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Edited by

Paul Fletcher

University College Cork

Jon F. Miller

University of Wisconsin-Madison

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Language acquisition in children with a cochlear implant

Karen Schauwers, Steven Gillis and Paul Govaerts

1. Introduction

Children born deaf, or deafened at an early age, with a total or near-total sensorineural hearing loss (i.e. characterized by a malfunctioning cochlea) are unable to acquire language through audition and depend on a visual mode of communication (sign language, lip-reading, or written language). More specifically, it is accepted that a child with a hearing loss in excess of 60 dBHL will not develop good spoken language skills, because normal conversational speech sounds are presented in the 40 dB – 60 dB range. Early amplification by means of hearing aids is helpful for hearing impaired children, but for some children conventional hearing aids provide little or no benefit because their hearing loss is so severe that amplification does not reach the area of the speech spectrum.

A useful categorization of these profoundly hearing impaired children has been introduced by Osberger, Maso and Sam (1993), who divided them into three groups based on unaided and aided hearing thresholds at 500, 1000, and 2000 Hz. *Gold* hearing aid users have unaided pure-tone hearing levels of 90 to 100 dBHL and aided thresholds between 30 and 55 dBHL. In many but not all cases, these Gold hearing aid users will acquire speech and spoken language. *Silver* hearing aid users have unaided thresholds of 101 to 110 dBHL and aided thresholds greater than 55 dBHL. They receive few spectral cues and rely heavily on timing aspects of speech. *Bronze* hearing aid users have unaided thresholds greater than 110 dBHL, which is suggestive of vibrotactile rather than auditory sensation, and these children receive negligible benefit from conventional hearing aids.

For the Silver and Bronze hearing aid users, cochlear implants (CI) can provide access to the auditory information that is essential for spoken language development. A cochlear implant is an electronic device that functions as a sensory aid, converting mechanical sound energy into a coded electrical stimulus that directly stimulates the remaining auditory nerve fibers, bypassing damaged or missing hair cells of the cochlea. Part of the CI is surgically implanted into the cochlea and the mastoid, and the remaining part is worn externally. The external components consist of a microphone, a signal processor, and a transmitter coil. The microphone receives acoustic signals and converts them into an analog electrical signal that is sent to the processor, which modifies the signal into an electrical or digital pattern that is transmitted to the internal part by means of the two coils (the external transmitter coil and the internal receiver coil). The internal part then stimulates the electrodes in the cochlea. The electrodes are thus able to deliver electrical stimulation to excite the cochlear neurons of the auditory nerve. Some 4 weeks after surgery, the initial tuning session of the CI takes place, which is often called "switch-on". In this session, the external parts of the device are programmed and rehabilitation can be started.

In the early days of pediatric implantation, candidacy requirements included an unaided pure-tone average (PTA) of 100 dBHL or more (i.e. Silver and Bronze hearing aid users), aided thresholds of 60 dBHL or worse, and absence of open-set speech discrimination and word recognition with well-fitted hearing aids. Recently, profoundly hearing impaired children with hearing losses of 90 dBHL or sometimes even better also have been considered potential candidates for cochlear implantation. The final decision about their eligibility depends largely upon their performance after prolonged hearing aid use and their ability to discriminate speech sounds.

Most implant users improve to hearing thresholds in the 20 to 40 dBHL range across all frequencies with their device, which corresponds to a mild hearing loss. This means that the implant enables detection of virtually all conversational sounds and provides a hearing sensitivity and functioning which is superior to that obtained with conventional hearing aids. A sensorineural hearing loss is not only characterized by an elevated threshold on pure-tone audiometry, but also by a lower frequency resolution. A good frequency resolving power of the cochlea, however, is essential for normal speech and language development, and lack of it is the key problem in hearing impairment. Hearing impaired people not only fail to hear many sounds, but if they hear them, they often fail to discriminate them. Conventional hearing aids unfortunately only amplify the sound, and don't improve the frequency discrimination. Frequently, the hearing impaired patient reports to hear sound better with a hearing aid, without necessarily better understanding the words. 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 the major advantage of a CI over a hearing aid in cases where the hearing loss is severe to profound and the cochlear tuning becomes deficient.

