The Characteristics of Prelexical Babbling After Cochlear Implantation Between 5 and 20 Months of Age

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Objective: **To compare the characteristics of prelexical babbling of 10 deaf children, who received a cochlear implant (CI) between 5 and 20 mo of age with that of hearing children.**

Design: **Prospective controlled longitudinal trial comparing 10 congenitally deaf children of hearing parents, who received a multichannel Nucleus-24 CI in their first or second year of life with 10 normal-hearing (NH) children. During the entire babbling period, monthly video samples of 20 min were selected and transcribed. The characteristics of babbling were investigated at three levels: (1) segmentally by means of inventories of consonant (C) and vowel (V) types, (2) intrasyllabically by assessing preferred consonant-vowel (CV) combinations, and (3) intersyllabically by assessing reduplication and variegation of successive CV syllables.**

Results: **(1) Segmental analysis – no statistical difference: both groups preferred to produce coronals and labials with regard to C place, and stops and glides with regard to C manner. Mid-front and mid-central vowels were the predominant V types in both groups. (2) Intrasyllabic analysis – no statistical difference: both groups preferred to combine coronal Cs with front versus and labial Cs with back versus, and disliked coronal-back and labial-front CV combinations. These four significant CV combinations, however, emerged earlier in the babbling period of NH group than that of CI children. (3) Intersyllabic analysis: in comparison with the NH group, the CI children used significantly less variegated CVCV and in case of variegation, the proportion of combined C + V variegations was significantly lower. In case of C variegations, complex C variegations (manner + place) occurred considerably less frequently in the babbling of the CI children in comparison with that of the NH children (although this difference was not statistically significant).**

Conclusions: **This study shows that the qualitative babbling characteristics of early implanted CI children are very similar to those of hearing children from the onset of babbling onward. Only when combining CV syllables into CVCV utterances, CI children prefer simplicity to complexity in comparison with hearing children.**

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Introduction

Severe congenital hearing impairment, which is almost always located in the inner ear (cochlea), is known to cause extensive problems in different developmental areas (emotional, social, . . .), including substantial delays in language development (e.g., Bollard, et al., 1999; Smith, 1975; Marschark & Harris, 1996; Marschark, et al., 1994; Robbins, et al., 1997; Traxler, 2000). Cochlear implants (CIs) bypass the cochlear function, and thus can have a thorough impact on a congenitally deaf person's hearing, speech, and language abilities. In adults with acquired deafness, CIs have been proven to yield excellent results in speech perception (Callanan & O'Connor, 1996; Gates & Miyamoto, 2003). In children and adults with congenital deafness, however, the results are often far less spectacular. An increasing number of investigations suggest that the timing of implantation seems to be a critical factor in the outcomes of this population in various areas such as speech perception and language (Govaerts, et al., 2002; Hehar, et al., 2002; Rubinstein, 2002). To date, the positive speech and language outcomes in children with a CI have allowed the age limit to be systematically lowered to 1 yr of age or even below to take advantage of the sensitive period of speech and language learning in the first and second years of life. The implementation of universal neonatal hearing screening programs enables the identification of congenital hearing loss immediately after birth, and allows intervention at the beginning of the infant's life. With regard to speech and language development, this means that cochlear implantation before the age of 1 yr allows auditory stimulation and intervention within the earliest stages of language acquisition, that is, the prelexical period.

The insight in the prelexical vocal development of normally developing children has increased immensely in the past 20 yrs. The current understanding is that vocal development follows a regular

