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Cochlear Implantation Between 5 and 20 Months of Age: The Onset of Babbling and the Audiologic Outcome

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Objective: The objective of this study was to investigate the onset of prelexical babbling and the audiologic outcome of 10 deaf children who received a cochlear implant (CI) before the age of 20 months.

Study Design: A prospective longitudinal observation and analysis.

Patients: Ten congenitally deaf infants implanted at an age between 6 and 18 months.

Intervention: All children received a Nucleus-24 multichannel cochlear implant.

Main Outcome Measures: 1) The onset of babbling defined as a) the first appearance of multiple articulatory movements and b) a canonical babbling ratio of .2 or higher; 2) the babbling spurt defined as a sudden increase of babbled utterances; 3) the audiologic outcome defined by the CAP score (Categories of Auditory Performance) and the results of the A§E (Auditory Speech Sound Evaluation).

Results: All children started babbling after a short interval of 1 to 4 months after activation of the device so that the onset of babbling in the youngest subjects occurred at a chronologic age comparable to that of normally hearing infants. The outcomes of the different babbling measures correlated significantly with the age of implantation: the earlier the implantation, the closer the results approached the outcomes of normally hearing infants. The children implanted in their first year of life showed a normal CAP development as early as 3 months after implantation. All CI children were able to discriminate phoneme pairs of the A§E immediately after the fitting of the device.

Conclusions: The earlier the implantation took place, the smaller the delay was in comparison with normally hearing children with regard to the onset of prelexical babbling and with regard to auditory performance as measured by CAP. **Key Words:** Babbling—Children—Outcome—Pediatric cochlear implant.
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For hearing parents, one of the main expectations from a cochlear implant for their deaf child is the acquisition of spoken language. Many prelinguistically deaf children have experienced significant improvements in speech perception (1–3), speech production (4,5), and language skills (6,7) after cochlear implantation. Recent studies (8) seem to suggest that receiving an implant before the age of 2 could lead to greater and faster improvements in speech perception and speech production than implantation later in childhood. Currently, children with severe hearing impairment receive a cochlear implant at a steadily decreasing age: the age of implantation has dropped to below 1 year. However, the question remains if there is an additional benefit to be expected from implantation in the first year of life. Perceptual development in the first year provides a crucial argument.

The speech perception capacities that children exhibit during the first 6 months appear to be language-universal rather than language-specific. They are able to discriminate speech sounds that are not relevant in their native language (no phonemic discrimination). This "universal discrimination ability" can be seen to gradually "tune in" into the peculiarities of the ambient language (9). Infants appear to lose their sensitivity for non-native speech contrasts. This language-specific discrimination capacity does not only have important consequences for the child's perceptual or auditory functioning, but also for his or her speech and language development. We can expect that cochlear implantation as early as possible in the first year of life could allow the child to take advantage of this naturally occurring process and to progress through stages of speech development similar to those of infants with normal hearing.

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Implantation before the age of 1 now allows us to assess the speech production at the stage when the child does not yet produce meaningful words, viz. the prelexical period. Our insight in the prelexical vocal development of normally developing children has increased immensely in the last 20 years. The current understanding is that vocal development follows a regular sequence of stages from birth to the emergence of words. Although researchers have approached the study of infant prelexical vocalizations from different theoretic perspectives and used different analytical procedures (10–14), a homogenous picture has occurred from the literature. Table 1 provides a comparative overview of the stages of prelexical vocal development; it shows that although the terminology and the analytical points of departure differ, similar stages are identified, and also the order in which prelexical stages occur is consistent across the various analyses.

A major landmark in prelexical development is the onset of babbling, which can be defined as the production of consonant–vowel sequences. The onset of the babbling stage is critical, because it represents the point at which infants produce mature phonetic syllables that can function as "the phonetic building blocks of words" (15). Although the details of a formal definition of babbling differ as to phonetic content and syllabic structure (for instance, is reduplication of consonant–vowel sequences required? do vowel–consonant sequences also count as babbling? and so on), the onset of babbling (stage 5 in Table 1) in normally developing children is situated between 6 and 10 months of age (10,13–18).

