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INFLUENCE OF LACK OF AUDITORY FEEDBACK: VOCALIZATIONS OF DEAF AND HEARING INFANTS COMPARED*

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Abstract

To establish how and from what age onwards speech perception influences the development of vocalizations in the first year of life, we studied the speech production of deaf and hearing infants longitudinally from 2.5 months until 7.5 months of age. Several differences between deaf and normally hearing infants were observed, indicating that lack of auditory feedback influences speech production already at this early age. Differences can be found in several aspects of the speech production, like number of utterances, duration, phonation, and articulation.

1 Introduction

Some recent studies suggest a deviant speech production of hearing impaired compared to normally hearing infants in the first year of age (e.g. Kent et al., 1987). No canonical babbling was found in deaf infants before the age of eleven months while most hearing infants start babbling before that age (Oller & Eilers, 1988). In several studies differences were observed in consonantal features and phonetic repertoire size (e.g. Stoel-Gammon, 1988).

Until now - to our knowledge - no systematic study has been performed on the vocalizations of deaf infants starting within the first half year of life. For instance, no systematic study has done on number of utterances and utterance duration of deaf infants within the first year of life. Studies done, so far, on consonantal features result in some cases even in conflicting conclusions. For example, Kent et al. (1987) found more stops in the vocalisations of a deaf infant compared to his hearing twin brother, while Stoel-Gammon's results showed less stops in the vocalisations of deaf infants compared to hearing peers. Unclear and contradicting results are caused by the use of small subject-groups, a small amount and irregular number of recordings, diversity within the subject-groups (e.g. moderate and profound hearing impairment combined), several definitions of terms like 'babbling', and so on.

The present study reports on longitudinal data of six deaf and six normally hearing infants between 2.5 (or somewhat older) and 7.5 months of age. The main question we address is: do hearing impaired infants differ from normally hearing infants with respect to number, duration, and type of vocalizations?

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2 METHOD

2.1 Subjects

Twelve mother-infant pairs participated in this study; six infants profoundly hearing impaired (group HI) and six matched infants with normal hearing (group NH). The HI infants were found by contacting all Audiology Centres in the Netherlands. The NH infants were found in most cases with help of Infant Welfare Centres in the geographical neighbourhood of the HI infants. All infants have normally hearing parents. No clear health problems, like cognitive or motor delays, were found in a health screening right after birth (Apgar score), nor later on, according to the Denver Developmental Screening Test and the Bayley Developmental Scales, examined at 12 and 18 months of age (Bayley, 1969).

The HI infants had an average hearing loss over 90 dB at the best ear, established by Auditory Brainstem Response audiometry (ABR) in the first six months of life. The profound hearing loss was confirmed by several pure-tone audiometric tests at later ages. Hearing aids were frequently used by three subjects (HI-1, HI-2 and HI-3) within the studied period. Two HI infants were raised with Dutch Sign Language / TC (Total Communication), two infants by TC, and two mainly by the Oral method. All HI infants participated in early intervention programs, including hearing training. In table 1 the relevant characteristics of the HI subjects are described. The indicated hearing losses for the HI infants in table 1 were based on the last audiometric test per subject, by averaging response levels at 500, 1000 and 2000 Hz.

Table 1. Characteristics of HI subjects

Subject	Hearing loss (dB) best ear	Loss with Hearing aids (dB)	Age at last test (months)	Age at diagnosis (months)	Hearing aids from age(m)	Language method	Start of recordings(m)
HI-1	97	55	45	1.5	2.0	Oral	2.5
HI-2	93	55	37	3.0	3.5	TC	5.5
HI-3	110	65	32	4.0	4.5	Oral	5.5
HI-4	> 120	not tested	26	0.5	no	NGT/TC	2.5
HI-5	120	not tested	26	3.0	6.5	NGT/TC	3.5
HI-6	> 100	> 100	19	5.0	7.5	TC	5.5

The NH infants were matched with the HI infants on the following criteria: sex of the child, birth order within the family, duration of pregnancy, age of the mother, socio-economical status of the parents, and dialect of the parents. All NH infants were recorded from the age of 2.5 months onwards, two HI infants from the age of 2.5 months, one from 3.5 months and three from the age of 5.5 months onwards.

2.2 Data collection

Audio recordings, lasting about half an hour each, were made every two weeks. The mothers of the infants themselves made the recordings at home after proper instructions and regular feedback. The mothers were asked to talk with their children in a face-to-face situation while the children were sitting in an upright position.

2.3 Procedure of analyses

A. Transcriptions:
Of every monthly audio recording, all mother and infant utterances during the first 10 minutes were transcribed. Every infant sound production was categorized as utterance or non-utterance. An infant utterance was defined as a sound production during one breath cycle, starting with inspiration. Non-utterances were sounds like laughing, crying and vegetative sounds, and were excluded for further analysis. Two trained phoneticians performed and verified the transcriptions. The inter-judge agreement based on all material (62 recordings) was 93% for the infant utterances.