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sequence of stages from birth to the emergence of words, and that the onset of canonical babbling is one of the most important milestones of these stages (Koopmans-van Beinum & van der Stelt, 1986; Nakazima, 1975; Oller, 1986; Roug, et al., 1989; Stark, 1986). Babbling is defined as the production of consonant (C) and vowel (V) sequences and represents the ability of a child to produce mature phonetic syllables as the basis for later word production (Oller & Eilers, 1988). Normally developing children start to babble between 6 and 10 mo of age (e.g., Koopmans-van Beinum, et al., 2001; Oller & Eilers, 1988; Oller, et al., 1976; Roug, et al., 1989; Smith, et al., 1989; Stoel-Gammon & Otomo, 1986). On the segmental level, the C and V inventories of their babbled utterances seem to be relatively universal (viz similar across different linguistic environments) (e.g., Cruttenden, 1970; Davis & MacNeilage, 1995; de Boysson-Bardies & Vihman, 1991; Emmorey, 1985; Kent & Bauer, 1985; Locke, 1983; Roug, et al., 1989; Stoel-Gammon, 1985; Vihman, et al., 1985, 1986). The consonantal inventories contain roughly equal proportions of coronals and labials with regard to place of articulation, and predominantly stops with regard to manner of articulation. Fricatives, affricates, and liquids occur at very low frequencies. Vowels tend to concentrate around the lower left quadrant of the vowel space, including mostly low-front, mid-front, and neutral/central vowels (e.g., Cruttenden, 1970; Davis & MacNeilage, 1995; de Boysson-Bardies, et al., 1981; Emmorey, 1985; Holmgren, et al., 1986; Kent & Bauer, 1985; Kent & Murray, 1982, 1985). High vowels are produced infrequently in infant vocalizations. When these Cs and versus are combined into consonant-vowel (CV) syllables, it has been shown by MacNeilage and Davis (1990) that children prefer to combine labial consonants with central vowels [e.g., /ma:/ (SAMPA, www.phon.ucl.ac.uk/home/sampa/home.htm)], coronal consonants with front vowels (e.g., /ti/), and dorsal consonants with back vowels (e.g., /ku/). At the intersyllabic level, researchers now agree that children show concurrent use of reduplicated CVCV sequences (i.e., the Cs and versus are identical from syllable to syllable) and variegated CVCV sequences (i.e., the Cs and/or versus are different from syllable to syllable) from the onset of babbling onward (Mitchell & Kent, 1990; Smith, et al., 1989), instead of going through two separate successive stages of reduplicated and variegated babbling (Elbers, 1982). When considering variegation, MacNeilage and Davis (1990) and Davis and MacNeilage (1995) found higher proportions of C manner changes and V height changes.

In the light of the recent development of very early cochlear implantation, babbling in children with a CI has not been investigated extensively yet. Speech and language research in prelingually deafened children with a CI belongs to a relatively new scientific field and numerous difficulties exist that make the interpretation of data problematic. The principal difficulty is that children with a CI constitute a very heterogeneous group with very different audiological and educational characteristics like the age at onset of deafness, the age at implantation, and the communication mode. Also, the individual history of each child may be very different from others, such as the age at fitting of conventional hearing aids (before receiving the CI), the type of deafness (i.e., congenitally, prelingually, or postlingually), the speech therapy before and/or after implantation, the level of sign language ability before and after implantation (Lederberg & Spencer, 2005), etc. All these factors are thought to influence the speech and language development and, unfortunately, they are often poorly defined or even lacking. In addition, the study of a child in development requires a longitudinal and comparative study design. Unfortunately, longitudinal cohort studies are very time-consuming. Most longitudinal studies that have been reported so far, are either case studies or they are characterized by short follow-up times or long intervals between successive assessments. In addition, a matched control group is frequently lacking, making the interpretation of data difficult. Without ignoring these difficulties, the small number of available data (mostly of English-learning children) about babbling, however, seems to suggest that early cochlear implantation contributes to near-to-normal babbling characteristics.

With regard to the onset of babbling, Schauwers et al. (2004) showed that 10 (Dutch-learning) children implanted between 5 and 20 mo of age started babbling within 4 mo after the activation of the implant. This means that the onset of babbling of the youngest subjects occurred at a chronological age comparable with that of children with normal hearing (viz between 8 and 11 mo of age). Colletti et al. (2005) reported similar results: they found an early onset of babbling within 1 to 3 mo after implantation in 10 infants implanted before 1 yr of age. In the study of Kishon-Rabin et al. (2005), it took a median of 5 to 7 mo of CI experience to reduplicate CV syllables in a group of 24 children with a mean age of implantation of 18.9 mo. With regard to the segmental content of babbling, it was shown in a report on four children with a CI (age at implantation: between 10 and 28 mo of age) that a predominance of labial nasal consonants before implantation shifted toward a predominance of labial stops after implantation (Ertmer & Mellon, 2001; Ertmer, et al., 2002; McCaffrey, et al., 1999). Also other stop consonants—mainly coronal ones, like /d/, /t/—emerged between 6 and 10 mo after CI and their frequency of occurrence increased steadily until stops became the dominant manner type of production (60%–80%). The vowel inventories of these children more than doubled after only 1 to 5 mo of implant experience (in contrast to children with a profound hearing impairment but without a CI). By the end of the first year of implant use, all vowel categories were represented. With regard to the intra- and intersyllabic organization of babbling, McCaffrey et al. (1999) found preferences for coronal-front CV syllables and labial-central CV syllables in a deaf child who received a CI at 25 mo of age, which was in line with the data of children with normal hearing. In addition, this child also demonstrated a preference for consonantal manner variegation, but not a preference for height variegation of vowels.