Not only anatomic and physiological constraints, but also auditory perception and feedback seem to determine the onset of babbling. Oller and Eilers (15) studied normally hearing children and hearing-impaired children across the first 2 years of life. They showed that their 21 normally hearing children started to babble between 6 and 10 months of age, whereas none of the nine deaf children in their study started babbling before 11 months of age (range, 11–25 mo). Similarly, Koopmans-van Beinum et al. (19) found that the onset of babbling in hearing-impaired children was much later than in normally hearing children; none of the profoundly hearing impaired children in their study reached the babbling stage before 18 months of age, except for one child who started babbling at age 7.5 months (a child with considerable usable residual hearing).

At present, babbling in cochlear implant (CI) children has hardly been investigated. A case study of a child implanted at 19 months of age (20) revealed a large increase of babbled utterances after 5 months of implant use. However, the generality of this finding remains to be investigated from several respects: does it hold for other children implanted at around the same age? Does it also hold for children implanted at a much earlier age?

With regard to auditory performance, CI children implanted between 5 and 72 months of age were studied by Govaerts et al. (21). They followed up their subjects for 2 years after implantation and reported that the audiologic outcome of cochlear implantation in children with congenital deafness decreased with age of implantation. As an outcome measure, Govaerts et al. used the CAP scores (Categories of Auditory Performance, see the

TABLE 1. *Comparative overview of stages of prelexical vocal development*

	Koopmans-van Beinum and van der Stelt (10)	Oller (13)	Stark (12)	Roug, Landberg and Lundberg (14)	Nakazima (11)
Basis of analysis	Articulatory and phonatory	Metaphonologic	Phonetic and acoustic	Phonetic	Phonetic and acoustic
Stage 1	Uninterrupted phonation (0–6 weeks)	Phonation (0–2 months)	Reflexive crying and vegetative sounds (0–8 weeks)		Crying; beginning of noncry sounds (0–1 month)
Stage 2	Interrupted phonation (6–10 weeks)			Glottal stage (2–3 months)	Begin phonation of noncry sounds (1 month)
Stage 3	One articulatory movement with continuous or interrupted phonation (10–20 weeks)	Goo stage (2–4 months)	Cooing and laughter (8–20 weeks)	Velar/uvular stage (3–4 months)	Development of articulation (2–5 months)
Stage 4	Variations in the phonatory domain (20–26 weeks)	Expansion stage (4–6 months)	Vocal play (16–30 weeks)	Vocalic stage (4–6 months)	
Stage 5	Multiple articulatory movements (repetitive or variegated) (26–40 weeks)	Canonical babbling (7–10 months)	Reduplicated babbling (25–50 weeks)	Reduplicated consonant babbling (6–10 months)	Repetitive babbling (6–8 months)
Stage 6	Meaningful 'words' (after 40 weeks)	Variegated babbling (10–12 months)	Nonreduplicated babbling (after 50 weeks)	Variegated consonant babbling (10–12 months)	Development of prelinguistic communication in voice (9–12 months)

"Methods" section for details [22]) and found that children implanted after 4 years of age had only a small chance (20–30%) of reaching normal CAP scores and of participating in the mainstream school system in Belgium. However, children implanted before the age of 2 were very likely to reach age-appropriate CAP scores immediately after implantation and a majority of these children (90%) participated in mainstream kindergarten. Thus, offering children the aid of a cochlear implant at an earlier age does result in beneficial effects according to a number of outcome measures.

The aim of this article is threefold: first of all, we investigate the audiologic outcome of CI in children implanted between 5 and 20 months of age. Second, we investigate the onset of babbling as a major landmark in productive speech development in these children. Third, we assess the impact of the age of implantation on the children's perceptual and productive speech development. The basis of comparison is normally hearing children's early speech development and their auditory performance.

