CHAPTER 2

THE INFLUENCE OF HEARING IMPAIRMENT ON PREVERBAL EMOTIONAL VOCALIZATIONS OF INFANTS

Abstract

The aim of the study was to compare the vocalizations of normally hearing and profoundly hearing-impaired infants in the first year of life. After the first recording, all hearing-impaired infants were provided with hearing aids. We focused on three issues: (1) Are there different types of preverbal vocalizations in the vocal repertoire of normally hearing and hearing-impaired infants? (2) Do the vocal types emerge at similar age? (3) Does hearing impairment influence the acoustic structure of the preverbal vocalization types common to normally hearing and hearing-impaired infants? The study shows that both normally hearing and hearing-impaired infants have the same vocal repertoire. Except for babbling, there were no differences in the time of emergence of preverbal utterances. Structural differences could only be found in cries. In general, it seems that normal auditory input is not essential for the production of single preverbal utterances.

Introduction

The most obvious outcome of hearing impairment in early infancy is the delay or complete loss of spoken language, if no therapeutic efforts are undertaken to develop speech ability. Having no or only limited command of speech, leads to considerable communication problems in the speaking social environment. Since hearing impairment is relatively widespread (1-2 in 1,000 infants in Germany; Garvel & Tocci 1998) and its consequences are serious, a number of scientists of different fields, including linguists, psycholinguists, psychologists and phoniatricians, investigate the influence of hearing impairment on speech, cognitive, and social development.

One therapeutically important field of research is the development of prespeech utterances and speech in early childhood. It is a known fact that early diagnosis and early start of therapy - including hearing aids and hearing training/speech therapy - are essential factors for good skills in spoken language (Diller et al. 2001; Yoshinaga-Itano et al. 1999). Since the focus of earlier investigations lay on the question of how meaningful referential speech arises out of preverbal utterances, the methodological inventory to study this question was mainly taken from the linguists, and so the prespeech vocalizations were mainly characterized phonetically. As Oller (2000) pointed out, purely phonetic descriptions of infant sounds are misleading, because they imply well-formedness of syllables produced by the infants at every age. This, however, is not the case for the great majority of sounds before the age of approximately 6 months (in normally hearing infants). Oller (2000), who investigated especially canonical babbling and the development of speech capacity, recommended another approach to study infant sounds, the infraphonological model, which holds an intermediate position between operational categories (e.g. particular phonological features) and prime parameters (e.g. acoustic parameters, like duration and frequency).

Examples of studies using this modern approach are the comparative studies on canonical babbling (Eilers & Oller 1994; Kent et al. 1987; Oller & Eilers 1988; Oller et al. 1985). They came to the conclusion that canonical babbling is a useful preverbal behavior to judge auditory function. Canonical babbling is characterized by true consonant-vowel repetitions with regular timing between the consonant and vowel portions of the syllable; it appears between 7 and 10 months of age in normally hearing (NH) children. The canonical babbling of infants with severe to profound hearing impairments differs from that of NH infants in a number of ways (Eilers & Oller 1994; Oller 1980; Oller et al. 1985). In hearing-impaired (HI) infants, the onset of canonical babbling is much later (about 11-49 months of age), the variety of phonemes is reduced; HI infants babble less often and the transients between the consonant and the vowel are significantly longer than those of NH infants.

Although language is a central channel of human communication, there is another vocal behavior used for communication, which occurs much earlier than language and which persists throughout life: the nonverbal vocal expression of emotions (for example: crying, laughing, squealing, cooing, wailing). The structure and development, as well as the communicative and emotional content of these vocalizations, with the exception of crying, have not been studied in depth and are not completely understood. Comparative studies of nonverbal (non-babbling) emotional vocalizations of NH and HI infants are scarce. An exception is the study by Möller and Schönweiler (1999), who analyzed cries of NH and HI infants. First, they investigated whether experienced and inexperienced listeners were able to distinguish the cry bouts of the two infant groups; they found that experts could identify cry bouts of HI infants better than by chance. In a subsequent acoustic analysis, they found that the spectral characteristics as well as melodic and rhythmic parameters of the cries differed between NH and HI infants.

The lack of comparative studies on other call types than crying is regrettable, because knowledge about differences and similarities in the preverbal vocal communication of infants with and without normal hearing could lead to a better understanding of the role of auditory input for early preverbal vocalizations and also lead to improved diagnostic tools for detecting hearing impairment before the stage of canonical babbling. Therefore, we conducted a longitudinal study to investigate the vocalizations of NH and profoundly HI infants with the aim to characterize and compare the preverbal vocal utterances with respect to their acoustic structure, their development during the first year of life and their relationship to specific emotions. Since such preverbal utterances are hardly describable with linguistic methods, we decided to use a multiparametric acoustic analysis to examine the physical structure of the utterances in terms of time, frequency and energy characteristics.

