CHARACTERISTICS OF VOCALIZATIONS OF DEAF AND HEARING INFANTS IN THE FIRST YEAR OF LIFE

Chris J. Clement and Florien J. Koopmans-van Beinum
Institute of Phonetic Sciences & IFOTT, University of Amsterdam, The Netherlands
email: clement@fon.hum.uva.nl

ABSTRACT

The influence of hearing on sound production of infants is studied by comparing the vocalizations of six deaf and six hearing infants in the first year of life. Results indicated clear differences between deaf and hearing infants, even within the first six months of life. The difference was significant regarding such aspects as number of utterances, utterance duration, and place of articulation. For hearing infants, place of articulation of consonant-like segments develops systematically within the first year. None of the deaf infants studied showed a development of place of articulation similar to that of the hearing infants. Moreover, the number and the duration of utterances differed significantly between the two groups. Deaf infants produced *more* utterances than the hearing infants and at 3.5 months the average sound duration was significantly longer for the hearing infants than for the deaf infants. These findings strongly suggest that already in this early stage of speech development, sound production might not solely be determined by anatomical and physical constraints, but also by auditory perception.

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. [5]. No canonical babbling was found in deaf infants before the age of eleven months while most hearing infants start babbling before that age [10]. In several studies differences were observed in consonantal features and phonetic repertoire size, e.g. [12].

Until now - to our knowledge - no systematic study has been performed on characteristics, such as number of utterances and duration of the sound production of deaf infants starting within the first half year of life. Most studies, e.g. [5] investigate infants systematically not earlier than at the end of the first year of life. The present study reports on longitudinal data of six deaf and six normally hearing infants between 2.5 (or somewhat older) and 11.5 months of age. The main question we address is: do hearing impaired infants differ from normally hearing infants with respect to number of utterances, utterance duration and place and manner of articulation?

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). No clear health problems, like cognitive or motor delays, were found by means of developmental tests. The HI infants had an average hearing loss of 90 dB or more at the best ear, established by Auditory Brainstem Response audiometry (ABR) in the first six months of life. This profound hearing loss was confirmed by several pure-tone audiometric tests at later ages. Hearing aids were regularly used by five subjects within the period studied.

The NH infants were matched with the HI infants on the following criteria: sex, birth order, 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. Analysis Procedures

Audio recordings, lasting about half an hour each, were made every two weeks. Of every monthly audio recording, the first 10 minutes were transcribed with respect to infant utterances. An infant utterance was defined as a sound production during one breath cycle starting with inhalation. Laughing, crying, and vegetative sounds were not taken into account. Two trained phoneticians performed and verified the transcriptions. The inter-judge agreement based on all material (11274 infant utterances during 108 recordings) was 93% for the infant utterances (see [1] and [3] for more details about the subjects and procedure of analyses). The number of infant utterances during the first 10 minutes were counted.

Further on, for duration measurements and establishing of place and manner of articulation fifty infant utterances per recording were selected evenly from all the transcribed ten minutes. All 5381 (107 times 50 and 1 times 31) utterances were digitized with a sample frequency of 48 kHz and stored for further analysis. The duration was measured in ms if possible on positive zero-crossings.

As a third step, out of the 50 utterances per recording the utterances with articulation movements (consonant-like segments) were selected. We found a total of 1880 utterances with articulation movements. In a considerable number of the utterances only one articulation movement was produced (NH: 33.6%, HI: 28.5%), in a relatively small number of utterances two or more articulation movements during two or more syllables (babbling) were found (5.2% produced by and averaged over all six NH infants, 1.7% produced by only one HI infant). All randomly ordered articulation movements were judged on place (front, central, back) and manner of articulation (stops, fricatives/trills, nasals, glides, laterals) (see [2] for a detailed description). Neither vowels, nor glottals or voicing were taken into account in this analysis. In case two or more different articulation movements were found, they were counted as two separate articulation movements if they contained different places and manners of articulation (e.g. [bla]). If the same type of articulation movement occurred two or more times within the same utterance it was counted just once (e.g. [bebaba]). In total 2053 different articulation movements were found. The classification of place and manner of articulation movements was performed by one trained phonetician for the complete data set. Subsets of these data were also classified by a trained control listener and by a control group of trained students with an inter-judge agreement of over 80%.