METHODS

Subjects

Ten congenitally deaf children of hearing parents and without other patent health or developmental problems were selected. They were implanted consecutively, and informed consent was obtained from the parents to participate in this study. Table 2 gives an overview of the (auditory) characteristics of the CI children. The children had an unaided pure-tone average (PTA) of more than 90 dB hearing loss in the best ear, which was confirmed by auditory brain response in the first weeks of life and by pure-tone audiometry from the age of approximately 2 years on. In six cases, the cause of deafness was genetic (five of them were mutations in the connexin-26 gene). All hearing losses were detected in a neonatal screening test. Nine infants started wearing bilateral hearing aids within 1 to 4 months after detection of their hearing loss, one child at 8 months after detection. Most of them did not show any progress with conventional hearing aids. The aided thresholds stayed below the speech area, which covers the area between 15 and 55 dBHL (see Table 2). Only one child reached a PTA of 45 dBHL with his hearing aids. Two other children had a PTA of 60 and 70 dBHL. None of the infants were able to discriminate a set of speech sound contrasts as assessed by means of the Auditory Speech Sound Evaluation (A§E; P. J. Govaerts, Antwerp-Deurne, Belgium) (see subsequently). All children received a multichannel Nucleus 24 cochlear implant (Cochlear Corp., Sydney, Australia) in their first (N = 5) or second (N = 5) year of life. All 10 children were raised orally (Dutch) with support of Dutch signs.

A control group of 10 normally hearing children from hearing parents was followed up from chronologic age 6 to 11 months, the normal age range within which babbling is expected to occur. They did not show any patent health or developmental problems.

Data Acquisition

During 1 year, monthly video recordings of 80 minutes were made starting from the first month after activation of the CI. Six children were also recorded once before implantation. The normally hearing children were followed up in the same way. The recording sessions took place at their homes and consisted of spontaneous parent–child interactions (unstructured observation sessions). The recordings were made with a Panasonic NVDS12 digital video camera with a zoom microphone function.

Of every monthly video recording, approximately 20 minutes were selected in which the child vocalized. Subsequently, the recordings were imported in a Macintosh G4 computer and transcribed according to the CHAT conventions (23). The speech of the adult was transcribed orthographically. With respect to the utterances of the child, a distinction was made between prelexical and lexical vocalizations. The latter were transcribed orthographically (i.e., the adult model word was provided) and phonemically (i.e., the child's rendition of the adult target word was transcribed in phonetic script). The CI children's signs were also transcribed. For children's prelexical utterances, a special coding system was adopted.

Each prelexical vocalization of the child was annotated according to the model proposed by Koopmans-van Beinum and van der Stelt (10). In that model, the basic unit of analysis is the respiratory cycle: sound production in one respiratory cycle is considered. Only "comfort" sounds in the expiration phase are selected, i.e., discomfort sounds such as crying and whining, and vegetative sounds are excluded. The model analyzes speech(-like) sounds into two basic components, viz. phonation (the phonatory movements of the larynx) and articulation (the articulatory movements in the vocal tract). Each utterance is coded as one of two possible types of phonation (uninterrupted vs. interrupted, i.e., the airflow is uninterrupted or interrupted) and one of three possible types of articulation (no articulation, one articulation, or 2+ articulations).

