an audio recording (WAV) were obtained for each dyad. Recordings were coded with *ELAN software (EUDICO Linguistic Annotator, version 4.9.4)*. The codification of maternal humming was based solely on temporal segmentation criteria, without taking into account other parameters of musical and acoustic analysis, each humming time unit (milliseconds) was identified from the beginning to the end of the vocal emission before a breathing break or an intentional break, and these intentional breaks were codified when the humming time unit was interrupted for more than 300 ms, according to the temporal criteria established by Gratier et al. (2015).

Each time an infant's vocalization was detected simultaneously with maternal humming it was coded as an overlapping vocalization. For this study infants' overlapping vocalizations were counted and their location in relation to the humming temporal units was coded according to the following criteria: (1) overlapping vocalizations at the beginning of the humming phrase (overlapping or succeeding the initial note of the humming phrase), (2) overlapping vocalizations at the end of the humming phrase (overlapping or anticipating the final note of the humming phrase), (3) intermediate overlapping vocalizations (those that occurred between the beginning and the end of the humming phrase), and (4) overlapping vocalizations in the boundaries of the humming phrase (associating overlapping vocalizations 1 and 2).

Reliability

Two researchers performed independent coding of the data for 30% of the maternal and infant vocalizations. Inter-rater reliability was calculated through intra-class correlation coefficients (ICC). Regarding maternal humming variables, there was a high rate of agreement for the segmentation of phrases ($ICC = .999$, $p < .001$) as well as for pauses between phrases ($ICC = .999$, $p < .001$). There was also a high rate of agreement for infants' overlapping vocalizations ($ICC = .996$, $p < .001$).

Results

Maternal humming

Although invited to hum for their infants (improvising a melody without words), most of the mothers ($n = 26$, Group A) based their humming on known melodies, while the remaining mothers ($n = 10$, Group B) improvised their humming. Group A repertoire was made up of children's songs (78.3%), specifically, play songs (38.9%), and lullabies (61.1%). Play songs were

Table 1. Maternal humming phrases based on known melodies (Group A) and based on improvised melodies (Group B): frequency (Freq.), duration (Dur.) and variation coefficient (Var. Coef.).

Humming phrases		<i>M</i>	<i>SD</i>	<i>Min.</i>	<i>Max.</i>
Total sample (<i>N</i> = 36)	Freq.	49.08	11.33	29	72
	Dur. (ms)	2.84	0.7741	1.77	4.84
	Var. Coef.	34.46	14.96	7.64	74.18
Group A (<i>n</i> = 26)	Freq.	49.42	11.96	29	72
	Dur. (ms)	2.85	0.8249	1.77	4.84
	Var. Coef.	33.86	13.96	7.64	61.38
Group B (<i>n</i> = 10)	Freq.	48.20	10.02	32	64
	Dur. (ms)	2.81	0.6626	1.80	3.93
	Var. Coef.	36.03	18.03	17.10	74.18

mainly from an international repertoire (“Frère-Jacques,” “Twinkle, twinkle little star,” “Happy Birthday” or “The wheels on the bus”). The most frequent lullabies were “Rock-a-bye Baby” and Brahms’ “Wiegenlied.” Only two mothers sang Portuguese lullabies and two mothers sang the melodies of religious songs. In Group B, participants performed a melodic and cantabile humming, mostly characterized by conjunct motion, extreme repetition and a short range.

Mothers in Group A were between 24 and 48 years old ($M = 34.85$, $SD = 5.683$) and had a high level of education ($M = 15.77$, $SD = 3.724$, 6–24 years), while mothers in Group B were between 21 and 39 years old ($M = 32.50$, $SD = 5.401$) and had a lower level of education ($M = 14.20$, $SD = 3.553$, 9–20 years).

A comparative analysis was performed between Group A and Group B considering frequency, duration (ms) and the variation coefficient of the duration of the humming phrases. No statistically significant differences were found. Table 1 shows the results.