Detailed studies of the speech and language development of children using CI are just emerging. Initially, the primary function of a CI was to improve the speech perception abilities. As a consequence, research on the benefits of the implant has focused mainly on speech perception, and these studies revealed a continuous improvement of auditory perceptual skills in CI children after implantation (Osberger, Miyamoto, Zimmerman-Phillips, Kemink, Stroer, Firszt, & Novak 1991a; Waltzman, Cohen, Gomolin, Shapiro, Ozdamar, & Hoffman 1994; Snik, Vermeulen, Geelen, Brokx, & van der Broek 1997; Tyler, Fryauf-Bertschy, Kelsay, Gantz, Woodworth, & Parkinson 1997; Waltzman, Cohen, Gomolin, Green, Shapiro, Hoffman, & Roland 1997; Illg, von der Haar-Heise, Goldring, Lesinski-Schiedat, Battmer, & Lenarz 1999; Lenarz, Lesinski-Schiedat, von der Haar-Heise, Illg, Bertram, & Battmer 1999; Govaerts, De Beukelaer, Daemers, De Ceulaer, Yperman, Somers, Schatteman, & Offeciers 2002 and others). Many of these data demonstrate the ability of congenitally or prelingually deaf children to achieve significant and usable open-set speech perception following cochlear implantation at a young age. The increasing belief that cochlear implants also provide feedback to monitor one's own speech, incited a number of investigations in the last decade examining the speech and language production of prelingually deafened CI users.

In this chapter, we will focus on speech and language acquisition of CI children. The major results will be summarized in terms of different linguistic domains: prelexical babbling, phonology, intelligibility, vocabulary, morphosyntaxis, and pragmatics. The typical child reported on in these relevant papers is a prelingually deafened child, being implanted between 3 and 5 years of age and wearing the implant for 2–3 years. Most of the studies selected English-learning children as subjects. If another language is investigated, this will be stated in the text. In addition, an important part of this chapter will be dedicated to the possible factors affecting the language outcomes in CI children. Although a consensus seems to exist on the benefit of CI in children, the outcomes still seem to vary to a great extend. A number of alleged contributing factors will be discussed, including the age at implantation, educational approaches, and the length of CI experience.

2. Comments on methodology in CI studies

Speech and language research in prelingually deafened CI children belongs to a relatively new scientific field and numerous difficulties exist that make the interpretation of data problematic.

The principal difficulty is that CI children constitute a very heterogeneous group with very different audiological and educational characteristics like the age at onset of deafness, the age at implantation, and the communication mode. Also, the individual history of each child may be very different from others. This relates to the age at fitting of conventional hearing aids (before receiving the CI), the type of deafness (i.e. congenitally, prelingually, or postlingually), the amount and type of speech-language therapy before and/or after implantation, the level of sign language ability before and after implantation, etc. All these factors are thought to influence the speech and language development and, unfortunately, they are often poorly defined or even lacking.

It was not until recently that the FDA (i.e. Food and Drug Administration in the USA) approved cochlear implantation below the age of 2 years. As a consequence, the majority of the studies published so far about language acquisition in CI children showed results of deaf children implanted at a mean age between 3 and 5 years. To date this is considered to be "late", since the age at implantation has dropped to below 2 years and in some countries even below 1 year of age. As some studies seem to suggest that receiving an implant before the age of two may lead to greater and faster improvements in speech perception and production than implantation later in childhood (Waltzman & Cohen 1998), further research is needed as younger CI candidates become available.

Another factor that renders the interpretation of results difficult is the fact that CI technology is improving with time. Thus, over time, findings may become obsolete simply because they relate to technology that is no longer in use (like certain types of implants or of speech coding strategies).

Finally, the study of a child in development requires a longitudinal and comparative study design. Unfortunately, longitudinal cohort studies are very time-consuming. This is probably the main reason why the majority of CI investigations are either cross-sectional, or longitudinal over only a short period of time, or longitudinal with too long intervals, or longitudinal case studies. In addition, a matched control group is frequently lacking. The absence of proper longitudinal cohort studies is very problematic.

3. Effectiveness of CI: General measures

Before discussing CI studies in which specific sub-domains of language are considered, the development of language in general in groups of deaf children with a CI will be described. Research focusing on language acquisition frequently use a variety of formal language tests, like the Reynell Developmental Language Scales (RDLS), the Clinical Evaluation of Language Fundamentals (CELF), or the Grammatical Analysis of Elicited Language (GAEL) to evaluate receptive and expressive language skills before and after implantation. Data analysis relies mainly on three quantitative variables: *language age, language quotient*, and the *rate of language change*. For example, a language age (or age-equivalent) score of 36 months implies that the CI child has the language skills equivalent to that of a normally developing child of 3 years old. The language quotient is then calculated by dividing the language age by the chronological age. In order to determine whether there is a significant gain in language age over time, the rate of improvement is calculated by dividing the change in age-equivalent score over time by the change in chronological age over the same time period. A rate of 1.00 represents the "normal" rate of language development, i.e. an equal change of language age and chronological age in a given time period (for instance, 12 months of language growth in 12 months time).