The aim of this study was to investigate longitudinally the characteristics of babbling in a group of 10 children with congenital deafness, who received a CI in their first or second year of life. In particular, the segmental, intra- and intersyllabic characteristics of their babbling utterances were analyzed and compared with those of 10 children with normal hearing. Our study differed from existing CI data on several important issues: to our knowledge, there is no naturalistic study yet, which describes the onset and the development of prelexical babbling in children with a CI. We were able to put together a group of very young children with a CI, which was homogeneous with regard to the age at onset of deafness, the hearing level before implantation, the age at fitting of conventional hearing aids before implantation, the communication mode, and the linguistic background. In addition, both the CI group and the matched group of hearing children were followed longitudinally, and their prelexical development was mapped in a very detailed manner (as can be found in the Methods section). Therefore, we believe that our study contributed substantially to the existing data in describing the characteristics of babbling in children with deafness who received a CI at a very young age.

MATERIALS AND METHODS

Participants

The two groups of infants reported in this study are the same as those reported by Schauwers et al. (2004). Briefly, the CI group consisted of 10 children with congenital deafness of hearing parents. They showed no other patent health problems such as cognitive or motor delays, as assessed by routine clinical evaluation. Their hearing loss was detected in a neonatal screening program within the first month of life, and a profound hearing impairment [i.e., an unaided pure-tone average (PTA) at 500, 1000, and 2000 Hz of more than 90 dBHL in the better ear] was confirmed by auditory brain stem response in the first weeks of life. In seven cases, the cause of deafness was genetic (five of them were mutations in the connexin-26 gene, which is a commonly found cause of congenital deafness). All infants received bilateral hearing aids within 1 to 5 mo after detection of the hearing loss. After wearing the hearing aids for several months without any progress (only one child reached a PTA within the speech area with his hearing aids, viz 47 dBHL), all children received a multichannel Nucleus-24 CI (Cochlear Corp., Sydney, Australia) between 5 and 20 mo of age. The PTA with the CI, as measured by pure-tone audiometry in free-field condition at approximately 1 yr after the CI fitting (mean 15 mo, range 10–21 mo), decreased to 30 to 52 dBHL, and all children were able to discriminate a set of speech sound contrasts immediately after activation of the implant as assessed by means of the Auditory Speech Sound Evaluation (A§E®; Daemers, et al., 2006; Govaerts, et al., 2006). All children were raised orally (Dutch) with support of a limited num-

TABLE 1. Overview of the auditory characteristics of the children with a CI

ID	PTA unaided (dBHL)	Age HA (y;mm.dd)	PTA aided (dBHL)	Age CI (y;mm.dd)	Age CI fitting (y;mm.dd)	PTA CI (dBHL)
RX	117	0;4.0	107	0;5.5	0;6.4	43
AN	120	0;1.4	120	0;6.21	0;7.20	30
MI	120	0;1.21	107	0;8.23	0;9.20	43
YA	103	0;5.8	63	0;8.21	0;9.21	32
EM	115	0;1.18	113	0;10.0	0;11.20	33
RB	91 ↓ 117	0;3.6	45 ↓ 115	1;1.7	1;2.4	43
AM	120	0;9.3	120	1;1.15	1;2.27	47
KL	93	0;4.24	47	1;4.27	1;5.27	35
JO	113	0;10.0	117	1;6.5	1;7.9	42
TE	112	0;2.0	58	1;7.14	1;9.4	52

PTA, pure tone average, tested binaurally in free-field condition: in case of no response at 120 dBHL (i.e., the maximum output of the audiometer), this was coded as "120 dBHL"; HA, conventional hearing aids; ↓, progressive hearing loss.

ber of signs. Table 1 gives an overview of the auditory characteristics of the children with a CI.

A control group of 10 children with normal hearing (henceforth NH children) of hearing parents was selected, and, as in the case of the children with a CI, informed consent from the parents to participate in this study was obtained. This group was followed-up during the babbling period (see further) starting at a chronological age of 6 to 8 mo. One child withdrew from the study at the age of 11 mo because of time constraints. No patent health or developmental problems were present in these children with normal hearing, confirmed by routine clinical assessment in their first few months of life.

Data Collection and Transcription

To monitor the prelexical period in both groups of children, monthly video recordings were taken at home. The digital recordings of approximately 60 to 80 min were made starting from the first month after activation of the CI in the case of the children with a CI, and from the chronological age of 6 to 8 mo in the control group. Six children with a CI were also recorded once before implantation. The video sessions consisted of spontaneous unstructured interactions between the child and a parent (and in some cases a sibling). The recordings were made with a Panasonic NVGS3 digital video camera with zoom microphone function.

From each recording, a sample of approximately 20 min was taken. The sampling procedure was done by the same person for all recordings and aimed at selecting delineated sequences of interaction. More specifically, we selected stretches containing speech as much as possible, and stretches of pauses were cut. Subsequently, these selections were transcribed according to the CHAT conventions (MacWhinney, 2000). Transcription consisted of an orthographic transcription of the adult's utterances, and an orthographic and phonemic transcription of the lexical items of the child. For the children's prelexical utterances, a dedicated coding system was adopted (see Schauwers, et al., 2004). Briefly, each vocalization (and more specifically, each "comfort sound") was coded in terms of phonation (uninterrupted or interrupted) and articulation (no articulation, one articulation, or 2+ articulations) according to the model proposed by Koopmans-van Beinum and van der Stelt (1986). Each utterance also received a CV-code, that is, the utterance was broken up into a sequence of consonant- and vowel-like elements. The characteristics of each segment—C or V—were defined in terms of the place and the manner of articulation for consonant-like elements, and in terms of the articulation place and height for vowel-like elements.