B. Number of utterances and utterance duration:
The total number of infant utterances during the first 10 minutes per recording were counted. Next, fifty infant utterances per recording were selected evenly out of the transcribed ten minutes. The total of 3100 (62 times 50) utterances were digitized into a computer with a sample frequency of 48 kHz and stored for further analysis. The duration was measured in ms on positive zero-crossings.

C. Classification of phonation and articulation types:
Each utterance was classified according to one of five possible phonation types:

1) uninterrupted phonation
2) interrupted phonation
3) variegated phonation (variation in intonation, pitch, or loudness, e.g. screaming and growling)
4) a combination of interrupted and variegated phonation
5) no phonation.

Furthermore, each utterance was classified in one of three possible articulation types:

1) no articulatory movement
2) one articulatory movement (e.g. gooing)
3) two or more articulatory movements during two or more syllables, i.e. babbling.

This classification was based on an earlier study on infant speech development (Koopmans-van Beinum & Van der Stelt, 1986). The classification was performed by one trained phonetician. To test the reliability of the classification by this listener, part of the material (18 recordings) was also classified by a second trained listener and the inter-judge agreement amounted to 88%. For more details about the analysis procedure for establishing number of utterances, duration, articulation-type, and phonation-type see also Clement et al. (1994; 1995).

D. Classification of the articulation movements:

The articulation movements were classified in

a) place of articulation:	front (labial, labial-dental)
	central (dental, alveolar, palatal)
	back (velar, pharyngeal)
b) manner of articulation	fricatives and trills combined
	stops (including affricates)
	glides (/j/ or /w/-like)
	nasals
	laterals (/l/-like)

Glottals were not taken into account in the analysis. The central place of articulation and nasal and lateral manner of articulation were rarely found and therefore left out of consideration in this paper.

In case of two or more articulatory movements within one utterance the following conventions were used:

- Two or more articulatory movements with different places of articulation (e.g. "pɑɤ" or "ɑpɤ") were separately classified.
- Two or more articulatory movements with the same place of articulation were classified as one articulation if:

a) they were produced with the same manner (e.g. "ɤɑɤ"), or

b) they were produced with different manner and not separated by a vowel-like segment (e.g. "ɑɤk"; in this case a back stop).

- Two or more articulatory movements with a different manner, separated by a vowel-like segment (e.g. "kɑɤ") were classified separately.

Of the total of 980 utterances with articulatory movements 17 utterances were found to include two different articulation movements in the above described way. The classification of place and manner of articulation movements was performed two times by a trained phonetician. The intra-judge agreement based on all 997 different articulation movements was 89% for place of articulation and 87% for manner of articulation.

3 Results

3.1 Number of utterances

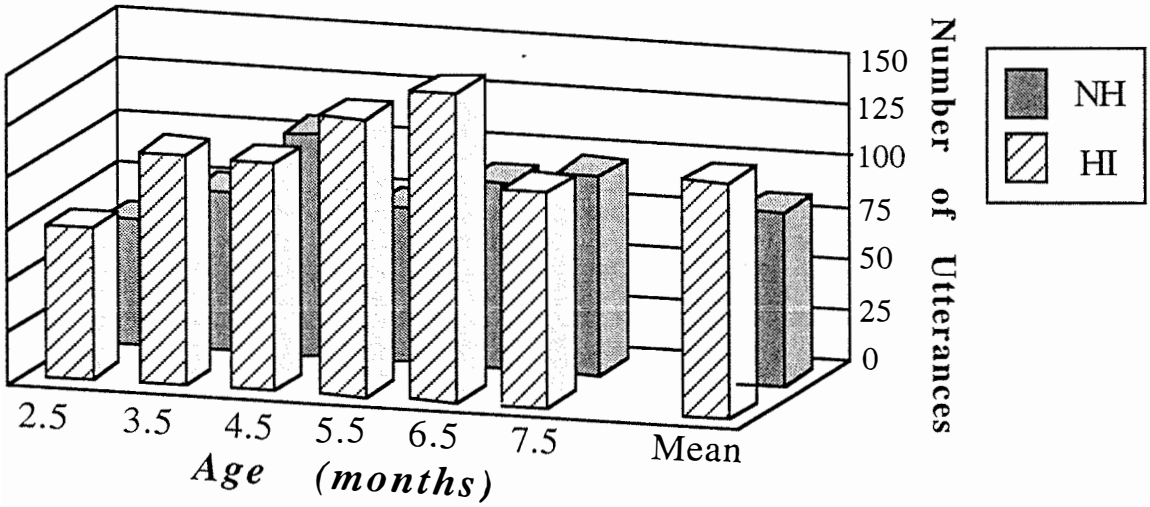

Figure 1. Mean number of utterances during ten minutes per recording as well as the average number over six months for both groups. (N=6 in case of the NH infants at every age. N=2, 3, and 3 at 2.5, 3.5, and 4.5 months respectively, N=6 at 5.5, 6.5, and 7.5 months in case of the HI infants.)

