Development in Utterance Structures of Deaf and Hearing Infants

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ABSTRACT

Both deaf and hearing infants produce many speech-like sounds in their first years of life. Hearing children in American-English language environments have shown to follow specific preferred patterns of combining consonant-like and vowel-like sounds when canonically babbling. In the present study concerning infants in the Dutch language environment, we investigated whether they show the same preferred patterns. In particular this paper concentrates on the question as to how far deaf or severely hearing-impaired children differ from their hearing peers with respect to their utterance structures. Utterances of five hearing and five deaf Dutch children from 10.5 to 17.5 months of age were analyzed for a number of speech characteristics, like phonation and articulation type, number of syllables, utterance structure, place of articulation and preferred combinations of vowel-like and consonant-like elements.

Results show that although deaf children produce many multi-syllabic utterances, alternations of CV movements are scarce compared to hearing children. Moreover the preferred patterns of the Dutch children deviate from those of American-English children.

1. INTRODUCTION

Babbling in its canonical form is generally considered to be a crucial phase in the development towards the production of full-fledged speech. In normally developing hearing infants the onset of babbling is about seven months of age and can be understood as a result of a nicely hierarchical course of mastering phonatory and articulatory skills [1]. Structures of the babbling utterances are primarily based on biomechanical or sensorimotor principals: frames of open-close alternations of mandibular movements. Subsequently and under the influence of the environmental language, consonantal and vocalic content is imposed resulting in utterance structures in agreement with the specific mother language, revealing a clear continuity between the pre-lexical and lexical stages. The predominant role of frames has been claimed to be obvious in a number of aspects of babbling and early use of words [2], independent of the environmental language. Three of these aspects concern favored consonant-vowel combinations: a) central vowels co-occur with labial consonants, b) front vowels co-occur with alveolar consonants, and c) back vowels co-occur with velar consonants. In the present paper we examined whether the patterns mentioned above could be found in Dutch as well. More specifically the availability of a Dutch database of deaf and hearing infants [4] provided us with the possibility to investigate the influence of spoken language input and auditory feedback on this predominant role of frames.

2. METHODS

The total Dutch database of deaf and hearing infants was described extensively in previous publications [4], and also in this issue [5]. Therefore we confine ourselves here to the information directly necessary for this paper only.

2.1. SUBJECTS

Subjects in this study were five deaf or profoundly hearing-impaired infants (HI) and five infants with normal hearing (NH). The hearing loss of the HI children varied from 93 dB to >120 dB in the best ear and the loss with hearing aids from 55 dB (two infants) to >100 dB.

2.2. SPEECH MATERIAL

From the audio-recordings, made in interactive situations by the parents themselves at their homes, we selected per month 50 non-vegetative comfort utterances, starting at the age of 10.5 months until 17.5 months. This resulted in a data set of 4000 utterances (8 x 50 x 10) in total. Starting our present study at the age of 10.5 months implied for all children a rather mature speech production instrument, at least a speech production instrument that anatomically and physiologically is capable to make canonical syllables. As published before [4], onset of canonical babbling in the five hearing infants was between 5.5 and 7.5 months, and even one of the deaf infants (with loss of 55 dB) had started to babble at 7.5 months of age.

2.3. DATA ANALYSIS

All selected utterances were digitized and coded auditorily for a number of characteristics. Use was made of the speech analysis program PRAAT [6] in order to combine the audible sound form with an oscillographic display and to make coding decisions easier and more reliable thanks to possible acoustic analyses like pitch detection and spectrography.

