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Language acquisition in very young children with a cochlear implant

Karen Schauwers, Paul J. Govaerts & Steven Gillis (eds.)

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Introduction

The papers in this volume are a first attempt to communicate research results on early language acquisition in very young children with a cochlear implant. Children born with a bilateral sensorineural hearing loss can be detected and appropriately diagnosed at a very young age due to universal hearing screening programs. Early detection opens the possibility of very early cochlear implantation. 'Very early' should be taken literally: in this volume the case is described of a baby who received a cochlear implant in her fifth month of life. In the introductory paper Paul Govaerts, Karen Schauwers and Steven Gillis describe this trend towards very early intervention and they point at the need for appropriate tools for charting out perceptual development as well as productive language development.

Children who receive a cochlear implant after a period of only restricted (if any) auditory stimulation, will start organizing 'the world of sounds'. Normal hearing children have been doing this from well before birth. In his paper "What infants learn about native language sound organization during their first year, and what may happen if they don't", Derek Houston examines speech perception and language skills of deaf infants before and after cochlear implantation. The editors of this volume are very grateful that Derek Houston took the theme of this paper, which was originally conceived by Peter J. Jusczyk, and developed it in a way that constitutes a genuine tribute to our dear colleague.

The papers by Steven Gillis, Karen Schauwers and Paul Govaerts and by Gisela Szagun assess the effects of a cochlear implant from the point of view of productive language use. Gillis, Schauwers and Govaerts investigate infants' vocalizations during the prelexical period, i.e. before they acquire their first words. They compare 'babbling' in infants implanted during their first year of life with babbling in infants implanted during their second year of life.

Gisela Szagun focuses on the development of the grammatical system of German in children with a mean implantation age of 29 months as compared to normal hearing infants. She investigates these infants' use in spontaneous speech of specific inflections (verb endings and noun plurals) and of case and gender marking on the definite article.

In the final paper "Cochlear implantation below 12 months of age: challenges and considerations", Christine Yoshinaga-Itano opens a broader perspective on cochlear implantation in very young children. She addresses several important issues and obstacles with regard to cochlear implantation of young children.

The papers in this issue of *Antwerp Papers in Linguistics* were presented at the 9th congress of the International Association for the Study of Child Language (IASCL), held at the University of Wisconsin, Madison, July 16-21, 2002. At that occasion, A. Baker (University of Amsterdam) acted as the discussant in the invited symposium "Language acquisition in very young children with a cochlear implant".

At a meeting held at the “Priorij Corsendonk” in June 2002, the symposium was prepared, and many technical issues were discussed with respect to cochlear implantation, assessment and linguistic outcome measures. At that meeting papers and technical notes were also presented by Sue Archbold (University of Nottingham), Anne Baker and Elke Huysmans (University of Amsterdam), Orly Herzberg and Dorit Ravid (Tel Aviv University), Harriet Jisa (University of Lyon), Elly van Knegsel (University of Nijmegen), Mieke Beers (University of Leiden) and Florien Koopmans – van Beinum (University of Amsterdam), as well as by the authors of the present volume.

We gratefully acknowledge the financial support of the Flemish Science Foundation’s Scientific Research Communities for *Computational Linguistics and Language Technology – CLIF* and the research community for *Psycholinguistics*: without their support the Corsendonk meeting would not have been possible.

Wilrijk, June 2002
Karen Schauwers, Steven Gillis, Paul Govaerts

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Language Acquisition in Very Young Children with a Cochlear Implant: Introduction

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Abstract

This symposium aims at sharing the preliminary data that are available on language acquisition in very young children with a cochlear implant. Congenital sensorineural hearing loss occurs in approximately 2 per 1000 newborns and results in significant and often irreversible retardation in the development of speech and language. Early detection is possible thanks to universal hearing screening programs. Early intervention consists of hearing aids or cochlear implants in case of severe losses followed by intensive (re)habilitation. Hearing aids are provided at ages as young as 3 months, but cochlear implants are not yet provided routinely before the age of 2 years. A trend however exists towards younger implantation, even before the age of 1 year, and it is anticipated that this will significantly influence the speech and language development of these children. Preliminary data are available on the audiological outcome of very young implantation and they will be presented. In addition, it is also important to assess the speech and language development of these children and to compare this with both normally hearing children and hearing impaired children with a hearing aid during the first years of their life. An attempt will be made to define relevant outcome measures in terms of speech and language development and some first results will be presented.

Congenital hearing loss

Congenital bilateral sensorineural hearing loss (>30 dB HL) occurs in approximately 1.2 to 3.2 per 1000 live births (Watkins 1991, White 1993, Mauk 1993, Parving 1993, Davis 1994, Northern 1994, Fortnum 1997, Stein 1999). This hearing loss is permanent and results in significant delay in speech and language development and consequently in important integration problems in the mainstream educational system (Brannon 1966, Davis 1974, Davis 1986, Andrews 1991, Geers 1989). Deaf-mutism is the most extreme consequence and this has been part of all cultures in human history. Until recently, no other therapy than hearing aids existed. Because of factors that will be discussed later, even hearing aids were unable to restore hearing sufficiently to prevent these severe consequences of congenital deafness.

This situation has dramatically changed in the last decade. The reason for this is the development of cochlear implants in the late seventies. These are implantable electronic devices that aim at replacing the cochlear function. Initially these implants were used to restore hearing in elderly patients with acquired deafness. With time, and encouraged by improving results and technology, the field of indications broadened towards younger patients and lower degrees of hearing loss. Initially congenital (or “prelingual”) deafness was considered a relative contraindication for cochlear implantation, because it was observed that these persons with severe speech and language retardation hardly improved after the intervention. However it was felt by many professionals in the field that cochlear implants could have significant impact on the speech and language development if they could be implanted at sufficiently young an age, meaning before the onset or at a very early stage of the linguistic development. For this to become possible, it would be crucial to detect congenital hearing losses at a very early stage and to develop proper diagnostic tools to gain certainty about the type and degree of hearing loss.

Fortunately and in parallel with the development of cochlear implants, new techniques became available to easily detect hearing losses in newborns. These techniques were based on the otoacoustic emissions that were discovered as a physiological entity in the late seventies (Kemp 1978). Commercial equipment became available in the late eighties and this was the incentive to start thinking of universal neonatal screening programs in order to detect all congenital hearing losses immediately after birth (White 1993). To date, universal neonatal hearing screening is a fact in several regions in the world. Infants with congenital hearing loss are receiving elaborate diagnostic work-up and they typically receive their first hearing aids by the age of 3 months. Audiological tools exist that allow early selection for cochlear implantation, which can be safely done before the age of 1 year.

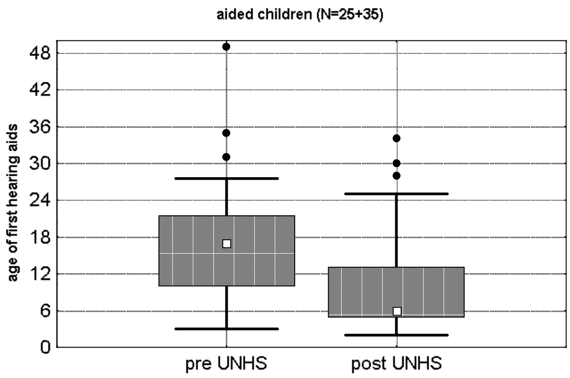

Figure 1. Results of a study of one birth cohort just before (“pre UNHS”) and another just after (“post UNHS”) the introduction in 1998 of universal neonatal hearing screening in Flanders, showing the decrease of the age at which the hearing impaired children received their first hearing aids. Both graphs are box and whisker plots in which the whiskers represent the lower and upper extremes (P0 and P100), the box the lower and upper quartile (P25 and P75) and the central dot the median (P50). (PJ Govaerts, unpublished results)

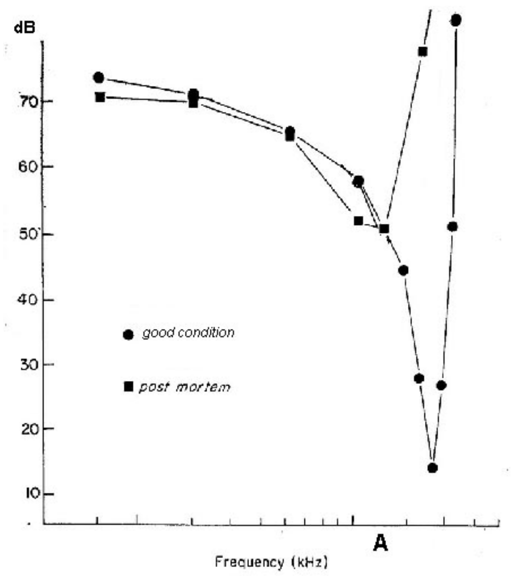

Figure 2. Typical tuning curve of a cochlea in good physiological condition. When compared to the tuning curve post mortem, it is clear that the sensitivity has increased (lower thresholds, especially near the characteristic frequency) and that the tuning has become sharper. This is the result of the active outer hair cell mechanism (figure modified after Sellick 1982).

A congenital sensorineural hearing loss is almost always characterized by a malfunctioning cochlea. The two major functions of the normal cochlea are (1) amplification and (2) frequency-resolution. This is expressed by the tuning curve (figure 2). In case of sensorineural hearing loss, the outer hair cells are virtually always affected. Only in rare cases of isolated retrocochlear types of hearing loss, this may not be the case. If the outer hair cells are affected, the tuning curve shows a higher threshold and a broader tip. The higher threshold results in an elevated threshold on pure tone audiometry. The broadened tip results in a lower frequency resolving power of the cochlea, which is more difficult to assess in the clinical setting. But a good frequency resolving power is essential for normal speech and language development. So this is the key problem in hearing impairment and it is the link between the hearing loss and the speech and language retardation.

Conventional hearing aids unfortunately don't interfere with the tuning, they only amplify the sound. Figure 3 shows how this affects the tuning curve. The result for the patient is that with a hearing aid the detection level of sound decreases but that the frequency resolution of his hearing does not really improve. The patient will therefore report to hear sound better with a hearing aid, without necessarily better understanding the words.

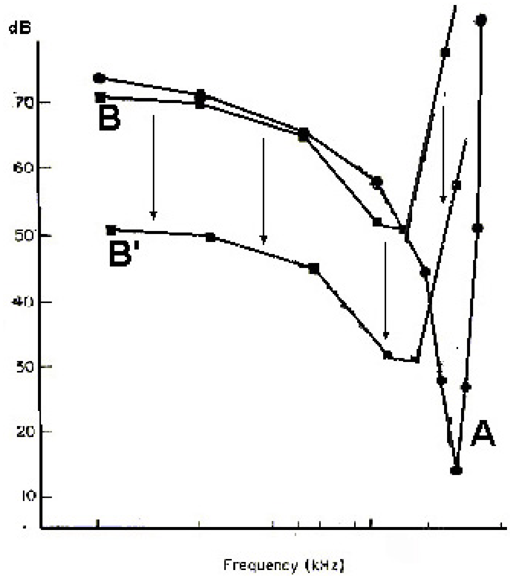

Figure 3. Effect of a hearing aid on the tuning curve of a cochlea. This Figure is based on Figure 2. The sharply tuned curve (A) is the typical curve of a normal cochlea. Curve B is of a hearing impaired cochlea with elevated thresholds and broad tuning. With a hearing aid, this curve shifts downward but the shape does not change (B'). The effect is that the cochlea will detect sound at lower levels, but that the frequency resolving capacity of the cochlea does not improve.

Cochlear implants in contrast not only amplify the sound, but they also aim at a (partial) restoration of the frequency resolution of the cochlea. This is achieved by the spatial selectivity of the stimulation at different points in the cochlea. A cochlear implant has an electrode array with multiple electrode contacts. The Nucleus® 24 device (from Cochlear Ltd, Australia) will be described to illustrate this. This implant has 22 intracochlear and 2 extracochlear electrodes. Different stimulation modes are possible, of which the monopolar mode is commonly used. This means that the current flows between the intracochlear and the extracochlear electrodes. In consequence the spatial current spread at the site of the electrode is small and results in a local stimulation of the cochlear nerve. The smaller the spatial spread, the more selective the stimulation will be. This should be reflected in the tuning curves.

With a cochlear implant, tuning curves not only show better thresholds, they also show remarkably fine tuning (Figure 4). This is the major advantage of a cochlear implant over a hearing aid. Hearing aids are doing fine as long as the hearing loss is not too severe and cochlear tuning is still acceptable. In such a case, amplification alone is sufficient. If dynamic compression strategies (e.g. wide dynamic range compression), noise suppression paradigms and other quality-improving features are added, modern -often digital- hearing aids may serve the moderately to severely hearing impaired patient well. But as soon as the cochlear tuning becomes deficient, amplification alone doesn't suffice any longer and cochlear implants may yield better results.

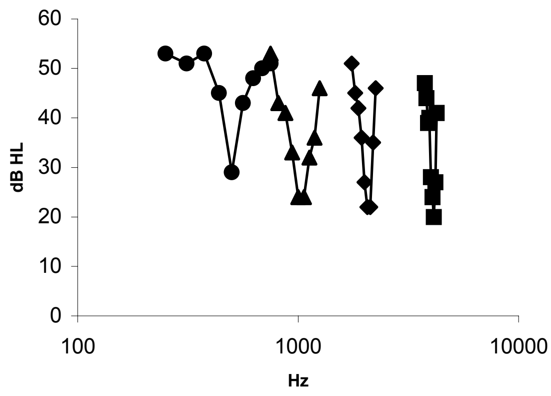

Figure 4. Psychoacoustic tuning curves of a patient with a Nucleus® 24 multichannel cochlear implant in monopolar stimulation mode. Tuning curves with probe frequencies at 500, 1000, 2000 and 4000 Hz and a simultaneous masking paradigm are shown. It can be inferred from the figure that the thresholds are approximately 25 dB HL and that the tuning is sharp (Govaerts 2002a).

How to assess the frequency resolving power of the cochlea?

One of the challenges in handling the pediatric hearing-impaired population is the assessment of hearing. Pure tone audiometry, otoacoustic emissions, automated brainstem audiometry etc. only assess hearing at its detection level. This may be sufficient to know whether a hearing problem exists or not, but it hardly reflects the capacity of the hearing impaired child to discriminate or identify language. So far, too little attention has been given to the fact that hearing impairment means both an increase in detection threshold and a loss of frequency discrimination. In consequence, improving the detection threshold to “within the speech zone” (e.g. 40 dB) does not imply that the aided subject also discriminates the phonemes presented at or above this sound level. Although this limitation has always existed, cochlear implants have forced us to look for supraliminal evaluation techniques. These are needed both in the selection of cochlear implant candidates and the evaluation of cochlear implantees. Supraliminal features of hearing are discrimination and identification of sounds. Tests for discrimination or identification of words and sentences exist, but especially in the preverbal child the results are strongly biased by their individually variable language impairment or cognitive skills. A “preverbal” child is a child with no or very limited functional speech, both comprehensive and productive. Normal hearing children use to become verbal by the age of 1 year (Barrett 1994, Gillis 2000). In hearing impaired children this age is very variable. It depends on the level of hearing loss and the type and intensity of stimulation. Their preverbal stage may typically last till the age of 4-5 years. Tests for this “preverbal” population are difficult and should be conceived in such a way that the dependence on the child’s linguistic and cognitive skills is minimal and that no reading and speech skills are required. Furthermore, the distinctive features should be very clear and unambiguous so as to leave no doubt which features are perceived by the child and which are not (Boothroyd 1997). At least some of the tests should provide the fitter with phoneme-based analytical information to guide the fine-tuning of the cochlear implant.

A common way to investigate auditory performance is the identification test. Identification tasks presuppose a degree of linguistic knowledge and higher functions that are not always present in the hearing impaired child. Thus most of the existing identification tests are only fit for verbal children. In normal hearing children they are feasible from the age of 2-3 years onwards but in deaf children or children with additional problems in language development they cannot be done at this young age.

Another and possibly more correct way to test preverbal children with minimal bias related to the level of linguistic development is testing discrimination instead of identification. No knowledge of the stimulus is required. The child has to discriminate between two or more successive stimuli and has to show a behavioural response (Dillon 1995, Bochner 1992). An additional advantage of discrimination tests as part of a test battery is that they allow for the assessment of the cause of systematic confusions as they may occur in identification tests. The Auditory Phoneme Evaluation (APE®, Melakos nv, Antwerp, Belgium, www.melakos.net) is an audiological evaluation tool that uses strictly defined phonemes as stimulus material for detection, discrimination and identification tests. The APE® was designed as a language-independent test to yield supraliminal information on the auditory function with as little cognitive bias as possible. The main purpose of the test is to evaluate the discriminatory power of the cochlea of very young, preverbal hearing-impaired children with hearing aids.

The phoneme discrimination test of the APE® is an oddity test in which two phonemes are presented and the infant is conditioned to react to the odd phoneme. Table 1 shows the basic set of the phoneme pairs as routinely used by the authors and coworkers in the assessment of the cochlear function.

The discrimination test of the APE® is routinely used by the authors to evaluate the cochlear function in hearing impaired children and adults. Infants as young as 7-8 months can be tested. As a measure of the frequency resolving capacity of the aided cochlea (with hearing aids), it has become an essential tool in the selection of cochlear implant candidates. If the patient fails to discriminate on several phoneme pairs, it is anticipated that his/her discrimination will be better with an implant. If all 22 phoneme pairs of the basic set are assessed, discrimination of less than 19 pairs is an indication to consider cochlear implantation. If only the minimal set of 7 phoneme pairs is assessed, discrimination of less than 6 is an indication to consider cochlear implantation. The phoneme pairs that are often the first fall-outs in hearing aid wearers, are /z/-/s/, /m/-/z/, /u/-/I/ and /v/-/z/. Obviously the phoneme discrimination is not the only selection criterion for cochlear implant and the results should be combined with other audiological and other results before a final decision is made.

a-r	I-E
u-∫	œ -E
u-I	œ -I
I-a	y-I
u-a	u-y
o-a	z-s
u-o	m-f
œ -a	m-z
œ -u	m-r
œ -o	s-∫
E-a	v-z

Table 1. “Basic set” of phoneme pairs of the APE®. The first phoneme of a pair is presented as the background phoneme and the second as the odd phoneme. The black fields represent the phoneme pairs of the “minimal set”.

Cochlear implantation before the age of 2 years

Thanks to new selection tools and to the ever-improving performance of the implants, the number of implants performed worldwide has increased exponentially over the years (Fig 5).

The first children below 6 years of age at our department were implanted in 1994, below 2 years in 1996 and below 1 year in 2000. This steady shift in the age of implantation (Figure 6) has resulted in a significant improvement in outcome.