Maternal antenatal and postnatal experiences of ID singing

Hypothesizing that maternal antenatal and postnatal experiences of ID singing may be related to the characteristics of humming, a comparative analysis was performed. Using the QSMEBAB questionnaire we estimated the average score for certain items related with ID singing before and after birth. Table 2 shows the results for the total sample ($N = 36$) and for each subgroup of humming style. For the total sample, items with highest scores were as follows: “After birth, I feel that my baby recognizes my voice” and “During Kangaroo care, I usually sing for my baby.” Concerning the humming styles, the highest scores for the selected items were found in Group A. Table 2 shows descriptive and comparative statistics.

Portuguese mothers were compared with African or Brazilian mothers according to maternal antenatal and postnatal experiences of ID singing. Significant differences are displayed in Table 3 suggesting that African or Brazilian mothers were more engaged with ID singing before and after birth than Portuguese Mothers. Table 3 also shows the comparison of these experiences according to the infants’ gender. Although the differences are not statistically significant, we found an interesting result. Mothers of female infants seemed more experienced engaged with ID singing than mothers of male infants as higher scores for the mothers of female infants were observed in items: “Before birth, I sang to my baby” and “After birth, I usually sing songs with words to my baby.”

Table 2. Comparative analysis of maternal antenatal and postnatal experiences of ID singing according to humming style.

Maternal antenatal and postnatal experiences of ID singing Likert Scale (0–5)	Humming style						Sig. (2-tailed) Group A vs. Group B
	Total sample (N= 36)		Group A (n= 26)		Group B (n= 10)		
	M	SD	M	SD	M	SD	p
“I sang to my baby before birth”	2.853	1.396	3.2	1.354	1.889	1.054	.013
“During my pregnancy, I had a special song that I used to sang for my baby”	2.059	1.89	2.4	1.958	1.111	1.364	.044
“After birth, I feel that my baby recognizes my voice”	4.235	0.855	4.440	.651	3.667	1.118	.017
“During Kangaroo care, usually I sing for my baby”	3.088	1.96	3.72	1.696	1.333	1.581	.001
“Usually I sing for my baby when he(she) is in the incubator”	2.794	1.981	3.28	1.860	1.444	1.740	.015
“After birth, I usually sing songs with words for my baby”	2.471	1.796	2.6	1.915	2.111	1.453	.058
“I always sing the same song for my baby”	2.412	1.811	2.8	1.780	1.333	1.500	.035
“After birth, usually, I hum to my baby improvised melodies without words”	2.853	1.579	2.88	1.590	2.778	1.641	.871

Infants' vocalizations in maternal humming

From a total of 1,767 humming phrases, we found 189 infants' vocalizations during humming of which 142 were overlapping vocalizations and 47 took place during the breathing breaks. Among overlapping vocalizations, 121 (85%) took place at the boundaries of the humming phrases of which 44 (30.98%) occurred at the beginning and 77 (54.22%) at the end of the musical phrase; of these, 74 (52%) occurred precisely on the final note. The average duration of the final note was 702.67 ms ($SD = 234.34$). In Figure 1, transcripts of three excerpts from audio recordings of maternal ID humming are displayed. These show the occurrence of infants' overlapping vocalizations (IOVs, in Figure 1, are marked with an *) at the end of maternal musical phrases; these vocalizations occurred overlapping the final note or immediately before the final note or even immediately after the final note. In this figure, each line corresponds to a specific dyad.

Table 3. Descriptive analysis and significant differences in antenatal and postnatal experiences of maternal singing according to mothers' nationality and infants' gender.^a

Maternal antenatal and postnatal experiences of ID singing Likert scale (0–5)	Portuguese nationality (PN) (n = 26)		African or Brazilian nationality (ABN) (n = 10)		Sig. (2-tailed) PN vs. ABN <i>p</i>	Female infants' mothers (n = 16)		Male infants' mothers (n = 20)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
"I sang to my baby before birth"	2.541	1.382	3.6	1.174	.042	3	1.309	2.736	1.484
"During my pregnancy, I had a special song that I used to sing for my baby"	1.875	1.727	2.5	2.273	.388	2	1.964	2.105	1.882
"After birth, I feel that my baby recognizes my voice"	4.291	.908	4.1	.738	.559	4.266	.799	4.210	.9176
"During Kangaroo care, usually I sing for my baby"	2.875	2.028	3.6	1.776	.333	3	1.89	3.157	2.061
"Usually I sing for my baby when he/she's in the incubator"	2.333	1.88	3.9	1.853	.033	2.666	1.952	2.894	2.051
"After birth, I usually sing songs with words for my baby"	2.125	1.727	3.3	1.767	.082	2.866	1.642	2.157	1.893
"I always sing the same song for my baby"	2.666	1.761	1.8	1.874	.208	2.266	1.668	2.526	1.954
"After birth, usually, I hum to my baby improvised melodies without words"	2.416	1.53	3.9	1.197	.010	2.866	1.356	2.842	1.772