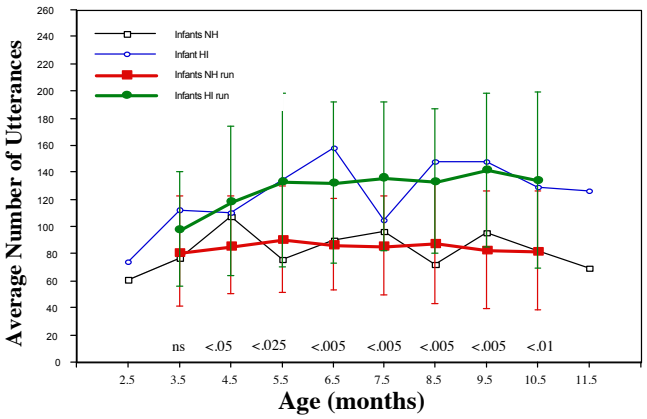

Figure 1. Number of utterances produced by each group, as a running average over three months (bold line), as well as per month (dashed line). Also the standard deviation per three months is shown. N = 6 in case of NH infants at every age, except 8.5 and 9.5, when N=5. In case of the HI infants. N=2, 3, and 3 at 2.5, 3.5, and 4.5 months, respectively, N=6 from age 5.5 onward.

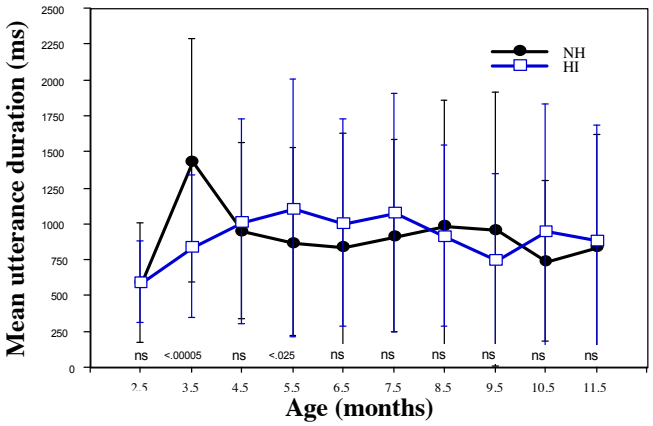

Figure 2. Mean utterance duration and standard deviations of the 50 selected utterances for the HI and the NH group per month. N is 300 at each age of the NH infants, except at 9.5 and 10.5 months when N = 250. N is 100, 150 and 150 at 2.5, 3.5 and 4.5 months respectively and 300 at 5.5 to 11.5 months in the case of the HI infants.

3. RESULTS

3.1. Number of utterances

The mean number of utterances over the whole period was higher for the HI infants (130.1, sd = 57.8) than for the NH infants (82.2, sd = 38.1). A z-test on the data of the combined ten months indicates a significant difference between the two groups ($p<.0005$).

Looking at the data per month the same tendency can be observed as in the whole period studied, even within the first half year of life. 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, but at all later ages, a Mann-Whitney U-test shows that HI infants produce significantly more utterances than their hearing peers do. In figure 1 the average number of utterances per month and the running averages per three months are shown for both groups. The standard deviations for the running averages are also shown [see also 1,2].

3.2. Utterance duration

In figure 2 the mean utterance duration of the 50 selected utterances is presented per month.. An analysis of variance shows a significant effect for age and for the interaction group*age ($p<.00001$). A Tuckey post-hoc test indicates that this interaction effect is caused by the long utterance duration at 3.5 months for the NH infants. The mean duration at 3.5 months of the NH infants is considerably longer than that of the HI infants at that same age or at any other age in the studied period ($p<.00005$). Tuckey post-hoc test on the data at 3.5 months shows a significant difference ($p<.01$) between the three HI infants and the six NH infants, except one NH infant who produces the peak in duration at 4.5 months (see also [2,3]).

3.3 Place and manner of articulation

In figure 3.a the *place* of articulation for HI, NH, 2-years-olds and adults is shown. It can be observed that the HI infants produced mainly back articulations during the first year of life. Although the percentage back articulations decreases slowly, it is the main place of articulation over the whole period. The percentage front and central articulations is relatively low. For the NH group, however, we see a different developmental process. In the first months the NH group produced also mainly articulations in the back part of the vocal tract. Over 70 % of the articulations at 2.5, 3.5, and 4.5 months combined were produced at the back place of articulation. However, in the beginning of the second half year the front articulations are produced over 50 % with a peak of 55 % at 7.5 months. At the end of the first year central articulations take over and are produced over 50 % on average. In figure 3.a it can be seen that also for adult Dutch speakers the central place of articulation occurred most often (70.8 %), followed by the front place (17.1 %), while the back place (12.0 %) was produced least frequently by adult speakers (Celex database, see also [3]). Children of 2.0 years of age show the same pattern as the infants and adults for place of articulation [4]. Their percentages seem to be in between the infants and adults. In general, it seems that already at the end of the first year, the place of articulation for hearing infants is similar to that of the two years olds and the adults.