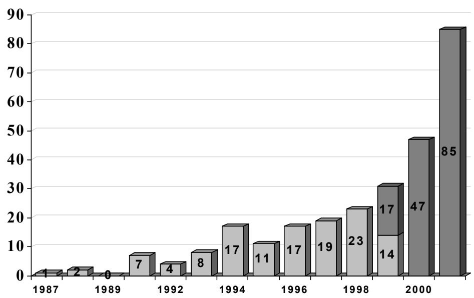

Figure 5. Annual number of cochlear implants at the University ENT Department of the St.-Augustinus Hospital. Light grey: LAURA™ implants; dark grey: Nucleus® 24 implants

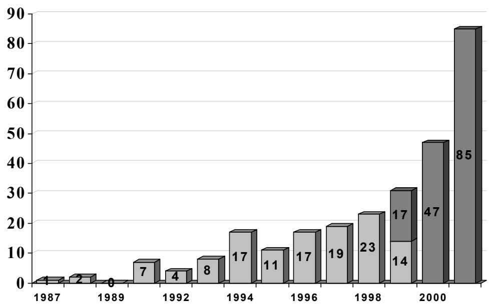

Figure 6. Age distribution of the cochlear implantees at our department for the period 1995-2000. The small figure zooms in on the youngest group (less than 5 years) and it shows that the age distribution in this group has clearly shifted to the younger than 2-year-old children in 2000. (Govaerts 2002a).

Briefly, in children with congenital severe to profound hearing loss, implantation above the age of 4 years gives a moderate auditory performance (even in the long run) with only 33 % of the children being able to integrate in the main-stream educational system. Implantation between 2 and 4 years of age gives good auditory performance, be it with a significant delay of 2-3 years, and a mainstream integration in two out of three. Implantation at 12-18 months gives immediate high auditory performance with an integration rate of 90 % already in the first year of the kindergarten (Figure 7 and Table 2).

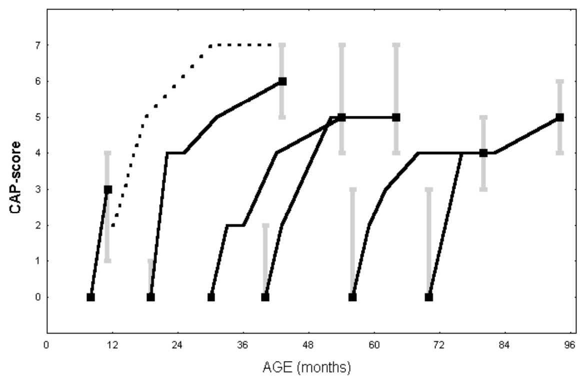

Figure 7. Results of a longitudinal study with the consecutive median CAP-scores (categories of auditory performance, Archbold 1995 and 1998) for six age cohorts defined by the age of implantation. Five cohorts have a follow-up of two years. For each cohort, the range of the CAP-score is

given preoperatively and 2 years postoperatively. The dotted line is the median CAP-score of the control group. (Govaerts 2002b)

Age group	Age (with range) of first hearing aids (months)	Mainstream integration (%)	Age of integration (months)
0	2 (1-4)		
1	7 (3-12)	67 (89)	37
2	13 (9-21)	57 (63)	67
3	13 (3-32)	23 (54)	96
4	15 (10-37)	17 (33)	79
5	20 (10-44)	14 (14)	84

Table 2. Integration of cochlear implantees. The figures in the third column refer to the percentage of children that have been integrated in the mainstream school system so far. The figures between brackets are the same ones plus those that are anticipated to be able to integrate in the near future. (Govaerts 2002b)

Conclusions

In conclusion, the age of implantation in congenital hearing loss is decreasing. The selection criteria are shifting thanks to new evaluation tools. Evidence is being built up of the audiological outcome of young implantation and it seems that implantation before the age of 18 months has advantages. Time has come to assess the outcome in terms of speech and language development.

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What Infants Learn about Native Language Sound Organization during their First Year, and What May Happen if they Don't

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Abstract[1]

Within the first six months of life, infants display excellent capacities for discriminating and categorizing information in the speech signal. These perceptual capacities appear to be general in the sense that infants show similar facility in processing native and non-native language input. However, during the latter half of their first year infants begin to display sensitivity to the particular sound organization of their native language. The information that infants gain about the phonetic and prosodic structure of their native language seems to provide an important foundation for acquiring a vocabulary. This talk will focus on the knowledge that infants gain about native language sound organization during their first year and how this knowledge may facilitate infants in learning words. We will consider what consequences, if any, arise for infants' word-learning skills if they fall behind in learning about the sound organization of their language during the first year. Finally, we will report on findings from new investigations of the speech perception and language skills of deaf infants before and after cochlear implantation.

Introduction

Technological advances in cochlear implants (CIs) have allowed an increasing number of deaf individuals to have access to auditory information. For postlingually deafened adults, CIs restore access to sound and spoken language. For prelingually deaf children, CIs presents a novel sensory input, which provides a way to learn spoken language. The success of cochlear implantation in enabling deaf children to learn spoken language has led to a broadening of candidacy criteria to include younger and younger children. In the U.S., the FDA has approved cochlear implantation for children as young as 1-year of age, and some surgeons are implanting even younger infants when there is clear evidence that they are not receiving benefits from conventional hearing aids.

Recent investigations conducted at several CI research centers have shown that deaf children who receive CIs at younger ages tend to perform better on language comprehension and production tasks than deaf children who

[1] Topic originally conceived by Peter W. Jusczyk

receive CIs at older ages (Fryauf-Bertschy, Tyler, Kelsay, & Gantz, 1997; Tobey, Pancamo, Staller, Brimacombe, & Beiter, 1991; Waltzman & Cohen, 1998). For example, Kirk and her colleagues (Kirk, Miyamoto, Ying, Perdew, & Zuganelis, in press) reported results of a study that tested receptive and expressive language skills of children every 6 months up to 2 years following cochlear implantation. They found that the rate of improvement on the language measures was greater for children implanted before 2 years of age than for children implanted between 2 and 4 years of age. Given these and other similar findings, it is possible that cochlear implantation at even earlier ages (i.e. before the first year) will provide even greater benefits for prelingually deaf children. In order to get an idea of what potential benefits deaf children might gain from earlier cochlear implantation, it would be useful to consider what normal-hearing (NH) infants learn about the organization of sounds in their native language during their first year of life. We first review what is known about NH infants' development of speech perception skills that are important for learning words. Then, we will report on findings from new investigations of the speech perception and language skills of deaf infants before and after cochlear implantation.

Speech perception skills during the first year of life

Speech Discrimination. Over the last 30 years, developmental scientists have used several behavioral procedures to measure the perceptual and linguistic capacities of NH infants. The speech perception capacities that infants exhibit during the first six months appear to be general rather than language specific. Infants are born equipped to learn any of the world's languages. During the first half-year, NH infants are able to detect and discriminate fine-grained differences in speech sounds. Numerous investigations have shown that young infants are able to discriminate vowels and consonants that differ with respect to voicing, place, and manner of articulation. Moreover, up to about 8 months of age, infants are able to detect many contrasts that are not relevant for their native language but do distinguish words in other languages (see Jusczyk, 1997 for a review).

The initial, language-general, speech perception capacities give way to language-specific speech perception skills during the second half of the first year of life. For example, Werker and Tees (1984) tested English-learning 6- to 8-month-olds and 10- to 12-month-olds' ability to detect sound contrasts that were distinctive in Hindi but not to English. They found that 6- to 8-month-olds but not 10- to 12-month-olds were able to discriminate these contrasts, suggesting that sometime during the second six months of life, NH infants lose sensitivity to acoustic phonetic characteristics of speech that are not relevant for their native language. This loss of perceptual sensitivity to nonnative speech contrasts reflects a shift from language general to language-specific speech perception skills. Learning about the organization and characteristics of sounds in the ambient language helps infants discover how to segment continuous speech into word units (Jusczyk, 1997).

Segmenting words from fluent speech. In order to build a vocabulary, infants must develop other skills that allow them to extract words from the context of fluent speech and recognize them. Sensitivity to language-specific aspects of speech appears to be important for speech segmentation during the second half of the first year. In their seminal study, Jusczyk and Aslin (Jusczyk & Aslin, 1995) tested 6- and 7.5-month-olds ability to recognize words in fluent speech. During a *familiarization phase*, infants were presented with repetitions of two words presented in isolation (*cup* and *dog* or *bike* and *feet*). During a *test phase*, the infants were presented with four passages, two contained the familiarized words and two contained the unfamiliar target words. The 7.5-month-olds, but not the 6-month-olds, attended significantly longer to the passages with the familiarized words. These findings suggest that by 7.5 months of age, infants are able to segment and recognize words in fluent speech.

Infants' loss of perceptual sensitivity to nonnative speech contrasts and their ability to segment fluent speech occur around the same time in development. It is possible that infants at this age focus in on language-specific properties of their native language and that sensitivity to these properties may play an important role in speech segmentation. Over the past 10 years, Peter Jusczyk and his colleagues have explored this hypothesis in detail by delineating infants' sensitivities to language-specific properties and describing their segmentation skills. In one study, Jusczyk, Cutler, and Redanz (1993) investigated English-learning infants' sensitivity to the rhythmic properties of English words. Approximately 90% of content words in English begin with a stressed (or "strong") syllable (Cutler & Carter, 1987). Jusczyk and colleagues tested English-learning infants' preferences for lists of bisyllabic words that follow the predominant strong/weak stress pattern of English (e.g., doctor, candle) versus lists of bisyllabic words that follow a weak/strong stress pattern (e.g., guitar, surprise). They found that 9-month-olds but not 6-month-olds attended significantly longer to the lists that followed the predominant stress pattern of English words – strong/weak. In a subsequent study, Jusczyk, Houston, and Newsome (1999) discovered that 7.5-month-old English-learning infants were able to segment strong/weak words from fluent speech but not weak/strong. Taken together, both sets of findings suggest that English learning infants' sensitivity to the rhythmic properties of words in their language plays an important role in their ability to segment words from fluent speech.

English-learning infants may, at first, rely heavily on rhythmic information to locate word boundaries in fluent speech. However, if infants relied only on the location of stressed syllables to find word onsets, they would be unable to recognize many words in English that do not begin with a stressed syllable. Recently, Jusczyk (1997, 2002) has proposed that segmenting the speech stream at every stressed syllable may be a good first-pass strategy for word segmentation. Breaking the input signal into smaller, more manageable chunks allows infants to notice the organization and properties of sounds at different locations within words. Attention to these properties can further inform infants about the types of sounds or sequences of sounds that are more likely to occur within or between words, which will contribute to more mature and sophisticated speech segmentation skills. Indeed, Mattys and Jusczyk (2001) recently found that by 9 months of age, English-learning infants can use information about the sequencing of sounds within and between words to locate word boundaries. In sum, during the first year of life, particularly the second half of the first year, infants attend to language-specific properties of speech that enable them to extract the sound patterns of words from the context of fluent speech. These early word-segmentation skills are important for eventually attaching meaning and organizing the sound patterns of words in lexical memory.

Attention to speech. The speech perception skills that NH infants acquire during the second half of the first year of life require more than just the peripheral auditory system. Good auditory acuity will not necessarily ensure that the infant will notice that more words in English begin with a stressed syllable than with a weak syllable or that /dr/ can occur at word onsets but that /db/ cannot. In addition to being able to discriminate speech sounds infants must, either implicitly or explicitly, selectively attend to the sounds around them in order to become sensitive to how they are distributed. NH infants attend to and learn about the organization of sounds in their native language naturally, without any explicit training. The same might not be true for deaf infants born without access to auditory information. Congenitally deaf infants, even after intervention with a CI, might not attend to sound in the same way as NH infants because of the effects of auditory deprivation during early neural development *in utero* and after birth. As a result, these infants may not readily develop sensitivity to the organization of sounds in their native language, which may in turn lead to difficulty acquiring speech segmentation, speech discrimination, and word learning skills. We have begun to investigate these important issues in deaf infants who have received CIs.

Assessing speech perception skills of infants who use cochlear implants

Infants' attention to and discrimination of speech sounds is crucial for further language acquisition. To assess these skills in infant CI users, we have set up a new research laboratory within an audiology clinic at the Indiana University School of Medicine to assess the speech perception and language skills of deaf infants before implantation and at regular intervals following cochlear implantation. One of the procedures we have adapted is the Visual Habituation (VH) procedure, which has been used extensively for the past three decades to assess the linguistic skills of normal-hearing (NH) infants (Best, McRoberts, & Sithole, 1988; Horowitz, 1975; Polka & Werker, 1994). Our goals are to: (1) validate behavioral measures of auditory and linguistic skills with this population of deaf and hard-of-hearing infants, and (2) use these behavioral techniques to track and assess speech perception and language skills before and after cochlear implantation. Other than parent reports, there are no other methods available to assess benefits and outcomes of CIs in this population.

Measuring and tracking the perceptual and linguistic development of young prelingually deaf infants who receive CIs is important for both clinical and theoretical reasons. From a clinical perspective, it is essential that new behavioral techniques be developed to assess the benefit of implanting infants with CIs at very young ages. At this time, we do not know if providing CIs at increasingly younger ages will actually provide additional benefits and help spoken language development in this population. With new measures of speech perception and novel word learning performance, clinicians and researchers will be able to assess the development of speech perception abilities in deaf infants after cochlear implantation and will be better able to make more informed decisions about the age at which infants should undergo CI surgery.

From a theoretical perspective, it is of great interest to compare language development of normally hearing infants to infants who have been deprived of auditory input and then have their hearing restored at a later age via a CI. Do these children follow the same developmental time course as normal-hearing infants, even though their early auditory experience was radically different? Also, how does the initial absence of auditory information affect an infants' ability to attend to and acquire spoken language? From a theoretical perspective, studying the speech perception and language skills of this unique clinical population will further our understanding of neural plasticity and development vis-à-vis language learning and the effects of sensory deprivation on sensitive periods of language development.

Experiment

VH has been used extensively over the years to assess NH infants' ability to discriminate speech contrasts (e.g., Best et al., 1988; Polka & Werker, 1994). In the standard implementation of VH, infants are first habituated to several trials of a repeating speech sound (e.g., *ba, ba, ba*,…), which is paired with a visual display (e.g., a checkerboard pattern) during a habituation phase. The same stimuli are presented on each trial, and the infant's looking time to the visual display is measured. When the infant's looking time decreases and he or she reaches a habituation criterion, a novel auditory stimulus (e.g., *pa, pa, pa*,…) is presented with the same visual display that was used during habituation. An increase in looking time to the display when the novel auditory stimulus is presented is taken as an indication that infant was able to detect the difference in the speech stimuli and respond to the novelty.

We have modified the VH procedure to assess infants' attention to speech as well as speech discrimination. During the habituation phase, only half of the trials include an auditory stimulus ("sound trials"). On the other half of the trials, the infants are presented with only the visual display ("silent trials"). By comparing infants' looking times to the visual display on sound and silent trials, we can assess their attention to speech. In this study, both NH infants (6- and 9-month-olds) and deaf infants before and following cochlear implantation were tested to assess their attention abilities and speech discrimination skills. We believe that these basic skills are clinically relevant and important for understanding deaf infants' potential for perceiving speech and learning language. Another goal of this investigation was to validate the VH procedure with a population of infants whose speech perception and language skills are completely unknown.

Method

Participants. To date, we have tested 11 prelingually deaf infants who are enrolled in the IU Medical School cochlear implant program. Nine of the infants were tested prior to cochlear implantation (mean age = 11.6 months, range: 6 – 20.5 months). Seven were tested at both the 1-month (mean age = 17.2 months, range: 8.5 – 25 months) and 3-month (mean age = 19.2 months, range: 10.5 – 27 months) post cochlear implantation intervals. Eight were tested at the 6-month cochlear implantation interval (mean age = 22.1 months, range: 13.8 – 31.3 months). One participant, (CI01), who was the youngest cochlear implant recipient at IU School of Medicine received a CI at 6 months of age. We have followed CI01 closely and will report his individual data collected across several testing sessions. Finally, for comparison, we have also tested 24 NH 6-month-olds and 24 NH 9-month-olds.

Apparatus. The testing was conducted in a double-walled IAC sound booth. Infants sat on their caregiver's lap in front of a large 55" wide-aspect TV monitor, which was used to present all of the visual and auditory stimuli. The experimenter observed the infant via a hidden camera and coded how long and in which direction infants looked by pressing keys on a computer keyboard. The experiments were implemented on the computer using Habit software package (Cohen, Atkinson, & Chaput, 2000).

Stimulus Materials. To validate VH with this population of infants, we selected two very simple speech contrasts. These speech sounds are used clinically and have been found to be among the first sound contrasts that hearing-impaired children can detect and discriminate. One stimulus contrast was a 4 sec. continuous ("ahhh") vs. 4 sec. discontinuous ("hop hop hop") contrast. The other contrast was a 4 sec. rising /i/ vs. 4 sec. falling /i/ intonation contrast. A computer representation of a red and white checkerboard pattern was created to serve as the visual display. Using VH, we assessed cochlear implant recipients and NH infants' ability to detect and discriminate these simple speech sounds.

Procedure. This procedure was similar to the standard VH speech discrimination experiment. There was a habituation phase and a test phase. However, our habituation phase consisted of two types of trials. *Sound trials* consisted of a pairing of the visual display and one of the sound stimuli (e.g., "hop hop hop"). *Silent trials* consisted of the visual display only with no sound. There were two sound and two silent trials presented, in random order, in each block of four trials. Infants' attention was drawn to the TV monitor was using an "attention getter" (a small video of a laughing baby). Each trial was initiated when the infant looked to the visual display. The trial continued until the infant looked away from the visual checkerboard display for 1 sec. or more. The duration of the infant's looking time toward the checkerboard was measured for each trial. During the habituation phase, the blocks of trials continued until the infant's average looking time to the visual display across a block of 4 trials (2 sound, 2 silent) was 50% or less than the average looking time across the first block of 4 trials. When this habituation criterion was met, the infant was then presented with two more trials (order of trials counterbalanced across participants) during a test phase. The *old trial* was identical to the sound trials that the infant heard during the earlier habituation phase. The *novel trial* consisted of the other speech sound (e.g., “ahhh”) of the pair and the same visual display. We predicted that if speech sounds elicited infants’ attention then they would look longer to the visual display during the sound trials than during the silent trials. Also, we predicted that if the infants could discriminate the speech sounds, they would exhibit longer looking times during the novel trial than during the old trial.

Results

We obtained two measures of performance. Infants’ attention to speech sounds was measured as the difference in their looking times to the sound versus the silent trials. Speech discrimination was measured as the difference in their looking times to the novel versus the old trial.

Attention to Speech. The data were combined across all stimulus conditions. Figure 1 displays the average difference in looking times (and 95% CI bars) to the sound vs. the silent trials for the NH 6- and 9-month olds (solid bars) shown on the left and the deaf infants at the pre-implantation interval and then at the 1-, 3-, and 6-month post cochlear implantation intervals (striped bars) shown on the right. Bars above the line at zero represent longer looking times to the sound trials than to the silent trials. As shown here, the NH infants attended longer to the sound than to the silent trials. Two-tailed t-tests revealed that this difference was statistically significant for both the 6-month-olds ($t(23)=4.98$, $p<.001$) and the 9-month olds ($t(23)=6.95$, $p<.001$). Prior to cochlear implantation the deaf infants did not attend longer to the sound than to the silent trials. In contrast, the deaf infants following cochlear implantation did attend longer to the sound than to the silent trials, although with the small number of subjects these differences were not statistically significant.