The Age Period Studied

For each subject, data analysis was initiated when the child started canonical babbling (Schauwers, et al., 2004), and terminated on the session where the child produced at least 10 word types. To determine the age at which the child produced at least 10 different words, we followed the procedure for identifying words proposed by Vihman and McCune (1994). Henceforth, this period is referred to as the babbling period.

The onset of babbling in these 10 children with a CI and 10 children with normal hearing was reported elsewhere (Schauwers, et al., 2004). The hearing children started babbling between the ages of 6 and 8 mo (median, 6 mo), and the children with a CI started babbling between 8 and 21 mo of age (median, 15 mo), which was between 1 and 4 mo after activation of the implant. The children with a CI produced their first 10 words between the ages of 17 to 26 mo (median, 22.5 mo). The hearing children reached their 10-word stage between 14 and 20 mo of age (median, 18 mo).

For the babbling analyses, the babbling period was divided into consecutive 3-mo-intervals. These quarterly periods are represented as: T1 = the first 3 mo of babbling, T2 = the next 3 mo, and so on, up to the last session of the babbling period with a maximum of four quarters.

Analysis of Babbling

Segmental characteristics • To determine the segmental inventories of the children's babbling, all prelexical utterances with at least one CV or VC syllable were analyzed. Singleton consonants, singleton vowels, and vegetative vocalizations like cries, coughs, and sneezes, were excluded from the analysis. Consonants were grouped with regard to place of articulation into coronals, labials and dorsals. The palatal glide /j/ and the palatal fricatives /S/ and /Z/ were classified as coronals. With regard to manner of articulation, we classified consonants into stops, nasals, glides, fricatives, and liquids. Vowels were grouped into front, central, and back with regard to the place of articulation, and into high, mid, and low with regard to the vowel height. As a guideline, we used the classifications of the Dutch consonants and vowels according to Collier and Droste (1982) and Booij (1995) (Table 2). A total of T2
19,628 consonants (range, 739–3578) and 20,819 vowels (range, 909–3749) were analyzed in the NH population, and in the CI group, 13,524 consonants

TABLE 2. Classification of Dutch consonants and vowels (using SAMPA transcription)

Consonants	Coronal	Labial	Dorsal
Stop	/t/ /d/	/p/ /b/	/k/ /g/
Nasal	/n/	/m/	/N/
Glide	/j/	/w/	
Fricative	/s/ /z/ /S/ /Z/	/f/ /v/	/x/ /G/
Liquid	/r/ /l/		
Vowels	**Front**	**Central**	**Back**
High	/i/ /y/		/u/
Mid	/I/ /E/ /e:/ /Y/ /2:/	/@/	/o:/ /O/
Low		/a:/	/A/

(range, 357–2561) and 14,896 vowels (range, 441–2804) were coded.

Intrasyllabic phonotactic patterns • For the analysis of CV phonotactic patterns, all CV syllables of each child were selected. In total, 14,918 (range, 645–2643) and 11,921 (range, 276–2354) CV syllables were analyzed in the NH group and the CI group, respectively. Each CV syllable was analyzed and characterized by the articulation place of consonants (coronal, labial, dorsal) and vowels (front, central, back) (see Table 2), yielding nine possible co-occurrences of C and V. To find out whether certain CV combinations were predominant in a group, the actual prevalence of each CV combination was compared with the "expected prevalence." The expected prevalence of a CV co-occurrence was calculated from the overall frequencies of the individual consonants and the individual vowels in the corpora. This represented the prevalence that a specific CV would occur in case the C and V were combined without preference, that is, randomly. If, however, the child preferred to use a specific CV rather than other combinations, the observed prevalence of this CV was higher than the expected prevalence. Analytical statistics were used to verify whether the observed prevalence of each CV combination differed significantly from its expected prevalence. For this, we converted the binomial parameters (N = total number of CV co-occurrences for one child, p = expected prevalence of a CV co-occurrence) into the parameters of a normal distribution with mean = $N \times p$ and standard deviation = $\sqrt{[N \times p \times (1 - p)]}$. This yielded a z-value for each observed CV co-occurrence. The cutoff level for significance was set at 0.05 ($-1.96 < z < 1.96$).