By comparing both groups per age, significant differences can be found from age 5.5-7.5 months onwards. At that age normally hearing infants produce - as a group - significantly more front articulations ($p<.01$), and fewer back articulations than their hearing impaired peers ($p<.05$). Until 8.5-10.5 months of age the NH infants keep on producing significant more utterances with front articulation (mainly front stops which are hardly produced by the HI infants) and until 9.5-11.5 months fewer with back articulations compared to the HI infants. The back articulations produced by the HI group were mainly back fricatives and trills, which the HI infants kept producing very frequently (around 40 % on average) during the whole first year, while in the NH group the percentage back fricatives gradually decreased from 33 % at 3.5-6.5 months until 5.1 % at 9.5-11.5 months. At the age of 8.5-10.5, and 9.5-11.5 months the NH infants produced significant more utterances with central articulation (mainly central stops and central nasals) than HI infants.

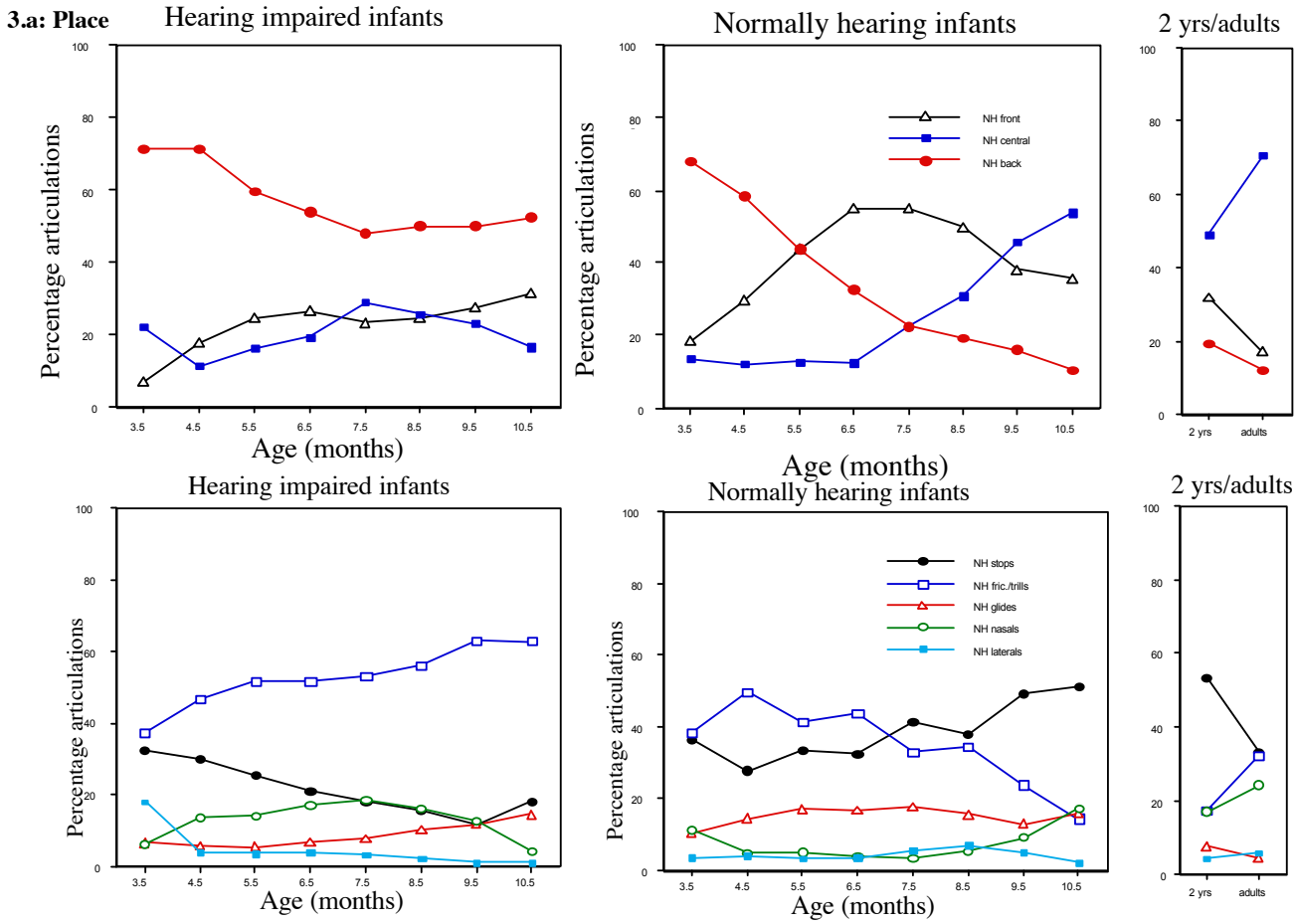

Figure 3.a. Mean number of utterances with back, central, and front articulation per age in months for both groups and 3.b. mean percentage of stop, fricative/trill, glide, nasal, and lateral articulations per month for the NH and HI group separately. For N see figure 1. Included are frequency of occurrence of place and manner of articulation of 2.0 years old (normally hearing and phonologically normally developing) Dutch speaking children and adult Dutch speakers (see [3,4] for more details).