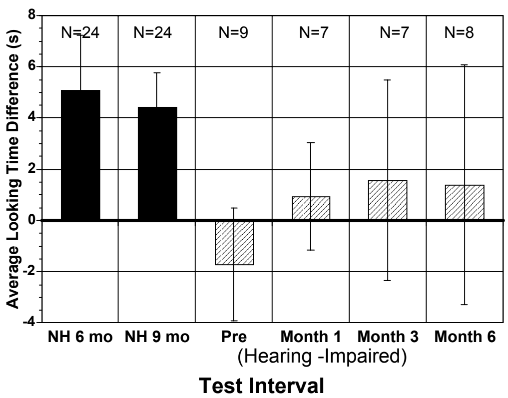

Figure 1. Attention to speech sounds. Looking time difference to the sound versus the silent trials at different CI intervals and for NH controls

Figure 2 displays the data from CI01. He was tested three different times between 1 and 3 months after cochlear implantation. Over this time period, he showed very little difference in looking times for sound versus silent trials. However, he was also tested five times between 6 and 15 months after cochlear implantation. Over this period, he showed a trend to look longer during the sound than during the silent trials ($t(4)=2.30$, $p=.08$).

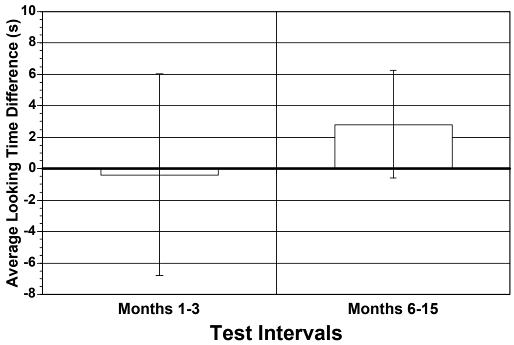

Figure 2. CI01 Attention to speech sounds. Looking time differences to the sound versus the silent trials for participant CI-01

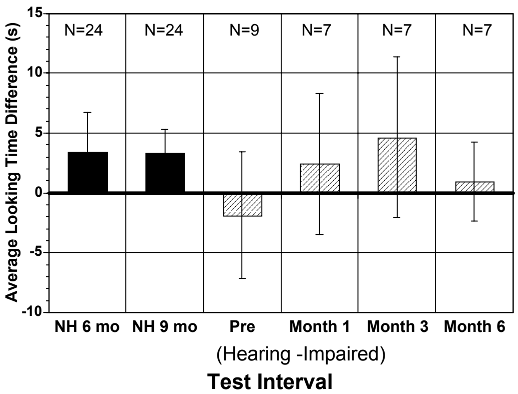

Figure 3. Speech discrimination. Looking time difference to the novel versus the old trial at different CI intervals and for NH controls

Speech discrimination. Measures Figure 3 displays differences in looking times to the novel versus old trials for the same groups of infants. The NH infants are on the left; the deaf infants who use CIs are on the right. NH infants attended longer to the visual display during the new trials than during the old trials. The looking time differences for the NH infants were statistically significant for both the 6-month-olds ($t(23)=2.12$, $p<.05$) and the 9-month-olds ($t(23)=3.56$, $p<.01$). Prior to implantation, the deaf infants did not attend longer to the visual displays during the new trials old trials. In contrast, after implantation, the deaf infants did attend longer to the novel than to the old trials, however, these differences were not statistically significant.

Figure 4 displays the looking times of CI01 during early (1-3 month) and later (6-15 month) post-implantation intervals. CI01 showed no preference for the novel stimulus during the early intervals, but displayed a trend to look longer during the novel trials at his later post-implantation intervals ($t(4)=2.34$, $p=.08$).

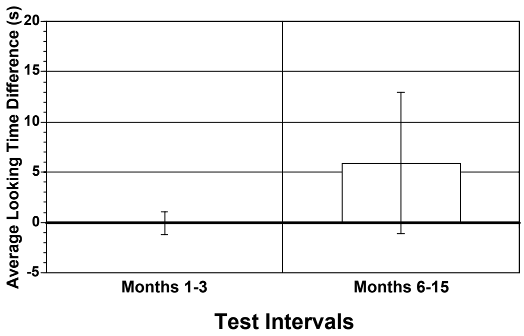

Figure 4. CI01 speech discrimination. Looking time differences to the novel versus the old stimulus trial for participant CI-01

Discussion

The attrition rate in the VH task was similar across both groups of deaf and NH infants – about 20 - 25%. These rates are comparable to what has been reported in other speech perception experiments with NH infants. Hence, it appears that VH is a viable behavioral technique to use with deaf infants before and after cochlear implantation.

During the habituation phase, NH infants paid more attention to a visual display in the presence of a repeating speech sounds than when there is no sound. Following cochlear implantation, deaf infants also showed a similar trend, but it was much smaller. However, the youngest CI recipient, CI01, exhibited a preference for the sound trials at his later post-implantation intervals that was more similar to the NH infants. These findings are consistent with the hypothesis that early exposure to speech is important for the development of auditory attention, although more data are needed to see if these trends are reliable.

During the test phase, NH infants looked significantly longer to novel trials than the old trials. Deaf infants exhibited a similar preference for the novel than for the old trials. Further investigations will examine if deaf infants following cochlear implantation also demonstrate discrimination when the differences in speech sounds are more subtle, such as minimal pair contrasts, which will give us more information about the acuity of their speech perception skills.

In summary, we have adapted the VH procedure to assess the speech perception skills of deaf infants who have received CIs. So far, the results are encouraging. The attrition rates are relatively low, and deaf infants following cochlear implantation are showing trends in their looking responses that are similar to NH 6-month-olds. This pattern was especially true for one participant who received his CI at 6 months of age and was studied repeatedly over time. It is possible that earlier implantation may facilitate the development of attention to speech sounds because sound and auditory information is available at an earlier point in neural development. Attention to speech and spoken language is an important prerequisite for learning about the organization of sounds in the ambient language and developing knowledge of the sound patterns and regularities of sounds.

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Babbling Milestones and beyond: Early Speech Development in CI Children

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Abstract

Prelinguistic babbling is investigated in a group of nine infants with a cochlear implant. The infants'age at activations of the device ranges from 6 to 21 months. All children start babbling after a relatively short interval of zero to four months after activation of the CI, so that the youngest subjects' onset of babbling occurs at a chronological age comparable to that of normally hearing infants. The youngest CI infants start babbling before they acquire their first manual signs, but infants implanted at a later age show the reverse order of acquisition.

Introduction

Currently, hearing-impaired children receive a cochlear implantation at a steadily decreasing age: while the lowest age at implantation was somewhere in the second year of life several years ago, that age has dropped to below one year (Govaerts et al. this volume). This evolution foregrounds a number of psycholinguistic questions with extremely important clinical consequences.

First of all, the question crops up how beneficial a CI is at a very early age in terms of children's development at various levels (i.a. auditory, speech and language acquisition, communicative development)? In other words, ultimately we want to elucidate what gain there is in implanting children at a very early age (e.g., at six months of age) in comparison to implanting them at a later age (e.g. at 18 months). Work on children's early perceptual development (i.a. Jusczyk 1997) reveals that in the latter half of the first year of life crucial developments take place from a 'universal' discrimination ability to a language specific one. It is at least intuitively clear that this 'tuning in' on the ambient language does not only have important consequences for the child's perceptual or auditory functioning but also for his/her speech and language development (De Boysson-Bardies & Vihman 1991, De Boysson-Bardies 1997, Koopmans - van Beinum &van der Stelt 1999). However, much remains to be investigated about the actual impact of these developments on children's speech and language development, and even less is known about whether a child can 'catch up' after a CI at a later age.

Studying very young children also brings in fundamental methodological problems, in addition to fundamental psycholinguistic questions. There is a need for appropriate tools for assessing very young children's speech perception abilities and for assessing their actual speech and language production. Testing one-year-olds or younger children requires different methods than testing a three- or four-year-old. Moreover, assessing the sound and speech production of a child in the first year of life, requires different descriptive categories than those used for older children: the traditional grammatical categories (such as phonemes, words, grammatical constructs) used in psycholinguistic investigations are obviously not adequate and/or appropriate.

The aim of this paper is to provide the preliminary results of a longitudinal investigation of CI children's sound and language production. Our subjects are CI children implanted in the course of the first (4 subjects) and the second year of life (5 subjects). We specifically study their 'prelinguistic' vocalizations and the appearance of 'babbling' as a milestone in their vocal production. The set-up of the study permits us to formulate provisional answers to the question about the impact of age of implantation on the quality and the quantity of early vocal development and to the question how these CI children's early vocal development relates to normally hearing (henceforth: NH) and hearing impaired (henceforth: HI) children's development.

In what follows we will first dwell upon the nature of children's prelexical vocalizations, and upon what is known of NH and HI children's vocal development. This will constitute the background against which we will cast CI children's development.

Prelinguistic vocal development

The literature shows a coherent picture of hearing children's vocal development during their first year of life (or more precisely: during the prelexical period) notwithstanding analyses according to rather divergent analytical frameworks. Researchers analyzed prelexical vocalizations from various perspectives. They provided phonetic and acoustic characterizations (Roug, Landberg & Lundberg 1989, Nakazima 1975, Stark 1980, 1986), phonological analyses (Stoel-Gammon 1989, 1994), metaphonological analyses (Oller 1980, 1986), as well as articulatory and phonatory studies (Koopmans – van Beinum & van der Stelt 1986). There is fair agreement as to the order of appearance of particular developmental stages which reflects the highly organized way in which various vocalization types occur. In Table 1 an overview is presented of the stages of vocal development (with approximate age indications) that have been identified in the literature. Although not all ages and not all stages completely coincide, inspection of the table reveals that a highly similar development is identified. The stage that is identified most readily and is defined most clearly in all analyses presented in Table 1 is the 'babbling' stage. Babbling is defined as

Table 1. Comparative overview of stages of speech development in the first year of life

	Koopmans- van Beinum & van der Stelt (1986)	Nakazima (1975)	Oller (1980, 1986)	Roug et al. (1989)	Stark (1980, 1986)
Stage 1	Uninterrupted phonation (0 - 6 weeks)	Crying; beginning of noncry sounds (0 - 1 month)	Phonation (0 - 2 months)	Glottal stage (2 - 3 months)	Reflexive crying and vegetative sounds (0 - 8 weeks)
Stage 2	Interrupted phonation (6 - 10 weeks)	Begin phonation of noncry sounds (1 month)	Goo stage (2 - 4 months)	Velar / Uvular stage (3 - 4 months)	Cooing and laughter (8 - 20 weeks)
Stage 3	One articulatory movement with continuous or interrupted phonation (10 - 20 weeks)	Development of articulation (2 - 5 months)	Expansion stage (4 - 6 months)	Vocalic stage (4 - 6 months)	Vocal play (16 - 30 weeks)
Stage 4	Variations in the phonatory domain (20 - 26 weeks)				
Stage 5	Reduplicated articulatory movements (26 - 40 weeks)	Repetitive babbling (6 - 8 months)	Canonical babbling (7 - 10 months)	Reduplicated consonant babbling (6 - 10 months)	Reduplicated babbling (25 - 50 weeks)
Stage 6		Development of prelinguistic communication in voice (9 - 12 months)	Variegated babbling (10 - 12 months)	Variegated consonant babbling (10 - 12 months)	Nonreduplicated babbling (after 50 weeks)

reduplicated sequences of consonants (C) and vowels (V).[2] The repetition of CV sequences gives rise to the labels 'repetitive babbling', 'reduplicated babbling' or 'canonical babbling'. Babbling represents an important achievement in the child's vocal development, since a CV sequence is considered to be the 'simplest' syllable and the syllable is the phonetic building block of adult words. This means that when the child starts babbling, he/she is at least phonetically speaking at the threshold of word use, at the border between the prelexical and the lexical stage. The studies reviewed in Table 1 agree that children start babbling in the age range from 6 to 10 months.

In the babbling stage a distinction is made between 'reduplicated' and 'variegated' babbling. In 'reduplicated' babbling the same syllable is repeated throughout the babbling episode. In 'variegated' babbling consonants, or vowels or both can be different. According to some studies reduplicated and variegated babbling occur in two successive stages (Oller 1980, Stark 1980, Elbers 1982). Other studies have shown that not all children exhibit such a clear progression: variegated babbling has been shown among the very early babbling sequences (Davis & MacNeilage 1995, Mitchell & Kent 1990, Smith, Brown-Sweeney & Stoel-Gammon 1989).

In Table 1 also other important distinctions are made: for vocal development the distinction between cry and non-cry sounds is crucial. The latter sounds are egressive such as normal speech sounds, while the former are ingressive as well as egressive. For vocal development the distinction between vegetative and non-vegetative sounds implies the use of the vocal tract for phonation (as in normal speech sounds) versus the use of other sources of phonation. These distinctions point at 'non-vegetative, non-cry comfort sounds' as the main locus to look for precursors of babbling (and later language).

The origin of babbling. The fact that babbling consists of CV syllables and that CV is the universally preferred syllable type leads to the hypothesis that something innate is at stake in children's use of CV syllables in their early vocal production. Indeed, if all languages of the world share CV syllables while other types of syllables (such as CVC, CCV, VCC, etc.) do not occur across languages, and if all children start with CV syllables while other types of syllables are later to appear (Levelt & Van de Vijver in press), may be somehow 'given' to the child.

Evidence for this hypothesis comes from studies of children's motor development. In an investigation of 51 children's gross motor development, Van der Stelt & Koopmans – van Beinum (1986) found a particular sequence in motor development, and established the specific place that babbling appears to occupy in it. Just as rolling from prone to supine and rolling from supine to prone occur in a particular developmental order, babbling also seems to occupy a fixed position in that developmental order. Similar views are expressed by other investigators: Wallace, Menn & Yoshinago-Itano (2000, see also Koopmans – van Beinum & van der Stelt 1998) argue that the onset of babbling requires rhythmic jaw movements and simultaneous phonation, a coordination

[2] Note that some authors accept a child's vocalization as a 'babble' if it consists of a consonant and a vowel (i.a. Oller et al. 1976). In this paper, as in most of the relevant literature the reduplication of CV sequences is considered to be a defining characteristic of babbling.

that seems to be linked to the onset of rhythmic limb waving (Thelen 1991) and, hence, probably driven in large part by the child's timetable for motor maturation. Mandibular oscillation is also advanced as the core explanatory concept of babbling by MacNeilage and colleagues (Davis & MacNeilage 1990, 1994, 1995, MacNeilage & Davis 1990a, b, 1991, MacNeilage, Davis, Kinney & Matyear 1999, Matyear, MacNeilage & Davis 1997, Redford, MacNeilage & Davis 1997).

The safest conclusion that can be drawn from these studies is that babbling is determined to some extent by maturation, and in this sense it can be considered as a motorical milestone (Koopmans – van Beinum & van der Stelt 1986). The question remains if the onset of babbling is more than just a motorical milestone. If that were the case, we would expect (severely) hearing impaired children to start babbling at the same age as normal hearing children.

Babbling and audition. Do young HI children start babbling at the same age as NH children? As to the timing of the onset of babbling, the current view expressed in the literature is that HI children start babbling much later than NH children. Oller & Eilers (1988) found that the 21 NH children in their study started babbling between 6 and 10 months of age, while none of the 9 HI children started babbling before 14 months of age. Koopmans – van Beinum and colleagues report similar findings: the mean age at which the 54 infants in their sample started babbling was 30.8 weeks (Koopmans – van Beinum & van der Stelt 1986). But of the 6 profoundly HI children only one child started babbling in the expected age range, while none of the other HI children started babbling before 18 months of age (Koopmans – van Beinum, Clement & van den Dikkenberg – Pot 2001). The difference in the ages reported may be due to slight differences in the definitions of babbling used, but the bottom line is quite clear: HI children start babbling but they do so much later than NH children.

Timing of the onset of babbling is only one aspect of the deviant sound production of HI children. Once they start babbling, their babbling ratio is lower than that of NH children, and on the whole their vocal production is characterized by a restricted formant frequency range, limited phonetic and syllabic inventories, longer duration, and lack of expressive jargon (Ertmer & Mellon 2001, Kent, Osberger, Netsell & Hustedde 1987, Lynch, Oller & Steffens 1989, Oller & Eilers 1988, Stark 1983, Stoel-Gammon & Otomo 1986, Stoel-Gammon 1988).

The conclusion that can be drawn from this short overview of the relevant literature is that HI children's babbling is deviant from NH children's babbling both quantitatively and qualitatively. Thus hearing has an impact on the onset of babbling. Two notes of caution are in order here: first of all, this conclusion only holds for babbling (reduplicated CV sequences with or without variation) and not for all kinds of other vocalizations that children produce during their first year of life (see Table 1). In a series of studies comparing HI and NH children's vocalizations in the first and second year of life, Koopmans – van Beinum and colleagues found that HI children vocalize more than NH children in their first year of life and the amount of vocalizations is statistically significant in the first year of life – though not in the second year of life (Clement, den Os & Koopmans – van Beinum 1994, Clement & Koopmans – van Beinum 1995, van den Dikkenberg – Pot & Koopmans – van Beinum 1997, van den Dikkenberg – Pot, Koopmans – van Beinum & Clement 1998, Koopmans – van Beinum, Clement & van den Dikkenberg – Pot 2001). What also significantly differs between the two populations are the timing of the onset of babbling and the quality of the vocalizations (see below).

A second note of caution relates to the definition of HI children, more specifically the amount of hearing loss. We already mentioned that some HI children do start babbling at approximately the same age as NH children. A case in point is mentioned by Koopmans – van Beinum et al. (2001): one of their subjects started babbling at 7.5 months of age, while all the other HI children did not start babbling before 18 months of age. The explanation the authors suggest is that the child had a usable hearing residue, particularly in the lower frequency range. This residue may have provided enough auditory input for babbling to take off. However, as Koopmans – van Beinum (p.c.) remarks, residual hearing is necessary for babbling, but it does not appear to be sufficient since children with a hearing loss comparable to the child mentioned above do not start babbling until much later. Thus even if children have a severe hearing loss, they may start babbling at the appropriate age. Consequently, it may concluded that indeed audition is necessary for the onset of babbling, and residual hearing may lead even HI children with a severe hearing loss to start babbling, though residual hearing does not seem to be sufficient in each case for babbling (though the exact conditions under which HI children start babbling at the appropriate age and other HI children do not start babbling at that age, are largely unknown).

Describing prelexical vocalizations

In this study we investigate young children's prelexical vocalizations in relation to their chronological age and their age at implantation. In Table 1 an overview was presented of the major stages and milestones in NH children's vocal development, but the question was not answered if the notions mentioned in the overview were all operationally defined. For babbling there is a clear definition, i.e. a sequence of CV-syllables. But young children produce many more different types of vocalizations (even before they start babbling). Thus the problem is how to characterize and describe them. Except for babbling, the question rises for clear links between the actual sound production and the descriptive categories used in the analysis.