It can be observed in figure 1 that the mean number of utterances for the combined six months is higher in case of the HI infants (115, sd=45) compared to the NH infants (85, sd=37). A t-test on the data of the combined six months indicates a significant difference between the groups (t (60)=2.95, p≤.005, one-tailed). We can get some indication of a developmental effect by performing running statistics on each time three months combined: a) 2.5, 3.5, 4.5; b) 3.5, 4.5, 5.5; c) 4.5, 5.5, 6.5; d) 5.5, 6.5, 7.5. By means of a Mann-Whitney U-test no significant differences between the HI and NH infants are found at 2.5-4.5 months. At the later ages, a Mann-Whitney U-test shows that HI infants produce significantly more utterances than their hearing peers (3.5-5.5: p<.005; 4.5-6.5: p<.025; 5.5-7.5: p<.005).

3.2 Utterance duration

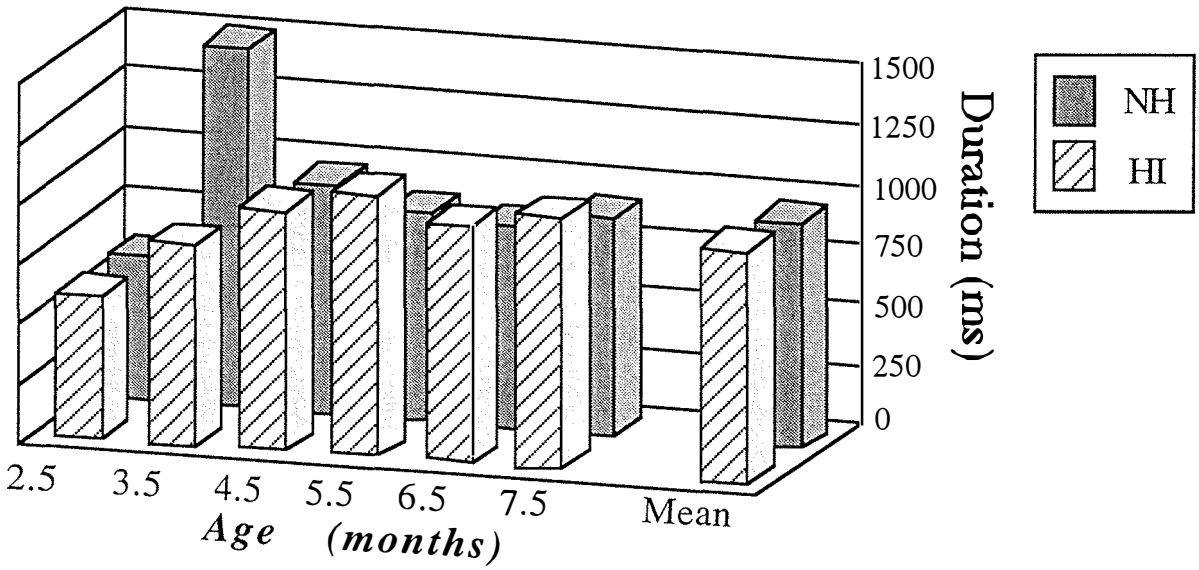

Figure 2. Mean utterance duration for the HI and the NH group per month, as well as the mean duration for the six months combined. (N=300 at every age of the NH infants. N=100, 150, and 150 at 2.5, 3.5, and 4.5 months respectively. N=300 at 5.5, 6.5, and 7.5 months in case of the HI infants.)

In figure 2 the mean utterance duration of the 50 selected utterances is presented per month, as well as the average duration over the six months for both groups. It can be observed that the mean utterance duration for the six months combined is somewhat longer for the HI infants (997 ms, sd=761) than for the NH infants (948 ms, sd=761) although not significant. A z-test on the months combined shows a low significant difference (z=1.77, p≤.05). A z-test performed on the utterance duration per month indicates that from 5.5 months to 7.5 months the HI infants produce longer utterances (5.5: z=3.72, p≤.0005; 6.5: z=2.65, p≤.005; 7.5: z=2.63, p≤.005) than the NH infants. At the age of 2.5 and 4.5 months no significant differences between the two groups are found. At the age of 3.5 months, however, the mean duration of the NH infants is considerably longer than at any other age in the studied period. A z-test indicates that the NH infants produce significantly longer utterances at the age of 3.5 months than the HI infants (z=9.45, p≤.0005). All NH infants show this 'peak' in the duration at 3.5 months, except one infant who produces the peak at 4.5 months.

3.3 Phonation

The utterances with interrupted phonation (without articulation), and with variegated phonation (possibly with one articulation movement) are presented in figure 3. It can be seen that NH infants produce more interruptions in the airflow specially in the later months ($p \leq .025$ for the data at 4.5-6.5 and 5.5-7.5 months according to a Mann-Whitney U-test). Although a tendency for more variegated phonation by the HI infants can be observed, no significant differences are found.