3.1 Results on the Reynell Developmental Language Scales (RDLS)

Studies using the RDLS in deaf children agree that the receptive and expressive language growth (or rate of language development) is roughly half that of peers with normal hearing. Robbins, Svirsky and Kirk (1997), for example, found a receptive language rate of 0.50, meaning about 6 months of growth in 1 year, and an expressive language rate of 0.42, or a growth of about 5 months in 1 year. Before CI children receive their implants, this is their language rate. After implantation, an acceleration of this language development had been reported (Robbins et al. 1997; Miyamoto, Svirsky, & Robbins 1997; Miyamoto, Kirk, Svirsky, & Sehgal 1999; Bollard, Chute, Popp, & Parisier 1999; Robbins, Bollard, & Green 1999; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto 2000a; Kirk, Miyamoto, Lento, Ying, O'Neill, & Fears 2002; Svirsky, Chute, Green, Bollard, & Miyamoto 2000b; Kirk, Miyamoto, Ying, Perdew, & Zuganelis 2000). Rates close to or even greater than those of normally hearing children were found. As a consequence, the gap in absolute scores between children with implants and normally hearing children shown before implantation remained roughly constant after implantation, instead of increasing as in the case of deaf children

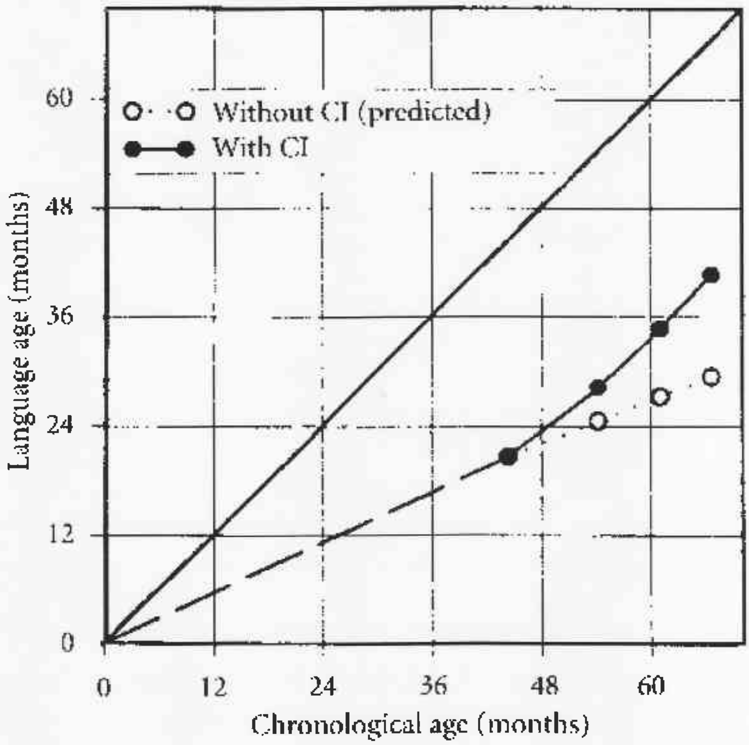

Figure 1. Average language age as a function of chronological age for CI children (black circles). The white circles represent the language growth of deaf children without CI. The solid diagonal line illustrates language growth of normally hearing children (Svirsky et al. 2000a: 156, reprinted with permission from Blackwell Publishing, Oxford).

without implants. Figure 1 (taken from Svirsky et al. 2000a: 156) clearly illustrates these findings. Some studies (Robbins et al. 1999; Svirsky et al. 2000b; Kirk et al. 2002) even indicated that CI children, implanted at approximately 3 years of age, were starting to "catch up" their hearing peers following cochlear implantation, with language rates as high as 1.27 (Svirsky et al. 2000b) and 1.40 (Robbins et al. 1999). These higher-than-normal language rates suggested that the CI children were closing the gap between their language age and their chronological age, a process not completed yet after 4 years of implant use.