^aComparing female infants' mothers vs. male infants' mothers, there were no significant differences.

Table 4 displays the descriptive statistics of the infants' overlapping vocalizations relative to their location in the humming phrase (beginning, middle, end, boundaries, and final note).

A statistical analysis for paired samples (Wilcoxon) revealed significant differences between the frequencies of different types of infants' overlapping vocalizations in the musical phrase ($N = 142$): (1) at the beginning vs. at the end, $Z = -2.697$, $p = .007$; (2) in the middle vs. at the end, $Z = -2.716$, $p = .007$; (3) in the middle vs. at the boundaries, $Z = -3.976$, $p < .001$; and (4) in the middle vs. in the final note, $Z = -2.241$, $p = .025$. According to these results, the infants' overlapping vocalizations are more frequent at the end than at the beginning or in the middle. Also, overlapping vocalizations are more frequent at the boundaries and in the



Figure 1. Infants' overlapping vocalizations (IOVs) during maternal humming phrases.
* IOVs; pauses between phrases (≥ 300 ms).

Table 4. Descriptive analysis of the locations of the infants' overlapping vocalizations in humming phrases ($N=36$).

Localization	<i>M</i>	<i>SD</i>	<i>Min.</i>	<i>Max.</i>
Beginning	1.22	2.071	0	8
Middle	1.139	2.16	0	10
End	2.139	2.50	0	12
Boundaries	3.36	4.257	0	19
Final note	2.055	2.725	0	13

final note than in the middle. Infants' overlapping vocalizations during the final note are more frequent when maternal humming is based on known melodies ($M = 2.50$, $SD = 3.05$) than if maternal humming is based on improvised melodies ($M = .90$, $SD = .99$) and this difference is significant ($p = .028$).

Table 5 shows the descriptive statistics about the frequency of the infants' vocalizations (total vocalizations, overlapping vocalizations, and vocalizations during breathing breaks) according to the humming style (Group A vs. Group B). Following these results, a higher frequency of infants' vocalizations of Group A was found but only one significant difference was identified for the infants' vocalizations during breathing breaks, $t = -1.605$, $p = .029$.

Table 5. Descriptive analysis of frequency of the infants' vocalizations (TVH, OVH, VBB) during maternal humming in total sample, in Group A and in Group B.

Maternal humming	Frequencies of infants' vocalizations	<i>M</i>	<i>SD</i>
Total sample (<i>N</i> = 36)	TVH	5.61	6.64
	OVH	4.30	5.33
	VBB	1.30	1.90
Group A (<i>n</i> = 26)	TVH	6.35	7.21
	OVH	5.00	6.26
	VBB	1.62	2.09
Group B (<i>n</i> = 10)	TVH	3.70	4.64
	OVH	3.20	3.82
	VBB	0.50	0.97

TVH: Total of Vocalizations during Humming; OVH: Overlapping Vocalizations during Humming; VBB: Vocalizations during Breathing Breaks.

Infants' vocalizations during maternal humming were compared according to the mothers' nationality; more infants' vocalizations during the humming of African and Brazilian mothers were found but the differences are not statistically significant.

Assuming that the maternal antenatal and postnatal engagement in ID singing may be a predictive factor of the frequency of infants' overlapping vocalizations, dyads whose infants had none or just one overlapping vocalization were compared with dyads whose infants produced two or more overlapping vocalizations. More maternal engagement with ID singing before and after birth was found for the mothers of the infants that produced more overlapping vocalizations. However, no statistically significant differences were observed.