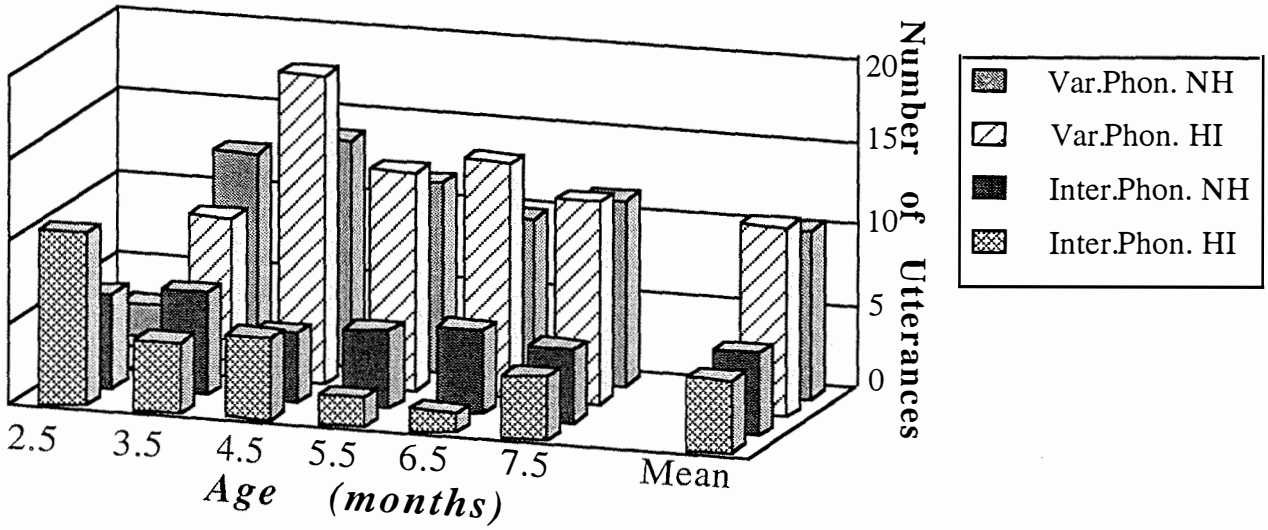

Figure 3. Mean number of utterances with interrupted or variegated phonation for the NH and HI group per month, as well as the mean for the 6 months combined. (N: see fig. 1)

3.4 Articulation

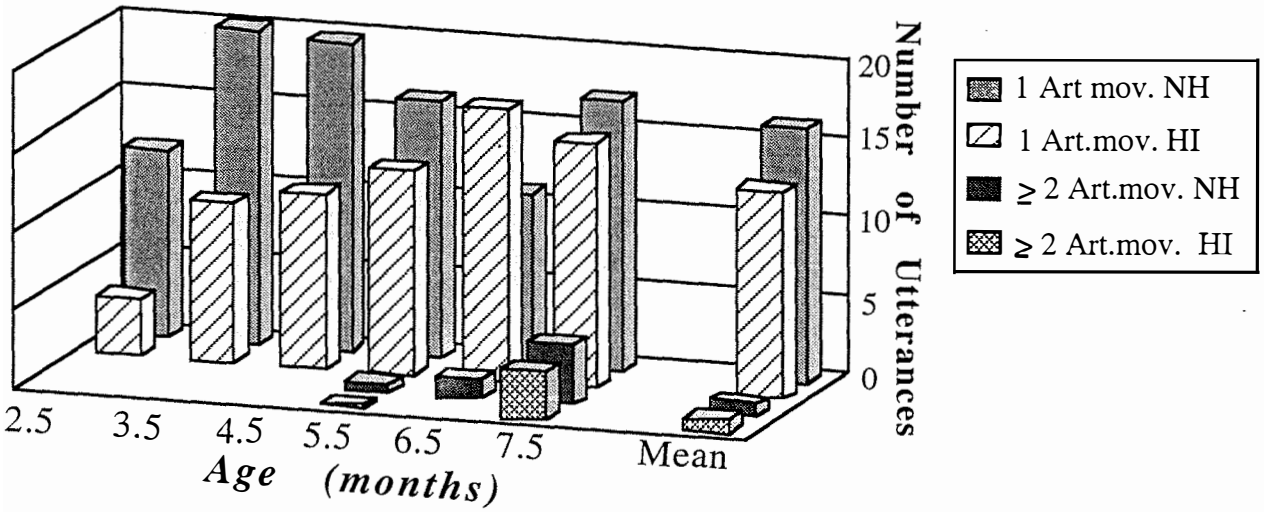

Figure 4. Mean number of utterances with 1 articulation movement and with 2 (or more) articulation movements for the NH and HI group per month, as well as the mean for the 6 months combined (N: see fig. 1).