In a previous study (Scheiner et al. 2002), we investigated the utterances of NH infants. We were able to distinguish one inspiratory and eleven expiratory call types, which could be differentiated on the basis of a small number of acoustic parameters. All call types occurred in positive as well as in negative emotional contexts. Most of the call types appeared within the first 2 months; some emerged not before the 5th (laugh) or 7th month (babble) in the majority of infants. Within individual call types, there were only minor changes in the acoustic structure during the first year of life. These age-related changes were mainly characterized by an increase in harmonic-to-noise ratio and homogeneity of the calls, a decrease in frequency range and a downward shift of acoustic energy from higher to lower frequencies. Emotion-related differences were found in the acoustic structure of individual call types as well as in the frequency of occurrence of particular call types. A change from positive to negative emotional state was accompanied by an increase in call duration, frequency range and peak frequency. Negative emotions, in addition, were characterized by a significantly higher rate of cry, hic and ingressive vocalizations than positive emotions, while positive emotions showed a significantly higher rate of babble, laugh and raspberry.

The present paper focuses on the comparison of the preverbal vocalizations of NH and HI infants. The aim is to examine the influence of auditory control on preverbal vocalizations in the first year of life. We concentrated upon three questions: (1) Are there different call types in the vocal repertoire of NH and HI infants? (2) Do the call types emerge at similar age? (3) Does hearing impairment influence the acoustic structure of specific call types?

Material and Methods

Subjects

NH Infants

The 7 infants selected to participate in the investigation consisted of 5 boys and 2 girls, all members of middle-class families. All parents of the infants were native speakers of German. All infants were born at term and healthy. Contact was made through 2 cooperating pediatricians, who asked the parents at the third medical checkup of the infants at week 4-6 whether they were interested to participate in the study. Then they were visited by one of us in order to obtain their informed consent. Thereafter the infants were examined at the Department of Phoniatrics and Pedaudiology of Georg-August University, Göttingen to make sure that they were normally hearing. The examinations included a complete otorhinolaryngological status, sound field audiometry, tympanometry, acoustic reflex threshold and measurement of transient evoked otoacoustic emissions.

HI Infants

The group of HI infants also consisted of 5 boys and 2 girls. The parents of 1 boy spoke Turkish; the parents of 2 other boys were hearing-impaired but able to speak German; the parents of the other 4 infants were native speakers of German. All infants were born at term and had no further anomalies besides hearing impairment. Contact was made through cooperating physicians, who procured contact to the parents of the HI infants after making the diagnosis of profound hearing impairment (about100 dB ore more hearing loss on both ears; 1 infant had a hearing loss of 80 dB on the right ear and >100 dB on the left ear). All infants were provided with hearing aids on both ears soon after diagnosis and received aural rehabilitation training. The first recording was made before the provision of the first hearing aids, afterwards all infants had hearing aids which they wore more or less regularly. Two children, HI 1 and HI 6, were provided with a cochlear implant on one ear, because their hearing capacities were not satisfactory with hearing aids. HI 1 got his cochlear implant after the study, HI 6 after the fifth recording.

Vocal Recordings

The vocalizations of the infants were recorded 6-8 times during the course of 1 year. Recordings of the NH infants started at the age of 7-10 weeks and ended at the age of 53-58 weeks. Unfortunately, there is still no generally accepted newborn hearing screening in Germany, although meanwhile increasing activities are under way. Due to this regrettable circumstance, the HI infants were older than the NH infants. Recordings of the HI infants started at the age of 10-23 weeks and ended at the age of 51-76 weeks (Table 1).

TABLE 1. *Age in weeks of the recorded infants. For NH infants, the age at the end of each recording session is given. For HI infants, the age at the day of each recording is given.*

Recording Nr.	NH 1	NH 2	NH 3	NH 4	NH5	NH 6	NH 7	HI 1	HI 2	HI 3	HI 4	HI 5	HI 6	HI 7
1	7	10	7	9	7	9	8	10	23	19	22	17	21	21
2	14	14	14	15	16	15	14	18	29	29	29	24	27	28
3	20	20	20	21	24	22	20	29	36	34	38	38	36	39
4	26	26	25	29	32	26	25	34	42	35	47	42	41	44
5	31	33	31	36	47	32	31	38	50	42	57	46	54	49
6	38	37	38	46	56	39	37	45	56	48	68	53	75	54
7	45	45	47	56		49	44	51	64	56	76	61		62
8	54	53	54			58	53		71	62				

The recordings were made with Sony WM TCD-100 DAT recorders and Sennheiser directional microphones (K6 power module and ME64 recording head). To obtain a comprehensive vocal repertoire of the infants, the parents of the NH infants themselves recorded their children in familiar surroundings, after an introduction into the recording method. Each session lasted 1 week and included recordings of vocalizations from 11 defined situations of normal infant life. The parents were instructed orally and in written form, how to record the situations. Each of the situations had to be recorded twice over the course of 1 week. For each recorded situation, the parents had to name the emotion they assumed their infant expressed, choosing between joy, contentment, interest, surprise, unease, anger and pain.