Close scrutiny of the relevant literature brought Koopmans – van Beinum & van der Stelt (1986, 1998) to the conclusion that clear and unambiguous operational definitions were needed for describing young children's prelexical sound production. They proposed a sensori-motor approach that will be adopted in this study. The approach relies on the following distinctions and premises:

- the basic unit of analysis is the *respiratory cycle* or the *breath unit*;
- two main aspects of the sounds produced in a breath unit are described: *phonation* (the larynx makes phonatory movements) and *articulation* (the vocal tract makes articulatory movements);

- with respect to phonation, the basic distinction is between *no phonation*, *continuous* and *interrupted* phonation;
- with respect to articulation the basic distinction is between no articulation, one articulatory movement, and two or more articulatory movements.

Given these descriptive categories, each prelexical utterance can be described in terms of its phonatory and articulatory properties. For instance, the typical 'gooing' [∂R∂] (see Table 1) that children produce around the age of two months is described as a phonation that is interrupted by one articulatory movement, while a babble like [tatata] is described as phonation interrupted by two (or more) articulations.

Koopmans - van Beinum & van der Stelt (1986) analyzed children's sound production according to these categores and the established the development order displayed in Table 1. It shows the growing complexity of children's vocal production. The underlying regularity appears to be the coordination of the phonatory and the articulatory movements, which culminates in 'babbling' in the prelexical stage.

Method

Participants

The participants in this study were 9 HI and 5 NH children and their parents. All children had normal hearing parents. No clear health problems such as cognitive or motor delays were found in the children. Table 2 gives an overview of the auditory characteristics of the HI children who received a CI. In what follows they will be referred to as CI children. The CI children were diagnosed at the University Otolaryngology department of the St-Augustinus Hospital. In all cases in which diagnosis was possible, the cause of deafness was genetically based. All children were raised orally with sign support. Table 2 shows that all children had a hearing loss of more than 120 dB, except for Kl and Te. Their hearing loss with a hearing aid was, in most cases, not significantly different, except for Kl and Te. During the study Ro received a second CI, but this was at an age well beyond the critical babbling milestones that are studied in this paper.

Table 3 provides details of the children's ages at the onset of data collection. It can be readily seen that for three CI children the pre-CI recordings are missing (for one child, Mi, recordings made by the child's parents are available). The other children were observed before surgery and approximately one month after surgery for the first post-CI. For the NH children, the first observation was scheduled at age 0;6.

Table 2. Overview of the characteristics of the CI children

Participant ID	Ethiology	Hearing loss (dBHL)			Device Type	Age at implantation	Age at activation
		Fl unaided	Fl aided	Fl with CI			
Ro	e.c.i.	R: 120	/	R: 43	Nucleus 24 RCS	0; 5. 5	0;6.4
		L: 120	/	L: 43	Nucleus 24 RCS	1;3.9	1;4.8
As	connexine 26	130	130	30	Nucleus 24 RCS	0;6.21	0;7.20
Mi	connexine 26	130	100	45	Nucleus 24 M	0;8.23	0;9.20
Em	e.c.i.	130	130	30	Nucleus 24 RCS	0;10.0	0;11.20
Rb	e.c.i.	130	130	45	Nucleus 24 RCS	1;1.7	1;2.4
Am	connexine 26	130	130	45	Nucleus 24 RCS	1;1.15	1;2.27
Kl	connexine 26	80	45	35	Nucleus 24 RST	1;4.27	1;5.27
Jo	connexine 26	130	130	45	Nucleus 24 RST	1;6.5	1;7.9
Te	e.c.i.	110	60	?	Nucleus 24 RCS	1;7.14	1;9.4

Table 3. Overview of the onset of the recording sessions

Participant ID	Recording Pre CI	First Recording Post CI
CI		
Ro	No	0;6.27
As	0;6.9	0;8.16
Mi	No	1;2.29
Em	0;10.20	0;11.30
Rb	1;2.0	1;2.25
Am	1;2.6	1;3.21
Kl	No	1;6.13
Jo	1;7.15	1;8.13
Te	1;8.21	1;9.23
NH		
Wi	n.a.	0;5.30
Sa	n.a.	0;6.5
Br	n.a.	0;5.30
Lu	n.a.	0;6.5
Ma	n.a.	0;6.2

Data collection and transcription

The children were visited in their homes by one of the authors (KS) once a month. Video-recordings of up to 60 minutes were made of spontaneous unstructured interactions between the child, one of the parents, and in some cases a sibling.

The digital recordings were stored on a hard disk for further processing. From each recording a sample of approximately 20' was taken. The sampling procedure was done by one person (KS) for all recordings and aimed at selecting delineated sequences of interactions. The selected sequences were subsequently transcribed according to the CHAT conventions (MacWhinney 1995). Transcription consisted of an orthographic transcription of the child's and the adult's (or adults') utterances, and in case of prelexical vocalizations the utterance was transcribed with a placeholder (see below). For each utterance a link was established between the written transcript, the sound and the video images, so that in subsequent phases of data coding and analysis the actual recording could easily be inspected. The linking of the transcript and the audiovisual material was done in CED, the CHILDES dedicated editor.

Subsequently the recordings were coded. First of all, each prelexical child utterance was coded for phonation and articulation characteristics. Each prelexical vocalization (more specifically, each 'comfort sound') was coded according to the descriptive categories established by Koopmans – van Beinum & van der Stelt (1986). This coding consisted of determining for each sound where it fitted in the following matrix:

	Articulation type		
Phonation type	No Articulation	One Articulation	Two or more Arrticulations
No Phonation	n.a.		n.a.
Uninterrupted Phonation			
Interrupted Pho-nation			

Each utterance also received a CV-code, i.e., the utterance was broken-up in a sequence of consonant- and vowel-like elements. For each segment – C or V – the defining characteristics were established in terms of place and manner of articulation (for consonants) and in terms of vowel height and closure (for vowels). Once the children started using lexical items, these were transcribed phonemically, while their signed utterances were transcribed with a separate code as part of the orthographic transcription.

Transcription and coding were organized in three phases. In a first pass a trained full-time research assistant or a student research assistant transcribed/coded the data. In a second pass the transcription/coding were checked by the second author of this paper, KS. In a third pass AWK scripts developed by G. Durieux were run over the transcripts / codings in order to eliminate all remaining formal errors in the transcript files.

Results

In Figure 1 the evolution of our youngest subject's (Ro) vocalizations is plotted. The figure shows the percentage of vocalizations according to the number of articulatory movements (0 Art, 1 Art, 2+ Art). At first, vocalizations without articulatory movements predominate. Vocalizations with one movement soon reach the 20% level (at age 0;8.29). The main point of interest is the line representing two or more articulatory movements, i.e. babbling. When does Ro start babbling? It depends on the criteria used: either the first occurrence of babbling is selected, or the well pronounced and often remarked 'babbling spurt' is selected. Thus for Ro the onset of babbling is at age 0;8.1 and the babbling spurt occurs between 0;9.26 and 0;11.2. In what follows we will study babbling using both criteria seperately: the *onset of babbling* and the *babbling spurt*. For the onset of babbling the age of the first occurrence of vocalizations with two or more articulatory movements is selected, provided that a minimum of two such vocalizations occur and provided that babbling occurs in three consecutive observation sessions (unless the babbling spurt intervenes). The babbling spurt occurs when the percentage of vocalizations with two or more articulatory movements suddenly increases, i.e. jumps over 10% of the child's vocalizations and reaches a level that is at least the threefold of that of the previous observation session.

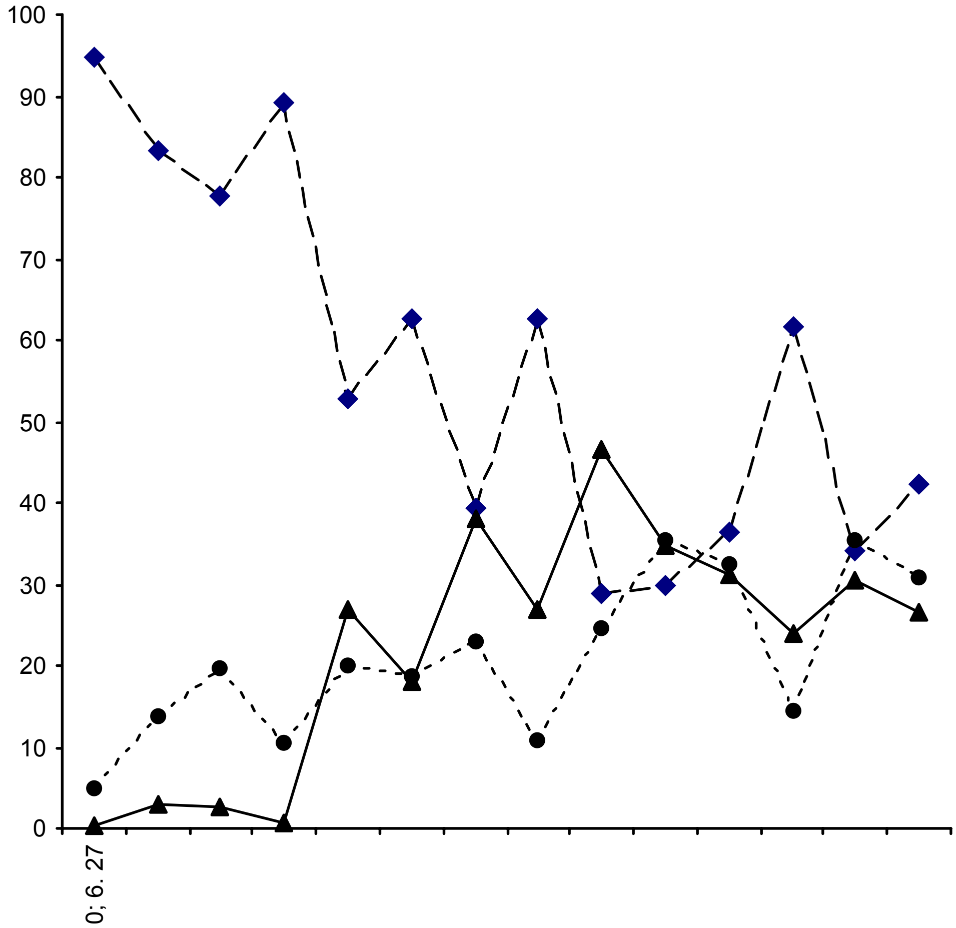

Figure 1: Percentage vocalizations without articulatory movements (0 Art), with one (1 Art) and two or more articulatory movements (2+ Art) of subject Ro

On the basis of these criteria we can assess the age at the onset of babbling and the age which the babbling spurt occurs. As a matter of course, the ages can be calculated in two ways: (1) we can consider the child's chronological age and (2) the of time lapse between the activation of the CI and the occurrence of the babbling spurt, i.e. the child's 'hearing age'.

Babbling and chronological age. Table 4 shows that all children start babbling at some point: the NH children in the age range 0;6 – 0;8, as expected, and the CI children start babbling after they received their implant. There are two exceptions: for Te the onset of babbling occurred pre-implant, and we suspect that also Kl started babbling before he received his implant (unfortunately there is no pre-implant recording).

The expected age for the onset of babbling is 31 weeks (SD 6.3 weeks) according to Koopmans – van Beinum & van der Stelt (1986), and between 7 and 10 months according to Oller & Eilers (1988). According to the latter figures, the earliest implanted infants, Ro and As, fall in the normal age range, i.e., they start babbling at a chronological age at which NH are expected to start babbling. If we take the former figures, both children are also within the normal age range (mean age + 2SDs). On the basis of their chronological age, all the other CI children start babbling later than expected.

Table 4. Chronological age at which CI and NH infants reach the onset of babbling and the babbling spurt

Participant ID	Age at Activation	Onset of Babbling	Babbling spurt
CI			
Ro	0;6.4	0;8	0;10-0;11
As	0;7.20	0;10	1;1-1;2
Mi	0;9.20	1;2	1;4-1;5
Em	0;11.20	1;1	1;5-1;6
Rb	1;2.4	1;5	1;9-1;10
Am	1;2.27	1;5	1;9-1;10
Kl	1;5.27	< 1;7	1;7-1;8
Jo	1;7.9	1;10	2;3-2;4
Te	1;9.4	<1;9	1;9-1;10
NH			
Wi	n.a.	0;8	0;7-0;8
Sa	n.a.	0;6	0;8-0;9
Br	n.a.	0;8	0;9-0;10
Lu	n.a.	0;6	0;9-0;10
Ma	n.a.	0;6	0;9-0;10

The data on the babbling spurt in Table 4 reveal that NH children ‘spurt’ between 0;7 and 0;10 months of age. Again our youngest subject, Ro, is within this range. The other subjects’ spurt occurs later. The babbling spurt is related to age of implantation: the later the implant, the later the babbling spurt, as well as the onset of babbling, occur.

Babbling and age of activation. Table 5 displays the same data as Table 4 but instead of chronological age, the age at which the infants’ CI was activated is taken as the reference point.

The onset of babbling, i.e. the first reduplicated CVs, appears soon after activation of the device (range from 1.6 months to 4.0 months). There is no straightforward relation with the age of activation, though there is a tendency for the onset of babbling to occur earlier in older implanted children. Two infants, Kl and Te, are exceptional in this respect: Te already babbled in the pre-implant observation session, and Kl babbled in the first session after the implant (and he might have started babbling earlier). Note that these are the two children with most residual hearing (see Table 2).

The babbling spurt occurs for most children in an age range from 4 – 5 months to 8 – 9 months after activation. In comparison with NH children, this

Table 5: Number of months between CI activation and onset of babbling, babbling spurt, first words and first signs ('?' means that the child has not yet acquired the type of behavior)

Participant ID	Age at Activation	Onset of Babbling	Babbling spurt	First word		First Conventional Sign
				Preword	Conventional	
CI						
Ro	0;6.4	2.4	4 - 5	9.9	13.4	9.4
As	0;7.20	2.7	6 - 7	?	?	7.5
Mi	0;9.20	4.0	6 - 7	7.5	8.5	7.5
Em	0;11.20	1.9	5 - 6	8.3	12.3	3.4
Rb	1;2.4	3.3	7 – 8	8.4	9.8	9.8
Am	1;2.27	1.6	6 – 7	6	7.8	-1
Kl	1;5.27	0	1 – 2	1.9	2.7	0
Jo	1;7.9	2.7	8 – 9	1.5	?	0.5
Te	1;9.4	-1.2	pre - 1	2.6	5.3	0

range is less or equal to the amount of time it takes for the babbling spurt to occur. Again Kl and Te are the exceptions: their babbling spurt occurs around the time of the implant.

Babbling, words, and signs. Table 5 shows information about the occurrence of two important lexical milestones, viz. the occurrence of the children's first words and their first conventional signs. A first striking fact is that all children first go through a babbling stage before they acquire their first conventional words. As expected, the babbling stage preceding first word use is quite elongated for the younger children (e.g., 11 months for Ro) and much shorter for the older children. NH children often start with protowords such as onomatopoeia, interactional routine words, etc. (Gillis & De Houwer 1998 for a review of the evidence from Dutch speaking children). These protowords also occur in the CI children's repertoire before they acquire their first words.

An extremely interesting finding is the relationship in time between the CI children's vocal behavior and their (conventional) signs. Younger children start signing after they start babbling (Ro, As, Mi, Ro) while older children (Em, Am, Kl, Jo, Te) are already using conventional signs when they start babbling. Unfortunately, data about babbling in the manual mode are lacking so that we are not able to decide whether the relationship in time between prelexical and lexical entities also holds in the manual mode. In other words, we cannot answer the question whether babbling is a genuine prerequisite of symbolic signs, irrespective of the mode of expression.

A robust finding for al children is that they start using conventional signs before (or at the same time as, cf. Rb) they start using conventional words.

However, the time lapse between the occurrence of protowords and conventional signs is much smaller for most children, which suggests further analyses of the iconic and symbolic prerequisites for the use of these three types of linguistic elements.

Discussion and conclusions

In this paper we reported some preliminary analyses of young CI children's sound production. We especially focused on their production of prelexical vocalizations and in particular on babbling. We addressed the issue whether babbling is merely driven by motor maturation or whether audition plays a role in reaching the babbling milestones. If the former were the case, then we expect all children to start babbling at a particular chronological age, irrespective of their auditory abilities. This is not the case: an analysis of the NH and the CI children's onset of babbling reveals that only the youngest CI infants start babbling at an age comparable to that of the NH infants.

HI children also start babbling, thus the question turns up if auditory input is required for reaching the babbling milestones? When we take age at implantation as the yard stick, our analysis reveals that our CI subjects do not need the 6 to 10 months that NH infants need to attain the babbling milestones. In effect, CI children need only up to four months of exposure to sound to start babbling. This result holds for the children implanted around the age of six months as well as for the children implanted in their second year of life. Whether this is due to their more advanced maturation in comparison to the NH infants, who are much younger, remains to be investigated. The most cautious conclusion that we can draw is that indeed children need a certain amount of auditory stimulation for babbling to appear.

A striking finding which also points in the direction of the facilitative role of audition is the fact that the CI infants with the highest level of residual hearing start babbling at around the time they received their implant or even before that event. These children were the very first to attain the babblings milestone relative to the age of CI activation. These children may have benefited from their residual hearing which may have provided them with enough auditory stimulation for babbling to take off. In the literature similar findings have been reported about HI children. In the group of HI children studied by Koopmans – van Beinum et al. (2001) there is one HI child who starts babbling at around the same age as the NH infants, while the other HI infants did not start babbling before the age of 18 months. Also in this case the HI child had some residual hearing that may have facilitated the onset of babbling. Thus, these findings seem to point at a facilitative role of audition in the sense that children with residual hearing may start babbling earlier than children with a more severe hearing loss.

An aspect of babbling development that remained unanalyzed relates to the 'mode' of babbling. HI children have been reported to babble manually (Cheeck, Cormier, Repp & Meier 2001). A fascinating avenue of research is an analysis of babbling in the vocal and the manual mode: what is the relationship between both types of babbling? For instance, do later implanted children start babbling manually at an earlier age, while earlier implanted children do not? Does babbling in the manual mode in a way 'pre-empty' babbling in the vocal mode? We do not have any answers to these and related questions.

Our preliminary analysis of early lexical behavior shows that all children went through a babbling stage before they arrived at their first meaningful conventional word. As expected younger CI children acquire their first conventional signs after they start babbling in the vocal mode, and before they start using conventional words. However, older children are already using conventional signs when they start babbling. This seems to indicate that at a cognitive level they are well prepared to enter the lexical stage, the prerequisites at the symbolic level for actual word use are fulfilled, hence they start using lexical signs. The question remains why they do not start using words at the same moment as they start using signs? Future research will have to elucidate in what respect babbling is a genuine prerequisite for words. In this respect it is interesting to see that the time lapse between the occurrence of protowords and conventional signs is much smaller for most children than the time lapse between words and signs, which may suggest that at the symbolic / iconic level protowords may be closer to signs than to spoken words.

