Noisy but Effective: Crying Across the First 3 Months of Life

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Summary: Objective. To evaluate the developmental occurrence of subharmonic (SH) and noise (N) phenomena and to quantify their extent in the spontaneous cries of healthy infants across the first 3 months.
Study Design. Populational prospective study.
Participants. Spontaneous elicited cries from 20 infants (10 male) were repeatedly recorded across the first 3 months of life.
Methods. Frequency spectra and waveforms were used to identify the occurrence of SH and N and to measure the percentage of their combined occurrence in overall monthly crying behavior (expressed as a quantitative noise index [NI]).
Results. SH and N episodes were prevalent in the cries of young infants during the first 2 months, being present in more than 50% of the recorded cries. A developmental trend was evident in NI with a significant decrease across the 3-month period. A corresponding significant increase in mean duration of single cries was observed during the same period.
Conclusions. SH and phonatory noise are regularly occurring phenomena in healthy infant crying because of the characteristics of pediatric larynx anatomy and neurophysiological control mechanisms underlying cry production. The reduction in NI appears to correspond with the development of an infant's crying complexity. The utility of NI as a metric of cry phonatory behavior should next be validated on infant groups with known or suspected health problems.
Key Words: Fundamental frequency–Cry–Phonation–Development–Infant–Phonatory noise–Subharmonic.

INTRODUCTION

For the altricial neonate, crying is a very effective means of communication and human infants use it to express their needs and feelings from birth.[1–3] Crying requires a well-functioning respiratory, laryngeal, and supralaryngeal muscle network and intact neurophysiological coordination.[4–6] Early research examining spectrographic features of infant cries identified phonatory behaviors that were suggestive of underlying neurologic or structural pathology.[1,7–11] Notable among these behaviors are specific irregularities in vocal fold vibration, generating subharmonics (SH), and noise-like phenomena within cries. Truby and Lind[4] were some of the first of researchers to describe these cry features as typical for infant crying. They termed cries exhibiting these phenomena as "dysphonation" or "turbulence." Twenty-five years later, Mende et al[12] demonstrated with the aid of Poincaré sections and dimensional analysis that these noise-like phenomena can be interpreted as low-dimensional deterministic chaos. This interpretation was then confirmed by other scientists,[13] who suggested that the presence of this phonatory noise is indicative of chaotic vocal fold oscillation, whereby the vocal folds act as a desynchronized coupled oscillator generating nonperiodic irregular vibrations.[14–16]

SH and bands of phonatory noise (N) are thought to reflect nonlinearities in vocal fold mechanics.[12,13] An SH is a vibratory pattern where one or more parallel harmonics occur simultaneously with the fundamental frequency (F_0) and its harmonics. SH are also referred to as bifurcations, whereby a new vocal fold oscillation cycle prevails and becomes stable with almost double or further multiplying of the original period. SH instances of further cascading of oscillatory cycles may result in noisy-like phenomena, which can be depicted in a spectrogram as a loss of typical F_0 structure and harmonics.

SH and N episodes have been found in cries of both healthy infants[4,12,15] and infants with certain morphologic and/or neurophysiological disorders.[4,7,8,15] The typical alterations of the basic mode of glottal oscillation that generate SH and noise-like episodes in infant crying are not surprising. The anatomy of the laryngeal structures in neonates and young infants differs markedly from that of adults.[17] The infant vocal folds consist of an immature monolayer compared with the adult vocal folds, which is a laminated structure comprised multiple tissue layers.[18–20] These essential differences between immature and mature laryngeal structures and corresponding control mechanisms result in differences in vocal fold biomechanics between infants and adults.[21] Applying a phylogenetic perspective, Schweinfurth and Thibeault[22] postulated that the homogenous compact collagen structure of the young infant vocal folds developed to enable long periods of sustained near-maximum levels of pitch and loudness in crying. However, the enormous subglottal pressure associated with crying regularly evokes oscillatory instabilities of the infant's vocal folds.[4,12,13,15,23]

The most comprehensive study to date which documents the occurrence of SH and N components in healthy infant crying was performed by Robb.[15] Based on the examination of pain cries produced by infants at the first month of life, SH and N were found to occur in approximately 40% of the cry samples. A similarly high occurrence of these phenomena in pain cries

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was reported by Michelsson[24] for neonates. The high occurrence of these features during the first month of life led to the suggestion that SH and N may undergo developmental change with a subsequent diminishing occurrence as a function of vocal maturation. More recent research by Buder et al[25] would seem to support this suggestion, albeit for noncry vocalizations. These researchers labeled a range of nondistress phonatory behaviors exhibited by three children aged between 4 and 11 months. During the period of study, SH and various N features (labeled stops, biphonations, and chaos) were found to decrease with age, which was attributed to the child's emergence of control over modal voice production.