Though we had planned to ask the parents of the HI infants to record their children in exactly the same way, we were forced to modify the recording method. Some of the parents were not able to record the vocalizations of their children, partially due to their own hearing impairment, partially due to the stress induced by the diagnosis of hearing impairment of their infant and the following frequent appointments with physicians, therapists and hearing aid acousticians. We therefore changed the recording method for all HI infants in the way that one of us visited the families at home and made the recordings in the course of 1 day. The same situations were recorded as in NH infants, and again the parents named the emotion they assumed their infant expressed.

Acoustic Analysis

In order to extract acoustic parameters correlating with the emotional state, we carried out a multiparametric analysis. First, the vocalizations were inspected for quality and digitized, using RTS 2.0 (Engineering Design, Belmont, Mass., USA). Only calls of good quality and low background noise were used. Depending on the quality of the recordings, we selected 20-30 calls from each recording (more specifically, we chose this number of calls from each recording of the 11 defined situations; since each situation had to be recorded twice, we optimally digitized 20-30 calls out of each of 22 recordings per infant and month). This resulted in a total sample size of about 31,400 (NH: n = 16,300; HI: n = 15,100) digitized vocalizations. If the recording of a situation contained more than 20 calls of good quality and low background noise, half of the calls digitized were chosen from the beginning of the recording and the other half from the end. Sampling frequency was 30 kHz. For each call, we calculated two fast Fourier transformations (1,024 pts; Signal 3.0, Engineering Design) at a frequency range of 4 and 12 kHz (frequency resolution 10 and 29 Hz, respectively). Time resolution was 10 ms in both cases. The resulting frequency-time spectra were analyzed with LMA 9.2 (developed by K. Hammerschmidt). LMA is a software tool to extract different sets of call parameters from acoustic signals (Hammerschmidt 1990; Hammerschmidt & Fischer 1998). We used the spectra with the better frequency resolution (frequency range: 4 kHz, frequency resolution: 10 Hz) to calculate the fundamental frequency and parameters related to fundamental frequency and its variations. For the calculation of parameters describing the energy distribution, we used the spectra with the higher frequency range (frequency range: 12 kHz, frequency resolution: 29 Hz). Parameter calculations were carried out in the same way for the vocalizations of HN and of HI infants and are described in detail in Scheiner et al. (2002).

Vocal Repertoire and Emergence of Call Types

The categorization and analysis of the vocal repertoire of the NH infants is described in detail in our previous publication (Scheiner et al. 2002). We classified eleven expiratory and one inspiratory call types (Figure 1). Utterances that did not fit in this classification (mostly utterances consisting of two or more call types) were put into a rest group.