To understand if the infants' gender had an influence on the infants' vocalizations during humming, a linear regression analysis was performed for the locations of overlapping vocalizations in the musical phrase (beginning, middle, end, final note and boundaries) and also for the total of infants' overlapping vocalizations.

To control for the impacts of sociodemographic and clinical variables, several models were used to introduce predictor variables—Model 1: mothers' age, education and nationality; Model 2: infants' corrected age and birth weight; Model 3: infants' gender. The analysis showed that the infants' gender played a significant role in infants' vocalizations. Model 3 offers significant contributions to the explanation of total overlapping vocalizations ($p = .032$) and also for overlapping vocalizations during the final note ($p = .049$). These results are displayed in Table 6.

To verify the significance of the differences between male and female infants' overlapping vocalizations, nonparametric analyses of independent samples were performed. For the female sample ($n = 16$), the results of the Wilcoxon test revealed that the mean value of overlapping vocalizations at the end of the musical phrase ($M = 5.00$, $SD = 5.64$, $min. = 0$, $max. = 19$) is significantly higher ($p = .005$) than the mean value of overlapping vocalizations in the middle of the musical phrase ($M = 1.75$, $SD = 3.02$, $min. = 0$, $max. = 10$). In the male sample ($n = 20$), the results of the Wilcoxon test showed that the mean value of overlapping vocalizations at the end of the musical phrase ($M = 2.05$, $SD = 2.03$, $min. = 0$, $max. = 7$) is significantly higher ($p = .006$) than the mean value of overlapping vocalizations in the middle of the musical phrase ($M = .65$, $SD = .93$, $min. = 0$, $max. = 3$).

Table 6. Linear regression analysis: PV, infants' gender; CV1, total infants' overlapping vocalizations; CV2, infants' overlapping vocalizations during the final note.

Model	R	R ²	Adjusted R ²	SE of the estimate	R ² change	F change	df1	df2	p
CV1—total infants' overlapping vocalizations									
1	.207	.043	-.047	5.448	.043	0.475	3	32	.702
2	.281	.079	-.074	5.518	.036	0.594	2	30	.558
3	.465	.216	.054	5.178	.137	5.069	1	29	.032*
CV2—infants' overlapping vocalizations during the final note									
1	.316	.100	.015	2.704	.100	1.179	3	32	.333
2	.358	.128	-.017	2.748	.029	0.496	2	30	.614
3	.489	.239	.082	2.611	.111	4.219	1	29	.049*

Model 1, PVs: mothers' age, education and nationality.

Model 2, PVs: infants' corrected age and birth weight.

Model 3, PV: infants' gender. PV: predictor variable; CV: criterion variable; SE: standard error.

* $p < .05$.

When comparing infants' overlapping vocalizations according to gender, a *t*-test showed significant results. For the total number of overlapping vocalizations, there was a significant difference, $t(34) = 2.239$, $p = .032$, between male and female infants, with female infants presenting a higher frequency of total overlapping vocalizations ($M = 6.75$, $SD = 7.67$) when compared to male infants ($M = 2.70$, $SD = 2.36$). A significant difference between male and female infants was found in relation to overlapping vocalizations at the end of the musical phrases, $t(34) = 2.066$, $p = .047$. This means that female infants present a higher frequency ($M = 3.06$, $SD = 3.29$) of overlapping vocalizations at the end of the musical phrase when compared to male infants ($M = 1.40$, $SD = 1.31$).

Another significant difference was observed for overlapping vocalizations in the musical phrase boundaries (beginning and end of the musical phrases) relative to the gender variable, $t(34) = 2.173$, $p = .037$. Once more, it was the female group that presented the highest frequency of overlapping vocalizations in musical phrase boundaries ($M = 5.00$, $SD = 5.64$) when compared to the male group ($M = 2.05$, $SD = 2.03$).

As female infants made more overlapping vocalizations in the final note than male infants, we analyzed the duration of the final note of maternal humming to see if the final note directed to female infants was longer compared to the final note directed to male infants. However, no significant difference was found for the duration of the final note of musical phrases between maternal humming directed to female and to male infants; 700 ms was the average duration for the total sample.