In figure 3.b the mean percentage of articulation for five *manners* of articulation are shown. It can be seen, that the HI infants produced a large (and slowly increasing) percentage of fricatives/trills during the whole period. The percentage stops decreases slowly, while the percentage nasals, glides, and laterals stays relatively low.

Again, we find a different graph for the NH infants. In the first months NH produce more fricatives than stops, while they produce in the last months mainly stops (51%), followed by nasals, glides, and fricatives/trills, while laterals were quite uncommon. The Dutch children of 2;0 years of age show overall a frequency of occurrence of the manners of articulation which is similar to that of the last months (9.5-11.5 months) of the NH infants. Looking at the data of the Dutch adult speakers in figure 3.b it can be seen that in this group the percentage stops is relatively small, and that of fricatives/trills relatively high. Thus, from the end of the first year of NH infants it seems that place of articulation is already 'prepared' for the Dutch phonological system of adults while manner of articulation still needs to go through a more radical development.

In some place and manner combinations (not shown in figure 3), such as the central nasals, there is an increased percentage starting at 9.5 months, which results in an equal percentage for the 2;0 years old children compared to that of the adults. Some of those place and manner combinations are produced with a significantly different percentage by the NH and HI groups even within the first half year of life. For example, front stops (often produced during babbling) are produced significantly more often by the NH infants than by the HI infants already from 4.5-6.5 months onward.

4. DISCUSSION

In summary, already within the period investigated, (between 2.5 and 11.5 months of age) several differences in the speech production of HI and NH infants can be observed. Some differences can be observed already within the first half year (number of utterances, duration, place and manner of articulation). This is probably due to lack of auditory feedback on the speech production already from that age.

We found a larger number of utterances produced by the HI infants than by the NH infants (see figure 1). Also in some other studies it is observed that hearing impaired infants produce more utterances than their hearing peers [5,9]. Some researchers (e.g. [12]) report a peak in quantity for hearing impaired infants followed by a noticeable decrease. However, none of the hearing impaired infants in the present study showed a reduction in number of utterances within the period studied. It seems that this reduction in number of utterances takes place only after the period we studied,

namely after the first year (another part of this project describes utterances of the same deaf and hearing children between 12 and 24 months, see also [13]).

To explain why hearing impaired infants produce more utterances compared to their hearing peers in their first year of life, we can refer to the suggestion of Locke and Pearson [8]. They suggest that hearing impaired infants use their own vocalizations as a way to get extra auditory stimulation for their brains to compensate for the lack of auditory input. For a more thorough discussion of this point see [2,3].

Furthermore, we found a longer utterance duration for the NH infants at age 3.5 months compared to the HI infants (see figure 2). All NH infants produced this "peak" in the duration except one NH infant who made the peak at 4.5 months. It seems that infants can produce longer utterances after their third month of life, when their rib cage has restructured toward the adult configuration [6]. 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 [11]. According to Lieberman, [7] 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 a lack of exercising in this period might result in an extremely poor control of sub-glottal air pressure and of larynx muscles by older deaf children. The lack of the "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 on average somewhat longer utterances than the NH infants.

Moreover, we found differences between the two groups with respect to place and manner of articulation. Although both groups start in the first months with a high percentage back articulations and a higher percentage fricatives/trills than stops, the HI infants keep the back articulations and fricatives/trill as their main form of articulation during the whole period studied, while the NH infants, change their main place of articulation halfway the first year to front, and end the period studied with mainly central articulations. Also, we see a shift from more fricatives/trills in the first months to more stops by the last months in the NH group. It is not known yet, why the HI produce such high percentages of back articulations, and fricatives/trills. Strikingly, the HI infants do not produce more of the visible front articulations, than of the invisible back articulations, thus we can exclude a visual component in this early part of the phonological development. It might be more likely that HI infants compensate their lack of auditory input by visual and tactile/kinesthetic stimulation. This can explain why the hearing impaired infants in our study produced many sounds with a lot of tension in the (back part of the) vocal tract, for instance with vocal fry, or velar/pharyngeal trills [3].

In the future it might be that information about utterances of HI infants as described above can contribute to early detection methods of hearing impairment.

5. CONCLUSION

It seems that already within the period investigated, i.e., between 2.5 and 11.5 months of age, several differences in the sound production between HI and NH infants can be observed with respect to number of utterances, utterance duration and place and manner of articulation. NH infants seem to follow a developmental process in the direction of a complete phonological language system at later age, which partially starts already before the end of the first year of life of hearing infants, especially with respect to place of articulation. HI infants, with such a severe hearing loss as our subjects, do not follow the same developmental process as that of NH infants. Our results suggest that a lack of auditory feedback influences the speech production already in this very early stage of development.

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