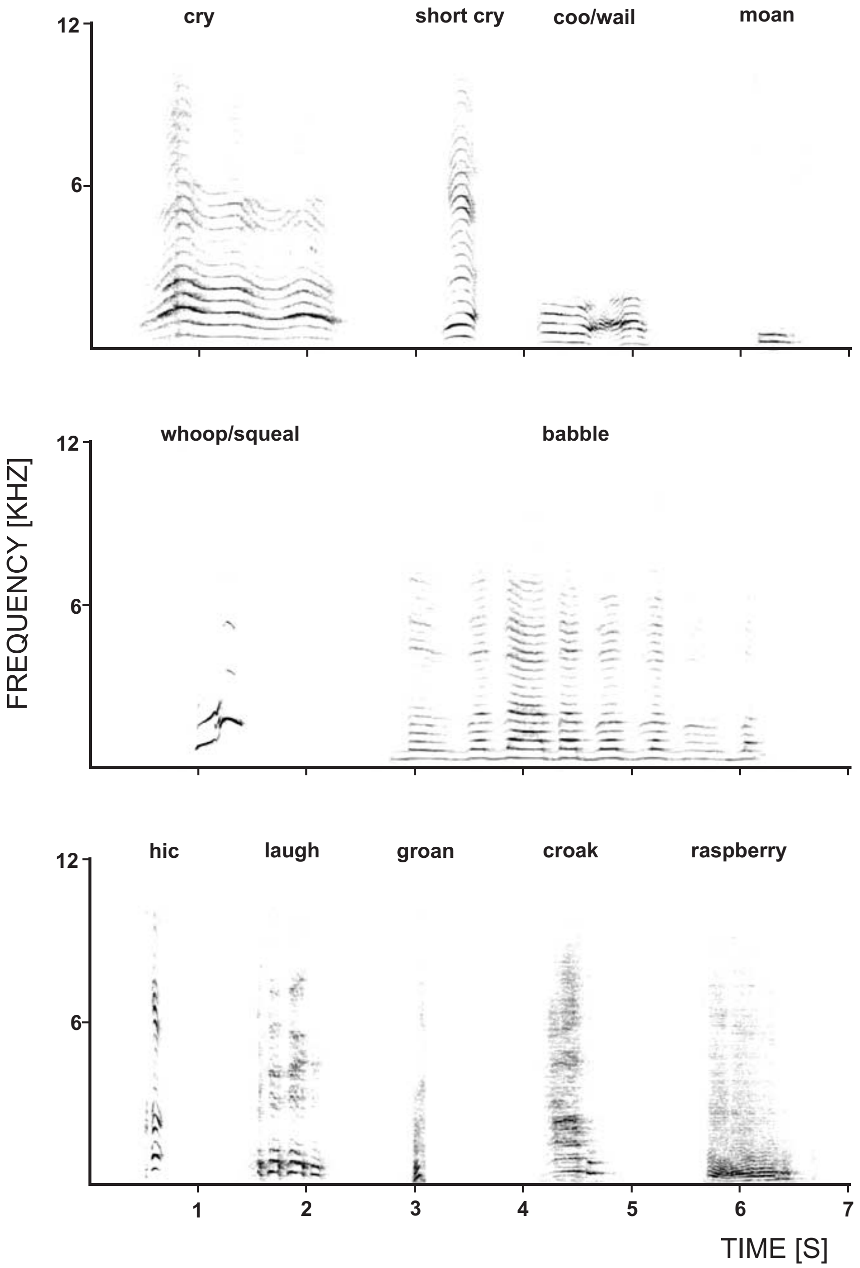

FIGURE 1. Call types

Age Groups

Since the ages of the HI infants were not exactly the same in corresponding recording sessions, due to various organizational reasons, we formed age groups for better comparability (Table 2). Each age group spanned 8 weeks. For statistical analysis of differences between HI and NH infants in call structure, we only used calls of age groups 2, 4 and 5, as these were the only groups that contained recordings of all 7 infants.

Differences in Call Structure Related to Hearing Impairment and Emotion

From our previous study on NH infants (Scheiner et al. 2002) we knew that infant vocalizations, even of the same call type, have a high variance. This is especially true when they are uttered under different emotional conditions. Furthermore, not all of the infants showed the whole range of emotions during one recording session. We were therefore forced to take utterances out of more than one session for analysis of differences in call structure related to hearing impairment. Due to obvious reasons, the HI infants were supplied with hearing aids as soon as possible after their impairment was recognized (see above). For that reason, we had only one recording of each infant without hearing aids. In order to find out whether pooling of vocalizations of the HI infants before and after provisioning with hearing aids was an acceptable procedure, we conducted an initial test on whether the supply with hearing aids had an influence on the call structure. We tested the call types coo/wail, cry and moan. Age group 2 (17-24 weeks, no hearing aids) was tested against age group 5 (41-48 weeks, wearing hearing aids for 13-36 weeks). Separate tests were conducted for the call types out of positive and negative emotions to reduce possible influences of emotions on call structure. For the call type moan, we did not have enough recordings in negative emotional context for all infants; moan, therefore, was tested only for positive emotions.

Afterwards, we tested three of the most frequent call types for which we had enough calls for all categories. The three call types (coo/wail, moan and cry) have an essentially tonal structure. To establish a balanced data set, we only used HI calls of age groups 2, 4 and 5 (Table 2). So, HI calls were used from 17 to 48 weeks of life (mean 30.1 weeks). The calls of the NH infants included in this analysis were uttered between 7 and 58 weeks of life (mean 33.5 weeks).

TABLE 2. *Arrangement of age-classes.*

Age-class (No.)	Age (weeks)	HI 1	HI 2	HI 3	HI 4	HI 5	HI 6	HI 7	No. of infants recorded
1	9-16	1	0	0	0	0	0	0	1
2	17-24	1	1	1	1	2	1	1	7
3	25-32	1	1	1	1	0	1	1	6
4	33-40	2	1	2	1	1	1	1	7
5	41-48	1	1	2	1	2	1	1	7
6	49-56	1	2	1	0	1	1	2	6
7	57-64	0	1	1	1	1	0	1	5
8	65-72	0	1	0	1	0	0	0	2
9	73-80	0	0	0	1	0	1	0	2

The numbers in the columns HI 1-7 refer to the number of recordings made in the corresponding age-class.

Calls were balanced with respect to the infants and to the four different emotions, but not with respect to age group, because we knew from previous analyses (Scheiner et al. 2002) that emotion has a stronger influence on the call structure of the investigated call types than age. With this balanced data set, we performed a principal component analysis to reduce the number and the correlation between the different acoustic measurements. Principal component analysis resulted in 16 factors with an eigenvalue above 1. The total explained variance was 76.2%. To get a better interpretation of factor loadings, we did a subsequent varimax rotation with Kaiser normalization (KMO = 0.930). For further statistical tests, we used the factors with an explained variance above 3 and explainable factor loadings. The explained variance and description of these factors is given in Table 4. Based on the factor loadings, we calculated the means per call type, emotion and infant. With these means, we tested the general hypothesis of differences between HI and NH infants. For these tests, we used a multivariate general linear model test, normal and repeated measures (GLM, SPSS 10), and did subsequent univariate tests in case the multivariate tests were significant.

