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THE DEVELOPMENT OF VOCALIZATIONS OF DEAF AND NORMALLY HEARING INFANTS *

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Abstract

Already before the child utters his or her first words, at about twelve months of age, speech production develops in an organized way. The development of vocalizations is determined by several factors like anatomical growth, physiological constraints, maturation of the brain, and, in addition, auditory speech perception. So far, it is not well established how and from which age onwards, speech perception influences the development of vocalizations in the first year of life. To get more insight into this problem, we study the speech production of deaf and normally hearing infants. In this stage of the study we will report on data of three deaf and three hearing infants from five until ten months of age. The first ten minutes of each monthly recording have been analyzed. The analyses consider the number of utterances of mother and child, as well as the type of infant utterances with respect to articulation and phonation. Out of the ten minutes, fifty utterances have been selected for further analysis (utterance duration, mean F0, and number of syllables per utterance). Preliminary results show several differences between the deaf and the hearing infants, for instance concerning the number of utterances and use of articulatory movements. This suggests that lack of auditory feedback influences speech production already at this early stage of speech development.

1 Introduction

The role of audition and the influence of the surrounding language input on the speech production of infants during their first year of life, excite an intriguing research question. Several studies have shown that infants with different language backgrounds produce differences in intonation patterns and in speech sounds already in the second half year (De Boysson-Bardies et al., 1986; 1989; De Boysson-Bardies and Vihman, 1991; Whalen et al., 1991; Levitt and Utman, 1992). This suggests that there is a general influence of auditory speech perception on the production of speech in the first year of life. From this point of view we may expect that a *deficiency* in auditory perception will influence the speech production as well. Severely hearing impaired infants are lacking auditory speech input and also the internal auditory feedback of their own speech productions. A number of studies showed children's difficulties at the formal language level, like in lexical and syntactic domains (Moores, 1987; Schirmer, 1985), but is has not yet been determined systematically which difficulties these children face during the pre-lexical stage.

In a number of studies (e.g. Mavilya, 1969; Smith, 1982) no evidence was found for an effect of the lack of auditory perception on speech production within the first

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half year. Lenneberg et al. (1965) and Lenneberg (1967) implied that deaf and hearing infants' vocalizations are similar in the first year. According to Gilbert (1982) the results of these studies are often incorrectly interpreted, and this caused the widespread belief that deaf infants not just produce canonical babbling, but also from the same age as normally hearing infants do. Smith and Stoel-Gammon (1977) have also found similarities in the vocalizations of hearing impaired and normally hearing infants, for instance with respect to the presence of reduplicated canonical babbling. The interpretation of the results of these studies is complicated, due to the ambiguous use of the term babbling and the mixing up of the results of studies concerning mild to severely hearing impaired infants with those of profoundly deaf infants.

However, several recent studies suggest a deviant speech production of hearing impaired infants in the first year of age. Oller et al. (1985) concluded that vocalizations of hearing impaired infants were strikingly different from the productions of normally hearing infants. They suggested that the vocalizations of the hearing impaired subjects at an older age were similar to those of hearing infants at a younger age. Oller and Eilers (1988) found no canonical babbling in deaf infants before the eleventh month of age. Stoel-Gammon (1986, 1988), Stark (1983), and Kent et al. (1987) observed differences in consonantal features as well as a smaller phonetical repertoire. Kent et al. (1987) observed differences in formant frequencies of vocalic segments and in syllabic structure, already in the first recorded speech sample at eight months. He suggests that differences might be noted earlier.

Until now there is (as far as we know) no systematic study performed on the vocalizations of deaf infants from a very young age onwards: starting in the first half year of life. The present study (part of a larger project) reports on longitudinal data between 5.5 and 9.5 months of age of three deaf and three normally hearing infants. The main question is: do infants with and without hearing loss differ in the number and the type of utterances?

First, the number of utterances of both mother and child during ten minutes of each monthly recording of each mother-infant pair was established. Secondly, we classified all infant utterances out of these ten minutes per recording, based on the system of Koopmans-van Beinum and Van der Stelt (1986). Per recording 50 infant utterances were selected for further analysis: per utterance the number of syllables, the duration of the utterances, and the fundamental frequency were established.