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The Acquisition of Grammar in Young German-Speaking Children with Cochlear Implants and with Normal Hearing

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Abstract

The acquisition of grammar was studied longitudinally in a sample of 22 children with cochlear implants (mean implantation age 2;5) and a control group of 22 normally hearing children. Children were matched for initial language level. Spontaneous speech samples were collected at regular intervals over a period of 27-36 months. Grammatical progress as measured by MLU was slower in the cochlear-implanted group, but individual differences were substantial. Ten cochlear-implanted children progressed at pace with normally hearing children, but 12 children remained well behind. Pre-operative hearing was a better predictor of subsequent linguistc growth than age at impantation. At comparable MLU levels the two groups of children did not differ in their use of inflectional morphology on nouns and verbs, but error rates for case and gender marked articles were significantly higher in the cochlear-implanted group. This indicates that grammatical markings of low perceptual salience are particularly difficult for these children.

Introduction

Studies on linguistic competencies in children with cochlear implants have largely focused on speech perception and speech production skills (Tye-Murray, Spencer & Woodworth, 1995; Fryauf-Bertschy, Tyler, Kelsay, Gantz & Woodworth, 1997). In these studies linguistic performance was best in children who received their cochlear implant before the age of 5 years, but there was also substantial individual variability between children.

The present research takes a developmental psycholinguistc approach to the study of language. From this viewpoint grammar is a core characteristic of human language. Thus, in order to find out to what extent children with cochlear implants are capable of acquiring language, tests of speech perception and imitative speech production do not suffice. We must find out to what extent these children are capable of constructing a grammar. The present study is the first comprehensive study on cochlear-implanted children's language acquisition from a developmental psycholinguistic viewpoint.

For children with typical language development it has been suggested that rapid growth in synaptic connectivity in different brain regions around 16-24 months increases their capacity for storage and coding of information, and thus enables rapid growth in vocabulary and grammar (Bates, Thal & Janowski, 1992). Children can store large amounts of vocabulary and they can make use of distributional information in the input language to construct a grammar,31
such as patterns of co-occurrence of word final phonemes and inflectional morphemes (MacWhinney, 1987; Plunkett & Marchman, 1993).

What kind of language acquisition is possible when children start receiving auditory input much later and have missed the optimal time window (16-24 months) for starting language? Theories of a 'sensitive phase' for language learning are relevant here. Currently, different views on sensitivity for language learning are held in developmental science. The 'sensitive period' view holds that humans have an enhanced capacity for learning language early in life which is based on the brain's increased sensitivity for learning the behavior. This capacity decreases gradually up to puberty (Oyama, 1979; Johnson & Newport, 1993). More specifically, Locke's (1997) 'critical period' view holds that an analytic mechanism for building grammar is turned on around 24 months and when the child has acquired sufficient vocabulary. During a 'critical period' between 24 and 36 months this mechanism functions optimally for setting off grammatical development. If the process of grammar acquisition does not get off the ground during this critical time window, language acquisition will be slow and less efficient. Locke's (1997) 'critical period' view is thus very specific about an age of first decline of the organism's sensitivity for learning language.

These two views lead to different predictions for language acquisition in children with cochlear implants. The 'critical period' view (Locke, 1997) precludes grammatical progress at pace with normal development. For, even if children are implanted around 2 years of age, they are unlikely to acquire a sufficiently large vocabulary within the critical time span of 24 – 36 months to get grammatical development started. The critical time span has been missed. The 'sensitive period' view would predict slower language growth than in normally hearing children, as sensitivity for language learning may already be reduced. But acquisition within the range of normal variation is not precluded, if children are implanted young, because a longer extension of the sensitive time period is assumed.

Language acquisition in prelingually deafened children with cochlear implants may also be influenced by these children's pre- and post-operative hearing. Due to lack of pre-operative auditory experience neuronal pathways necessary for aquiring language via audition may not have been created. After cochlear implantation the children remain hearing-impaired, and their impaired post-operative hearing is assumed to have an effect on the acquisition of spoken language.

Here, overall grammatical progress, as measured by MLU, will be studied in a group of cochlear implanted children and a control group of normally hearing children. In addition to group comparisons individual differences will be studied. Individual differences in speed of language development are well documented for typically developing children (Fenson, Dale, Reznick, Bates, Thal & Pethick, 1994). Therefore, any variability observed in a group of cochlear-implanted children must be assessed against variability in a control group of normally hearing children in order to draw any meaningful conclusions. For cochlear-implanted children the relations between implantation age, pre-operative hearing and subsequent grammatical development will be examined. It is hypothesized that prelingually deafened children with cochlear implants acquire language more slowly due to maturational and experience-dependent factors. As sensitivity for language learning decreases with increasing age, children with lower implantation ages should make faster linguistic progress. In so far as pre-operative hearing contributes to building neural pathways for language learning, children with better pre-operative hearing should make faster linguistic progress.

Further, it is assumed here that impaired post-operative hearing has a selective influence on the acquisition of grammar. It should make linguistic elements which are low in perceptual salience particularly difficult to acquire. In German this would affect articles. Articles are in prenominal sentence position and do not receive stress. Yet, in German they carry a lot of grammatical information, marking for case, gender, and numerosity. Children with cochlear implants should find articles and inflectional markings on articles more difficult to acquire than inflectional markings on nouns and verbs. This is because articles lack perceptual salience, whereas nouns and verbs are content words which tend to be stressed in sentences.

Method

Participants. Participants were 22 deaf children with cochlear implants and a control group of 22 children with normal hearing. There were 12 girls and 10 boys in each group. The cochlear-implanted children were between 14 and 46 months at the time of cochlear implant surgery, mean implantation age 29 months, SD = 9 months. For 17 children the etiology of hearing loss was from unknown congenital causes, for 2 children it was hereditary, and 3 children had acquired hearing losses due to meningitis at ages 1, 8 and 18 months. All the children were considered prelingually deafened. For the deaf children pre-operative audiograms under hearing aid conditions rendered hearing thresholds between 50 and 100 dB SPL for frequencies of 1000 Hz or 500 Hz. Pre-operative audiometric assessment rendered no responses for the auditory brainstem evoked response during electric response audiometry (ERA). No child showed reactions below 80 dB nHL during an electrocochleography. The sample of children was drawn from the youngest children, i.e. under 4 years at implantation, attending the Hannover Cochlear Implant Center and starting their rehabilitation during the years 1996 and 1997. Only children from monolingual environments with no sign language and with no diagnosed handicap besides their hearing impairment were included. To control for cognitive status, the children were given the Snijders-Oomen Non-verbal Intelligence Test (Snijders, Tellegen, Winkel, Laros & Wijnberg-Williams, 1996). They scored within the normal range. For further bibliographical detail about the cochlear-implanted children , see Szagun (2001a).

The 22 children with normal hearing had no diagnosed developmental delays or hearing problems. They were 16 months old when data collection started and demonstrated age-appropriate levels of cognitive development as measured by object permanence tests of the Infant Psychological Developmental Scales (Sarimski, 1985). All the children were growing up in monolingual environments. They were resident in Oldenburg, northern Germany, and were recruited from three pediatricians' practices and two daycare centers in Oldenburg.

Design, data collection, and data transcription. The study was longitudinal. For each child spontaneous speech samples were collected and audio recorded. One and a half hours of spontaneous speech were recorded every 4 months. In a first phase, data collection covered a period of 18 months for all 44 children. In a second phase, data collection continued for another 9 months for the 22 cochlear-implanted and 6 normally hearing children, thus covering a total of 27 months. For another 11 of the cochlear-implanted children data collection continued for up to 9 months thereafter in a third phase, covering 36 months altogether. For children with cochlear implants age was calculated from the date of first tune-up, because their chronological ages varied. First tune-up is the first fitting of the device to the child's level of comfortable hearing and takes place 6 weeks after implantation. For a subgroup of 6 normally hearing children (the same children children who were recorded over a period of 27 months) and a subgroup of 10 cochlear-implanted children data were recorded at closer time intervals, every 5-6 weeks for the normally hearing children and every 10-12 weeks for the cochlear-implanted children.

Normally hearing children and children with cochlear implants were matched for initial language level, as measured by MLU (mean length of utterance) and number of words. In the cochlear-implanted group initial MLU's ranged from 1.0 to 1.23 (mean = 1.04, SD = 0.06), in the normally hearing group MLU's ranged from 1.0 to 1.20 (mean = 1.05, SD = 0.08). Vocabulary, as assessed by parental report, was between 0 and 72 words, (mean = 20.9, SD = 20.8) for the cochlear-implanted group, and between 0 and 88 words (mean = 17.5, SD = 19.4) for the normally hearing group.

Data collection took place in a playroom at the Cochlear Implant Center Hannover for the children with cochlear implants, and in a playroom at the University of Oldenburg for the normally hearing children. The situation was free play, and a parent and a female investigator were present and played with the child. Toys were similar in the two settings: cars and garage, dolls, doll's house, zoo animals, farm animals, forest animals, children's picture books, puzzles, medical kit, ambulance, hospital room, firestation. Digital auditory tape recording (DAT) was carried out, using portable Sony DAT-recorders and high-sensitive Sony or Aiwa microphones. In Oldenburg video recording was also made, but not in Hannover, because the playroom was much smaller and did not allow non-intrusive video-recording.

Everything spoken by the child was transcribed using the CHILDES system for transcribing and analyzing child speech (MacWhinney, 1995). An adaptation to German for transcribing child speech, for coding MLU, and for morphosyntactic coding (Szagun, 1999) was used. Transcription was performed by eight trained transcribers. Reliability checks on transcription were calculated for 7.3% of the transcripts with percentage agreements between 96% and 100% for different pairs of transcribers. Coding for MLU was performed by three researchers. Reliability checks on MLU were performed on 20% of the transcripts. As a measure of reliability Cohen's kappa was calculated. Kappas ranged between .94 and .98. CLAN programs (MacWhinney, 1995) were used for calculating MLU.

Results

Grammatical development in terms of MLU. Mean length of utterance (MLU) measured in morphemes was used as a general indicator of grammatical progress. MLU was calculated on the basis of the spontaneous speech samples according to the rules laid down by Brown (1973) and their adaptation to German (Szagun, 1999).

First, a two-way ANOVA was computed comparing 22 CI (cochlear-implanted) and 22 NH (normally hearing) children over the 5 data points of the first time period of data collection, with repeated measures on age (5) and group as between subjects factor (2). There was a significant effect of age, $F(4,168) = 187.28$, $p < .001$, a significant effect of group, $F(1,42) = 18.34$, $p < .001$, and a significant age x group interaction, $F(4,168) = 28.54$, $p < .001$. Post hoc comparisons revealed that for the NH group MLU increased significantly between adjacent age levels from data point 4.5, but for the CI group only the increase between the last two age levels was significant (Tukey for repeated measures, $p < .05$). At the last two data points MLU values were significantly lower for the CI group (Tukey, $p < .05$). In order to find out if CI and NH children differed in terms of MLU over a longer period of time, a two-way ANOVA was computed comparing the 6 NH children for whom data are avaible for two time periods of data collection, i.e. up to 27 months after the start of data collection, with 22 CI children. An ANOVA with repeated measures on age (7) and with group (2) as between subjects factor rendered a significant effect of age $F(6,156) = 120.48$, $< .001$, a significant effect of group, $F(1,26) = 18.91$, $p < .001$, and a significant age x group interaction, $F(6,156) = 15.97$, $p < .001$. MLU values for CI and NH groups differed significantly at every data point from 13.5 months onwards (Scheffé, $p < .05$), and for CI children MLU increased significantly from data point 18 to 22.5. Figure 1 presents MLU means for CI and NH children over time.

In order to explore individual differences between children, subgroups of children with very similar progress in MLU were formed within each of the two major groups, CI and NH. Criteria for subgroup placement were that a) an individual child reached a target MLU indicative of one of Brown's (1973) stages of grammatical development ranging from the one-word stage to complex grammar at the end of the data recording period for the entire group, NH or CI, and/or b) that children displayed very similar MLU curves

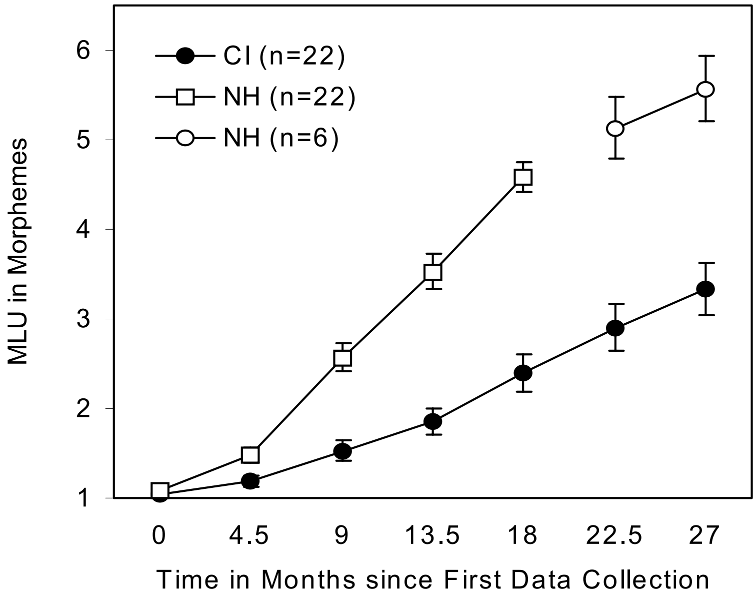

Figure 1: Mean MLU for cochlear-implanted (CI) and normally hearing (NH) children

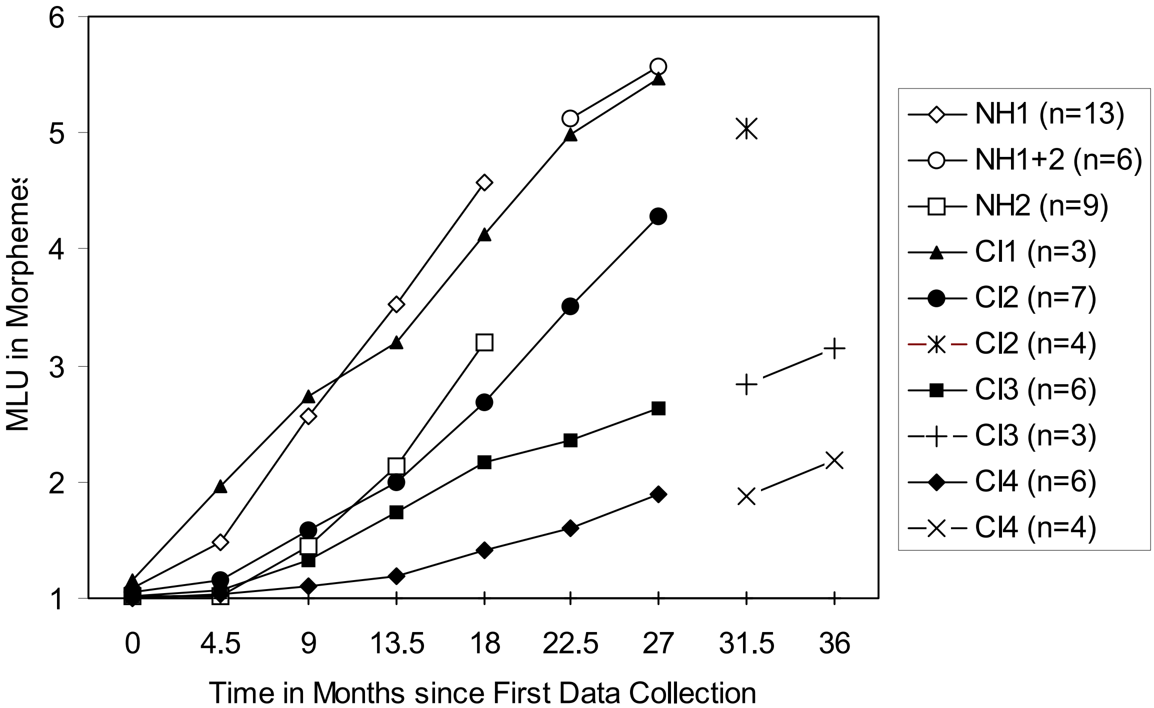

Figure 2: Mean MLU for subgroups of cochlear-implanted (CI) and normally hearing (NH) children

(SD's ranging from .01 to .52). (For more details on this procedure, see Szagun (2001a). There were 2 subgroups for NH and 4 subgroups for CI children. Figure 2 shows mean MLU curves for subgroups of CI and NH children. Figure 2 indicates that 3 CI children (subgroup CI1) progressed as rapidly as 13 NH children (subgroup NH1) reaching the stage of complex grammar, target MLU 4.0, 18 months after the one-word stage, which was the start of data collection in this study. Seven CI children (subgroup CI2) reached the stage of multi-word combinations, target MLU 3.5, 27 months after the first data collection and had similar MLU curves to 9 more slowly progressing normally hearing children (subgroup NH2). However, 6 CI children (subgroup CI3) remained at the two-word stage, target MLU 2.25, and 6 CI children (subgroup CI4) remained even below that MLU level 27 months after the start of data collection. Figure 2 shows that the slow CI subgroups (CI3 and CI4) remained at low MLU levels during the next 9 months, i.e. they had not progressed above the two-and one-word stages even 36 months after the beginning of data collection. Thus, the differences between CI children with fast and slow progress became more pronounced with time.

Relation between implantation age, pre-operative hearing, and linguistic growth. For cochlear-implanted children the relation between age at implantation and linguistic growth, as well as between pre-operative hearing and linguistic progress was tested by correlational analysis (Pearson product-moment correlation coefficients). Pre-operative hearing under hearing aid conditions was measured in terms of thresholds in dB SPL at 1000 Hz (for 6 children at 500 Hz). Two of the children deafened by meningitis whose pre-operative auditory experience was not comparable to that of congentially deaf children were excluded from this analysis. To have a measure of linguistic growth rather than outcome, growth rates of MLU were calculated. Growth rates were obtained by fitting mathematical functions to each child's MLU values using SPSS curve estimation procedures. For MLU there were significant linear and quadratic trends in the data. For the linear trend increase is indicated by the b_1 coefficient in the regression equation. The b_2 coefficient indicates the additional change in increase rate due to the quadratic trend. As language growth measures the b_1 and b_2 coeffient was used.

Partial correlations were calculated between growth rate in MLU and age at implantation controlling for pre-operative hearing, and between growth rate in MLU and pre-operative hearing controlling for age. Correlation coefficients are presented in Table 1. Pre-operative hearing corrrelated significantly with linear growth in MLU accounting for 53 % of the variability. Age at implantation correlated significantly with linear growth in MLU, but less strongly, accounting for 25 % of the variability. Correlations with the quadratic trend did not reach significance.

Use of specific inflections. The use of specific inflectional morphology was compared in the two groups of children. For this purpose children were matched by MLU so as not to confound progress in the acquisition of specific inflectional markings with overall grammatical development. Data from 6 normally hearing children and from 9 cochlear-implanted children were used for the analysis, because for these children a sufficient number of speech samples with closely matching MLUs was available. The 6 normally hearing children were the ones recorded at closer time intervals, and the 9 cochlear-implanted children were from the subgroups CI1 and CI2 whose language development in terms of MLU was equivalent to that of normally hearing children. The 6 normally hearing children and 9 cochlear-implanted children were compared at 4 comparable MLU levels. Means and standard deviations of the MLU levels are presented in Table 2. The total number of speech samples per MLU level ranged between 16 and 19 per group. The median of speech samples per child per MLU level was between 2 and 3.