TABLE 2. *Overview of the auditory characteristics of the cochlear-implanted children in this study*

Subject	Etiology	PTA unaided in FF (dBHL)	PTA aided in FF (dBHL)	PTA with Cl in FF (dBHL)	Age of implant	Age at activ
Rx	Genetic	120	110	43	0; 5.5	0; 6.4
As	Connexine 26	130	130	32	0; 6.21	0; 7.21
Ya	Unknown	130	70	38	0; 8.21	0; 9.21
Mi	Connexine 26	130	100	45	0; 8.23	0; 9.20
Em	Unknown	130	130	33	0; 10.0	0; 11.20
Ro	Unknown	130	130	43	1; 1.7	1; 2.4
Am	Connexine 26	130	130	47	1; 1.15	1; 2.27
Kl	Connexine 26	80	45	38	1; 4.27	1; 5.27
Jo	Connexine 26	130	130	42	1; 6.5	1; 7.9
Te	Unknown	110	60	47	1; 7.14	1; 9.4

PTA, pure-tonc average; FF, free field; CI, cochlear implant.

Outcome Measures

The Onset of Babbling

The onset of babbling was determined in two ways:

1. Babbling was defined as the presence of multiple articulatory movements in one breath unit combined with continuous or interrupted phonation (10). The onset of babbling was defined as 1) the first appearance of at least two babbled utterances in one observation session, and 2) the occurrence of babbled utterances in three consecutive sessions. For the CI children, the onset of babbling was computed in two ways: in terms of their chronologic age (in months) as well as in terms of the number of months after the activation of the implant.
2. The canonical babbling ratio (CBR) (15) was used as a second measure for determining the onset of babbling. The CBR is a measure adopted from Oller and Eilers (15) to quantify the onset of babbled utterances: the onset of babbling is taken to occur when the proportion of babbled utterances on the total number of analyzed utterances exceeds 0.2. The operational definition of "canonical babbling" (in Oller and Eilers' terminology; see also Table 1) includes the occurrence of consonant–vowel or vowel–consonant syllable (15). This definition deviates from the one used in the first measure presented in the sense that in our definition, "reduplication" was considered to be a necessary characteristic of babbling. For the computation of the CBR, 50 vocalizations were randomly selected from each session. The age at which a ratio of 0.2 or higher was reached was considered to be the onset of the canonical babbling stage.

The Babbling Spurt

Typically, children start babbling sporadically and at a particular point in time; the frequency of babbled utterances increases dramatically. The latter point is easily identifiable and is called the "babbling spurt." The occurrence of the babbling spurt was defined as the age at which the amount of vocalizations with multiple articulatory movements (10) suddenly increased, i.e., the point in time when the difference in relative number of these vocalizations between two consecutive recordings was most salient. The babbling spurt of the CI children was again computed in terms of chronologic age (in months) as well as in terms of number of months after the activation of the implant.

Auditory Performance: CAP Scores

Categories of Auditory Performance (CAP) (22) is a global outcome measure of auditory receptive abilities. It comprises a nonlinear, hierarchical scale on which children's developing auditory abilities are rated according to eight categories of increasing difficulty.

The categories identified by Archbold et al. (22) are:

Score 0 = no awareness of environmental sounds
Score 1 = awareness of environmental sounds
Score 2 = response to speech sounds
Score 3 = recognition of environmental sounds
Score 4 = discrimination of at least two speech sounds
Score 5 = understanding of common phrases without lip reading
Score 6 = understanding of conversation without lip reading with a familiar talker
Score 7 = use of a telephone with a familiar talker

In this study, the CAP score of the CI children is calculated before implantation and every 6 months after implantation based on the parents' and a professional therapist's assessment of the scale.

Phoneme Discrimination: A§E Scores

The A§E is an audiologic evaluation tool that uses strictly defined speech sounds as stimulus material for detection, discrimination, and identification tests. As a measure of the frequency-resolving capacity of the aided cochlea (with hearing aids), it has become an essential tool in the selection and evaluation of cochlear implant candidates (24). The A§E is independent of lexical items. It provides supraliminal information about the auditory function. The main purpose of the test is to evaluate the discriminatory power of the cochlea of preverbal children. The discrimination test of the A§E is based on the "operant head turn paradigm" (9), modified to make it clinically applicable. For the 10 CI children, we considered the results on an arbitrary selection of seven contrasts: three contrasts involving the cardinal vowels (/u/-/i/, /i/-/a/ and /u/-/a/), a voicing contrast (/z/-/s/), two contrasts in articulation place (/s/-/§/ and /v/-/z/), and one contrast in articulation place and nasality (/m/-/z/).