Despite an impressive body of research in the field of cry research, the lack of knowledge of developmental processes influencing the acoustic signature of cries has hampered the general impact of the findings. Systematic studies with regard to quantitative differences in SH and N, taking into account developmental changes, are still pending. Consequently, an identification of a potentially pathologic cry phonation from a normal one based on acoustic measures requires an investigation of developmental trajectories of relevant entities/properties.

The present study

Although the occurrence of SH and N features has been reported for early infant crying and the nondistress vocalizations of children aged 4 months and beyond, little quantitative information is available regarding the developmental course of these features across the first 3 months of life. The first 3 months are a particularly important period in an infant's vocal development. The infant's oral communication is primarily dependent on vocal fold vibratory behavior.[4] Supraglottal articulations begin to decisively shape vocalizations toward the end of the third month, as a result of remodeling of the infant's vocal tract and maturation of corresponding neurophysiological control systems.[26–28] However, before this time, the cry is of paramount importance for communication in mother-infant dialogs.[3,29–31] Infant cries are heavily loaded with emotions. The infant sends messages regarding his or her sensations, feelings, and wants. These messages are "body near," in that they immediately express bodily conditions and emotional states, and they are in large part intuitively "intelligible" to the mother. It is therefore not surprising to find researchers seeking to understand the underlying emotional content of an infant's crying and to differentiate, for example, between cries of hunger, pain, and frustration.[1,2,10,32] Furthermore, Wemke et al[3,33] suggest that prosodic primitives, in the form of complex melody patterns that develop during this time, provide a platform for subsequent language development.

Hence, the quantitative investigation of SH and N phenomena, as signs of immaturity and inadequate transitory vocal control, may ultimately prove useful as one of the early risk markers for later language outcome. Dysfunction of basic control mechanisms underlying laryngeal vocal production could be inferred by examining these particular cry features.

The purpose of the present study was twofold. First, we wanted to quantify the frequency of occurrence of SH and N phenomena in healthy infant crying across the first 3 months. Second, beyond noting the occurrence of these phenomena, we focused on quantifying the proportion of these "disturbed" oscillation patterns to regular ones by applying a special measure–the noise index (NI).

METHODS

Participants

Spontaneous cries of the first 3 months produced by 20 healthy full-term infants (10 males) were considered in the present study. Participants were recruited, recorded, and medically examined at the Children's Hospital Lindenhof in Berlin, Germany. These infants were part of a broader study examining language development from birth to 5 years of age in which the third author served as the principal investigator for the earliest stages (http://glad-study.cbs.mpg.de). After approval by the ethical committee, the parents of each infant were informed as to the purpose of the study and each parent provided written consent for their infant's participation. All infants selected for the study demonstrated normal development throughout the data collection period and undertook regular medical and developmental checkups. The hearing capabilities of the infants across the observation period were assessed to be normal based on a combination of otoacoustic emission and brainstem evoked response audiometry.

Data collection

Cry samples ($n = 2361$) were collected from each infant across the first 3 months of life. The average numbers of cries collected from each infant across the first 3 months were 50, 40, and 29 cries, respectively. Cry signals were recorded using a portable digital recorder (Sony TCD-D100) and microphone (SONY ECM-950/957; Sony Corporation, Tokyo, Japan). All cry samples were obtained in quiet areas in the hospital (first week) or home environment (thereafter). The infants were recorded lying in a supine position in their mother's presence. The microphone was handheld at a distance of approximately 10–15 cm from the child's mouth. Only spontaneous cries were recorded (ie, when the infants were hungry or thirsty) and no cries were induced through inflicting pain. Vegetative vocalizations (eg, burps and sneezes) and comfort vocalizations (eg, coos) were not considered in the present analysis. Recordings had an average duration of 2 minutes per session.

Data analysis

The cries produced by each infant were analyzed using a commercially available hardware system (CSL-4500, KayPENTAX; Montvale, NJ). Examples of SH, N, combined SH + N, and noise-free cries are illustrated in Figure 1. As previously established by the present researchers, a cry was defined as the onset and offset of identifiable acoustic energy in the waveform that occurred on the expiratory phase of a single respiratory cycle.[15,34,35] Only cries in excess of 500 ms were considered in the analysis, as cries of shorter duration often