2 Method

2.1 Subjects

Six mother-infant pairs participated in this study. Table 1 gives an overview of the main characteristics of the subjects. Three infants are profoundly hearing impaired (group HI), the three other infants are normally hearing (NH). All infants have 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, in the Denver Developmental Screening Test and the Bayley Developmental Scales, examined at 12 and 18 months (Bayley, 1969).

All subjects are boys, born as the second child in the family. The HI infants were born profoundly deaf, which was established by Auditory Brainstem Response audiometry (ABR) in the first months of life. This was confirmed by pure-tone audiometric tests at a later age. The hearing thresholds for the HI infants in table 1 were determined by pure-tone audiometric tests, with average response level at 500, 1000 and 2000 Hz, established between 2 and 3 years of age.

Table 1. Characteristics of the subjects

Subject	Hearing level threshold		Age of diagnosis (months)	Hearing aids from age (months)	Language method	Age at start recordings (months)
	Left	Right				
HI-1	108	93	1.5	2.0	Oral	2.5
HI-2	92	98	3.5	5.0	TC	5.5
HI-3	110	110	4.5	5.5	TC/Oral	5.5
NH-1	normal					2.0
NH-2	normal					2.5
NH-3	normal					1.5

A threshold of 91 dB and higher is considered to indicate a profound loss (Clark, 1981). All HI infants participated in early intervention programs, including hearing training. They all used hearing aids, although only subject HI-1 used his hearing aids frequently during the first year. In all cases the cause of deafness was genetically based.

The NH infants were matched with the HI infants on the following criteria: sex, birth order, duration of pregnancy, age of the mother, social-economical status of the parents (defined as having comparable professions), dialect of the parents (defined as living in and originating from the same region).

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 their homes. This procedure was chosen in order to keep the situation during the audio recordings as natural as possible. The mothers were asked to talk with their children in a face to face situation, while the children were sitting in an upright position. The recordings were made on the audio channel of a Panasonic videorecorder (VHS NV-F 55 and 65 EV), with a Sennheiser microphone (Black Fire 527).

2.3 Procedure of analyses

Analysis A:

Of every monthly audio recording, the first 10 minutes were transcribed. The criterion used to establish one infant utterance was: the infant's sound production during one respiration cycle, starting with inspiration. Vegetative sounds, laughing, and crying were left out of consideration. These transcriptions were made by one of the authors, only indicating whether a sound could be marked as an infant utterance according to the criteria mentioned above. The speech of the mother was transcribed orthographically by one of the authors. Criteria for segmenting one mother utterance were: semantic content in combination with intonation, and a pause duration of about 1 sec. or more between the utterances. One of the other authors checked the transcriptions, establishing if she agreed on each mother and infant utterance. The inter-judge agreement based on all material (five hours in total) was 97% for the mother utterances and 96% for the infant utterances. After discussion and agreement upon the final decision, the number of utterances spoken by the mother and by the infant during the 10 minutes of recording were counted.

Analysis B:
Two independent judges (two of the authors) classified all utterances of the infants produced during the transcribed 10 minutes. Each utterance was classified in one of three possible types of articulation and in one of four possible types of phonation, based on classification of movements in infant speech development, as described by Koopmans-van Beinum and van der Stelt (1986).

Articulation:
1. no articulatory movement (NoArt)
2. one articulatory movement, like in gooing (1Art)
3. two or more articulatory movements during two or more syllables, i.e. babbling (2Art)

Phonation:
1. no phonation or uninterrupted phonation: there is no interruption of the voiced airstream or there is no phonation at all (UnPhon)
2. interrupted phonation: the voiced airstream is interrupted (IntPhon)
3. variegated phonation: every possible variation in the intonation except falling or level intonation; screaming and growling are included (VarPhon)
4. a combination of interrupted and variegated phonation (ComPhon)

The inter-judge agreement for all utterances amounted to 89%. This system allows to transfer the results to the most important speech developmental stages, like gooing and babbling, as described by Oller (1980); Stark (1980); Mowrer (1980); Koopmans-van Beinum and van der Stelt (1986); Roug et al. (1989).