Statistics

Each babbling outcome measure is considered relative to chronologic age (in months) at activation of the implant as well as relative to the number of months after activation of the implant by means of linear regression analysis. A significance level of 0.05 is used and the linear correlation coefficient R^2 is noted for every relation.

RESULTS

The Onset of Babbling

Figure 1A shows the chronologic age (in months) at which the CI children started to babble relative to their chronologic age (in months) at activation of the cochlear implant. The expected age at onset of babbling is 30.8 weeks (95% confidence interval, 18–43 wk) (10). This normal age range is indicated in Figure 1A by the straight lines. The normally hearing children in this study fell within this range, viz. they started babbling between the ages of 6 and 8 months, indicated in Figure 1A by the dotted lines. Similarly, the two earliest implanted CI children fell within the normal age range, viz. their onset of babbling appeared at 8 and 10 months of age. Another two early implanted children started babbling at 11 months of age. The chronologic age of the other CI children at the onset of babbling fell beyond the age of normally hearing children. The linear correlation coefficient R^2 was 0.92 ($p < 0.05$).

The onset of babbling relative to the number of months after the activation of the implant revealed no statistically significant linear correlation ($R^2 = 0.30$, $p >$ 0.05). Thus, the delay between activation of the CI and the onset of babbling was constant with a median value of 1 month and a mean value of 1.6 months (standard deviation [SD], 1.3 mo).

Figure 1B displays the chronologic age (in months) at which the infants attained a CBR of 0.2 (see the "Methods" section) relative to the age at activation of the CI. The control group of normally hearing children reached

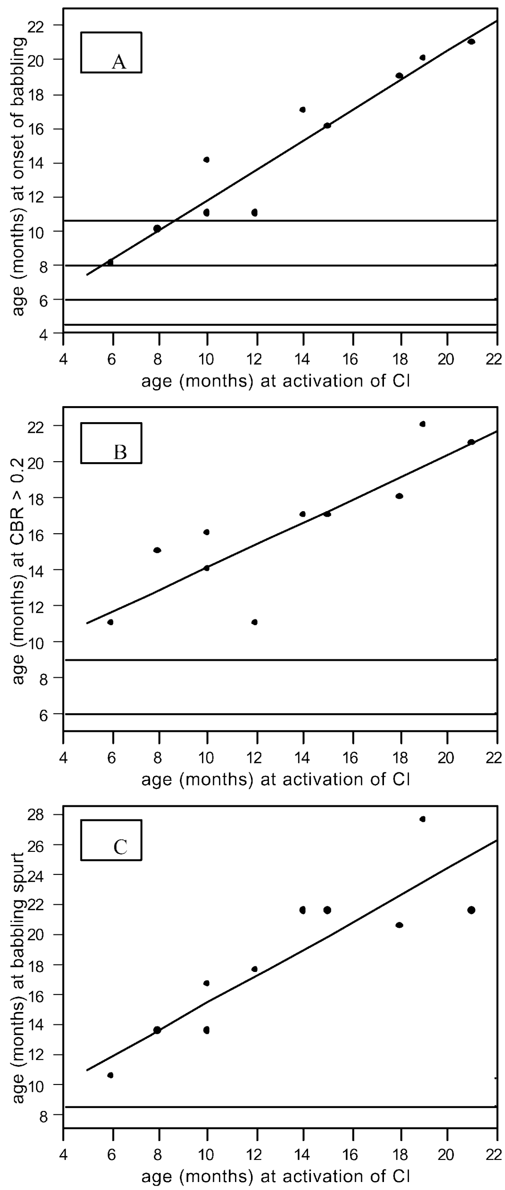

FIG. 1. Age (in months) of the 10 cochlear-implanted children (*A*) at the onset of babbling, (*B*) at canonical babbling ratio ≥0.2 and (*C*) at the babbling spurt. Dotted lines represent the range of outcomes of the 10 normally hearing children. Straight lines in *A* mark the 95% confidence interval (18–43 wk) from the study of Koopmans-van Beinum and van der Stelt (10).