Intersyllabic patterns • The analysis of intersyllabic patterns focuses on how consonants and vowels vary from one CV syllable to the next. Therefore, all possible pairs of successive CV syllables in the corpora of the children with a CI (total, 6075; range, 74–1284) and children with normal hearing (total, 5237; range, 214–971) were selected. In utterances with more than two syllables, each syllable, except the first and last one, was analyzed twice: once as the first of two syllables and once as the second. If the two syllables of a CVCV pair were the same, the sequence was labeled "reduplicated." A "variegated" sequence was defined as a CVCV sequence in which the consonants or the vowels or both were different from each other with regard to place and manner of articulation for consonants, and with regard to place and height for vowels. Voicing differences were not considered.

Statistics

For all babbling analyses, nonparametric statistics were used (Kruskal–Wallis test, Mann–Whitney U test, Spearman Rank Correlation) to compare the CI group with the NH group and to test the effect of age at implantation in the CI group.

Because it is impossible to calculate the β-error with nonparametric statistics, we have made an estimate of the statistical resolution of the study design, meaning the minimal difference between groups that would have been detected with the current study-design. This was done based on an analysis of variance, where the average standard deviation was calculated for all results (percentages of occurrence) based on the interquartile range. This yielded average standard deviations of 18% for the CI group and 14% for the NH group, and in consequence to two standard errors of the mean of 11% and 9%, respectively, for study groups of 10 subjects. Taking into account a safety margin of 20% in view of the nonparametric type of analyses, it is fair to take 14% as an indication of the minimal difference between groups that would have been detected with the current study-design.

Intertranscriber Reliability

Analyses were performed to determine transcriber agreement (1) on the classification of the vocalizations as being "babbling utterance" or "no babbling utterance," and (2) on the transcription of the major categories of the consonant- and vowel-like sounds of babbling. An experienced observer transcribed all material, and after that, a second experienced observer independently retranscribed 10% of all material for comparison. Cohen's kappa and percentage agreement were used to examine reliability.

For the "babbling—no babbling" classification, the two transcribers showed a kappa-score of 0.75 (which is considered to be "substantial"; Landis & Koch, 1977, p. 165) and a percentage agreement of 91.9 for the same classification. The average kappa-score and the average percentage agreement, re-

TABLE 3. Consonants: place of articulation

	T1	T2	T3	T4
NH				
Coronals	23% (25)	42% (16)	42% (23)	44% (9)
Labials	58% (26)	47% (15)	46% (17)	38% (8)
Dorsals	13% (12)	10% (5)	12% (12)	13% (13)
CI				
Coronals	38% (24)	40% (46)	53% (40)	55% (49)
Labials	54% (34)	51% (49)	34% (53)	34% (20)
Dorsals	8% (14)	9% (9)	10% (29)	10% (31)

The median percentages of occurrence (and interquartile ranges) are given for the NH and CI group in the four babbling quarters (T1–T4).

TABLE 5. Vowels: place of articulation

	T1	T2	T3	T4
NH				
Front	31% (23)	37% (23)	37% (12)	40% (5)
Central	45% (18)	35% (13)	38% (10)	33% (16)
Back	23% (10)	24% (19)	28% (20)	24% (18)
CI				
Front	38% (25)	24% (21)	35% (33)	43% (11)
Central	38% (10)	39% (14)	29% (20)	31% (20)
Back	21% (19)	34% (19)	32% (15)	37% (19)

The median percentages of occurrence (and interquartile ranges) are given for the NH and CI groups in the four babbling quarters (T1–T4).

spectively, for the different C and V articulation types were as follows: C place 0.76 and 82.9%; C manner 0.79 and 85.7%; V place 0.60 and 73.5%; and V height 0.69 and 84.4%. On the whole, the kappa-scores of the experienced transcribers pointed at substantial agreement (Landis & Koch, 1977).

RESULTS

Segmental Characteristics

Consonants: Place of articulation • In the study samples of both the NH group and the CI group, coronals and labials predominated during the entire babbling period. Table 3 shows that, although not statistically significant, labials tended to decrease over time and coronals tended to increase over time in both groups of children. The prevalence of dorsals remained low during the entire babbling period.

When comparing the NH group and the CI group by means of the Mann–Whitney U test, no statistically significant differences were found in the proportions of the three C place types.

Consonants: Manner of articulation • Stops and glides were the predominant C manner types during the babbling period of both the children with normal hearing and the children with a CI. As displayed in Table 4, the NH group preferred to produce stop consonants in all quarterly intervals, followed by glides, nasals, fricatives, and liquids. The same order of preference was found in the CI group, except at T1, at which the glides slightly outnumbered the stops. The median proportions of fricatives and liquids never exceeded 12% in the children's babbling.

The Mann–Whitney U test revealed that the children with a CI differed significantly from the children with normal hearing only in the proportions of liquids ($p < 0.01$).

Vowels: Place of articulation • In the NH group, front and central vowels were produced more frequently than back vowels in the four babbling quarters, as shown in Table 5. In the CI group, no clear preference patterns were found.