In figure 4 the "articulation types" are shown per age for both groups. A tendency can be observed that the HI infants produce fewer utterances with articulation movements than NH infants in the first months, although this turned out to be not significant according to a Mann-Whitney U test, nor in the later age period. As expected, utterances with 2 or more articulation movements (babbling) are produced more often by NH infants than by HI infants in the later 3 months combined ($p \leq .05$). The total amount of this utterance type in the HI group is due to only subject HI-2 who started to babble at 7.5 months of age. None of the other HI infants started babbling before 18 months of life. All NH produce some babbled utterances within the described period, although only two of the NH infants produce this type extensively (6 and 14 out of the 50 utterances of the recording at 7.5 months). The other four NH infant make at least six babbled utterances out of the 50 utterances per recording at 8.5 or 9.5 months of age.

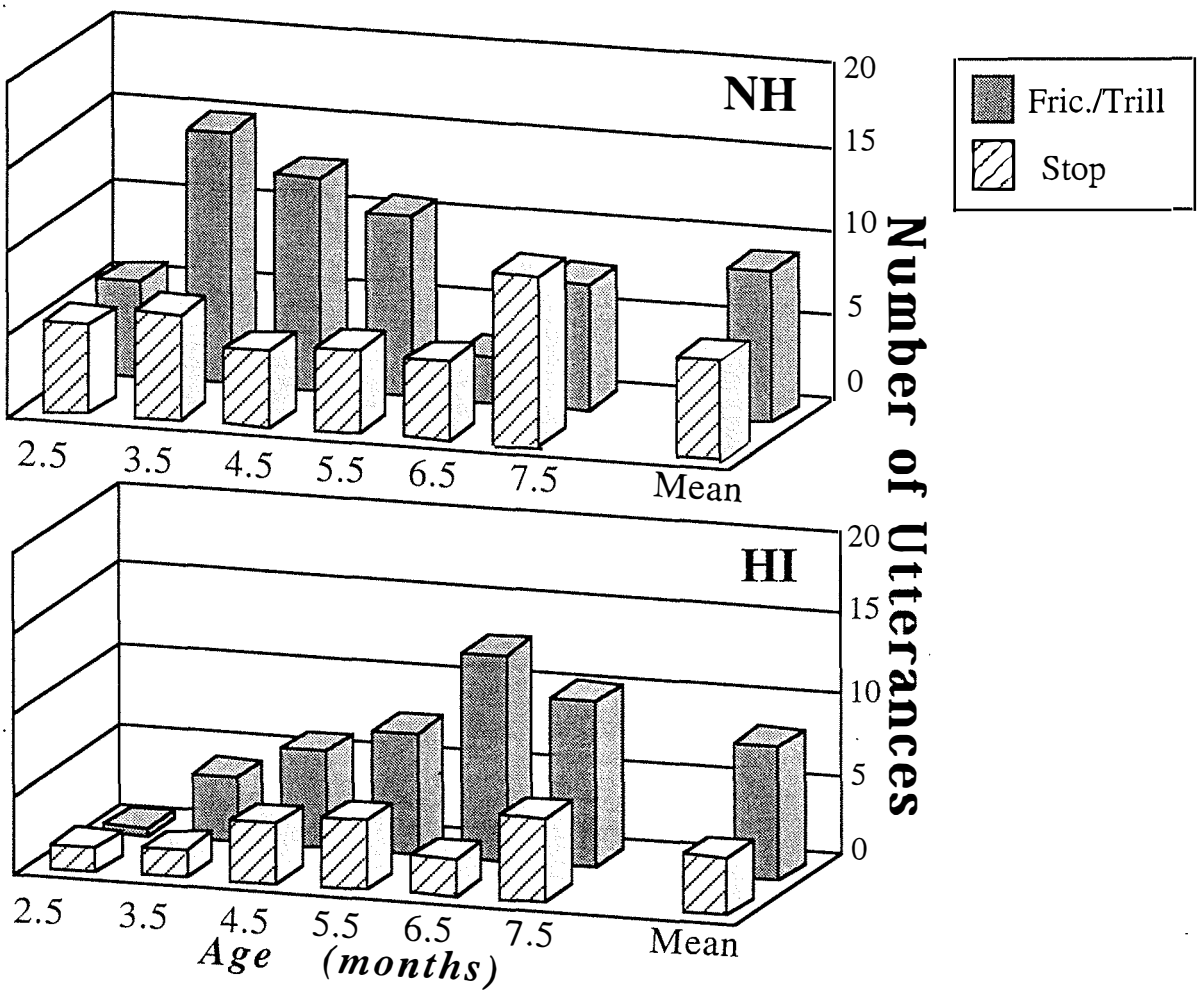

Figure 5. Mean number of utterances with fricative/trill articulations and stop articulations per month, as well as the mean for the six months combined, for the NH and HI group separated (N: see fig. 1).

Figure 5 shows the number of utterances with fricative/trill and with stop articulations per month for both groups. It can be seen that the NH infants produce more fricatives and trills than stops in the first months (3.5-5.5 months: $p \leq .025$ by

means of a Wilcoxon Signed-Ranks test). At 7.5 months the number of stops increased compared to the first period. The HI infants produce an increasing number of fricatives and trills until 6.5 months compared to the number of stops ($p \leq .025$ at the age of 4.5-6.5 and 5.5-7.5 months according to a Wilcoxon Signed-Ranks test. According to a Mann-Whitney U test the differences between the HI and NH infants for fricatives/trills and stops are not significant.