the canonical stage before 10 months of age, which is indicated by the dotted lines in Figure 1B. For the CI children, the results revealed a positive correlation ($R^2 = 0.72$, $p < 0.05$) between the age at activation of the device and the age at which the 0.2-criterion was achieved.

There was a negative correlation between age at activation of the CI and the attainment of a CBR of 0.2 or higher in terms of number of months after CI ($R^2 = 0.60$, $p < 0.05$).

The Babbling Spurt

We considered the chronologic age at which the CI children and the normally hearing children showed a salient increase in the amount of babbled utterances (i.e., the babbling spurt). The results are displayed in Figure 1C. The 10 normally hearing controls had their spurt between 8.5 and 10.5 months of age, indicated by the area between dotted lines in Figure 1C. The youngest CI child again fell within this range. The other CI recipients "spurted" later. The linear correlation coefficient was statistically significant ($R^2 = 0.78$, $p < 0.05$).

No significant correlation was found between the babbling spurt in terms of number of months postimplantation and the age at activation of the implant ($R^2 = 0.06$, $p > 0.05$). The median delay between activation of the CI and the babbling spurt was 6 months (mean, 5.2 mo; SD, 2.5 mo).

Auditory Performance: CAP Scores

The study of Govaerts et al. (21) provided normative data of CAP scores in 113 normally hearing children: at 12, 18, 24, and 30 months of age the infants reached a mean CAP score of 2, 5, 6, and 7, respectively. Regarding the CI children in this study, we considered the CAP scores in terms of number of months after implantation. Eight of the 10 CI children in our study already reached CAP level 5 or 6 1 year after implantation. At 18 months after implantation, they all had level 5 or 6 and one CI child even reached the highest CAP level 7. Another two CI children reached CAP 7 at 24 and 30 months after surgery. Figure 2 presents the earliest moment in time (in terms of number of months after implantation) at which the 10 CI children reached a normal CAP level as a function of the age at activation of the implant. The figure reveals that children implanted in their first year of life reached a normal CAP score as early as 3 months after implantation, whereas children implanted in their

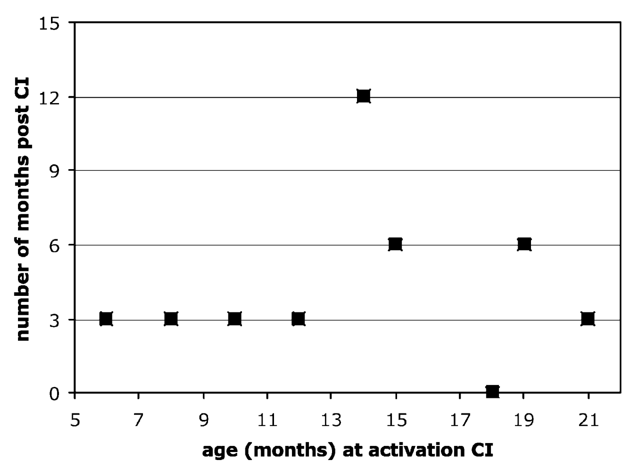

FIG. 2. Number of months after implantation at which the 10 cochlear-implanted children reached a normal CAP (Categories of Auditory Performance) level for the first time as a function of their chronologic age (in months) at activation of the implant.

second year of life needed up to 12 months to reach an age-appropriate CAP level.