Results

Vocal Repertoire and Emergence of Call Types

The HI infants produced the same call types as the NH infants and, like the NH infants, also uttered each call type in positive as well as in negative emotions. Interestingly, they also produced almost all call types at approximately the same age as the NH infants (Figure 2; for a detailed description of the call production by NH infants, see Scheiner et al. 2002). The only clear difference was the emergence of babbling, which occurred later in HI infants than in their NH peers.

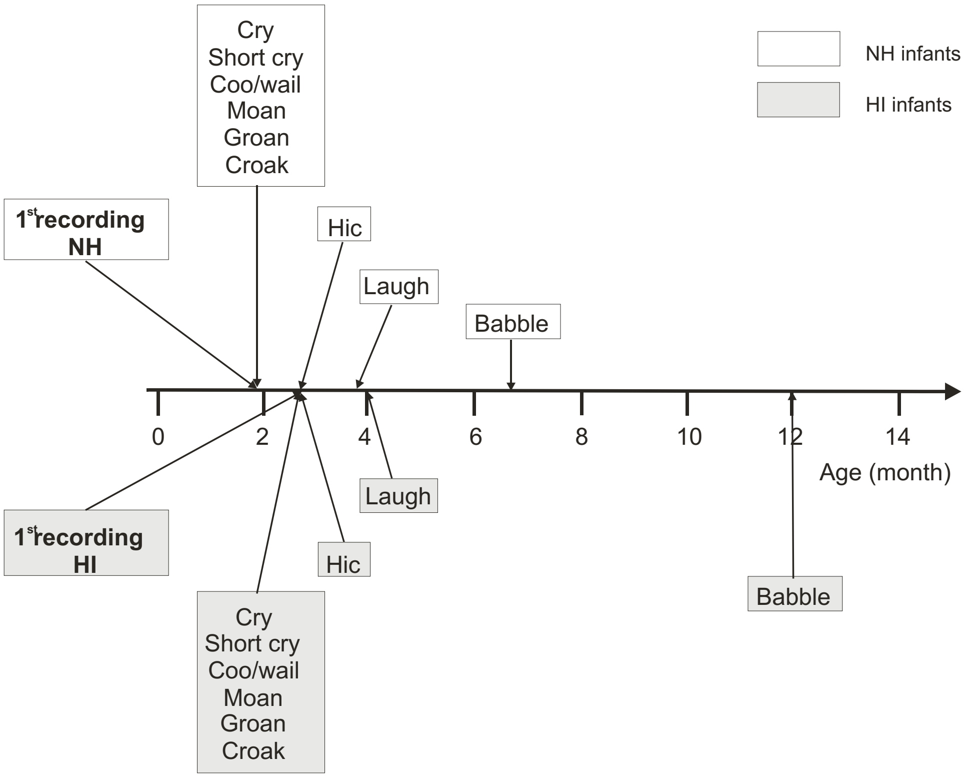

FIGURE 2. Emergence of call types. The figure indicates at which age at least half of the infants recorded in an age-class uttered a certain call type. Note that the age of first recording differs for NH and HI infants.

The call type raspberry is not included in Figure 2, because in our earlier investigation of NH infants, we had excluded this call type from analysis and, therefore, lacked data for comparison in the present study. Table 3 shows that also in the present study, raspberry was less regularly uttered than other call types.

In the following, the findings concerning babbling in HI infants will be explained in more detail, because there were considerable differences between the individuals. Infant HI 1 never babbled while recordings were made (until the age of 51 weeks). HI 7 babbled only once during its last recording at 62 weeks of life. HI 6 produced babbling twice, during the first recording (21 weeks) and once during the last recording (75 weeks). We do not know, however, whether HI 6 and HI 7 increased babbling later on. Babbling of HI 2 and HI 3 was obtained first at the age of 42 weeks; both infants continued to babble in the following recordings. The number of babblings of HI 2 increased steadily in the course of the study, whereas we had a high number of babbling samples from HI 3 at 42 weeks of life, but only low numbers in the following recording sessions. HI 4 produced babbling first at the age of 29 weeks and continued in the following recordings. The number of babbling utterances of HI 4 increased dramatically in the recording at 57 weeks. The onset of babbling in HI 5 is less clear. We recorded a small number of babblings at the early age of 24 weeks, no babbling at the age of 38 weeks and then found large numbers of babbling at the age of 42 weeks and afterwards.

TABLE 3. *Emergence of call types in the HI infants The numbers refer to the number of individuals that produce a specific call type in a given age-class. Note that the total number of recorded individuals differs in the age-classes..*

Age (weeks)	**10**	**17-24**	**25-32**	**33-40**	**41-48**	**49-56**	**57-64**	**65-72**	**73-80**
Total (individuals)	***1***	***7***	***6***	***7***	***7***	***6***	***5***	***2***	***2***
Call type:									
Coo/wail	1	7	6	7	7	6	5	2	2
Moan	1	6	6	7	7	6	5	2	2
Cry	1	7	6	7	7	6	5	2	2
Short cry	1	7	5	4	6	5	4	2	2
Babble	0	2	1	1	4	3	5	2	1
Hic	1	7	6	7	5	6	4	2	2
Laugh	0	6	5	7	6	6	5	2	2
Groan	1	7	6	7	7	6	5	2	2
Croak	1	7	6	7	5	5	5	1	2
Whoop/squeal	1	7	6	7	7	6	5	2	2
Raspberry	0	3	3	4	5	4	1	1	1

Comparison of Call Structure

The principal component analysis performed on the 88 original acoustic variables generated 16 factors with an eigenvalue greater than 1. These 16 factors explained 76.2% of the total variance. The eight most important factors we used for further statistical tests are explained in Table 4.

