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Report

Newborns' Cry Melody Is Shaped by Their Native Language

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Summary

Human fetuses are able to memorize auditory stimuli from the external world by the last trimester of pregnancy, with a particular sensitivity to melody contour in both music and language [1–3]. Newborns prefer their mother's voice over other voices [4–8] and perceive the emotional content of messages conveyed via intonation contours in maternal speech ("motherese") [9]. Their perceptual preference for the surrounding language [10–12] and their ability to distinguish between prosodically different languages [13–15] and pitch changes [16] are based on prosodic information, primarily melody. Adult-like processing of pitch intervals allows newborns to appreciate musical melodies and emotional and linguistic prosody [17]. Although prenatal exposure to native-language prosody influences newborns' perception, the surrounding language affects sound production apparently much later [18]. Here, we analyzed the crying patterns of 30 French and 30 German newborns with respect to their melody and intensity contours. The French group preferentially produced cries with a rising melody contour, whereas the German group preferentially produced falling contours. The data show an influence of the surrounding speech prosody on newborns' cry melody, possibly via vocal learning based on biological predispositions.

Results

Cries of 60 healthy newborns, 30 born into French and 30 born into German monolingual families, were analyzed. Melody in neonates' cries is characterized by single rising-and-then-falling arcs. These melody arcs were analyzed by determining the relative (normalized) time at which the maximum pitch ($F0_{max}$) was reached [$t_{norm}(F0_{max})$] (see "Melody Contour Analysis" in Experimental Procedures). Intensity contour analyses were performed in a corresponding manner for each cry.

As shown in Figure 1, a marked difference in the median values of $t_{norm}(F0_{max})$ points to group-specific preferences for produced melody contours (French group, 0.60 s; German group, 0.45 s). The arithmetic means of $t_{norm}(F0_{max})$ were significantly different in French (0.58 ± 0.13 s) and German (0.44 ± 0.15 s) newborns (Mann-Whitney test, $p < 0.0001$). Whereas French newborns preferred to produce rising melody contours, German newborns more often produced falling contours (exemplified in Figure 2). These results show a tendency for infants to utter melody contours similar to those perceived prenatally. A significant difference was also found for the intensity maxima of melody arcs [$t_{norm}(I_{max})$: mean 0.59 ± 0.12 versus 0.47 ± 0.12 for French group versus German group; Mann-Whitney test, $p < 0.001$]. The difference in the median values of $t_{norm}(I_{max})$—0.61 s versus 0.45 s for French versus German—are also displayed in Figure 1.

In addition, melody and intensity were significantly correlated in both groups (Spearman rho 0.45, $p < 0.05$ and 0.69, $p < 0.01$ for the French group and German group, respectively). However, despite the robust correlation between melody and intensity, there is some evidence that they are controlled by separate neurophysiological mechanisms [19–21]. Indeed, several cries exhibited independent melody and intensity contours.

Discussion

Prosodic features such as melody, intensity, and rhythm are essential for an infant acquiring language [22]. There is compelling evidence that infants are sensitive to prosodic features of their native language long before speech-like babbling sounds are uttered or first words are produced [22, 23]. Indeed, auditory learning starts as early as the third trimester of gestation [24, 25], and prosodic features are well preserved across the abdominal barrier, whereas phonetic aspects of speech are disrupted, making prosodic characteristics very salient for the human fetus [26]. In newborns, traces of early auditory learning processes are reflected in perceptual preferences for melodies to which they were exposed prenatally [1, 10, 14, 27, 28].

The present study is different from former investigations in that it focuses on a possible influence of the surrounding language on newborns' sound production instead of investigating perceptual preferences for the native language. This influence was investigated by analyzing melody contours of newborns' crying.

The observed melody contours of French and German newborns' crying show that they not only have memorized the main intonation patterns of their respective surrounding language but are also able to reproduce these patterns in their own production. Newborns produced significantly more often those melody types and intensity contours that were prosodically typical for their native languages: French newborns preferentially produced rising (low to high) contours, whereas German newborns preferentially produced falling (high to low) contours (for both melody and intensity contours).