Phoneme Discrimination: A§E-Scores

The results of the discrimination part of the A§E for the 10 implantees are presented in Table 3. In the table, the ability (indicated by + sign) or inability (indicated by − sign) to discriminate the tested phoneme pairs is displayed at 6 months and/or 12 months after implantation (depending on whether or not the test was administered). Empty cells in the table represent phoneme pairs that were not tested at that time.

Before implantation (i.e., in the period they wore conventional hearing aids, indicated by HA in Table 3), none of the CI infants discriminated a single speech sound contrast (with one exception: subject Kl was able to discriminate the pair /i/-/a/, as displayed in Table 3). At 6 and 12 months after implantation, almost every tested phoneme pair was discriminated by the CI children.

DISCUSSION

Encouraged by improving results and technology, hearing-impaired children receive a cochlear implantation at a steadily decreasing age. Initially, congenital (or "prelingual") deafness was considered as a contraindication for cochlear implantation. At the same time, many professionals in the field felt that age at implantation was the critical key to success: superior results could be obtained if children were implanted at a much younger age. At present, children are implanted at an age when their normally hearing peers are still in their prelinguistic stage, i.e., before they produce their first conventional word. Hence, we are in a position to assess the potentially beneficial effects for children's language acquisition and development of implantation at a very young age, and to evaluate the differential effects on language acquisition of implantation in the early linguistic stage (e.g., 18 mo) versus the prelinguistic stage (i.e., in the first year of life).

Methodologically, this poses a real challenge: it is difficult to reliably assess the auditory performance of very young children, so that indirect measures such as the CAP score are routinely used (22). Moreover, the effects of a cochlear implant are not only audiologic; important repercussions for children's speech and language development are also expected. Although psycholinguists

TABLE 3. *Phoneme discrimination as assessed by the A§E test*

CI children	/u/ − /i/	/i/ − /a/	/u/ − /a/	/z/ − /s/	/m/ − /z/	/s/ − /j/	/v/ − /z/
Rx							
Ha	−	−	−	−	−	−	−
12 m	+		+	+	+	+	+
As							
Ha	−	−	−	−	−	−	−
6 m	+	+	+	+	+	+	−
Ya							
HA	−	−	−	−	−	−	−
12 m	+	+	+	+	+	+	−
Mi							
HA	−	−	−	−	−	−	−
6 m	+	+		+			
Em							
HA	−	−	−	−	−	−	−
6 m	+						
12 m	+	+	+	+	+	+	+
Ro							
HA	−	−	−	−	−	−	−
6 m	+	+	+	+	+	+	−
Am							
HA	−	−	−	−	−	−	−
6 m	+		+	+	+		−
12 m	+	+	+	+	+	+	
Kl							
HA	−	+	−	−	−	−	−
6 m	+			+	+		
12 m	+	+	+	+	+	+	+
Jo							
HA	−	−	−	−	−	−	−
6 m	+				+		
Te							
HA	−	−	−	−	−	−	−
12 m		+		+	+		+

The ability (+) or inability (−) to discriminate seven phoneme pairs of the A§E test for the 10 CI children (indicated by two characters of their name) at 6 and/or 12 months after implantation. The test was also administered to every CI child before implantation when they still wore their hearing aids (indicated by HA). Empty cells in the table represent phoneme pairs that were not tested at that time.

CI, cochlear implant.

have made considerable progress in mapping out normally hearing children's language acquisition (25), the psycholinguistic assessment of prelexical speech development is relatively new. Not surprisingly, CI children's prelexical development has hardly been investigated.

In this article, we attempt to fill this gap in our understanding of the speech development of very young implantees. We report on the auditory and prelexical outcomes of CI in the first year of life and early in the second year of life.