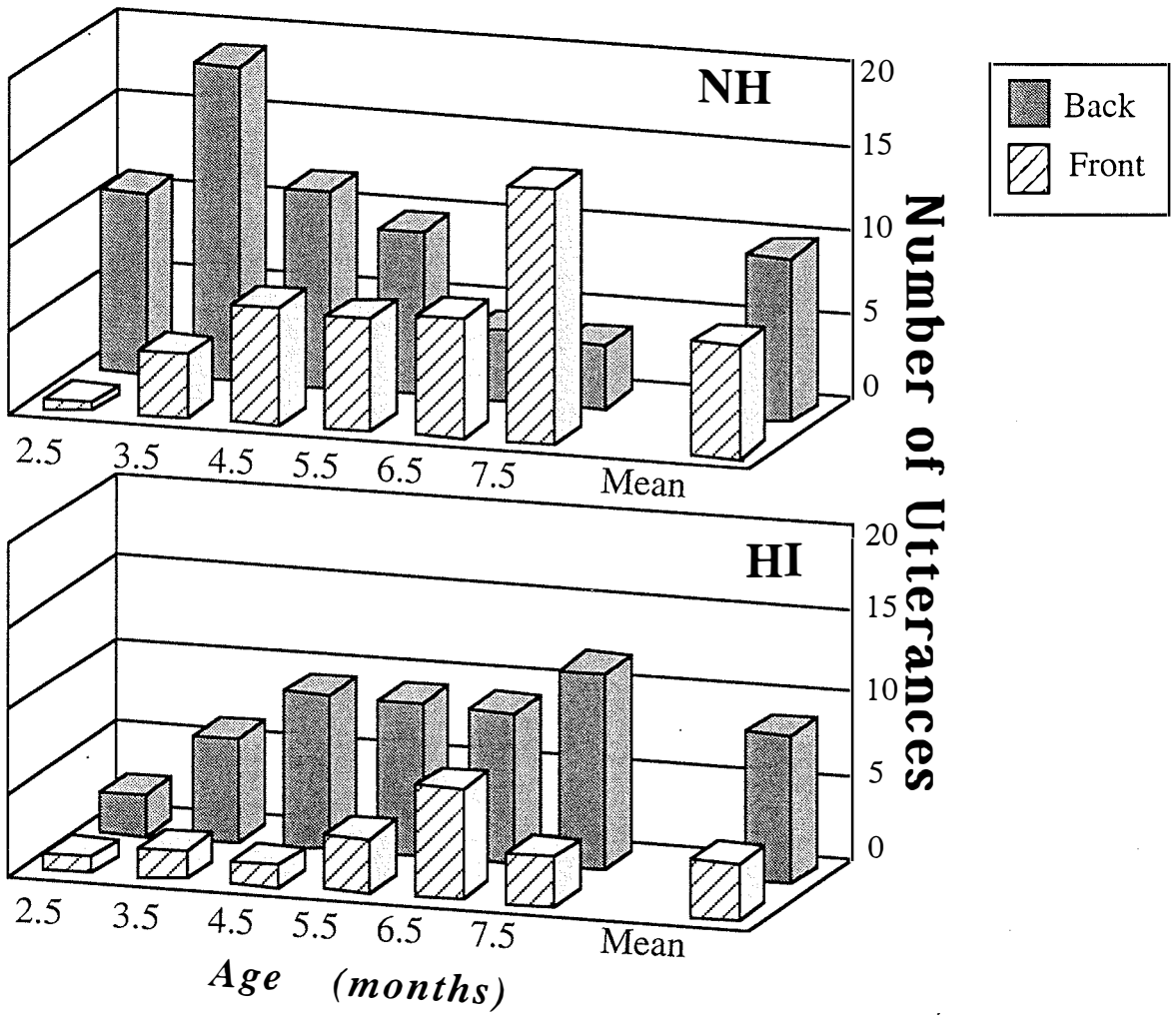

Figure 6. Mean number of utterances with back and front articulations per month, as well as the mean for the six months combined for the NH and HI group separated (N: see fig. 1).

In figure 6 the mean number of utterances with back and front articulation are shown per age for both groups. It can be observed that the NH infants produce more utterances with back articulation movements than with front articulations in the first couple of months (2.5-4.5 months: $p<.01$ and 3.5-5.5 months: $p<.025$ according to a Wilcoxon Signed-Ranks test). At the age of 7.5 months the front articulations increase dramatically. The HI infants produce a higher number of back articulation movements compared to front articulations from the first months until the last studied month (2.5-4.5 months: $p<.025$, 3.5-5.5 months: $p<.01$, 4.5-6.5 months: $p<.05$ and 5.5-7.5 months: $p<.025$ according to a Wilcoxon Signed-Ranks test).