Analysis C:
Fifty infant utterances per recording were used for further acoustic analysis. The first selection criterion was full agreement about both articulation type and phonation type. The second criterion was that the utterance had to be suitable for acoustic analysis, for instance no disturbance of the sound signal due to noises or clipping should be present. The utterances were selected evenly out of the ten transcribed minutes; e.g. in case of 150 utterances per ten minutes each third utterance was chosen.

Next the 50 selected utterances were digitized with a sample frequency of 48 kHz. Per infant utterance the duration was measured. For the F0 measurements a pitch-detection program based on autocorrelation was used (Boersma, 1993). For the case that a difference is established between the auditory perception and the program output, the program provides the possibility to make a decision by measuring by hand the period duration of several periods.

Analysis D:
With respect to the 50 selected utterances two independent judges (two of the authors) established the number of syllables per utterance; three classification categories were used: utterances of one syllable, utterances of two or three syllables, and utterances of four or more syllables. The definition for 'syllable' was rather broad; pseudo-syllables consisting of only a continuant or a vowel were included. According to Koopmans-van Beinum (1993) listeners are, generally spoken, well aware of the syllable-like structure of the early infant sound productions. The inter-judge agreement in the present study was 87 %.

Table 2. Number of utterances produced during 10 minutes per infant age for each of the infants and their mothers individually.

NUMBER OF UTTERANCES								
Infants	Hearing Impaired				Normally Hearing			
Age	HI-1	HI-2	HI-3	Mean	NH-1	NH-2	NH-3	Mean
5.5	135	169	106	137	89	52	50	64
6.5	72	231	149	151	132	64	60	85
7.5	98	106	86	97	135	77	152	121
8.5	169	146	218	178	82	80	121	94
9.5	81	205	205	164	208	62	41	104
Average	111	171	153	145	129	67	85	94
Mothers of	Hearing Impaired				Normally Hearing			
Age	HI-1	HI-2	HI-3	Mean	NH-1	NH-2	NH-3	Mean
5.5	83	137	141	120	142	121	208	159
6.5	85	122	174	127	207	92	232	177
7.5	45	75	186	102	171	147	229	183
8.5	123	118	181	141	130	163	196	162
9.5	77	107	107	97	180	168	202	183
Average	83	112	158	117	166	138	213	173

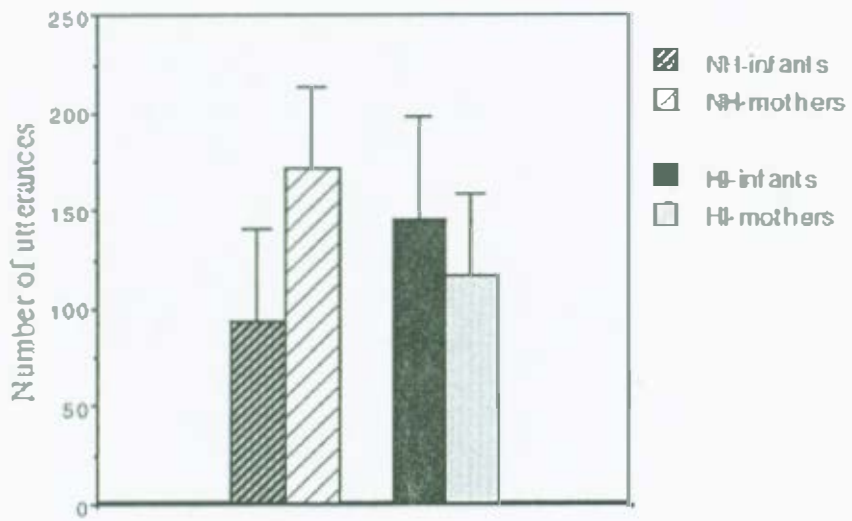

Fig. 1. Mean number of utterances with standard deviations, during ten minutes of interaction over the five recordings, presented for the two groups of infants and the two groups of mothers.