The audiologic outcome is promising: eight of the 10 CI children in our study already reached CAP level 5 or 6 1 year after implantation. At 18 months after implantation, they all had level 5 or 6 and one CI child even reached the highest CAP level 7. Another two CI children reached CAP 7 at 24 and 30 months after surgery. Seven of our subjects reached a normal, that is, age-appropriate, CAP score as early as 3 months after implantation (Fig. 2), which is in line with the study of Govaerts et al. (21) in which infants implanted before the age of 2 were shown to follow the normal development. Children who receive their implant at approximately 18 months of age lag a bit behind their normally hearing peers (Fig. 2), whereas those receiving their implant in their first year of life follow the normal line.

Phoneme discrimination as assessed by the A§E test revealed that none of the CI children was able to discriminate any of the seven speech sound contrasts before implantation (with hearing aids, except for one subject who was able to discriminate one contrast; see the "Results" section). All subjects passed the test after implantation, which proves the change in the children's hearing after implantation.

As to speech development, the onset of babbling takes place and seems to be triggered by the cochlear implant. It took a median of 1 month of auditory exposure to start babbling, regardless of the age of implantation. Because babbling in normally hearing children starts at a mean age of 8 months, only very early cochlear implantation is able to keep the infants within the normal age range. This was the case for our two youngest CI subjects (see Table 2), who started babbling at 8 and 10 months of age. The impact of age of implantation was very clear: the earlier the implant, the earlier the onset of babbling occurred (Fig. 1A).

The babbling spurt, a sudden substantial increase in the amount of babbled utterances, which is also very salient for parents of normally hearing children, was also apparent in all 10 CI children. A significant positive correlation between age at activation of the implant and age at the spurt supports the positive influence of very early implantation (Fig. 1C). Again, the youngest implanted children fell in the age range of our 10 normally hearing controls. A median of 6 months of auditory exposure was required for the babbling spurt, irrespective of the age of implantation.

The authors believe that this cannot be attributed to maturation effects. This is because the study focused on the onset of babbling and the babbling spurt. From a maturational point of view, hard-of-hearing children will show a significant delay in the onset of babbling (later than 18 mo of age), and some will not even come to this stage at all. This is in contrast to normally hearing children, who all start babbling before the age of 10 months or 43 weeks. Almost all CI children in the current study started babbling before 18 months of age. In light of the aforementioned data, this could therefore not be a maturational effect. It is also striking that all CI children in the current study started babbling at approximately 2 months after implantation, irrespective of the age at implantation. This clearly is suggestive of a trigger effect. In addition and as mentioned before, all hearing losses were detected neonatally and all children received early (re)habilitation and hearing aid fitting. Their babbling was indeed assessed at different stages, but all except one failed to babble before the implantation. So the later onset of babbling cannot be attributed to later detection or (re)habilitation.

At a more practical level, integration in the mainstream school system is a pertinent question. In Belgium, children with severe to profound hearing impairment are referred to dedicated rehabilitation centers. These centers provide hearing training and education throughout the educational career of the child. However, the centers are stimulated and financially supported to promote the integration of a hearing-impaired child in the mainstream kindergarten or primary school. Govaerts et al. (21) showed that approximately 60% of children implanted between the ages 2 to 4 were integrated in the mainstream school system at the age of 7 years. In contrast, implantation before the age of 2 resulted in 67% of the children attending mainstream school at the age of 3 years (which is the first class in kindergarten) and the authors anticipated that approximately 90% would ultimately be able to attend primary school at the normal age. Four of the 10 CI children are indeed attending the first kindergarten class at the age of 2.5 to 3 years of age. As judged by professional therapists, the other CI infants are likely to attend kindergarten classes as well, although at a later age (4–5 yr).

In conclusion, the present results indicated that early implantation led to early onset of babbling and to good auditory performance. Even in this age group (5–20 mo), the earlier the implantation, the better the results appeared to be in line with those of normally hearing children. This study, however, did not deal with the reversibility or irreversibility of the delay that is seen in case of late implantation. It is therefore conceivable that late implantation might not only trigger the babbling onset as shown in this study, but that this could eventually lead to the same speech development as in the case of early implantation.

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