3.2 Results on other general language tests

Studies using other tests than the RDLS to assess receptive and/or expressive language in CI children implanted at approximately 4–5 years of age (Geers & Moog 1994; Tomblin, Spencer, Flock, Tyler, & Gantz 1999; Allen & Dyar 1997; Moog & Geers 1999; Moog 2002; Hammes, Novak, Rotz, Willis, Edmondson, &

Thomas 2002; Boothroyd & Boothroyd-Turner 2002) also demonstrated language scores within 2 standard deviations of normally hearing peers (Moog 2002; Moog & Geers 1999) and language learning rates similar to or even greater than those of hearing peers (Hammes et al. 2002) after implantation. The average performance of CI children was at the 70th percentile when compared with profoundly deaf children (Geers & Moog 1994; Boothroyd & Boothroyd-Turner 2002) and at the 2nd percentile when compared with normally hearing children after 3–5 years of implant use.

3.3 Conclusion

These results suggest that early implantation may have a significant impact on language development in children with profound hearing impairment. Since no study to our knowledge has proven that the existing language delay at the moment of implantation can ultimately be reversed, and since only very few studies claim a language rate of more than 1.00, the only way to get rid of the initial delay may well be to prevent it from occurring by very early implantation.

4. Language in CI children: Development in specific sub-domains

4.1 Prelexical babbling

Early vocal development is characterized by the gradual emergence of increasingly complex and speech-like utterances during the first 18 months of life (Oller 1980; Stark 1980). A major landmark in prelexical development is the onset of babbling, which can be defined as the production of adult-like consonant-vowel sequences and typically occurs between 6 and 10 months of age. Babbling utterances are generally recognized as the "foundation" for meaningful words and phonological development: segmental characteristics and syllable shapes found in late prelexical babbling are also common in first words (Vihman, Ferguson, & Elbert 1986). Research in profoundly hearing impaired children has shown that hearing plays a major role in this early vocal development (Oller & Eilers 1988). Indeed, several differences are found in the prelexical utterances of deaf infants compared to normally hearing infants. In general, the early speech of deaf infants is characterized by a late onset of babbling and a low babbling ratio, with reports of delays of as much as 15 to 18 months (Oller & Eilers 1988). Also, the productive output is limited: the size of the consonantal inventory is smaller and hearing impairment alters the nature of place and manner of consonant production (Stoel-Gammon & Otomo 1986). Hearing impaired children have a strong preference for labials over other places of articulation and for nasals over other manners of articulation. Vowels show a tendency towards neutralization, having schwa-like properties. As a consequence, the vowel space is much reduced, with a predominance of mid and central vowels.

It can be anticipated that early cochlear implantation might result in a more normal prelexical vocal development. With regard to onset of babbling, the available studies (Ertmer & Mellon 2001; Ertmer, Young, Grohne, Mellon, Johnson, Corbett, & Saindon 2002; Wright, Purcell, & Reed 2002; Moore & Bass-Ringdahl 2002; Gillis, Schauwers, & Govaerts 2002; Schauwers, Gillis, Daemers, De Beukelaer, & Govaerts 2004) show that only a few months of auditory exposure are needed for CI children to start babbling (ranging on average from 1 to 6.5 months after implantation) regardless of the age at implantation. Consequently, most CI children have a delayed onset of babbling in terms of chronological age, but they start to babble much earlier than normally hearing infants in terms of "hearing age". Moreover, two very early implanted children in the study by Schauwers et al. (2004) who were implanted before the age of 1 year started to babble at a normal chronological age, namely at 8 and 10 months of age. The striking finding that all CI children in these studies started to babble within a short interval of less than 6 months after activation of the implant, irrespective of the age at implantation, is suggestive of a trigger effect of the cochlear implant.

With regard to the segmental characteristics of babbling, children with a CI appeared to babble with greater phonetic diversity than non-implanted hearing impaired infants (Ertmer & Mellon 2001; Ertmer et al. 2002; McCaffrey et al. 1999). Before implantation, the phonetic inventory of CI children was very much like that of profoundly hearing impaired infants. The labial nasal consonant /m/ (SAMPA, www.phon.ucl.ac.uk/home/sampa/home.htm) accounted for 80–90% of all consonants produced and the mid central vowel /@/ accounted for almost 70% of all vowels produced prior to implantation. Relatively soon after activation of the implant however, the strong preference for labials was replaced by a marked increase in "less visible" consonant types like coronals and velars. The large proportion of nasals changed into large proportions of oral stops. Members of the consonant classes that are rare in the babbling of normally hearing infants – fricatives, liquids, and affricates – were also rare in the babbling of CI children. The vowel space expanded from mainly mid central vowels towards a more equal distribution of all vowel categories by the end of the first year of implant use.