There were no statistically significant differences between the NH group and the CI group with regard to the proportions of the V place types, as assessed by the Mann–Whitney U test.

Vowels: Height of articulation • Over all babbling quarters, both the children with normal hearing and the children with a CI produced mid vowels most frequently, followed by low vowels (Table 6). High vowels occurred only sporadically, with median proportions of less than 10%.

No statistically significant differences were found between both groups of children in the proportions of

TABLE 4. Consonants: manner of articulation

	T1	T2	T3	T4
NH				
Stops	33% (19)	48% (24)	41% (17)	45% (16)
Nasals	20% (22)	11% (10)	10% (25)	6% (19)
Glides	22% (31)	27% (21)	32% (15)	27% (14)
Fricatives	6% (4)	5% (4)	12% (5)	10% (12)
Liquids	5% (5)	6% (7)	6% (5)	8% (8)
CI				
Stops	27% (25)	54% (14)	56% (16)	74% (12)
Nasals	21% (33)	11% (21)	14% (12)	7% (12)
Glides	31% (28)	24% (13)	20% (11)	13% (7)
Fricatives	5% (13)	4% (5)	6% (7)	4% (5)
Liquids	1% (4)*	0% (1)*	0% (0)*	1% (1)*

The median percentages of occurrence (and interquartile ranges) are given for the NH and CI groups in the four babbling quarters (T1–T4). Asterisks (*) mark significant differences in proportions between the NH group and the CI group ($p < 0.01$).

TABLE 6. Vowels: height of articulation

	T1	T2	T3	T4
NH				
High	6% (5)	5% (7)	8% (7)	10% (12)
Mid	60% (14)	56% (18)	62% (25)	64% (17)
Low	31% (14)	39% (24)	29% (21)	23% (7)
CI				
High	3% (7)	7% (13)	5% (6)	4% (15)
Mid	56% (22)	46% (17)	62% (27)	59% (18)
Low	35% (23)	38% (23)	31% (23)	25% (19)

The median percentages of occurrence (and interquartile ranges) are given for the NH and CI groups in the four babbling quarters (T1–T4).

TABLE 7. Intrasyllabic phonotactic patterns

	C	V	T1		T2		T3		T4	
			Ob	Ex	Ob	Ex	Ob	Ex	Ob	Ex
NH	Coronal	Front	11	10	24	18	23	18	24	20
	Coronal	Central	12	12	13	14	15	16	13	14
	Coronal	Back	6	7	8	12	9	12	7	11
	Labial	Front	16	17	11	17	10	15	12	17
	Labial	Central	20	21	15	14	15	13	13	12
	Labial	Back	12	11	16	12	14	10	14	10
	Dorsal	Front	3	4	3	3	6	5	6	5
	Dorsal	Central	5	4	3	2	4	4	3	4
	Dorsal	Back	2	2	1	2	2	3	3	3
CI	Coronal	Front	21	13	16	11	31	20	27	21
	Coronal	Central	9	12	12	13	8	11	18	15
	Coronal	Back	3	9	9	13	8	16	13	21
	Labial	Front	6	15	10	15	7	16	7	11
	Labial	Central	17	14	17	17	11	9	5	8
	Labial	Back	18	11	23	17	20	13	18	11
	Dorsal	Front	2	2	2	2	2	3	2	3
	Dorsal	Central	2	1	3	2	3	2	3	2
	Dorsal	Back	0	1	1	2	3	3	5	3

The median observed (Ob) and expected (Ex) percentages are given for the NH and CI groups in the four babbling quarters (T1–T4). Black fields mark observed % that are significantly higher than expected %, and grey fields mark observed % that are significantly lower than expected %.

the three V height types during the babbling period, as assessed by the Mann–Whitney U test.

Time effect • On the one hand, the effect of age at implantation on the proportions of the different C and V types was assessed by means of the nonparametric Spearman Rank Correlation test on all quarterly results. We found a statistically significant positive correlation between age at implantation and the proportions of labial Cs ($p < 0.01$).

Alternatively, we divided the CI group into two subgroups, each consisting of five children, on the basis of their age at implantation: "earlier-implanted CI children" who were implanted before 12 mo of age, and "later-implanted CI children" who were implanted after 12 mo of age. By means of the nonparametric Wilcoxon ranking test, both subgroups were compared with regard to the proportions of the different C and V types. These analyses revealed that the earlier-implanted CI children produced significantly more fricatives ($p < 0.01$) and mid vowels ($p < 0.01$) than the later-implanted CI children. The latter subgroup produced significantly more labials ($p < 0.01$) and low vowels ($p < 0.01$) than the former subgroup.