These patterns are consistent with the intonation patterns observed in both of these languages. In French, intonation is characterized by a pitch rise toward the end of several kinds of prosodic units (words, intermediate prosodic phrases), except for the very last unit of an utterance, which presents a falling contour (see, e.g., [29, 30]). This is a crucial difference from German intonation, which typically exhibits a falling melody contour, e.g., from the accented high-tone syllable to the end of the intonational phrase [31]. This difference between French and other languages has already been observed to

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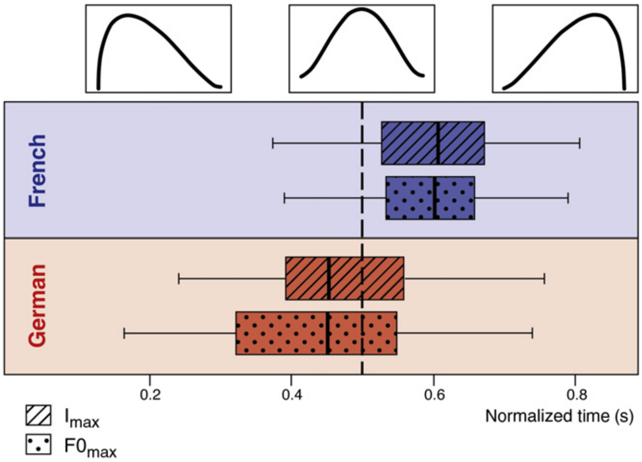

Figure 1. Box-Plot Diagram of the Values $t_{norm}(F0_{max})$ and $t_{norm}(I_{max})$

Distribution of all observed melody and intensity contours in German and French newborns' crying, displayed as box plots of the 25th to 75th percentile, with the solid vertical line inside each box representing the median and the bars outside each box representing the minimum and maximum values. The dashed vertical line represents a symmetric melody arc. The data indicate a preference for either rising (French group) or falling (German group) melodies.

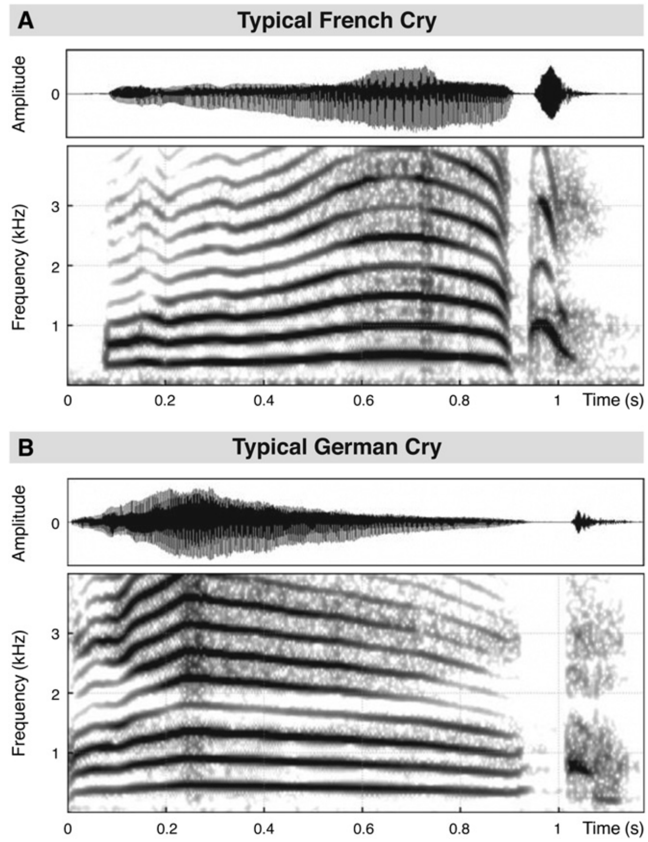

Figure 2. Time Waveform and Narrow-Band Spectrograms of a Typical French Cry and a Typical German Cry

have an impact on the sound production of 7- to 18-month-old infants: French infants have been found to produce more rising melody contours than English and Japanese infants [32, 33].

The newborns examined in the present study probably learned these characteristics of their mother tongue by listening to it prenatally (although we cannot completely exclude early postnatal learning during the first 2–5 days of life). Language-specific preferences for final versus initial stress patterns have already been reported in perception for French and German infants as young as 4 months of age via neurophysiological techniques [34]. The present cry production data show an even earlier impact of native language, because neonates' cries are already tuned toward their native language.