Overall, the phonetic inventories of babbling in CI children increase from 2–3 types before implantation to 7–10 types within 1 year after implantation. These increases are in contrast to the decreases in segmental inventories reported for hearing impaired infants (Stoel-Gammon 1988; Stark 1983). Thus, despite the limited number of young CI children studied, the prelexical vocal development of CI infants seems to be significantly different from that of profoundly hearing impaired infants with hearing aids and very similar to the prelexical utterances of normally hearing children.

4.2 Phonological development

A common approach to examine the speech production patterns in children is to investigate the articulatory features (like manner and place of articulation) of vowels and consonants. Three frequently used methods to obtain speech utterances of children in order to examine their segmental characteristics include videotaped spontaneous language samples of unstructured conversations or play situations between the child and a familiar adult (Serry & Blamey 1999; Blamey, Barry, & Jacq 2001; Serry, Blamey, & Grogan 1997; Robinshaw 1996; Grogan, Barker, Dettman, & Blame 1995; Tobey, Geers, & Brenner 1994; Osberger, Robbins, Berry, Todd, Hesketh, & Sedey 1991b; Tobey & Geers 1995; Tye-Murray & Kirk 1993; Tobey & Hasenstab 1991; Geers & Tobey 1992; Tobey, Angelette, Murchison, Nicosia, Sprague, Staller, Brimacombe, & Beiter 1991a), the imitation of CV-syllables (Kirk, Diefendorf, Riley, & Osberger 1995; Sehgal, Kirk, Svirsky, Ertmer, & Osberger 1998; Higgins, Carney, McCleary, & Rogers 1996; Tobey et al. 1994; Tye-Murray, Spencer, Bedia, & Woodworth 1996; Tobey & Geers 1995; Ertmer, Kirk, Sehgal, Riley, & Osberger 1997; Tye-Murray & Kirk 1993; Geers & Tobey 1992; Tobey & Hasenstab 1991; Tobey et al. 1991a), and the elicitation of production of words in isolation by means of picture-naming (Tobey, Pancamo, Staller, Brimacombe, & Beiter 1991b; Chin 2002; Chin 2003; Chin & Kaiser 2000; Kishon-Rabin, Taitelbaum, Muchnik, Gehtler, Kronenberg, & Hildesheimer 2002).

In most studies, the speech samples of the CI children (obtained by means of CV imitations, spontaneous speech recordings, or picture-naming) were analyzed in terms of the percentage of consonant features (manner, place, and voicing) and vowel features (height and place) produced by the child that matched the features of the target. Studies considered bilabial, coronal (or alveolar), palatal, and velar as the possible places of articulation of consonants, and stop, nasal, fricative/affricate, glide, and liquid as the possible manners of articulation of consonants. For example, if the target was /te/ and the child produced /be/, the feature of manner was counted as correct (viz. stop consonant), but no credit was given for the place or voicing feature. With regard to vowels, the place of articulation feature included front, central, and back, and the vowel height feature included high, mid, and low.

A major consequence of deafness in children appears to be a reduced repertoire of sound segments in comparison with normally hearing children. Consonant production in profoundly hearing impaired infants is characterized by a variety of errors, including substitutions of one sound for another, distortions, and omissions of word-final consonants (Osberger & McGarr 1982). Many place-of-articulation errors occur. As in babbling, profoundly hearing impaired infants use visible, front consonants much more frequently than less visible ones, like dorsals (Smith 1975; Gold 1980). Manner-of-articulation errors frequently appear as nasal-oral substitutions. Vowel production in profoundly hearing impaired children is also different from normal speech. A higher proportion of errors is found on vowels requiring a high tongue position than on vowels requiring a central tongue position (Smith 1975). Common processes in the vowel production of hearing impaired children are omissions, tense-lax substitutions, monophthongization of diphthongs and neutralization, which result in the overuse of the vowel /@/.