3 Results

3.1 Number of utterances

In table 2 the number of utterances produced during 10 minutes are given per infant age, for each of the infants and each of the mothers individually. In figure 1 the mean values and their standard deviations over the five recordings are presented for the two groups of infants and the two groups of mothers. A Wilcoxon signed-ranks test for matched pairs for the ages combined, was performed. It turned out that during ten minutes of interaction the HI infants produced significantly more utterances than the NH infants ($p \leq .05$, one-tailed). The mothers of the HI infants produced significantly less utterances than the mothers of the NH infants ($p \leq .005$, one-tailed). Furthermore, it can be observed that the mothers of the NH infants produced on average almost twice as many utterances as their children ($p \leq .005$, one-tailed). In the mother-infant pairs with the hearing impaired infants we find the opposite picture: the HI infants produced on an average more utterances than their mothers ($p \leq .05$, one-tailed).

3.2 Type of utterances

Table 3 shows the average percentage of each possible combination of articulation and phonation type of utterance, in relation to all the utterances during ten minutes of interaction. Horizontally the articulation type and vertically the phonation type is shown. Wilcoxon Signed Rank tests for matched pairs are performed for each utterance type (the combination of articulation and phonation type) to compare between the two groups. The significance of the differences are given below the percentages per group.

Table 3. Averaged percentage of each utterance type per group for all ages combined. Level of significance of the differences between the two groups for each type of utterance are indicated as well.

NoArt	= no articulatory movement	UnPhon	= no or uninterrupted phonation
1Art	= one articulatory movement	IntPhon	= interrupted phonation
2Art	= two or more articulatory movements during two or more syllables	VarPhon	= variegated phonation
		ComPhon	= combination of interrupted and variegated phonation

Phonation Type	Articulation Type							
	NoArt		1Art		2Art		Total	
	NH	*HI*	*NH*	*HI*	*NH*	*HI*	*NH*	*HI*
UnPhon	42.7	52.1	32.1	14.9	2.9	3.3	77.7	70.3
	ns		*p≤.005*		*ns*		*ns*	
IntPhon	8.6	10.8	3.1	0.9	3.8	0.1	15.5	11.8
	ns		*p≤.05*		*p≤.005*		*ns*	
VarPhon	3.4	14.6	1.6	0.8	0.2	0.6	5.1	16.0
	p≤.005		*ns*		*ns*		*p≤.05*	
ComPhon	0.6	1.8	0.7	0.1	0.3	0.0	1.6	1.9
	ns		*p≤.025*		*ns*		*ns*	
Total	55.3	79.3	37.5	16.7	7.2	4.0	100	100
	p≤.005		*p≤.005*		*p≤.05*			

It can be seen that the most commonly used type of utterance was a simple one with no articulatory movements and with uninterrupted phonation. About 79% of the utterances of the HI infants did not contain any articulatory movement, while this was 55% in the case of the NH infants. A Wilcoxon Signed Rank test for matched pairs showed that this difference is significant ($p \leq .005$, one tailed). HI infants produced significantly more utterances with a variegated phonation and no articulatory movements than NH infants ($p \leq .005$, one tailed). NH infants produced significantly more utterances with one or more articulatory movements and an interruption of the airstream ($p \leq .05$ and $p \leq .005$), like in the case of voiceless plosives.

3.3 Utterance duration

In figure 2 the mean duration of the 50 selected utterances are presented for the HI and the NH group, related to the age of the infants. It can be observed that the mean duration of the utterances of the HI infants are longer than for the NH infants. The analysis of variance performed on the duration with the factors group and age, indicates a significant effect for both factors ($p \leq .001$ and $p \leq .0001$), as well as for the interaction between both factors ($p \leq .0005$).

The mean utterance duration remains more or less the same over the five ages for the NH infants, whereas mean utterance duration gets shorter for the HI infants. A Tuckey post-hoc analysis performed on the interaction shows a significant longer duration for the HI as compared to the NH at the ages of 5.5 and 6.5 months ($p \leq .005$ and $p \leq .0005$).