In this way each utterance was analyzed for the following characteristics:

- *phonation type*: classifying phonation into one of five possible types, e.g., no phonation (0), simple uninterrupted (1) or interrupted (2) phonation, variegated uninterrupted (3) or interrupted (4) phonation.
- *articulation type*: classifying articulation into one of three possible types, e.g., no articulation movement (0), one articulation movement (1), two or more articulation movements during two- or more-syllabic utterances (2).
- *number of syllables*: ranging from 0 to ≥5, the criteria for a syllable or syllable-like element being a minimal rhythmic unit containing a vowel-like phase with or without a preceding or following consonant-like closing phase. Although these criteria are broader than those for a canonical syllable [7] and we are well aware of the problems that are inherent in our working definition, we decided to use this in order to include pre-canonical babbling as well.
- *structure of the utterance*: indicating co-occurrences of vowel-like (V) and consonant-like (C) elements within each utterance. To make our results manageable we distinguished twelve classes: V = single vowel-like sound; VV…= two or more vowel-like sounds; C…– = voiceless consonant-like sound(s); C…+ = voiced consonant-like sound(s); V…C…= one or more vowel-like sound(s) followed by one or more consonant-like sound(s); C…V…= one or more consonant-like sound(s) followed by one or more vowel-like sound(s); V…C…V…= one or more vowel-like sound(s) followed by one or more consonant-like sound(s) followed by one or more vowel-like sound(s); C…V…C…= one or more consonant-like sound(s) followed by one or more vowel-like sound(s) followed by one or more consonant-like sound(s); and finally four types of babbling series: utterances beginning with a consonant-like element and ending with a vowel-like element; the same series but ending with a consonant-like element; beginning with a vowel-like element and ending with a consonant-like element; the same series but ending with a vowel-like element. The distinction in open and closed utterances was considered to be probably essential for the Dutch language.
- *place of articulation per syllable*: classifying vowel-like elements into one of three possible categories (front, central, or back), and classifying consonant-like elements into one of three possible categories (labial, alveolar, or velar). Palatal elements were left aside, uvular and pharyngeal elements were grouped with velars. Per child we classified each syllable that met the requirements of a CV or VC structure. Since it is absolutely not clear in advance whether syllable boundaries in babbling series have to be thought after CV- or after VC-, we decided to make a double analysis: one for all occurring CV syllables and one for all occurring VC syllables. If order of consonant and vowel has no influence on the preferred combinations, both our analyses would give identical results.

2.4. RELIABILITY

Primarily a single transcriber analyzed all utterances, after an intensive training period. Two other transcribers analyzed parts of the material. Transcription reliability was examined in several ways. First of all intra-transcriber reliability was controlled by reanalyzing randomly chosen parts of the speech material. Subsequently a second transcriber analyzed ten percent of the material as well, whereas a third transcriber analyzed all speech material from 12.5 to 17.5 months of age for phonation type, articulation type, and number of syllables. Agreement tested so far was rather high (over 80%), which was considered to be sufficient.

3. RESULTS

In order to answer the questions put in the Introduction, we will give the results of the data analysis for the hearing-impaired (HI) and the normally hearing (NH) group by means of frequency counts and chi-square tests. For each of the children we counted frequencies over the whole period together (8 x 50 = 400 utterances per child).

3.1. PHONATION AND ARTICULATION TYPE

As a first step frequency counts of the five phonation types and the three articulation types were processed per group (HI and NH) over the total 8-months period. In the matrix of Table 1 for both groups frequencies of occurrence (in %) of each of the 15 combinations (five phonation types and three articulation types) have been displayed. Significant differences are underlined (single line for $p < 0.05$, double line for $p < .000$).

	Articulation					
	NoArt		OneArt		TwoArt	
Phonation	**HI**	**NH**	**HI**	**NH**	**HI**	**NH**
NoPhon	--	--	6.12	1.05	0.50	0.30
UnIntPhon	30.74	32.01	8.83	18.46	0.90	3.85
IntPhon	18.90	9.70	2.60	3.65	1.15	3.10
VarUnIntPhon	5.21	5.45	1.35	4.30	1.60	4.45
VarIntPhon	17.80	4.40	2.00	3.10	2.26	6.15

Table 1. Frequency of occurrence (in %) for each combination of phonation and articulation type for the HI (n=5) and the NH (n=5) infants over the eight months together. Significant differences are underlined (single line for $p < 0.05$, double line for $p < .000$).