Table 1: Partial correlations between age at implantation, pre-operative hearing with hearing aids, and growth rate of MLU (*p < 0.05, *** < p < 0.001)

growth rate	age at implantation	pre-operative audiogram (responses in dB SPL at 1000 Hz)
MLU, linear fit (b_1)	- 0.50*	- 0.73***
MLU, quadratic fit (b_2)	0.05	0.40

Table 2: Mean MLUs per MLU level per group of children

	mean MLU (SD)	
Level	NH	CI
1	1.89 (.26)	1.86 (.27)
2	2.86 (.21)	2.84 (.29)
3	3.77 (.32)	3.53 (.33)
4	4.82 (.38)	4.82 (.38)

Three types of specific inflectional morphology were studied, person endings on verbs, noun plural markings, and case and gender marking on the definite article. For each type of inflection correct and erroneous marking was categorized and relative frequencies of correct and erroneous use were calculated. The use of correct and erroneous inflectional marking was compared over MLU levels in the two groups of children. Using an arcsine transformation for the relative frequency data repeated measures analyses of variance with relevant post hoc tests were applied.

Verb endings. In German verbs are marked for tense, person, and numerosity. Suffixes for person marking in the present tense are presented in the Appendix in Table 3. Error categories for verbs were the following.

1) *Protoform in indeterminate function*: The verb stem+-*e* ending or just the verb stem is used. The function of the verb is unclear, i.e. whether it should agree

with the sentence subject, if this is recognizable at all, or whether it should be an infinitive. Example: *kuh setze* ('put cow').

2) *Infinitive in indeterminate function*: The infinitive is used in indeterminate function. Either the subject of the sentence is unclear, or it is unclear whether the infinitive form should be a finite form or is correctly used but a modal is lacking. Examples: *da auto fahren* ('there car ride'); *Anna brötchen haben* ('Anna bread roll have').

3) *Erroneous use of protoform*: The protoform verb stem+-*e* is used when a finite form or infinitive would be correct. Example: *kann man da abmache* (correct: *abmachen;* 'you can take it off there').

4) *Erroneous suffix or vowel*: An incorrect suffix is used on the verb, i.e. sentence subject and verb do not agree, or a vowel change does not occur. Examples: *ich machen eben* (correct: *mach* or *mache*; 'I'll do it'); *ich hat aua* (correct: *hab* or *habe*; 'I'm hurt'); *der fahrt zum baby* (correct: *fährt*; 'he is going to see the baby').

A three-way ANOVA was calculated with repeated measures on verb form (5) and MLU level (4), and group as between-subjects factor. There were significant main effects of verb form, $F(4,52) = 201.70$, $p < .001$, and of MLU level, $F(3,39) = 13.82$, $p < .001$, as well as a significant verb form x MLU level interaction, $F(12, 156) = 29.29$, $p < .001$. There was no difference between CI and NH children in their use of correct and erroneous verb forms. For both groups frequencies of protoforms in indeterminate function decreased significantly between MLU level 1 and 2 (Tukey's, $p < .05$), frequencies of infinitive in indeterminate function decreased significantly between MLU level 1 and 3 (Tukey's, p <. 05), and frequencies of correct verb forms increased significantly between every MLU level except levels 3 and 4 (Tukey's, $p < .05$). At every MLU level frequencies of correctly marked verb forms were significantly higher than erroneous or protoforms (Tukey, $p < .05$). Means and standard errors for categories of verb forms are shown in Figure 3.

Noun plurals. There are 8 ways of marking plural on nouns in German. German noun plural markings are presented in the Appendix in Table 4. Here, only the most frequent error categories of noun plural marking are presented (for more detail see Szagun, 2001b).

1) *Affixing –n*: An *–n* is affixed where this is wrong. Often, this is a case of double marking, i.e. the *–n* is affixed to a form already correctly marked for plural. Examples: *laufen alle weg, die tieren* (correct: *tiere*; 'they are all running away, the animals'); *da sin' die kindern* (correct: *kinder*; 'here are the children').

2) *Affixing –s*: An –s is affixed where this is wrong. Usually, this occurs after word final *–er*, pronounced [∂], where a -∅ marking would be correct. Examples: *da sin' die mülleimers* (correct: *mülleimer*; 'there are the dustbins'); *da komm'n die tigers* (correct: *tiger*; 'here the tigers are coming').

3) *Partial marking*: Partial marking occurs when two elements are required, i.e. a suffix and a vowel change (Umlaut) and the child uses only one of the elements. Examples: *zwei fuchse* (correct: *füchse*; 'two foxes'); *alle türm sammel ich wieder* da (correct: *türme*; 'I'm collecting all the towers again').

4) *No marking*: There is no plural marking on the noun, but the article and the verb are marked for plurality. Examples: *ah, da komm'n die klein'n nashorn* (correct: *nashörner*; 'ah, here the little rhinoceroses are coming'); *wo sin' die fisch* (correct: *fische*; 'where are the fish?')

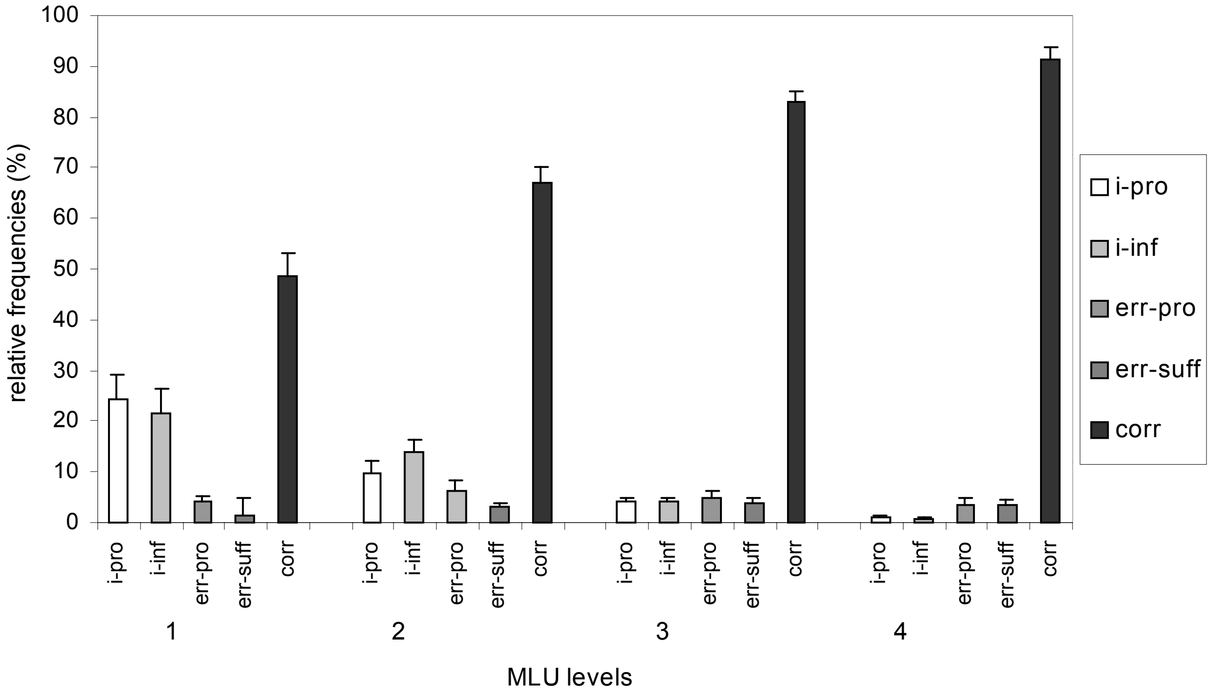

Figure 3: Relative frequencies of correct and incorrect verb form for both groups of children collapsed (key: i-pro = indeterminate use of protoform, i-inf = indeterminate use of infinitive, err-pro = erroneous use of protoform, err- suff = erroneous suffix)

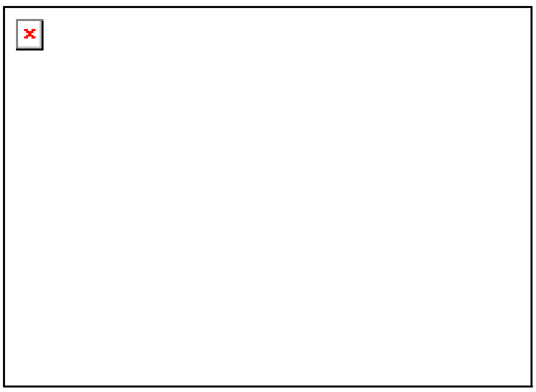

Figure 4: Relative frequencies of correct and erroneous noun plurals for both groups of children collapsed

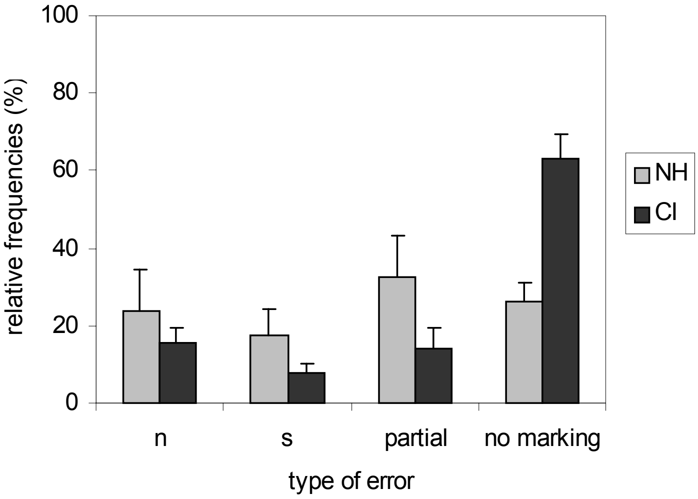

Figure 5: Relative frequencies of noun plural error types for cochlear-implanted (CI) and normally hearing (NH) children (key: n = affixation of *–n*, s = affixation of *–s*, partial = partial marking)

In an initial analysis all error types were collapsed, because there was an insufficient number of errors per error category and MLU level to calculate relative frequencies. A three-way ANOVA was calculated with repeated measures on plural form (2, correct and incorrect) and MLU level (4), and group as between-subjects factor. There was a significant main effect of plural form, $F(1,13) = 250.08$, $p < .001$. All other main effects and interactions were non-significant. Thus, there was no difference between CI and NH children in their use of correct and erroneous noun plurals. Both groups used significantly more correct plural forms (Tukey's, $p < .05$). Means and standard errors are presented in Figure 4. Correct plural forms were used with high frequency.

Next, types of errors collapsed over MLU levels were compared. A two-way ANOVA with repeated measures on error type (4) and group as between-subjects factor was calculated. There was a significant main effect of type of error, $F(3,39) = 6.12$, $p < .002$, and a significant type of error x group interaction, $F(3, 39) = 3.95$, $p < .015$. Whereas frequencies of error types did not differ in the NH group, in the CI group no marking was significantly more frequent than any other type of error (Scheffé, $p < .05$). Also, CI children made significantly more 'no marking' errors than NH children. Means and standard errors are presented in Figure 5.

Case and gender marking on the definite article. In German case and gender are marked on articles. Case and gender marking for the definite article is presented in the Appendix in Table 5. A categorization scheme for errors was developed and is presented below.

Nominative:

1) *Protoform*: The form [d∂] is used instead of *der, die, das*. Example: *de auto* (correct: *das*, 'the car').

2) *Omission*: The article is left out. Example: *jetz is tiger tot* (correct: *jetz is der tiger tot*; 'now tiger is dead').

3) *Errors of gender*: Nouns are marked incorrectly for gender. Examples: *wo is der auto*? (correct: *das auto*; 'where is the car?'); *die pferd* (correct: *das pferd*; 'the horse'); *die ball* (correct: *der ball*; 'the ball').

Accusative:

1) *Protoform*: The form [d∂] is used instead of *den, die, das*. Example: *de stall wieder zumachen* (correct: *den stall*, 'close the barn').

2) *Omission*: The article is left out. Examples: *alle wieder in auto einsteigen* (correct: *in das auto*; 'everybody get in the car'); *will zoo aufbau'n da* (correct: *den zoo*; 'want to build the zoo there').

3) *Errors of case - nominative error*: In the masculine paradigm children use the nominative form *der* instead of *den*. Examples: *nee, nur der papa eisbär gibt's* (correct: *den papa eisbär*; 'no, only the daddy polar bear is there'); *ich mal der mond weg* (correct: *den mond*; 'I paint the moon away').

4) *Errors of gender*: Case is correct, but noun gender is marked incorrectly. Examples: *jetz ham wa den puzzle* (correct: *das puzzle*; 'now we have the puzzle'); *auf'n klo* (correct: *das klo*; on the toilette'); *wo sieht man die krankenhaus*? (correct: *das krankenhaus*; 'where do you see the hospital?').

Dative:

1) *Protoform*: The form [d∂] is used instead of *dem, der, das*. Example: *ich geh zu de auto* (correct: *dem auto*, 'I'm going to the car').

2) *Omission*: The article is left out. Example: *da muss ich bei kasse hinstell'n* (correct: *bei der kasse*; 'I have to put this by the cash desk').

3) *Errors of case – accusative/nominative error*: Children mark case incorrectly. In the masculine paradigm *den* is used instead of *dem*, in the feminine paradigm *die* instead of *der*, and in the neuter paradigm *das* instead of *dem*. In the masculine paradigm children are using the accusative form, but in the feminine and neuter paradigm it is impossible to tell which of the two children are using, as the forms are identical. Examples: *der feuerwehrmann muss den feuerwehrmann helfen*; (correct: *dem feuerwehrmann helfen*; 'the fireman has to help the fireman'); *der war auf das dach* (correct: *auf dem dach;* 'he was on the roof'); *mit die schere* (correct: *mit der schere*; 'with the scissors')

4) *Errors of case and gender*: Case as well as gender are marked incorrectly. Often, the masculine accusative *den* is used for feminine and neuter nouns. Examples: *jetz is der mann wieder auf'n dach* (correct: *auf dem dach*; 'the man is on the roof again'); *mit'n pistole* (correct: *mit der pistole*; 'with a gun').

Relative frequencies of error categories and correct forms were compared for each case. Data from only 3 MLU levels were used, level 2, 3, and 4, as article use on the first MLU level was too infrequent.

For the nominative a three-way ANOVA was calculated with repeated measures on form (4) and MLU level (3), and group as between-subjects factor. Mean relative frequencies and standard errors are presented in Figure 6. There was a significant main effect of form, $F(3,39) = 76.93$, $p < .001$. The two-way form x group interaction was significant, $F(3,39) = 3.82$, $p < .017$, as well as the two-way form x MLU level interaction, $F(2,26) = 3.45$, $p < .004$. The three-

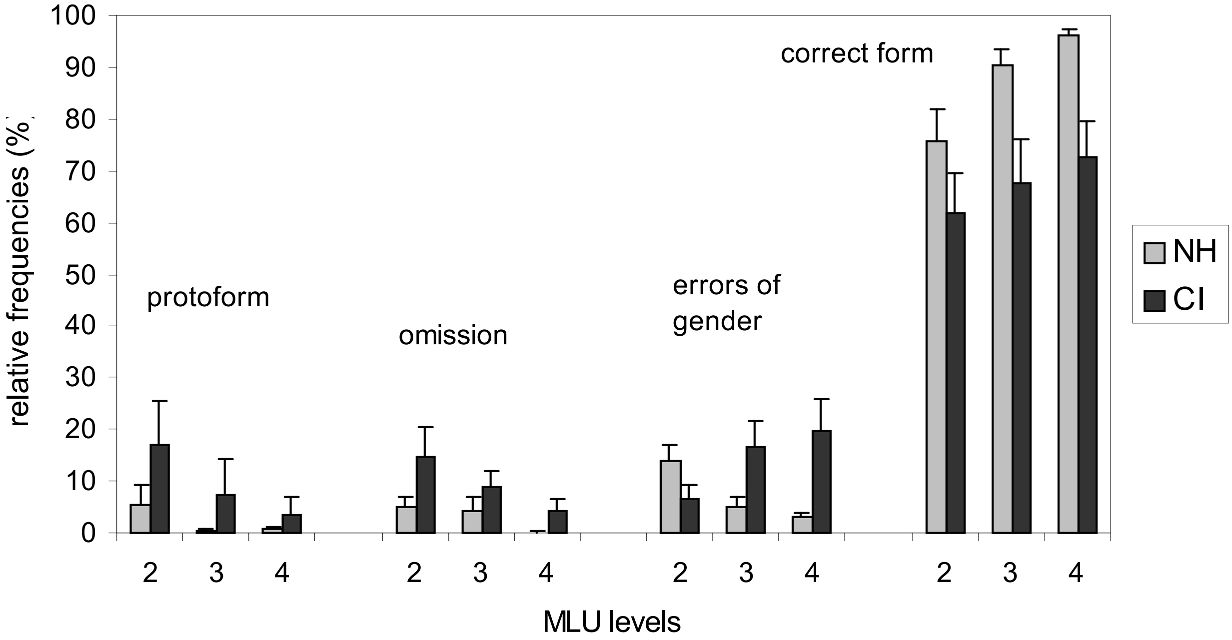

Figure 6: Relative frequencies of protoform, omissions, errors of gender and correct forms of the nominative of the definite article for cochlear-implanted (CI) and normally hearing (NH) children

way interaction of form x MLU level x group was also significant, $F(6, 78) = p < .2.38$, $p < .036$. In either group of children correct article forms were significantly more frequent than any of the other forms at every MLU level ($p < .05$). However, frequencies of correct forms were significantly larger for NH (normally hearing) than for CI (cochlear-implanted) children at MLU levels 3 and 4 (Scheffé, $p < .05$). CI children made significantly more gender errors at MLU level 4 than NH children, (Scheffé, $p < .05$). For the CI group errors of gender increased significantly over MLU levels 2 to 4, while frequencies of protoform decreased significantly (Scheffé, $p < .05$). At MLU level 4, the highest MLU level, errors of gender were the most frequent error type for CI children (Scheffé, $p < .05$).

For the accusative data for MLU levels 2 and 3 were collapsed, as absolute frequencies were too low for percentage calculations at separate levels. A three-way ANOVA with repeated measures on form (5) and MLU level (2), and group as between-subjects factor rendered a significant main effect of form, $F(4,52) = 39.58$, $p < .001$ and a significant two-way form x group interaction, F(4,52) = 5.92, $p < .001$. Mean relative frequencies with MLU levels collapsed are presented in Figure 7. NH children used correct accusatives significantly more frequently than any of the other forms, whereas for CI children only nominative errors were less frequent than the other forms, including correct ones (Scheffé, $p < .05$). NH children used significantly more correct forms than CI children, and CI children omitted articles significantly more frequently than NH children (Scheffé, $p < .05$).