Discussion

It is known that infants' abilities for processing sound and musical patterns develop rapidly from birth onward (Schmidt, Trainor, & Santesso, 2003). However, little is known about infants' specific ability to process metric cues, and there are few specific studies regarding preterm infants.

In a previous study based on the same sample, a higher frequency of preterm infants' overlapping vocalizations was observed during maternal humming than during maternal speech.

We realized it was important to identify the location of these overlapping vocalizations during the musical phrase and we also wanted to know more about the origin and the role of these overlapping vocalizations. So we set out to find a temporal marker of the preterm infants' vocal anticipation relative to musical phrase lengthening.

According to the results, maternal antenatal and postnatal experiences of ID singing are influenced by the mothers' nationality and also contribute to the humming style. Mothers who based their humming on known melodies reported more experiences of ID singing before and after birth than mothers who based their humming on improvising melodies.

Furthermore, during humming based on known melodies, there was a higher frequency of infants' vocalizations during the breathing breaks, and there were more overlapping vocalizations during the final note. Humming based on known melodies can probably provide a more predictable structure that encourages a baby to anticipate the end of the musical phrase. It is also probable that these mothers have already sung the same melodies to their infants, contributing to the recognition of these melodies through infants' vocal responses.

The results of our study may also contribute to broadening knowledge about the location of preterm infants' overlapping vocalizations during maternal humming. Our data show that infants' overlapping vocalizations in maternal ID humming occurred predominantly at the end of humming phrases, with almost half of the overlaps occurring during the final note which had an average duration of 700 ms. This suggests the existence of crucial markers of the increase of infants' overlapping vocalizations at the end of the humming phrase. It is also possible that the overlapping vocalizations occur due to the infants' detection of the breathing that follows the offset of the humming phrase.

In addition, the temporal features of the ID humming phrases, particularly the lengthening of the final note, may account for the overlapping vocalizations during the final note. Interestingly, the data about the duration of the final note matches descriptions from previous research on the way metric structures allow listeners to anticipate ID speech (Drake et al., 2000) as well as the significance of the duration of beat in ID singing (Trevvarthen, 1999). Furthermore, we found a tendency for overlapping vocalizations to occur simultaneously within the strong time of the musical phrase. In some cases, these overlapping vocalizations seem to be close to the tonal frequency of maternal humming.

According to results only two mothers sang Portuguese lullabies. This reinforces the question raised by Papousek (1996) about the decrease of the transmission related with the lullabies' traditional repertoire. However, when analyzing the musical characteristics of maternal humming in this study, we mostly identified musical features similar to lullabies (Sá & Carvalho, 2020).

According to the results, a gender difference related to the occurrence of overlapping vocalizations was found; more overlapping vocalizations were observed in female than in male infants at the boundaries, in the final note and relative to the total frequency of vocalizations. Surprisingly, no significant difference was found between the duration of the final note of musical phrases directed to female and to male infants during maternal humming. This suggests that female infants may be able to tune into the temporal features of ID humming earlier than male infants. This may lead to positive implications for the establishment of social interactions that appear to emerge earlier in the female group.

Interestingly, mothers of female infants reveal greater engagement in maternal antenatal and postnatal of ID singing than mothers of male infants. So, it is important to clarify if the differences found in female infants' vocalizations are associated with a greater maternal antenatal and postnatal investment in ID singing to female infants.

Taking into account that the expression of emotions is one of the functions of singing, we can hypothesize that a higher production of maternal singing directed to the female infant

reinforces the greater capacity of female group for emotional expression. Further studies are needed to analyze this hypothesis.

African and Brazilian mothers reported having sung more for their infants before and after birth than Portuguese mothers. Although the differences are not statistically significant, more infants' vocalizations during the humming of African or Brazilian mothers were found. Multimodal features of dyads' vocal interaction may contribute to the increase of infants' vocalizations during the maternal humming. In future studies, it will be important to clarify the impact of cultural differences on maternal ID humming before and after birth and also on the development of these dyads' vocal interaction. It is likely that this increase of the ID singing in African and Brazilian mothers suggests the existence of a cultural strategy to maintain the proximity and protection of offspring.