A number of striking differences between the HI and the NH infants will be mentioned here.

- HI infants produce far more utterances with interrupted phonation but without articulation than NH infants do. These simple repetitive phonation movements might be seen as substitutions for the more complex repetitive babbling movements.

- HI infants produce more utterances with one articulation movement but without phonation than NH infants do. The tactile sensation may play a role here.
- NH infants produce more utterances with uninterrupted phonation combined with one articulation movement than HI infants do.
- NH infants produce more utterances with two or more articulations movements like in canonical babbling than HI infants do.

3.2. NUMBER OF SYLLABLES

The analysis of phonation and articulation movements as described above suggests different utterance structures for the two groups of children, although both seem to make multi-syllabic utterances. The total number of syllables for the HI group was 4318, for the NH group 3323. In Table 2 for both groups frequencies of occurrence (in %) of syllables per utterance have been displayed. Significant differences ($p <. 000$) are underlined.

Number of syllables per utterance	HI	NH
0 syllables	6.77	1.50
1 syllable	43.88	57.27
2 syllables	20.11	27.06
3 syllables	11.88	8.05
4 syllables	6.87	2.90
5 or more syllables	10.48	1.90

Table 2. Frequency of occurrence (in %) of number of syllables within an utterance for the HI (n=5) and the NH (n=5) infants over the eight months together. Significant differences ($p < .000$) are underlined.

For each of the six classes the differences between the two groups of children turn out to be highly significant.

- HI infants outnumber NH infants considerably for the total number of syllables over all utterances. In view of the results on phonation and articulation as mentioned above, it is quite plausible that the high number of utterances with interrupted phonation without articulation in the HI group is cause of this difference.
- HI infants produce considerably more utterances with a zero syllable count than NH infants do. A zero syllable count has been assigned to those utterances that consist in an articulation movement without phonation. As mentioned above the tactile sensation might play a role here for the HI infants.
- HI infants produce more utterances with three or more syllables than NH infants do. Again the cause might be in the high number of utterances with interrupted phonation without articulation.
- NH infants produce more utterances with one or two syllables than HI infants do. The considerably higher number of utterances with phonation plus articulation movements in the NH group (see Table 1) is likely cause of this difference.

3.3. UTTERANCE STRUCTURE

Since the two groups differ considerably in the number of syllables in their utterances, it is not unlikely that they will differ in the complexity of their utterances as well. We thus counted frequencies of occurrence of the most common structures for the two groups, with the results as given in Table 3.

Structure of the utterance	HI	NH
V	35.35	37.4
VV…	37.21	14.15
C…–	6.51	1.10
C…+	4.26	3.30
C…V…	3.96	12.95
V…C…	4.36	3.95
V…C…V…	3.30	11.10
C…V…C…	0.60	2.90
C…V…C…V…(C…V…)	1.30	6.70
C…V…C…V…C…(V…C…)	0.20	0.70
V…C…V…C…(V…C…)	1.10	2.60
V…C…V…C…V…(C…V…)	1.80	3.10

Table 3. Frequency of occurrence (in %) of types of utterance structures for the HI (n=5) and the NH (n=5) infants over the eight months together. Significant differences are underlined (single line for $p < 0.05$, double line for $p < .000$).

Here again some striking differences arise, mainly in line with the results of the preceding sections.

- HI infants and NH infants produce a similar number of utterances consisting in a single vowel-like sound.
- HI infants produce considerably more utterances with series of vowel-like sounds than NH infants do.
- HI infants produce considerably more utterances consisting in a single voiceless consonant-like sound than NH infants do.
- NH infants outnumber HI infants considerably in all utterance structures with consonant-vowel alternations, except utterances with single VC structure.