For the dative article data from all MLU levels were collapsed in order to have sufficient frequencies. A two-way ANOVA with repeated measures on form (5) and group as between-subjects factor rendered a significant main effect of form, F(4,52) = 24.09, $p < .001$ and a significant two-way form x group interaction, F(4,52) = 2.68, $p < .042$. Mean relative frequencies are presented in Figure 8. NH children used correct datives significantly more frequently than any other form (Scheffé, $p < .05$) except the accusative/nominative error. CI children used correct datives significantly more frequently than any other form (Scheffé, $p < .05$) except omissions. In the NH group accusative/nominative errors reached 27% and were significantly higher than protoforms (Scheffé, $p < .05$). CI children used omissions very frequently, at a level of 25%, and significantly more frequently than NH children (Scheffé, $p < .05$). Thus, the preferred error type for NH children was an error of case, whereas it was an error of omission for the CI children.

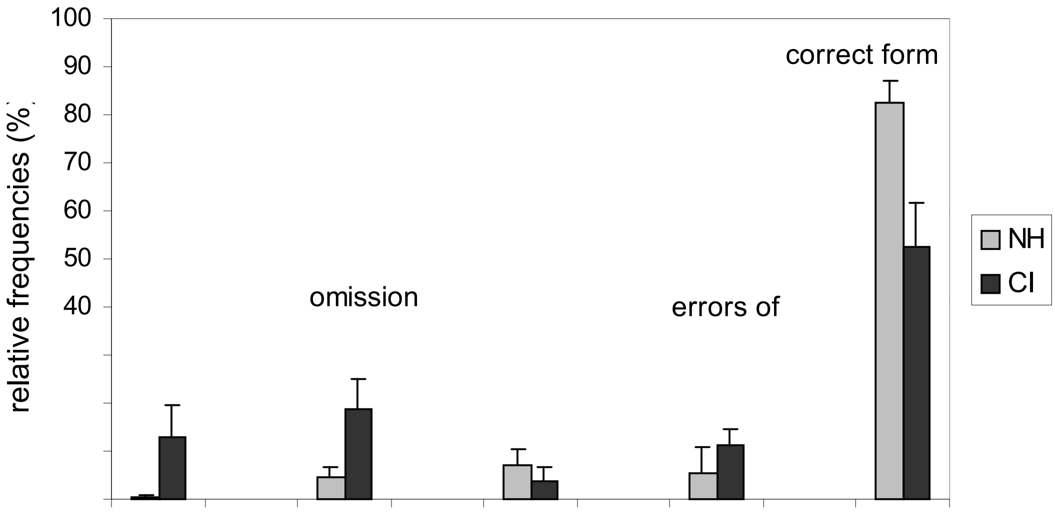

Figure 7: Relative frequencies of protoform, omissions, errors of case, errors of gender, and correct forms of the accusative of the definite article for cochlear-implanted (CI) and normally hearning (NH) children

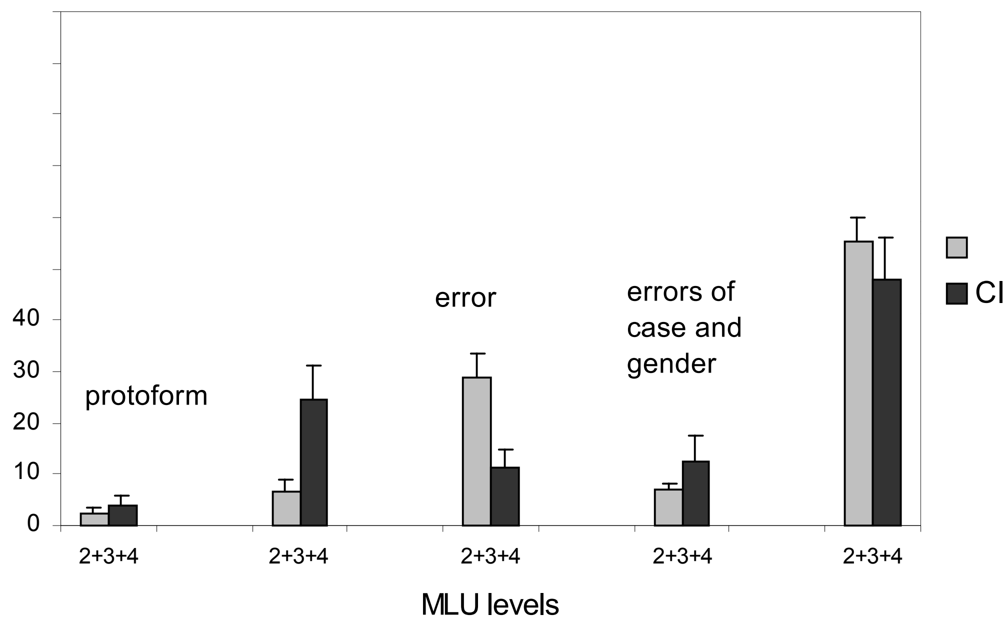

Figure 8: Relative frequencies of protoform, omissions, errors of case, errors of case and gender, and correct forms of the dative of the definite article for cochlear-implanted (CI) and normally hearning (NH) children

Summary of results and conclusions

The present results show that, when considered as a group, young cochlear-implanted children acquire language more slowly than normally hearing children. At the same time, the data reveal considerable individual differences in the grammatical development of young children with cochlear implants. Starting at the one-word stage, 3 cochlear-implanted children reached a stage of complex grammar within 18 months, progressing as fast as 13 normally hearing children. Another 7 cochlear-implanted children reached a similar level of grammatical competence within 27 months. They progressed like 9 normally hearing children with slower grammatical development. However, 12 cochlear-implanted children remained well below this level, not even surpassing the two-word stage. Thirteen months later, the difference between the 10 cochlear-implanted children who were comparable to normally hearing children and those 12 who were not, was even larger. In other words, slow learners do not catch up – at least not over the time period of the first 3 years of language acquisition studied here.

Pre-operative hearing with hearing aids as well as age at implantation were associated with subsequent linguistic growth. Children with better pre-operative hearing made more rapid progress in grammatical development, and so did children who were implanted at a younger age. However, the relation between pre-operative hearing and grammar acquisition was stronger.

The use of specific inflectional morphology was studied in a subgroup of 9 cochlear-implanted and 6 normally hearing children who were at comparable MLU levels. Four MLU levels ranging from mean MLUs between 1.8 and 4.8 were chosen. Three types of inflectional morphology were studied: person inflections on verbs, noun plurals, and case and gender marking on the definite article. For each type of inflection a categorization scheme for errors was established, and relative frequencies of erroneous and correct use were calculated and compared in the two groups of children. Results indicated that, overall, cochlear-implanted and normally hearing children did not differ in their use of inflectional morphology on verbs and nouns. For verbs, the indeterminate use of a protoform ending in *–e* and of infinitive decreased over MLU levels, and correct marking increased. For nouns plurals error rates did not differ in the two groups of children, but cochlear-implanted children had a stronger preference for the error type of 'no marking' as opposed to using an incorrect suffix.

With respect to case and gender marking on the definite article the two groups of children differed considerably. Use of article forms was significantly more deficient in the hearing-impaired group. Normally hearing children used more correct forms than hearing-impaired children, and their preferred error types were errors of case, especially the accusative/nominative error in the dative. The predominant errors in the hearing-impaired group were errors of gender and of omission. Errors of gender prevailed in the nominative and errors of omission prevailed in the oblique cases. Both error types were more frequent than in the normally hearing group. Use of the protoform *de* was also high in the hearing-impaired group but decreased at higher MLU levels, whereas errors of gender even increased over MLU.

These different error patterns are indicative of a more advanced case system in the normally hearing group. They err on case, i.e. they struggle with the case system as such. Hearing-impaired children have not got to this point yet, at least not to same extent. They simply omit the article or use a protoform rather than struggling with case marking. A similar argument can be made for noun plural marking. Here, too, cochlear-implanted children prefer not to mark at all rather than struggling with the use of approproate suffixes. However, overall, they do not make more errors than normally hearing children.

The present results are relevant for current theorizing about a sensitive phase for language learning. The fact that 10 cochlear-implanted children developed at pace with normally hearing children, argues against a "critical period" viewpoint with its narrow age range for setting off grammar (Locke, 1997). These children could not have acquired a vocabulary large enough by 24 – 36 months to turn on the analytic mechanism for grammatical learning. The "sensitive period" view (Oyama, 1979; Johnson & Newport, 1993) can accommodate slower grammatical development as well as development at pace with that of normally hearing children, because it does not specify an early age of first decline in language learning ability and extends the "sensitive phase" up to puberty.

Both views rely heavily on age as a determining factor for language learning. The present results show that, for children who underwent cochlear implantation before the age of 4 years, implantation age alone was not the only and not even the most potent factor influencing subsequent linguistic progress. The quality of children's pre-operative hearing was a better predictor. Thus, theories of sensitivity for language learning should recognize the role of experience more strongly. Sensitivity for language acquisition is dependent on age-related maturational as well as experiential factors.

Cochlear-implanted children's deficient article system is likely to be a consequence of their impaired post-operative hearing. Articles are in prenominal sentence position and lack perceptual salience. This presents difficulties for normally hearing children, and even greater difficulties for children with impaired hearing. They are likely to miss articles frequently in incoming speech. The present results show that the difficulties these children have in acquiring inflectional morphology – at least in German – are limited to such forms which are low in perceptual salience and do not extend to inflectional morphology on perceptually salient content words like verbs and nouns. Because MLU was controlled in the present study, the difficulties with the article system are not confounded with level of general grammatical development. Cochlear-implanted children's deficient article system can therefore be attributed to their impaired post-operative hearing.

The present results may allow the conclusion that, for children who undergo cochlear implantation before 4 years of age, it becomes evident around 2 to 2 1/2 years after the operation whether a child develops language near normal or not. From a practical point of view the question arises how to support those children who are not acquiring language naturally. All the children in the present sample received aural language training programs which is the favored method in Germany. It is conceivable that a program of total communication – as is practiced in countries such as the U.S.A., Great Britain, or Israel – would be of benefit. Using gestures or sign language would promote the use of symbols, which is an essential component of cognitive development, and could prevent a possible negative influence of insufficient symbol use on cognitive development. Additionally, language training programs in spoken language may usefully apply knowledge about which grammatical forms are most difficult for cochlear-implanted children and incorporate specifically designed linguistic sequences in their training.

Acknowledgments

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Appendix

Table 3: Person endings on verbs, and infinitive

Person	*Ending*	*Example*	*English Translation*
1st pers. sg.	*-e*, ∅	*ich sag-e*	*I say*
2nd pers. sg.	*-st**	*du sag-st*	*you say*
3rd pers. sg.	*-t**	*er, sie, es sag-t*	*he, she, it says*
1st pers. pl.	*-en*	*wir sag-en*	*we say*
2nd pers. pl.	*-t*	*ihr sag-t*	*you say*
3rd pers. pl.	*-en*	*sie sag-en*	*they say*
infinitive	*-en*	*sag-en*	*say*

Table 4: Plural markings

	Example		
Suffix (vowel change	*Singular*	*Plural*	*English*
-(*e*)*n*	Blume	Blume-n	flowers
	Bär	Bär-en	bears
-e	Hund	Hund-e	dogs
Umlaut+-*e*	Baum	Bäum-e	trees
-er	Kind	Kind-er	children
Umlaut+-*er*	Buch	Büch-er	books
-∅	Tiger	Tiger	tigers
Umlaut+-∅	Mutter	Mütter	mothers
-*s*	Auto	Auto-s	cars

Table 5: Case and gender marking on the definite article

Case		*Singular*		*Plural*
	masculine	*feminine*	*neuter*	
Nominative	der	die	das	die
Accusative	den	die	das	die
Dative	dem	der	dem	den
Genitive	des	der	des	der

Cochlear Implantation below 12 Months of Age: Challenges and Considerations

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Abstract

There are several important issues and obstacles that must be considered with regard to cochlear implantation of children under the age of twelve months. First, a new population of children with significant hearing loss identified within the first few months of life has emerged. This new population presents the opportunity to provide cochlear implants at much younger ages than the previous generation of implanted children who were typically between two and four years of age. Second, the earliest access to language development is critically important. Language development can be accessed through auditory and/or visual modalities. Third, There are significant medical obstacles in early implantation of these children. Careful consideration of these issues must be done in order to insure the safety of the infant. Fourth, significant audiological obstacles to the implantation of children between 6 and 12 months of life exit. Finally, the language outcomes and their relationship to speech perception and speech production will be discussed.

Early identification of hearing loss occurs in the neonatal period

The existence of a new early-identified population. As universal newborn hearing screening programs are established throughout the United States and in other countries throughout the world, the age of identification of hearing loss has been reduced to within the first few months of life. In the state of Colorado, universal newborn hearing screening (UNHS) programs are established in every birthing hospital within the state and over 99% of the state births are being screened for hearing within hours after birth. The average age of congenital hearing loss has been reduced from over 24 to 30 months to an average of 2 months of age. Fifty percent of the children born in screening hospitals with congenital hearing loss are identified by 5 weeks of age and 75% of the children are identified by 3 months of age. This statistic compares with a median age of identification for children born in Colorado hospitals without screening programs of 24 months of age and 75% of the children are identified by 30 months of age (Yoshinaga-Itano, Coulter & Thomson, 2000).

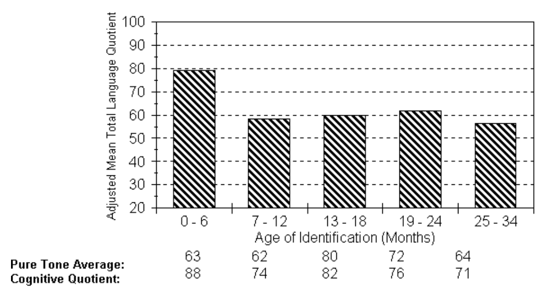
Of the children identified through UNHS programs approximately 10% of them have profound bilateral sensori-neural hearing losses (Mehl & Thomson,

2001) Of this number, approximately 35% have identified additional disabilities within the first year of life (Yoshinaga-Itano et al., 1998).

Earlier access to language is critical

Early identification with earlier intervention of hearing loss in the first six months of life results in better language outcomes than for children with later-identified hearing loss.

Children with early-identified hearing loss (within the first six months of life) have demonstrated language development within the low average range of development in the first four to five years of life. Their language development is significantly better than children identified between 1) 6.1 and 12 months of life, 2) 12.1 and 18 months, 3) 18.1 and 24 months, 4) 25.1 and 34 months (Stevens, 2002, Yoshinaga-Itano, Sedey, Coulter & Mehl, 1998) (see Figure 1).



Adjusted mean total language quotients for groups based on age of identification of hearing loss.

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Children with later-identified hearing loss and no additional disabilities had language development similar to children with early-identified hearing loss and additional disabilities. The language advantage of early-identification was found for all socio-economic levels, all ethnic groups, for children with hearing loss only and those with additional disabilities, at all testing ages from 12 months through 36 months of age, for both genders, for all degrees of hearing loss from mild to profound and for those who used speech only and those who used sign language.

Early-identified children have better speech intelligibility (Apuzzo & Yoshinaga-Itano, 1995; Yoshinaga-Itano, Coulter & Thomson, 2000), better language development and vocabulary knowledge (Yoshinaga-Itano, Coulter & Thomson, 2000), better social-emotional development (Yoshinaga-Itano, 2002), and development of self (Pressman, Pipp-Siegel, Yoshinaga-Itano, & Deas, 1999) and better emotional availability, and their parents have better attachment (Pressman, Pipp-Siegel, Yoshinaga-Itano, & Deas, 1999) and faster resolution of grieving (Pipp-Siegel, 2000).

Early implantation before 18 months. Children implanted before 18 months of age were found to have normal or even accelerated language development growth patterns (Hammes, Novak, Rotz, Willis & Edmondson, 2002; Novak et al., 2000). Children implanted prior to 18 months of age were also age to transition successfully from manual to oral communication as compared to fewer than 50% of those children implanted between 19-30 months. After the age of 30 months, the probability of transition from manual to oral communication is significantly diminished.

Sensitive period for access to language vs. auditory/visual access. Because early identification was equally advantageous to children whose families chose an oral, auditory approach to communication as to children whose families chose communication using some form of sign language, access to auditory language alone or the visual language alone cannot fully explain the early identification effect. Neither, the ability to identify, perceive, discriminate and remember the sounds of the language or the ability to identify, perceive, discriminate and remember the visual aspects of a signed language system can fully explain the phenomenon. Modality access is not necessarily synonymous to language access. Thus, early identification alone without early intervention beyond amplification is unlikely to result in optimal outcomes.

Auditory access alone cannot account for the early identification/early intervention effect. Children with mild hearing loss, who are able to process conversational speech without conventional amplification demonstrate significant delays in speech production through the first two and a half years of life (Yoshinaga-Itano & Sedey, 2000). Their phonetic repertoires are reduced when compared to the development of children with normal hearing. The typical vocabulary burst that occurs after 18 months of age is delayed among these children to 2.5 years of age. Most early-identified children with mild hearing losses do appear to decrease their language delays by the time they begin American kindergarten at five years of age (see Figure 2).

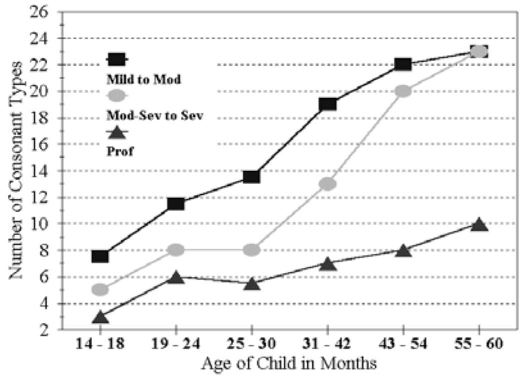

Figure 2. Number of consonant types by degree of hearing loss and age of the child.

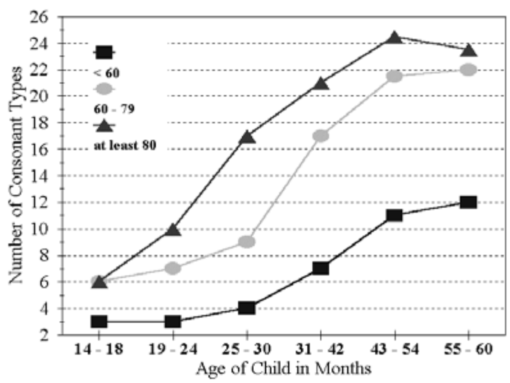

Figure 3. Number of consonant types by language quotient and age of the child. Reprinted with permission from the Volta Review.

Since even children with the mildest hearing losses in the first five years of life, when early-identified and receiving appropriate early intervention services, demonstrate significant auditory, speech and language delays, it can be anticipated that children with more significant profound hearing losses would experience even more delays in their auditory, speech and language development.

The most significant predictors of speech intelligibility among children with mild through profound hearing losses are: 1) language development and 2) degree of hearing loss (Yoshinaga-Itano & Sedey, 2000) (see Figures 3, 4 & 5). This finding is in strong agreement with the significant relationships found between language, speech perception and speech production in a longitudinal study of children with cochlear implants (Blamey, et al., 2001).