Intrasyllabic Phonotactic Patterns

Table 7 displays the intrasyllabic CV correlations in the NH group and the CI group from babbling quarters T1 to T4. Remarkably, both groups of children combined the different types of consonants and vowels at random in the first stage of babbling (i.e., T1), because none of the CV combinations reached significant prevalences. One exception was found in the CI group: they significantly preferred to produce coronal consonants with front vowels from the beginning onward. After the first 3 mo of babbling, four significant CV co-occurrence patterns emerged in the NH group: significantly more coronal-front and labial-back combinations were observed than expected and significantly less labial-front and coronal-back combinations were observed than expected. These four significant CV combinations were found up to the last babbling quarter. The children with a CI started to demonstrate the same four significant CV combinations from T3 onward, that is, one quarter later than the children with normal hearing. In both the NH group and the CI group, central vowels seemed to be rather randomly combined with coronals, labials, and dorsals, because their prevalences never reached statistical significance.

Table 8 shows that, in the CI group, an effect of T8
age at implantation on the attainment of the four significant CV combinations was noticed: the later-implanted CI children reached these co-occurrences earlier within their babbling period than the earlier-implanted CI children.

Intersyllabic Patterns

With regard to the intersyllabic complexity parameters, the results were pooled over the entire babbling period instead of in babbling quarters. This was justified because no longitudinal trends from T1 to T4 were present, and it allowed more robust statistical analysis of consistent between-group trends as seen over all periods.

TABLE 8. Intrasyllabic patterns: attainment of the four significant CV combinations

Children with a CI	Activation of CI (In terms of age quarter)	Babbling quarter
RX	3	T3
AN	4	T3
MI	4	—
YA	4	—
EM	4	T3
RB	5	T2
AM	5	T3
KL	6	T1
JO	7	—
TE	8	T1

The babbling quarter (T1–T4) at which the four significant CV combinations (see text) occurred for the first time as a function of the age at activation of the implant (in terms of the age quarter in which the implant was activated). The "—" in the last column represent the children who did not attain the four CV combinations within the babbling period.

Reduplication versus variegation • Table 9 shows that the children with normal hearing produced more variegated than reduplicated babbles (viz 60% vs. 40%, respectively), whereas the children with a CI preferred to produce reduplicated sequences (viz 55%) during the entire babbling period.

Between-group statistics (Mann–Whitney U test) revealed that the children with a CI used significantly less variegated (and thus more reduplicated) CVCV sequences than the children with normal hearing ($p < 0.01$).

Types of variegation • When considering the variegated CVCV syllables in more detail, both groups of children varied their vowels more than their consonants, as displayed in Table 9. And although between-group statistics (Mann–Whitney U test) did not reveal a significant difference, this preference for V variegation was stronger in the CI group than in the NH group (viz 62% vs. 54%, respectively).

In addition, although both groups of children preferred to vary Cs OR versus instead of Cs AND versus, the proportion of the combined variegations was significantly lower ($p < 0.01$) in the CI group (28%) than in the NH group (41%).

TABLE 9. Intersyllabic patterns

	NH	CI
Reduplication	40% (9)*	55% (6)*
Variegation	60% (9)*	45% (6)*
Vowel	54% (10)	62% (12)
Place	65% (3)	64% (13)
Height	35% (3)	36% (13)
Both	36% (8)	31% (10)
Consonant	46% (10)	38% (12)
Manner	58% (13)	63% (22)
Place	42% (13)	37% (22)
Both	35% (17)	25% (8)
Both	41% (12)*	28% (14)*

The median percentages of occurrence (and interquartile ranges) of the types of reduplicated and variegated CVCV sequences are given for the NH and CI group over the entire babbling period. Asterisks (*) mark significant differences in proportions between the NH group and the CI group ($p < 0.01$).

Types of consonant and vowel variegation • Both the children with normal hearing and the children with a CI showed a clear preference for place variegation with regard to vowels and for manner variegation with regard to consonants, as displayed in Table 9. The proportion of complex C variegations (i.e., manner and place) tended to be lower in the CI group (25%) than in the NH group (35%) (but this difference was not statistically significant according to a Mann–Whitney U test).

Time effect • No effect of age at implantation on the proportions of the intersyllabic babbling characteristics was found for the CI group (Spearman Rank Correlation test).

DISCUSSION

The present study addressed babbling of early implanted deaf children with emphasis on segmental and syllabic characteristics. Children with deafness are known to vocalize like hearing children in the prebabbling stages (Oller, et al., 1985). However, their canonical babbling is substantially delayed or may not occur at all (Oller & Eilers, 1988; Stoel-Gammon & Otomo, 1986). In a previous report, it was shown that cochlear implantation could initiate the onset of babbling in children with deafness (Schauwers, et al., 2004). In this article, we analyzed the CI children's babbles to test whether their qualitative characteristics are comparable with those of hearing children.