Evolutionary theories support the proposal that ID singing plays an important role in the protection and safety of human offspring by improving the "cohesion" and "bonding" between mothers and infants (Dissanayake, 2000, 2008, 2009; D. Falk, 2009; Mehr & Krasnow, 2017; Trehub, 2001, 2003). Mehr and Krasnow (2017) propose that ID singing is a way of signaling proximity to the caregiver, allowing the infant to calm down, stop crying and eventually fall asleep; this could function as a survival strategy by preventing detection by predators. At the same time, this calming effect allows the mother to engage in other tasks.

If we consider ID singing as a cohesion strategy, it is possible that the infants' overlapping vocalizations reinforce maternal attentional behavior and so help the dyads to become synchronized. Higher frequencies of mutual synchrony were found for mother and daughter dyads compared with mother and son dyads (Feldman, 2003). If we suppose that female infants' overlapping vocalizations express a higher degree of synchronization, our results suggest that dyadic synchronization is more developed in female dyads. In this way, synchronization can be seen as an important evolutionary protection against external threats that seems to be determined phylogenetically as a gender difference (Feldman, 2003).

Limitations of this study

One of the limitations of this study is the small sample size, which constrained the production of statistically significant results in some comparative analyses. Due to the difficulty of separating the infants' overlapping vocalizations from maternal vocalizations and the noise of the room, we opted to analyze only the frequency of overlapping vocalizations, not the duration of the overlapping vocalizations.

Another of the limitations of this study is related to the way the participants used humming based on the use of known melodies; the possibility that the infant had heard these before or after birth was not controlled. Our study included only a temporal analysis (frequency, duration and variation coefficient of duration) and did not include other acoustic and musical parameters of humming (pitch, melodic contours, rhythmic patterns, etc.). Studies on humming ID are still scarce and it is important to test other analysis criteria for the temporal segmentation of maternal humming.

In the future it will be important to identify, with a larger sample, the impact of other factors associated with maternal humming, including socio-cultural aspects such as nationality, musical training and previous maternal experiences of ID singing before and after birth at the NICU.

Implications of this study

The hypotheses concerning the contribution of infants' overlapping vocalizations to the synchronization of the preterm dyads should be an ongoing object of research. With this study we

wish to increase knowledge about which temporal features of maternal humming can increase the infants' overlapping vocalizations.

It is also important identify the real benefits of maternal ID humming in the promotion of contingent interaction in vulnerable dyads. It is equally important to clarify how maternal ID humming becomes contingent to enhance attunement in vulnerable dyads. Contingent humming (or singing) is used in the context of music therapy to induce attunement in vulnerable dyads in neonatal care (Shoemark, 2011; Shoemark & Grocke, 2010), where the musical features of singing are adapted according to the infants' facial expressions, postures and gestures.

This allows the music therapist to engage, guide and respond to the infant using musical parameters (rhythm, melody, tone, timbre, attack and silence). An essential balance between musical stimulus and infants' responses within a state of moderate arousal can be achieved through this strategy. This is only possible if the music therapist is able to recognize the infants' signals in real time during the interaction.

Despite the expertise of music therapists in the direct observation of infants' behaviors and signals in response to music, little is known about the specific musical characteristics of contingent singing that encourages infants' vocal responsiveness in a state of moderate arousal. By identifying the temporal markers of infants' overlapping vocalizations during maternal humming, our study may contribute to knowledge about the temporal characteristics of contingent singing in preterm dyads in the context of neonatal care units. However, more studies are needed to deepen the understanding of which musical characteristics of contingent maternal singing are most likely to facilitate the vocal responses of preterm infants within levels of moderate arousal. Studies are also needed to establish the short-term and long-term benefits, as well as risks, of arousing vocal interactions by contingent maternal humming between stable preterm infants and their parents in the NICU.

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Author contributions

The first three authors contributed to the design of the research, the first author collected and coded the data the first two authors performed the statistical analysis and wrote the text of the paper. The third and fourth authors reviewed the text and contributed to writing the final version of the paper.

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