TABLE 4. *Differences in call structure related to hearing impairment and emotion.*

		NH/HI	**Emotions**		
Factors	**Explained variance (%)**	**cry**	**coo/wail**	**moan**	**cry**
F1: Frequency range, main energy, frequency with the highest amplitude (=peak frequency / PF)	20.3	0.054	-	-	-
F2: Distribution of frequency amplitudes (DFA)	9.8	-	-	-	0.000
F3: Fundamental frequency	9.2	-	0.001	0.001	0.010
F4: Energy in the high frequencies	5.4	-		0.000	0.005
F5: Trend & modulation of PF	5.3	-	0.033	0.000	0.004
F6: Trend & modulation of the 1st dominant frequency band	3.7	-	0.020	0.000	0.021
F7: Duration, tonality	3.4	-	0.025	0.012	0.000
F8: Location of maximum of DFA or PF	3.4	0.018	-	-	-

First column: Description of the principal component analysis factors with an explained variance above 3. Second column: Explained variance values of Factors F1-8. Third column: Differences between the cries of NH and HI infants. The numbers refer to the p-values of the univariate tests, GLM repeated measure, SPSS 10. Fourth to sixth column: Differences between the four emotions (joy, contentment, unease & anger) for the call types coo/wail, moan and cry. The tests for differences between emotions were calculated for NH and HI infants together. The numbers refer to the p-values of the univariate tests.

Multivariate repeated measurement tests (GLM, SPSS 10) showed that there were no significant differences between the first recording (HI infants without hearing aid; age group 2) and age group 5 (infants had a longer experience with their hearing aids, except for 2 infants; see Material and Methods) in any of the call types (cry-positive: $F = 4.83$, $p = 0.8$; cry-negative: $F = 12.05$, $p = 0.217$; coo/wail-positive: $F = 2.06$, $p = 0.488$; coo/wail-negative: $F = 0.43$, $p = 0.822$; moan-positive: $F = 2.03$, $p = 0.488$). The F-values, in contrast, point to an identical structure of the vocalizations uttered before and after wearing hearing aids. Therefore, we pooled several recordings to have a more even sample for the following tests.

The following multivariate tests (GLM, SPSS 10) showed that there were no differences between NH and HI infants in any of the four emotions (joy, contentment, unease and anger), or any of the three call types (coo/wail, moan and cry). The p values ranged from 0.88 to 0.49 for coo/wail, from 0.74 to 0.41 for 'moan' and from 0.29 to 0.22 for cry. Because of the relatively low statistical power of testing 7 against 7 infants (NH/HI), it appeared advisable to calculate a multivariate repeated measurement test including all four emotions at the same time. This test revealed differences in the acoustic structure of cries (F = 6.57, p = 0.026; Hotelling's Trace, GLM repeated measure, SPSS 10), whereas coo/wail and moan did not reach significance (coo/wail: F = 1.02, p = 0.518; moan: F = 0.94, p = 0.557).