Similarities and Differences in Babbling Between Children With a CI and Children With Normal Hearing

At the segmental level, both groups of children preferred to use the coronal and labial place of articulation and the stop manner of articulation in their babbling utterances with regard to consonants. These findings are similar to the preferences found in the literature about babbling in several linguistic environments (e.g., Davis & MacNeilage, 1995; Locke, 1983; Roug, et al., 1989; Stoel-Gammon, 1985; Vihman, et al., 1986) and in other studies investigating the segmental babbling characteristics in children with a CI (Ertmer & Mellon, 2001; Ertmer, et al., 2002; McCaffrey, et al., 1999). The children with a CI, however, produced significantly less liquids than the children with normal hearing during their entire babbling period. But we have to take into account the very low frequencies of this C manner type in both groups of children. With regard to the vowel characteristics, the CI group demonstrated the same distributions as the NH group. Mid-front and mid-central vowels were produced frequently, and high vowels did not occur often. In sum, the segmental content of the babbling of the children with a CI was not different from that of the children with normal hearing. A relatively strong effect of age at implantation was found for labials and fricatives: earlier-implanted CI children produced significantly less labials and more fricatives than later-implanted CI children, which was more in line with the findings of the NH group.

Intrasyllabic, the babbling of the children with normal hearing as well as the babbling of the children with a CI revealed the same patterns: coronal-front and labial-back combinations were produced significantly more than expected, and coronal-back and labial-front combinations were produced significantly less than expected. These results were not consistent with the study of McCaffrey et al. (1999), who found preferences for coronal-front and labial-central CV syllables in a child who received a CI at 25 mo of age. We believe that the significantly high occurrence of labial-back CV combinations in our children's and adults' speech is a typical characteristic of the Dutch language. In this respect, we refer to a recent study by Zink (2005). She conducted similar analyses on babbling in a group of Dutch children, independent of our research. Her results demonstrated the same significant labial-back CV co-occurrences. In fact, the labial-back combination turned out to be the most strongly occurring combination in her study. Our analyses showed that both groups of children started combining their consonants and vowels purely at random in the first 3 mo of babbling before showing these four significant CV combinations in the following months of babbling. The children with a CI, however, seemed to be slower in reaching all four significant combinations than the children with normal hearing: they needed at least 6 mo of babbling experience, while the NH group showed the relevant combinations from 4 mo after the onset of babbling onward. This delay in the CI group, however, seemed to be linked with the age at implantation: we found a trend that children who received their implant at a later age, were able to produce the four relevant CV combinations in an earlier stage of babbling. This finding suggests that these children were ready to make the relevant CV combinations, but they did not start producing them until the necessary auditory input was provided.

The only significant differences between the CI group and the NH group were found in the analyses of the intersyllabic organization of CVCV utterances. The results showed that the children with a CI produced significantly less variegated babbling utterances than the children with normal hearing ($p < 0.01$). In the cases where variegation was used, both groups of children showed a preference for vowel variegation over consonant variegation, but this preference was more pronounced for the CI group. In addition, the children with a CI did not produce complex variegations as frequently as the children with normal hearing, which can be concluded from the significantly lower proportion of combined C + V variegations in comparison with the latter group ($p < 0.01$). In other words, during the entire babbling period, the children with a CI preferred to vary the characteristics of their vowels but not those of their consonants AND vowels. A possible explanation for this finding can be found in the relative salience of vowels (with higher intensities and lower frequencies) over consonants. Consequently, changes in vowel characteristics could be more audible for children with a CI (with a mild to moderate hearing loss) than changes in consonant characteristics. At a more detailed level of variegation, both groups of children preferred to vary vowel place to vowel height and consonant manner to consonant place, similar to the findings of McCaffrey et al. (1999). But as in the case of complex C + V variegations, complex C variegations (i.e., changes in manner AND place) occurred less frequently, although not statistically significant, in the babbling of the children with a CI in comparison with that of the children with normal hearing.

In sum, differences between children with a CI and hearing children in the characteristics of prelexical babbling could not be found on the level of individual segments and on the level of CV syllables. Only when combining CV syllables into CVCV utterances, children with a CI preferred simplicity to complexity in comparison with hearing children: reduplicated CVCV utterances occurred more frequently, and in most cases where the syllables varied from each other, only the vowels were different in the case of CI.

Conclusion

This study shows that the qualitative babbling characteristics of children implanted at an early age are very similar to those of hearing children from the onset of babbling onward. Only complex consonant-related variegations seem to occur slightly less in children with a CI. Since babbling constitutes an important linguistic step toward the production of meaningful words, these results suggest that, in the presence of normal babbling patterns, these children with a CI will proceed to normal word production. This remains to be investigated, however.

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AUTHOR QUERIES

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1—Kindly note that the references Clement, 2004; Cousse et al., 2004; and Kent et al., 1987 are given in the list but not cited in the text. Please check.