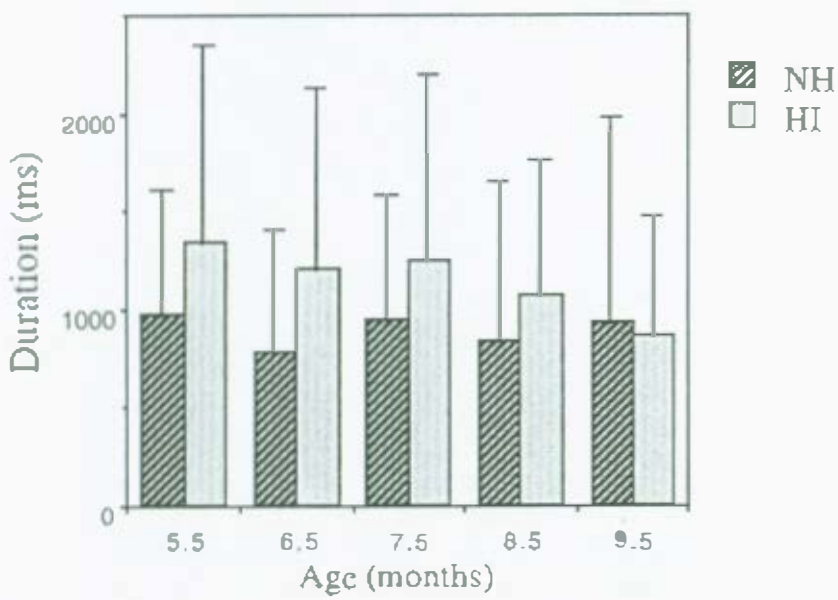

Fig. 2. Mean utterance duration and standard deviations of the 50 selected utterances for the HI and the NH group, related to age.

3.4 F0 measurements

Median F0 values in Hz for the 50 utterances, averaged over the subjects per group, are presented in figure 3. The median F0 lies around 400 Hz, except for the HI group at the age of 9.5 months when it is about 500 Hz. An analysis of variance was performed on the data with the factors group and age. The analysis shows a significant effect of group ($p \leq .0001$) and age ($p \leq .005$), and the interaction between group and age ($p \leq .0001$). The Tuckey post-hoc analysis performed on the interaction shows that these significant effects can be explained by the significantly higher pitch in the HI-group at age of 9.5 months ($p \leq .0001$).

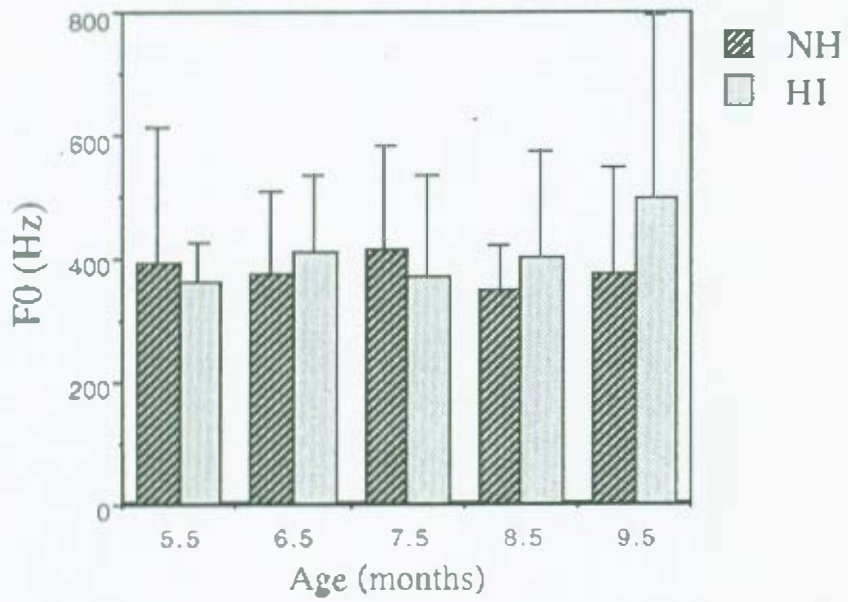

Fig. 3. Mean median pitch in Hz of the 50 selected utterances for the HI and the NH group, related to age.