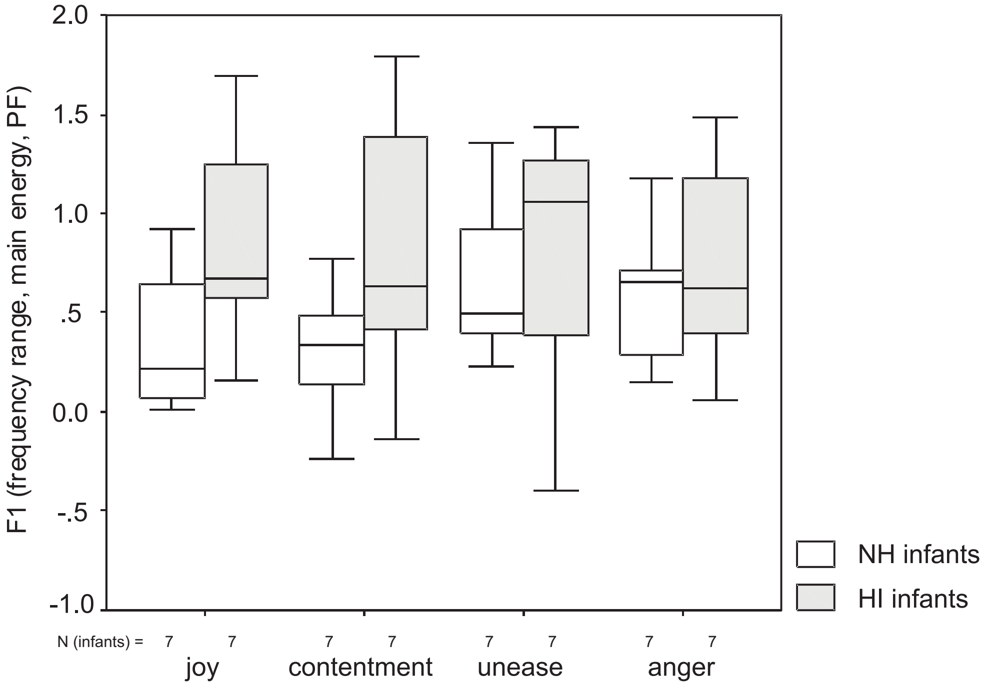

FIGURE 3. Differences between the cries of NH and HI infants in factor 1 (F1), differentiated according to emotion.

Subsequent univariate tests (GLM repeated measures, SPSS 10) revealed substantial differences for cries in two factors (Table 4). F1 failed to reach significance (F = 4.57, p = 0.054), but the boxplot in Figure 3 shows that HI infants exhibit a clear increase in F1 for the two positive emotions (joy and contentment). This indicates that the 'positive' cries of HI infants have a higher frequency range and a higher peak frequency (frequency with the highest amplitude) than the 'positive' cries of NH infants. F8 also did reach significance (F = 7.49, p = 0.018). Here, we found for three of the four emotions (contentment, unease, anger) that HI infants had an earlier maximum in the first dominant frequency band or peak frequency (Figure 4).

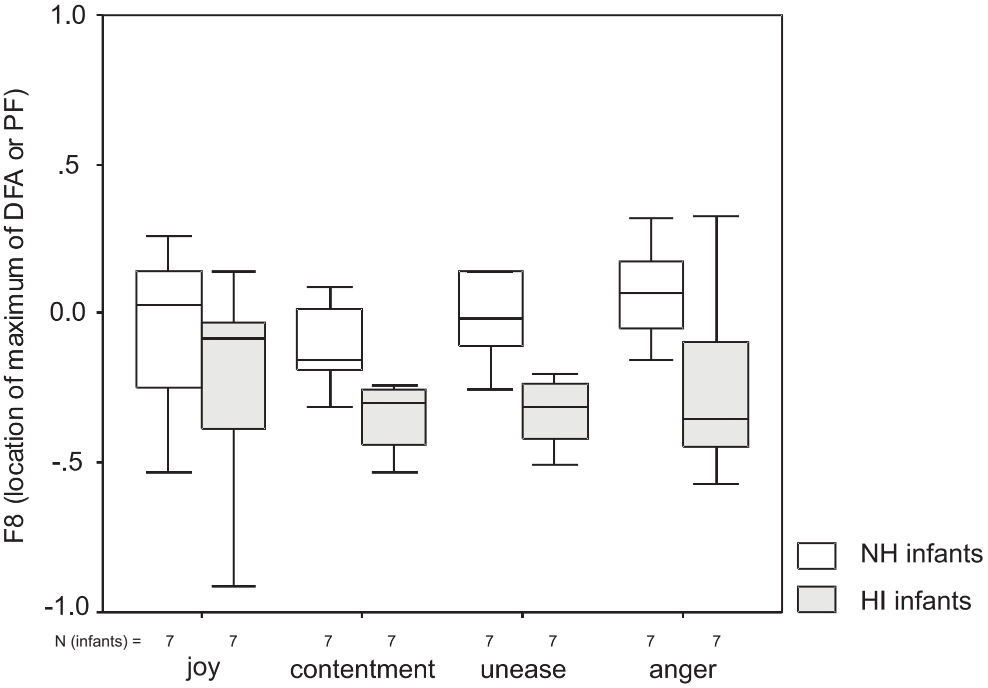

FIGURE 4. Differences between the cries of NH and HI infants in factor 8 (F8), differentiated according to emotion.

We found no differences in the emotional expression between NH and HI infants, although six out of the eight most important factors differ significantly regarding the four emotions. Interestingly, we found no interaction regarding hearing impairment or emotion. The two factors showing substantial differences between NH and HI infants differ from those showing differences in emotion (Table 4).

Discussion

The goal of the present study was to compare the preverbal vocalizations of NH and profoundly HI infants. In general, we found only small differences between NH and HI infants. Except for the onset of babbling, there were no differences in the time of emergence of preverbal utterances. Structural differences were only found in cries. No differences could be found in the expression of emotions.

Babbling in HI infants either was delayed in onset, compared to normally hearing infants, or did not appear at all during the recording period. This finding is in line with previous studies comparing the onset of canonical babbling in NH and HI infants (Beinum et al. 2001; Eilers & Oller 1994; Kent et al. 1987). Information about the emergence of other preverbal vocalizations in HI infants is nearly absent in the literature. One exception is the study by Oller et al. (1985), who compared the vocal repertoire of 1 deaf baby (recordings at the age of 8, 11, 12, and 13 months) with the vocalizations of 11 normally hearing infants (ages 4-6 months). They found that the relative number of various vocalizations (growl, squeal, clicks, trills and vibrants, quasi-resonant nuclei and full resonant nuclei) was not markedly different in the deaf baby from that in the hearing sample. Unfortunately, the study does not provide data on the onset of the different vocalizations, as the deaf baby was already 8 months old at the first recording session.