At the age of 5.5, 6.5 and 7.5 months the NH infants produce more utterances with front articulation ($p<.025$) and fewer with back articulations ($p<.05$) compared to the

HI infants according to a Mann-Whitney U-test. This increased number of front articulations in case of the NH infants can be related to the start of the babbling stage.

We can look more precisely at the articulation movements by combining the manner of articulation with the place of articulation (figure 7). At the age of 6.5 and 7.5 months combined the HI infants produce significantly more utterances with back fricatives and/or back trills compared to NH infants ($p<.025$ according to a Wilcoxon Signed-Ranks test). On average the HI infants produce 8.5 and the NH infants 2.3 back fricatives and trills.

In the same age period all NH infants produce many more front stops (/b/- or /p/-like segments) or front glides (/w/-like segments) than the HI infants do. NH infants make three or more front stops or front glides out of 50 utterances per recording (at least during one recording in that period). The HI infants produce maximal two front stops or front glides out of 50 utterances per recording, except HI-2 who started babbling in this period. On average the NH infants produce 8.3 front stops or front glides and the HI infants 1.8. This difference turned out to be significant by means of a Wilcoxon Signed-Ranks test ($p<.025$).

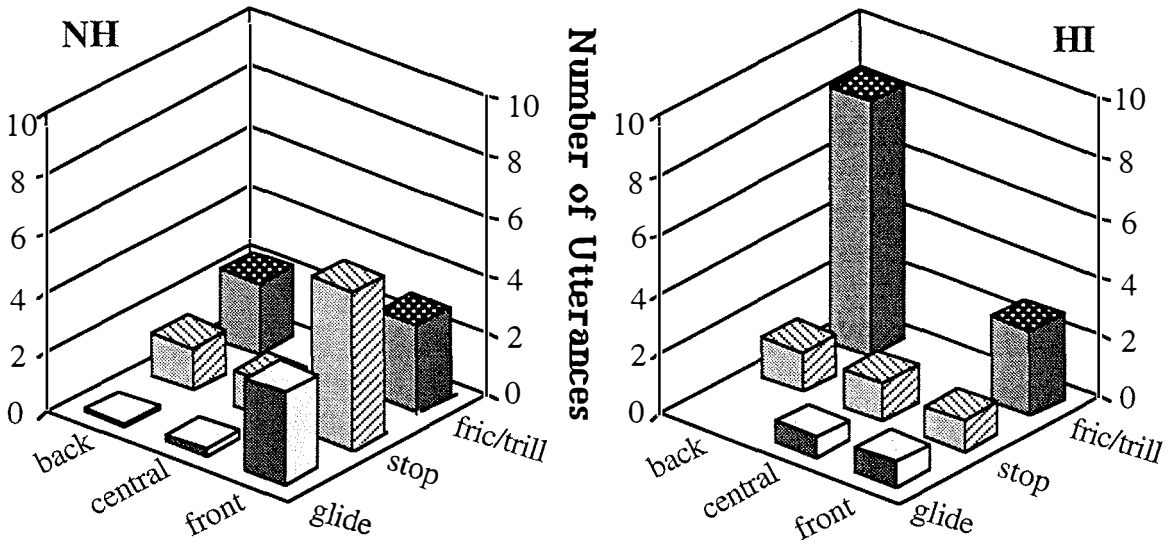

Figure 7. Mean number of utterances with the combination of place and manner of articulation at the age of 6.5 and 7.5 months combined, for the NH and HI group separated (N=12 in both figures).

4 Discussion

In the present study it could be observed that, as a group, the HI infants produced more utterances than their hearing peers in the period between 2.5 and 7.5 months. This was found as well in a previous study on a subgroup of the HI and NH infants between 5.5 and 9.5 months of age (Clement et al., 1994). These results support the suggestion of Locke and Pearson (1992) that deaf infants vocalize more than normally hearing infants do, possibly due to extra effort HI infants expend to get auditory stimulation. It might be that the often reported reduction in number of utterances takes place after the period we studied, namely towards the end of the first year (e.g. Maskarinec et al., 1981).

Furthermore, we found a longer utterance duration for the NH infants at age 3.5 months compared to the HI infants (see fig. 2). It seems that infants can produce longer utterances after their third month of life, when their rib cage has restructured towards the adult configuration (Langlois et al., 1980). From that age NH infants can control the duration of their utterances by regulating their sub-glottal air pressure, as is shown by examples of imitation of the duration and pitch of mother utterances by a three months old infant (Sandner, 1981). According to Lieberman (1986) it might be the case that the probably innate propensity for sub-glottal air pressure and laryngeal muscles needs to be exercised within a critical period. He suggests that the lack of exercising in this period might result in the extremely poor control of sub-glottal air pressure and larynx muscles by older deaf children. The lack of a "duration peak" by the HI infants at about 3.5 months in our study seems to support this idea. After the 5th month, the HI infants produce somewhat longer utterances than the NH infants.