3.5 Number of syllables per utterance

In figure 4 the mean number of utterances with one, with two or three, and with four or more syllables per utterances are presented. It can be seen that HI infants produced more utterances with only one syllable and with four or more syllables. However, these effects are not significant according to a Wilcoxon signed-rank test. The HI infants produced less utterances with two or three syllables ($p \leq .005$ one-tailed).

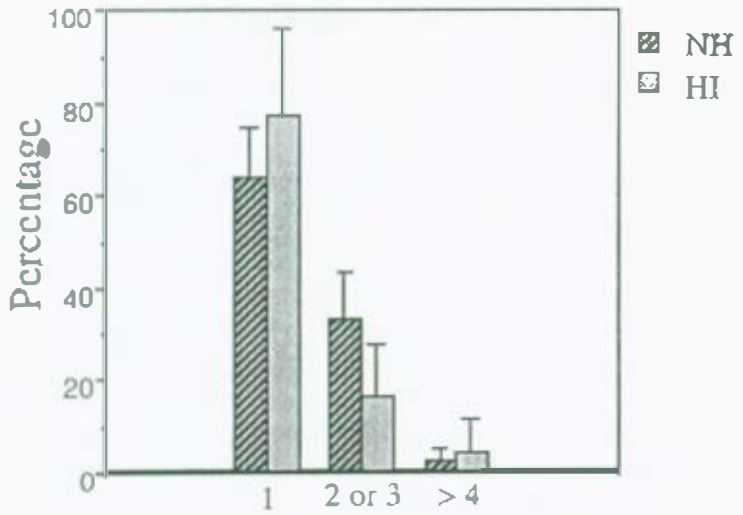

Fig. 4. Mean number of utterances with one, with two or three, and with four or more syllables per utterance for hearing impaired and for normally hearing infants.

4 Discussion

4.1 Quantitative data

It is often believed that hearing impaired infants in general produce fewer utterances than normally hearing infants. However, in our study the average number of utterances per 10 minutes in this period between 5.5 and 9.5 months is 145 utterances for hearing impaired infants and 94 utterances for normally hearing infants. This indicates that, at least as a group, these hearing impaired infants make more utterances than their hearing peers in this period. However, since the individual differences are quite large, as can be seen in table 2, we have to be very careful in drawing conclusions at this moment. Spencer (1993), for instance, found less utterances for hearing impaired infants of 12 months compared to normally hearing infants, although this difference was not significant. Some researchers, like Mavilya (1972), Maskarinec et al. (1981), and Stoel-Gammon (1986) report a peak in quantity by hearing impaired infants followed by a noticeable decrease. It seems that this reduction in number of utterances takes place after the period we studied, namely towards the end of the first year. This is reported by some of the parents of the subjects in our study as well; we will report about these data in a later stage of the project. According to Yoshinago-Itano et al. (1992) the measure that parents of HI infants most focus on to estimate the progress in the speech of their children, is the amount of utterances.

Moreover, we found that mothers of hearing impaired infants, as a group, produce significantly fewer utterances (although here individual differences are observed as well), than mothers of normally hearing infants do. This might be an artefact of the recording situation: recording time had to be filled as much as possible by the mother and the infant together. Since hearing impaired infants in this period produce more utterances than the hearing infants, less time is left for the mothers of the hearing impaired as compared to the mothers of the hearing infants. Moreover, one of the mothers in our study reported that she usually did not talk to her hearing impaired child if she had no eye contact with him. A decrease of eye contact is quite normal, due to child's increased interest in toys at an age of about eight months compared to an earlier age (Swisher, 1991).