The specific perceptual abilities of human fetuses and young infants for melody properties evolved over several million years of vocal and auditory communication and (more recently) spoken language [35]. Thus, rather than being specific to speech, most of the precocious perceptual performances of human infants have deep roots in a phylogenetically older primate auditory perceptual system. There are also obvious acoustic similarities between nonhuman primate calls and human infant cries (cf. review in [36, 37]). However, in contrast to nonhuman primates, human infants develop spoken language quickly and seemingly without effort. In spite of many similarities, human infants and nonhuman primates differ with respect to language-relevant perceptive capacities (cf. [38]) as well as early productive performances.

Thus, two aspects of the present data suggest that human infants' melody production is based on a well-coordinated respiratory-laryngeal activity, in contradiction to older studies that argued that cry melody was strictly constrained by the respiratory cycle (e.g., [39, 40]). First, newborns seem capable of an independent control of fundamental frequency and intensity, as suggested by the observed cases of cries where melody and intensity contours are decorrelated (see also [19]). Second, and more importantly, if newborns' cries were constrained by the respiratory cycle, then they should always follow a falling pattern, a simple physiological consequence of the rapidly declining subglottal pressure during expiratory phonation. The present data show that German and French infants produce different types of cries, even though they share the same physiology. In particular, the fact that the French newborns produce "nonphysiological" rising patterns supports former findings demonstrating that human newborns' cry melody patterns are already a product of a well-coordinated respiratory-laryngeal activity under the control of neurophysiological mechanisms [19, 20].

Apes' vocalizations (e.g., bonobo sounds) are described as exhibiting a strict correlation between F0 variations and intensity, suggesting a close association between F0, intensity, and subglottal pressure [41]. Many of the laryngeal muscle functions for swallowing, respiration, and vocalization are controlled by subcortical regions in nonhuman primates [42], whereas intentional control of breathing and crying in newborns originates in the cerebral cortex [36, 43]. The muscles of the larynx function as a part of the respiratory system before birth. Like other respiratory muscles, they undergo considerable use prior to birth [44]. For reproducing the melody contours perceived and stored prenatally, a coordinated action of melody and intensity may simply be a very economic and thus the easiest way to achieve the contour target, even though infants will manipulate these parameters independently in the process of learning to speak.

The present cry production data show an extremely early impact of native language. Thus far, a capability for vocal imitation had only been demonstrated from 12 weeks onward.

Listening to an adult speaker producing vowels, infants responded with utterances that perceptually matched the vowels presented to them [45]. To do this, infants must be capable of moving their articulators in order to reach a specific auditory target. Anatomical and functional constraints of the immature vocal tract mechanisms do not allow for the imitation of articulated speech sounds before about 3 months. Imitation of melody contour, in contrast, is merely predicated upon well-coordinated respiratory-laryngeal mechanisms and is not constrained by articulatory immaturity. Newborns are probably highly motivated to imitate their mother's behavior in order to attract her and hence to foster bonding [46, 47]. Because melody contour may be the only aspect of their mother's speech that newborns are able to imitate, this might explain why we found melody contour imitation at that early age. Hence, our data support the existence of imitation in newborns by fulfilling all the necessary prerequisites postulated by Jones [48]. Whether human newborns' preference for speech is innate [49] or acquired [26], the observed performances are based on biological predispositions, particularly for melody perception and production [47, 50].

Recent findings indicate a systematic melody development from simple to complex patterns beginning at birth and demonstrate a strong developmental continuity from crying via cooing and babbling toward speech (e.g., [20, 21, 50–52]). The significant finding of this study is that newborns, in their own sound production, already reproduce some of the prosodic properties of the specific language that they were exposed to prenatally.

Experimental Procedures

Participants

Cries of 30 French (11 female, 19 male; mean age 3.1 days, range 2–5 days) and 30 German (15 female, 15 male; mean age 3.8 days, range 3–5 days) newborns were analyzed. All subjects were healthy, full-term newborns with normal hearing from a strictly monolingual (French or German) family background. German infants had a mean gestational age of 39.5 weeks; French newborns had a mean gestational age of 39.6 weeks. The studies were performed with the approval of the ethics committees of Charité Berlin and Cochin Hospital (Paris). All participating families followed the institutional consent procedures in German or French.