The emergence of babbling in the HI infants took a long time (Figure 2), although the HI infants in the study were provided with hearing aids from about the second recording on. In contrast, the emergence of the other preverbal vocalizations, not consisting of consonant-vowel repetitions, was not influenced by the hearing impairment of the infants. They passed similar developmental stages as those of NH infants (Oller 1978; Oller 1980; Papoušek 1994; Stark 1980; Tonkova-Yampol'skaya 1969). These results suggest that normal auditory input is not essential for the emergence of these preverbal vocalizations, whereas the development of consonant-vowel repetitions needs an extensive auditory input. This assumption is further supported by the observation that there were no differences in the emergence of single preverbal vocalizations between the 2 infants who received cochlear implants at the end of the study and the other HI infants.

Structural differences in single utterances between NH and HI infants were only found in cries. These results are in agreement with Möller and Schönweiler (1999). By comparing cries of NH infants and HI infants that were not provided with hearing aids, these authors found that HI infants had a longer call duration, lower energy in the bands 2-4 kHz and 6.4-9.5 kHz and a more complex melody contour than NH infants. No differences between HI and NH cries were found in fundamental frequency and in tonality (percentage of harmonic to nonharmonic time segments). An additional analysis of cry bouts revealed that cry bouts of HI infants had lower rhythmic frequencies. Like Möller and Schönweiler (1999), we found no differences in fundamental frequency or tonality. We found significant differences in factor F8, however. HI infants showed an earlier maximum in the first dominant frequency band or peak frequency. The difference in the location of the maximum points to changes in the melody course. Möller and Schönweiler (1999) also reported that the melody structure was more complex in the HI infants. The lack of suitable melody parameters in the present study precludes a comparison with respect to this feature. Regarding the energy distribution, the picture is ambiguous. Except for F1, no other factor describing changes in energy distribution showed any difference. There was an increase in peak frequency and frequency range in our HI infants. It should be kept in mind, however, that we also included cries uttered in positive emotions, and that these cries showed the most prominent increases. Möller and Schönweiler (1999), in contrast, only used distress cries, elicited by putting on uncomfortable headphones.

Compared to the prominent differences in the energy distribution with respect to different emotions (Scheiner et al. 2002), the differences between NH and HI infants appear to be subtle in the case of cries and nonexistent in the case of the other two call types. Since our HI individuals were provided with hearing aids from the second recording on, there is the possibility that the lack of distinct differences in call structure was caused by their hearing experience. The multivariate tests between the first and later recordings, however, do not support this suggestion.

That it is difficult to distinguish between NH and HI infants on the basis of single calls is also supported by the study of Möller and Schönweiler (1999), who recorded only calls of HI infants without hearing aids. In a classification task, inexperienced and experienced listeners had to distinguish between cries of NH and HI infants. The test persons were not able to do this; even the experienced ones, midwives and nurses, were only slightly better than chance. Altogether, it seems that the acoustic analysis of single preverbal calls does not represent a useful diagnostic tool for the detection of hearing impairment in early infancy. One possible exception might be the analysis of melody parameters. Melody parameters have been suggested by Möller and Schönweiler (1999) to play an important role in the distinction of NH and HI infants. Another promising approach might be the analysis of the sequential and temporal organization of call series (Todt 1988; Zeskind et al. 1993). A possible influence of hearing impairment on the temporal organization of call sequences is indicated by the finding that rhythmic patterns in cry bouts and in babbling seem to differ between NH and HI infants. Möller and Schönweiler (1999) found that cry bouts of HI infants had lower rhythmic frequencies than cry bouts of NH infants. Oller and Eilers (1988) found that in babbling sequences the transients between the consonant and the vowel proved to be significantly longer in HI infants than in NH infants. Our own investigations of call sequences have shown that the composition of call sequences uttered by NH infants differs according to emotional context, while there are hardly any emotion-correlated differences in HI infants (Scheiner et al. 2003). As mentioned in the Introduction, call sequences of NH infants uttered in negative emotional context (anger and unease) are characterized by higher rates of cry, hic and ingressive vocalization than sequences uttered in positive emotional context (joy, contentment and interest). Positive emotions, on the other hand, show a significantly higher rate of babble, laugh and raspberry. Joy, furthermore, can be distinguished from contentment and interest by a higher number of the call types laugh and hic and a smaller number of the call type moan. In HI infants, positive and negative emotions only were separable by a higher amount of cries in negative sequences. The only significant difference between the emotion joy, contentment and interest was a higher number of whoop/squeal in joy sequences in comparison with contentment sequences.

In general, it seems that auditory feedback plays a greater role in the control of the sequential and temporal organization of calls than the production of single preverbal vocalizations.