4.2 Qualitative data

We found fewer utterances with articulatory movements in the HI group than in the NH group. This result is confirmed by the study of Kent (1985), who studied a monozygotic twin with one hearing impaired boy and one normally hearing boy. He found that, at an age of eight months, 92% of the utterances of the NH infant contained a consonant, while this was the case in only 12% of the utterances of the NH infant. Also Spencer (1993) found that NH infants produce seven times more canonical vocalizations (always including a consonant) than HI infants do.

In the phonation domain we found less obvious differences between the two groups. We did not find a difference in the median fundamental frequency at this early age. Ryalls and Larouche (1992, 1993) found a significant higher fundamental frequency for older profoundly hearing impaired children (between six and ten years) than either age-matched normally hearing or moderate-to-severely hearing impaired children. In a recent study by Elsendoorn and Beijk (submitted) it was found that differences in the fundamental frequency between normally hearing children and deaf children (ages between 4 and 20 years) were only revealed from the age of seven years onwards. From that age onwards deaf children speak at an average pitch about 50 Hz higher than their hearing peers. Thus, it seems that the influence of auditory feedback on the mean fundamental frequency starts at a later age than the period we studied, and that the anatomical and physiological development mainly determines the development and the values of the fundamental frequency in the early age period. However, we found differences in the number of utterances with a variegated phonation. It looks as if HI infants produce more utterances with a rising intonation, screaming, or with other variations in phonation. This might be the result of the lack of influence of the language background and its specific intonation patterns. Normally this effect starts to be manifest in the second half year of life (De Boysson-Bardies et al., 1986; 1989; De Boysson-Bardies and Vihman, 1991; Whalen et al., 1991; Levitt and Utman, 1992). Moreover the lack of feedback and therefore the lack of fine control of the voice (Kent, 1987) may play a role in deviant phonation as well.

4.3 Syllabification

All six infants, both HI and NH, produced utterances with several syllables (see table 3: all IntPhon, most 1Art, and all 2Art utterances), indicating that hearing capabilities are not needed for syllabification in this period. Two of the HI infants segmented the utterances into several syllables by simply interrupting the airstream. The other HI infant started to babble at 7.5 months of age; he frequently used articulatory movements for segmenting his utterances like normally hearing infants do. However, this babbling diminished again at 9.5 months. It is not clear why this child (HI-2) started to babble. His hearing was slightly better than that of the two other HI infants. In this respect we want to remark that the label 'deaf' has to be used carefully. The three infants in our study all have some residual hearing as can be observed in table 1. ABR and tone-audiometric tests cannot answer the question if and to which extent the deaf infants make use of this residual hearing for perceiving and using auditory information. Moreover, one has to keep in mind that our results are based on a limited number of infants. Analyses of data of three more deaf and three more hearing infants in our longitudinal study, will show whether the present results will hold. So far, it could be observed that none of the other three deaf infants started babbling before 12 months of age.

In our study we found a longer utterance duration for the HI infants than for the NH infants. Since the two groups of children did not differ significantly in the number of syllables, we may assume that syllable duration is longer for HI infants than for NH infants. In a study on syllable duration of six to ten years old hearing impaired and normally hearing children a clear effect of the hearing status on duration was found. Ryalls and Larouche (1992, 1993) found an average syllable duration of 294 ms for normally hearing subjects, 349 ms for moderate-to-severely hearing impaired children and 540 ms for profoundly hearing impaired children. The profoundly deaf children had a significantly longer syllable duration compared to the two other groups.

5 Conclusion

In the period between five and ten months, described in this paper, we observed a number of differences in the vocalizations between three deaf and three hearing infants. These differences can be found both in a quantitative and in a qualitative sense. The deaf infants produced significantly more utterances during ten minutes of interaction than the normally hearing infants did. With respect to mean fundamental frequency there are no clear differences in this age period. Therefore, we assume that the development of mean fundamental frequency at this age is mainly determined by anatomical and physiological growth and not influenced by the hearing status of the child. However, clear differences are found between deaf and normally hearing infants on the articulatory, durational, and syllabic level. This result suggests that a lack of auditory feedback influences the speech production already in this early stage of development.

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