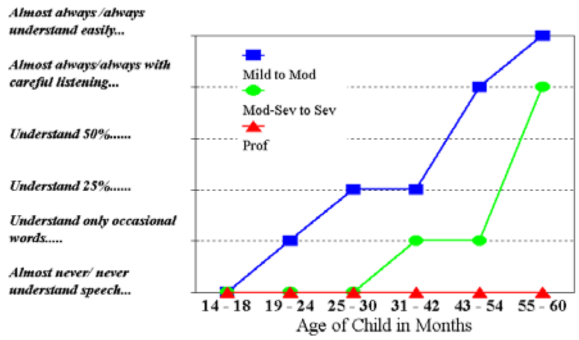

Figure 4. Speech intelligibility by degree of hearing loss and age of the child. Reprinted by permission from the Volta Review.

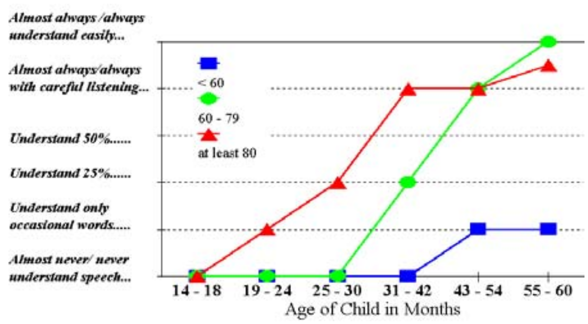

Figure 5. Speech intelligibility by language quotient and age of the child. Reprinted by permission from the VoltaReview.

Thus, outcomes of children with cochlear implants can range from limited benefit to children with age-appropriate speech, auditory, and language development, but the research to date indicates that the average child when followed longitudinally has significant lasting delays in auditory, speech and language development. The most significant improvements have been found in auditory perception of speech and speech production gains.

Implications for cochlear implantation in the first year of life

Candidacy requirements. Sinninger (2002) presents important considerations for cochlear implant candidacy of children under the age of 12 months. Sinninger

(2002) discusses important medical, audiological and family issues that should be considered and the following sections summarize information she has provided.

Age considerations. Cochlear implantation for children 18 months or older is available under standard guidelines. FDA approved investigations for infants as young as 12 months have been approved for Cochlear Corporation and Advanced Bionics Corporation. Strict adherence to degree of hearing loss guidelines must be maintained when implantation is conducted under FDA investigation for the very youngest children.

Hearing loss considerations. Candidacy is generally not questioned when the child has an average bilateral hearing loss in the speech range of 90 dB or more. When speech perception with hearing aids is poor, children over 18 months of age with better pure-tone hearing sensitivity can be considered as cochlear implant candidates.

Hearing aid trial. Generally for congenital hearing loss, a minimum of six months use of well-fitted amplification is necessary to determine if expectations for improved speech perception or auditory skills can be met. The trial period is generally waived for children with acquired deafness due to meningitis when there are indications that imminent ossification of the cochlear would make later implantation difficult or impossible.

Currently, for children under the age of 4, Advanced Bionics Corporation suggests the use of the MLNT (Kirk, Pisoni, Osberger, 1995) if they demonstrate scores 20% or less and the IT-MAIS (Zimmerman-Phillips, Robbins & Osberger, 2000), if they demonstrate parent questionnaire scores of 2 or less on questions 3, 5, or 6. However, these instruments were not designed for infants under the age of 12 months and have too few items for this age child to provide a discriminating tool for candidacy for children in the first year of life.

Family expectations. Realistic family expectations are changing as current research emerges. However, surgery represents a beginning in a long-term process that mandates a commitment from the entire family. Obvious changes in communication ability can take a year or more to materialize. Sinninger (2002) further states that “Children from families who expect that cochlear implant surgery will provide an easy, fast fix for deafness will not make good candidates.”

Physical and development considerations. In the neonatal period, approximately 40% of the children with early-identified hearing loss have other disabilities or developmental delays. The child’s ability to use the information provided by the device for development of auditory skills and speech perception must be weighed against the risks and costs of surgery and stress on the family. Children with visual-motor and developmental disabilities have been able to take advantage of cochlear implantation (Lenarz, 1998; Waltzman et al. 2000).

Certain issues related to the physical status of the ear and temporal bone may contraindicate implantation. Inner ear deformities, such as a common sac or Mondini Dysplasia may alter expectations and needs for special adjustments of the device even when they do not prohibit implantation. Complete aplasia of the inner ear or absence of the auditory nerve would contraindicate implantation.

Auditory neuropathy. Auditory neuropathy is a condition that can be identified shortly after birth in which a child has normal otoacoustic emissions response and absent or abnormal auditory brain stem response. Children with auditory neuropathy do not have ABR thresholds that agree with behavioral thresholds. Thus, predicting thresholds from ABR thresholds in this population in the first year of life should not be done. With the current technology and audiological diagnostic evaluation procedures, children with auditory neuropathy should not be implanted within the first year of life.

Medical challenges to early implantation

Obstacles that can be encountered are issues regarding the depth of the mastoid bone, potential migration of device or electrode, possible complications of otitis media, and increased risk of anesthesia.

Thickness of the temporal bone. To avoid migration of the receiver stimulator, a well is drilled into the temporal bone that serves as a seat for the device. The thickness of the temporal bone for children one and two years of age is 2 to 4 mm, while the device is 6 to 7 mm. Surgeons have drilled wells to very thin bone or down to the dura and used soft tissue covering that ranges from 5 to 9 mm of thickness in these children. The lower age limit of bone thickness and soft tissue necessary for adequate seating has not been explored.

Migration of the device or electrode. Roland et al.(1998) studied electrode position radio-graphically for up to 5 years in 151 children implanted at 14 months - 5 years. No migration was found over time. Hoffman (1997) found similar low incidence of migration for adults and children (<2%).

With the 6 month old infant and younger, the depth of the temporal bone is about 2-3 mm. Sinninger (2002) indicates that the full range of issues regarding seating of the device below 6 months of age has not yet been explored. It is not yet known whether surgery on very young infants will result in problems of migration of the device or electrode.

Otitis media complication. Clark et al. (1987) demonstrated that a fibrous sheath grows around the electrode and seals the cochleostomy preventing migration of pathogens from the middle ear. Others have found no increase in otitis media following implantation nor any degree of complications due to the otitis media when it occurs (Cohen and Hoffman, 1993; Dahm, Shepherd & Clark, 1993). However, these studies have all been conducted on older children.

Anesthesia risk. Nancy Young M.D. of the Children's Memorial Medical Center, Chicago reported that the incidence of complications of anesthesia is 8 times higher in infants under 12 months. "There is significant evidence that infants are at increased anesthetic risk in comparison to older children and adults." "Since infants six months of age and younger are the most likely to experience problems, implantation in this age group in the absence of urgent indication may be ill advised. "

Audiological challenges

The audiological obstacles include: 1) limitations to the audiological physiological battery that can be done in the infant period, 2) determination of functional benefit to conventional amplification, and 3) mapping of cochlear implant with behavioral responses.

The audiological physiological battery limitations. The audiological battery for a newborn typically consists of a combination of physiological tests that can include click auditory brainsteam response (ABR) testing, tone ABR testing, otoacoustic emissions testing, and high frequency or multifrequency tympanometry. There are limitations to each of these tests for definitive information about frequency specific responses versus low/high frequency or only high frequency information and configuration of the hearing loss, intensity limitation of the equipment sometimes preventing a distinction between severe versus profound hearing loss, and difficulty obtaining definitive information about the presence of a conductive component and the extent to which a conductive component is depressing thresholds.

Because of the audiometric limitations and the fact that behavioral thresholds are not typically obtained until a minimum of a six month age level, verification of the physiological data is difficult. Children with congenital profound hearing loss may be considerably older than 6 months before reliable behavioral thresholds are obtained. Even when behavioral responses are obtained, no research data is yet available about how close to threshold these responses are for children with congenital hearing loss. Without this verification, the fitting of conventional amplification is typically done very conservatively. Thus, there is always some chance of over or under amplification. The audiologist typically tries to err on the side of under amplification. Thus, a child with a profound hearing loss may not have had a true "hearing aid trial", if the hearing aids were not set an optimal level for the child.

Defining a good hearing aid trial. The average child with a congenital permanent bilateral hearing loss in the state of Colorado is fit with amplification between three and six months of age. The typical delays in fitting amplification are financial or medical (fluid in the middle ear). The FDA (Federal Drug Administration) regulations for cochlear implantation of young children currently include a 6 month amplification trial. If children are identified with hearing loss at two to three months of age and immediately receive amplification, they may complete a hearing aid trial by 8 or 9 months of age. Complications to the fitting of conventional amplification can result from difficulty obtaining threshold information, information about configuration of the hearing loss and type of hearing loss.

Determination of a profound bilateral sensori-neural hearing loss in the better ear in the infant period can be quite challenging. Equipment limitations can prevent determination of severe versus profound category of deafness. A “no response” (NR) in the high frequencies from a click ABR provides a non-frequency specific, high frequency threshold that can be either in the severe or profound range depending upon the equipment used for testing. If tone ABR thresholds are obtained in the high frequencies, these are considered to be frequency specific. In the low frequencies, a NR can indicate a severe to profound degree of loss. In some cases, separating severe from profound may be extremely difficult in the first year of life. Proponents of the use of new technology for the United States, the steady state evoked potential (SSEP) testing believe that this technology is capable of providing information about configuration of hearing loss at four to five frequencies, threshold information and information about the status of the middle ear. Only a small amount of data is available about the relationship of behavioral thresholds of infants but it is predominantly with those who have normal hearing not with those who have significant hearing loss. The stability of the thresholds of children with significant hearing loss over time has not been demonstrated in the research, nor has the range of deviation of the scores. There is some degree of controversy about the accuracy of the thresholds for different degrees of hearing loss.

Thus, the initial diagnostic audiological assessment may not be able to provide information about 1) hearing at all frequencies, 2) a differentiation between severe and profound hearing loss, and the 3) degree to which a conductive component could be depressing the thresholds. Thus, the fitting of amplification based upon physiological thresholds is not an exact science. Although the fitting should be checked frequently and adjusted according to behavioral observations, audiologists would prefer to err on the side of under amplification than over amplification, thus presenting the possibility that a hearing aid trial without true thresholds may be below the level of audibility for a child with a profound hearing loss.

Lack of speech discrimination assessments. At the present time, no behavioral or physiological assessments of speech discrimination of infants with significant hearing loss are available. Since the population of early-identified children with significant hearing loss is so new, there has, as yet, been no research measuring speech perception abilities in children with any degree of hearing loss at this age. Parents spend a considerable amount of time trying to understand the audiological information, how to use the hearing aid and what it does and keeping the hearing aids on the young infants. Although auditory skill development curriculums have been used for children with congenital hearing loss at older ages, very little has been written about techniques to enhance auditory perception in newly identified infants with hearing loss. Criterion checklists have been used but are rather basic methods for determining whether or not a child has the capability of benefiting from conventional amplification.

Inability to use speech production in the first year of life as a predictor of cochlear implant candidacy. Aside from the fact that there are no measures of speech perception ability in the first year of life, speech production measures are not good indicators of children who are deriving benefit from conventional amplification nor are they good indicators of cochlear implant candidacy. In the first year of life, we had hoped that a child's babble would provide information about the child's use of residual hearing. However, no differences were found between the babble of the child with a mild through profound loss in the first year of life. Differences by degree of hearing loss were found after 12 months of age. Absence of babbling was also not a good predictor of later speech intelligibility or vocal competence. Children with no babble in the first year of life could become effective and intelligible speakers and occasionally children who babbled within a normal range of development could fail to develop intelligible speech (Wallace, Menn & Yoshinaga-Itano, 2000).

Lack of behavioral information necessary for cochlear implant mapping. Because there are no functional behaviors that can be obtained at this age level, functional information about mapping the electrode when the child is implanted is also difficult. Specifically, information about the perception of loudness and discomfort is extremely difficult behaviorally in a very young infant. Although Neural Response Telemetry provides some interesting information, research data has not been provided that demonstrates that the information obtained the NRT provides information about sensitivity to loudness in infants below 12 months of age. .

Developmental outcomes of children with cochlear implants

Speech intelligibility and speech perception. Among older children with cochlear implants (implantation between 2 and 4 years of age), the literature does demonstrate that the average child reaps significant benefit. Speech perception, pre- implantation is typically unmeasurable or 0%, and the average child improves to a 55% discrimination level ranging to close to 100% for the children with the greatest benefit. Additionally, significant improvements in speech intelligibility have been measured. Children with cochlear implants with the most significant improvement may improve from 0% to 90-100% speech discrimination.

Theoretically, the children with the best pre-implant speech discrimination, or the best language development, or the best speech production, should benefit the most from cochlear implantation. However, even the most successful children differ from children with normal hearing.

Language development. However, the language development results have not been as promising. The most comprehensive longitudinal report to date is an analysis of the data from Australia's cochlear implant program (Blamey et al., 2001).

Blamey, et al. (2001) in a longitudinal study of 47 children with profound loss with cochlear implants and 40 children with severe hearing loss who used conventional hearing aids also reported language developmental rates between .43 and .60. The language developmental growth rates of children with significant hearing loss (language quotients or language age by chronological age) were reported to be between .43 to .60 (43% to 60%) (of typical development) for children between 4 and 18 years of age by Boothroyd, Geers and Moog (1991). One hundred twenty-three children had better pure tone averages (PTA) >105 dB, and 188 had better pure tone averages between 90 and 104 dB. Geers and Moog (1989) in a study of 44 children between 8 and14 years of age and 100 students between 16 and 18 years of age, and Svirsky et al., 2000 reported a predictive model of language growth for children who are D/HH, .45 to .50 for Pure Tone Average (PTA) of 90-100 dB and .38 to .41 for PTA 100 dB+.

Very little information is available about the characteristics of the language of children with cochlear implants in the first three years of life. Most of he literature on outcomes of cochlear implantation begin at about 3 years of age, since most children received their implants between two and four years of age. Unfortunately, this rate of language development is probably insufficient to prevent the traditionally reported reading and language plateaus at 3rd to 4th grade levels.

This rate of language development can be compared to the rate of language development for children with early-identified profound hearing loss in the first three years of life that was 90% of typical language growth. Additionally, recent studies conducted by Stevens (2002) indicated that about 90% of the children maintain their language development rate throughout the early childhood years. Some studies have reported that a small group of children were able to maintain language growth rates similar to typical development in the first 18 months after implantation. However, these growth rates were measured by Peabody Picture Vocabulary Test scores that provide only a narrow perspective of language abilities. At these young ages, the PPVT may also not be as reliable an index of language growth because it is at the beginning of the standardization of the test. In addition to language growth rate, it would have been helpful to know the actual language scores.

Auditory speech perception and speech production versus auditory language development. One of the greatest concerns regarding cochlear implantation in the first twelve months of life is that the auditory perceptual system was found to be delayed even for children with mild sensori-neural hearing losses who were both early-identified and early amplified. They were rated as only being 25% intelligible through the first two years of life. Between 2.5 and 3 years of age, children with early-identified mild hearing loss were just to have speech that was almost always intelligible. This development in speech intelligibility coincides with development of vocabulary that advances from approximately 200 words at 2.5 years to 700 words at 3 years for the most advanced children and from less than 200 words to 400 words for the average child.

It is surprising that congenital hearing loss even when early identified and when mild in degree has such an impact upon speech intelligibility that is evident for the first three years of life. If a child's language is dependent upon oral speech skills and auditory perception, this delay in speech production and presumably in auditory perceptual ability will undoubtedly have an impact upon vocabulary development. One of the interesting phenomena resulting from UNHS is the number of families of children with mild and moderate hearing loss who are taking sign language instruction in the first three years of their childrens' lives. They find that supplementing the speech with sign language for both reception and expression provides the child with an opportunity to develop language at a rate similar to children with normal hearing. Typically, as soon as the child is able to articulate the word correctly, they tend to drop the signs.

Cochlear implant research indicates that the benefit to children with profound hearing loss is similar to children with severe hearing loss. The benefit of UNHS has been that children with moderate and severe hearing loss are now similar in both speech and language production to children with mild hearing loss creating two rather than four or five hearing loss categories: hard of hearing (mild through severe) and deaf (profound).

Implantation after 12 months is still one year earlier than implantation at 24 months of age. Access to sound at earlier ages will most likely result in better speech perception and speech production and a more automatic rather than "therapized" development. However, better speech perception and speech production is not synonymous to language skills. Until cochlear implant research demonstrates that early-implanted children with profound hearing loss have language and speech skills similar to children with mild hearing loss, it would be unwise to assume that early implantation results in age-appropriate language and speech development. If a child must rely solely on speech and audition, implantation even at 6 months of age may still present significant delays in language as evident in the early-identified children with mild hearing loss. This may be because the child has already begun establishing an auditory pathway in utero since the cochlear is completed by 20 weeks in utero. If the child has above average intellectual potential, the child may be able to overcome any initial delays and catch-up to normal language levels but only if there is special attention to pre-implant language levels and rate of language growth, auditory perception growth and speech production growth.

The cochlear implant, even when implanted within the first year of life, has not yet been shown, *on average*, to provide benefit that children with mild hearing loss derive from conventional amplification. Thus, it is reasonable to assume that the speech perception and production development of early-implanted children could be slower than the development of children with mild hearing loss.

We still do not know the cause of the language advantage of early-identified children. Since some of the children who evidenced the language advantage either had no residual hearing or minimal, i.e. profound hearing loss who later received cochlear implants, we must assume that the language advantage is not explained as an auditory perceptual effect only. For some children the language was measured solely through sign language with no speech. The social-emotional advantage to the families, the ability to work through their initial grieving and learn communication strategies that can be effective with their children probably play a major role in better language outcomes for these children.

Windows of opportunity for language versus speech

Language development appears to have a much shorter sensitive period than for speech development. Whatever variables combine to result in such a different language development for those children identified in the first six months of life and provided with intervention versus those identified after six months of age, seems to have a lasting effect at least through the first four to five years of life. We are still analyzing data from our four and five year old children and have some indication that the first 12 months, not just the first 6 months, play a major role in prediction of language at this age level. The timeline for intelligible speech development appears to have a much longer window of opportunity. Children even as late as 3, 4 & 5 year olds have developed intelligible speech even when there was minimal speech development in the first three years of life. The probability of achieving intelligible speech does drop off as the child ages. Further research investigation needs to be done to determine the likelihood intelligible speech when auditory access occurs at 6, 12, 24, 36, 48 and 60 months of age.

Summary

In conclusion, there will undoubtedly be a significant number of early-identified children with profound hearing loss who will be implanted at 12 months of age. By this time, complete behavioral audiological information will be available. Some children will be considered for implantation below 12 months, the most likely candidates are those children with meningitis who show evidence of ossification of the cochlea. Centers are reporting candidacy of children with positive identification of the Connexin 26 gene and profound bilateral hearing loss. However, the research does not indicate that Connexin 26 gene is always associated with a profound loss of hearing, but rather research shows that a wide variety of audiograms are possible. Medical and audiological challenges must be adequately addressed before a child is considered a good candidate for early implantation. The best candidate is a child with strong language development in any mode of communication. Language development should be monitored regularly to insure that changes in the rate of language development are in a positive direction.

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