Cry Recordings

Recordings of the French newborns were made at Port-Royal Maternity of Cochin Hospital (Paris). For the German newborns, existing digital sound files of cries that were recorded as part of the German Language Development Study (http://glad-study.cbs.mpg.de) were used. Cry recordings were made during spontaneous, normal mother-child interactions (while changing diapers, before feeding, or while calming the spontaneously fussy baby) with a TASCAM DAT recorder (DA-P1, serial number 880096) and an Earthworks microphone (TC20, serial number 7642C). All recordings were made in pain-free situations (excluding, e.g., pain cries in response to heel lancing for blood sampling). During recording, the distance between the microphone and the newborn's mouth was about 15 cm. Individual recording time varied between 3 and 10 min, depending on the spontaneous crying behavior of the neonate. A cry was defined as the vocal output occurring on a single expiration. In total, 2500 cries were recorded.

Cry Analysis

Spectral analysis and high-resolution melody (fundamental frequency [F0] contour) computations were carried out with Computerized Speech Laboratory CSL 4400/MDVP (Kay Elemetrics Corp.) together with postprocessing for interactive removal of high-frequency modulation noise and artifacts (Cry-Data-Analysis-Program [CDAP]; see [19] for details). Frequency spectrograms of all cries were produced in order to identify voiced, harmonic cries and to exclude noisy, voiceless cries. Depending on physical state and the course of postnatal adaptation, newborns' crying may contain irregularities such as subharmonics or phonatory noise. Such phenomena are caused by strong nonlinearities in the restoring forces resulting from an extremely large amplitude-to-length ratio of the vocal folds in newborns [53]. From a perspective of nonlinear dynamics, voiceless (noisy) segments of newborn cries can be interpreted as low-dimensional chaos [53, 54]. Voiceless cries and cries containing broad regions of phonatory noise in their frequency spectra could not be used for the applied methodology because fundamental frequency (melody) cannot be reliably determined in those signals.

For the final melody analyses, 1254 voiced cries were used (French group, mean number of cries per neonate: 21, range 3–54; German group, mean number of cries per neonate: 18, range 10–38). The large interindividual variability in number of cries per session was due to the fact that we strictly avoided eliciting crying (through stimulation).

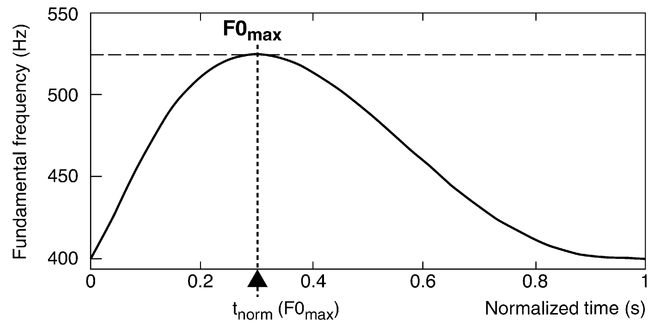

Figure 3. Diagrammed Cry Melody as Time Function of Fundamental Frequency F0 with Time-Normalized Duration

Melody Contour Analysis

Only simple cries containing single rising-and-then-falling melody arcs were analyzed. These cry types were selected because they predominate in the crying of healthy newborns. These melody arcs can be assigned to four basic melody types: (1) quickly rising and slowly decreasing melody: left-accentuated type—"falling contour"; (2) slowly rising and quickly decreasing melody: right-accentuated type—"rising contour"; (3) symmetrical rising-and-then-falling melody: symmetric type; and (4) a relatively stable fundamental frequency with a rising or falling trend: plateau type [20, 50]. These melody arcs were analyzed as follows (see Figure 3): after normalizing arc duration to 1 s, the normalized time [$t_{norm}(F0_{max})$] corresponding to the maximum pitch ($F0_{max}$) of each melody arc was determined. $t_{norm}(F0_{max})$ values < 0.5 s represent "falling contours"; $t_{norm}(F0_{max})$ values > 0.5 s represent "rising contours" (Figure 1). Intensity contour analyses were performed in a corresponding manner for each cry.

Newborns of both groups generated all four basic melody types typical at that age. This observation reflects a general aptitude for generating melodies with varying contours and explains the observed partial data overlap in Figure 1.

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