In the phonation domain we found differences between the two groups in number of utterances with interrupted phonation, particularly in the later ages of the studied period. We did not find evidence for the finding of Stark (1983) that the sound types which are characteristic of the "vocal play stage" (experimentation with squealing, growling, friction and other noises) are produced by HI infants to a limited extent only. A possible explanation for this difference in results might be that Stark studied the utterances of HI infants from 15 months onwards.

We agree with Oller et al. (1985), Stoel-Gammon and Otomo (1986), Stoel-Gammon (1988), and Kent et al. (1987) that HI infants differ from NH infants in phonetic properties of their vocalizations. In our study differences in both place and manner of articulation were found (see fig. 5, 6, and 7). Studying the two groups separately it could be observed that the NH infants produced significantly more fricatives/trills than stops in the period between 3.5 and 5.5 months of age. After this period the number of fricatives/trills and stops were not significantly different. Differently from NH the HI infants produced more fricatives/trills than stops until the end of the studied period (and significantly at the age between 4.5 and 7.5 months). Also Stoel-Gammon (1988) found in her study a lower proportion of stops and affricates by HI infants compared to NH infants.

With respect to the place of articulation we could observe approximately the same effect. NH infants produced in the periods of 2.5-4.5 and 3.5-5.5 months of age significantly more back than front articulations. In the periods of 4.5-6.5 and 5.5-7.5 months front articulations relatively increased and no significant difference could be found between back and front articulations. Like NH infants, the HI infants produced in the first couple of months mainly back articulations. HI infants, however, continued producing significantly more back than front articulations until the end of the studied period. Similar results were found by Smith (1982). In our study, observing the period of 6.5 and 7.5 months particularly, it was found that the HI infants produced significantly more back fricative/trill articulations than the NH infants did. This type of articulation movements is typically produced by NH infants in the first months of life (e.g. Stark, 1980; Koopmans-van Beinum & Van der Stelt, 1986).

Opposite to our results, Stoel-Gammon (1988) reported a higher number of labials produced by HI infants compared to NH infants. The explanation for this contradiction in results is that she combined recordings of a larger age period (4.2 to 25.8 months in case of the "young" HI infants) while in our study we were able to compare between the groups per month between 2.5 and 7.5 months of age. According to Smith (1982), not before the 15-18 month age range, labial productions clearly begin to predominate in the consonant productions of the HI children. The HI infants of our study produced significantly *fewer* front articulations compared to their NH peers, specially front stops and front glides, in the period between 5.5 and 7.5 months. Front stops and

front glides might be related to the beginning of babbling. Although not all front stops and front glides are 'babbled' (29.7 %) by the NH infants, most of the articulation movements in the babbled utterances are produced with front stops or front glides (84.8 %). This result suggests that the beginning of babbling is related with, or even conditioned by, the production of front stops or front glides.

The HI infants produced fewer babbling utterances within the studied age period than their NH peers. This result was found by Oller & Eilers (1988) as well, who observed that no canonical babbling was found in deaf infants before the age of 11 months, while hearing infants start babbling before that age (Koopmans-van Beinum & Van der Stelt, 1986). Also Spencer (1993) found that NH infants produce seven times more vocalizations with canonical syllables than HI infants at the age of 12 months. According to Spencer (personal communication, 1994) babbling before about 11 months always means a usable hearing residue. In our study the only HI child who started babbling within the studied period, turned out to have a usable hearing residue and enrolled in a school for hearing impaired children instead of a school for deaf children, although his average hearing loss was over 90 dB. This example proves that we should be cautious when 'labelling' the child as deaf, simply defining deafness as having a hearing loss of 90 dB or more at the best ear. It is absolutely not evident why and in what cases a specific hearing residue may indeed function as a usable hearing residue. We have to consider as well factors like the functioning of the child with his/her hearing loss and hearing aids and the form of the audiogram, for instance a flat curve (so called continuing audiogram) or a steep audiogram with a high tone loss. At this moment it is not totally clear if the amount of babbling or of other vocalization forms can be used as a diagnostic tool for early detection of hearing impairment or as a prognostic tool for speech development in HI children, but our preliminary results seem to be promising.

5 Conclusion

It seems that already within the investigated period, i.e., between 2.5 and 7.5 months of age, several differences in the speech production between HI and NH infants can be observed. The differences become more clear from about 5.5 months onwards, with respect to number of utterances, utterance duration, phonation type, place and manner of articulation, and babbling. This may be due to lack of auditory feedback on the speech production from that age. In the first months fewer differences between the two groups can be observed. This may suggest a stronger influence of biologically determined factors (e.g. anatomical growth) on vocalizations in these first months compared to a later period.

However, since the results of the present study are based on a small sample size, specially in the early months of age, caution should be taken when making any conclusion. In the period between 2.5 and 7.5 months, described in this paper, we observed a number of differences in the vocalizations between six deaf and six hearing infants. These differences can be found in several aspects like number of utterances, duration, phonation, and articulation. Our preliminary results suggest that a lack of auditory feedback influences the speech production already in this very early stage of development.

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