3.5. PLACE OF ARTICULATION

Each syllable that met the requirements of a CV or VC structure was classified in one of the nine combinations of front, central, or back (for vowel-like elements) with alveolar, labial, or velar (for consonant-like elements). Frequency counts of all possible combinations (in % per group) gave the results as shown in Table 4 (CV structures) and Table 5 (VC structures). As could be foreseen already from the results in the preceding sections, the total number of CV and VC occurrences for the HI children is considerably smaller than for the NH children (CV for HI = 368, for NH = 1164; VC for HI = 349, for NH = 891). The NH children outnumber the HI children in

the frequencies of almost all vowel-consonant combinations, both for the CV (Table 4) and for the VC combinations (Table 5). No essential differences are found between both tables, so we'll confine us to the CV data as given in Table 4. Differences still to be mentioned are:

- HI children outnumber NH children as for the use of labial consonants in combination with central vowels.
- HI children outnumber NH children as for the use of velar consonants in combination with central vowels.

The visual and tactile sensations, respectively, may play an important role here.

CV	**Consonants**					
	Alveolar		Labial		Velar	
Vowels	**HI**	**NH**	**HI**	**NH**	**HI**	**NH**
Front	2.45	8.59	2.17	2.49	3.81	1.80
Central	37.60	45.36	33.24	18.32	13.07	6.70
Back	2.72	5.67	4.63	7.64	0.27	2.40

Table 4. Frequency of occurrence (in %) of alveolar, labial, and velar consonants in combination with front, central, and back vowels in CV syllables for the HI (n=5) and the NH (n=5) infants over the eight months together.

VC	**Consonants**					
	Alveolar		Labial		Velar	
Vowels	**HI**	**NH**	**HI**	**NH**	**HI**	**NH**
Front	2.29	9.76	1.14	0.78	3.15	1.34
Central	31.80	47.25	29.79	16.27	19.77	7.07
Back	6.87	8.19	2.57	6.06	2.57	4.25

Table 5. Frequency of occurrence (in %) of alveolar, labial, and velar consonants in combination with front, central, and back vowels in VC syllables for the HI (n=5) and the NH (n=5) infants over the eight months together.

When inspecting the frequencies in Tables 4 and 5 for the NH and the HI infants, it becomes clear that the claims about favored consonant-vowel combinations (the diagonal in the tables) as made in [3] cannot be supported by our results. As distinct from the American-English data we found in our Dutch data a very high number of central vowels (for NH = 70% and for HI = 84%). Back vowels are rather few (for NH = 16% and for HI = 8%); front vowels in our dataset are lowest in frequency (for NH = 13% and for HI = 8%). This resulted in a preferred combination of central vowels especially with alveolar consonants, since alveolar consonants (for NH = 60% and for HI = 43%) outnumber labial and velar consonants largely, especially in the NH group (labial 28% and velar 11%; for HI 40% and 17%, respectively).

The cause of the deviations may be found partly in the Dutch mother language. We therefore compared our results with adult frequencies of occurrence of vowels and consonants known from the Dutch CELEX database, based on a million of Dutch words. If clustered in the same way as we did for the HI and NH infants, irrespective of other consonants, CELEX provides as frequencies for vowels: 32% front, 44% central, and 24% back, and as frequencies for consonants: 65% alveolar, 23% labial, and 12% velar. The main difference between our infant results and the adult ratios is in the very high frequency of central vowels, although central vowels are the most frequent group for Dutch adults as well.

4. CONCLUSIONS AND DISCUSSION

The results of our study all point into the same direction: although HI children between 10.5 and 17.5 months of age produce many multi-syllabic utterances, the structure of these utterances is quite different from those produced by the NH children. Alternations of CV movements are rather scarce compared to what NH children do. As stated before [4] coordination of articulation and phonation movements seems to require auditory feedback in order to provide the possibility to produce all variations in utterance structure as needed to achieve full-fledged adult speech in the end. The development of the utterance structures for each of the ten children individually during the period mentioned above will be next subject of our study. That also may give an answer why the HI group is more like the Dutch NH group in their CV preferences than like the American-English children.

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