It was demonstrated earlier that the use of conventional hearing aids was able to improve the production of speech (Geers & Tobey 1992). Cochlear implants, when carefully indicated, give better audiological performance and can be anticipated to contribute even more to a good speech production. Indeed, several studies showed that profoundly hearing impaired children fitted with a CI systematically acquire a diverse set of phonemes involving a wide range of articulatory features. In general, CI children produce 30–40% of consonant features correctly (i.e. matching the target segment) before implantation, and 60–70% after 2–3 years of implant use (Geers & Tobey 1992; Kirk et al. 1995; Sehgal et al. 1998; Chin & Kaiser 2000; Tobey et al. 1994). Scores of over 80% are obtained after 6 years of implant experience (Serry & Blamey 1999; Blamey et al. 2001; Serry et al. 1997). Qualitatively, significant improvements in the percentage of correctly produced consonants are observed for voiceless consonants (mainly voiceless fricatives), less visible coronal consonants (mainly the coronal stops /d/ and /t/), and for all manner categories, but particularly fricatives/affricates, liquids and glides (Geers & Tobey 1992; Sehgal et al. 1998; Tobey et al. 1991b; Chin & Kaiser 2000; Tobey et al. 1994; Osberger et al. 1991b; Tobey & Geers 1995). Vowels are more correctly produced than consonants both before and after implantation. In general, while 30–50% of monophthongs and 20–30% of diphthongs are produced accurately before implantation (Ertmer et al. 1997; Tye-Murray & Kirk 1993; Geers & Tobey 1992), these figures increase to 70–80% and 45–65% respectively after 2–3 years of CI use. Furthermore, evidence exists that these high figures do not even represent plateau levels since Blamey et al. (2001) found accuracies of 92% (monophthongs) and 89% (diphthongs) in CI children who had implant experience of 6 years. In comparison with conventional hearing aid users, CI children display significantly better production of consonant and vowel features than Silver HA users. In fact, the results after 2–3 years of implant use are comparable to those of Gold HA users, with 60–70% correctly produced consonant features and 60–90% correct vowel features (Kirk et al. 1995; Tobey et al. 1994).

Another presentation of phonological development is the construction of a phonetic inventory, in which an inventory is credited with having a consonant or vowel if this segment is produced at least twice, regardless of the target sound ("targetless") or matching the target sound ("target"). Results from such studies of children acquiring English (Serry & Blamey 1999; Blamey et al. 2001; Serry et al. 1997; Chin 2002; Chin 2003) suggest that very few segments are missing from the inventories of CI children implanted at approximately 3.5 years old after 5–6 years of implant use, in contrast to inventories of profoundly hearing impaired infants. Fricatives (/s, z, T, Z/), affricates (/tS/), and the nasal /N/ were lacking the most in most children.

A striking finding by Chin (2002) and Chin (2003) is that some of the CI children produce several non-English sounds, including labiodental stops and fricatives, uvular stops, and palatal and velar fricatives. No good explanation for this could be given.

4.3 Intelligibility

When measuring intelligibility, some CI studies (O'Donoghue, Nikolopoulos, Archbold, & Tait 1999; Allen, Nikolopoulos, & O'Donoghue 2000) rely on judges rating the speech of CI subjects (for instance, the SIR or Speech Intelligibility Rating), but most investigations use identification procedures (also called "write-down" procedures), in which normally hearing listeners are instructed to write down the words or sentences as produced by the child, and in which the intelligibility is indicated by the percentage of (key) words correctly identified (Dawson, Blamey, Dettman, Rowland, Barker, Tobey, Busby, Cowan, & Clark 1995a; Tobey, Geers, Douek, Perrin, Skellett, Brenner, & Toretta 2000; Tobey & Hasenstab 1991; Tobey et al. 1991a; Osberger, et al. 1993; Robbins,

Table 1. An overview of intelligibility scores after 2–3 years of implant use using the McGarr of BIT sentence tests. (Some data regarding younger-implanted CI children are lacking, indicated by a question mark).

	Non-experienced listeners		Experienced listeners	
	Pre-implant	Post-implant	Pre-implant	Post-implant
CI > 5 years	3–7%	15–18% > 4 y CI use: 40%	18%	43%
CI < 5 years	?	48–55% > 4 y CI use: 80%	?	?

Kirk, Osberger & Ertmer 1995; Osberger, Robbins, Todd, & Riley 1994). For the "write-down" method, the available test materials include sentences on the one hand (i.e. the McGarr sentences and the BIT or Beginners' Intelligibility Test) for the subjects to imitate or read, and single words in isolation on the other hand, elicited by imitation or picture-naming. A third possibility is to ask the child to retell a story by means of a set of 4 sequential pictures (i.e. the Story Retell Task), used in the study of Tye-Murray, Spencer and Woodworth (1995). Since many intelligibility assessments make use of adult listeners, it is important to take into account the experience of the listener with speech of children with hearing impairment, as suggested by McGarr (1983) and Monsen (1983).

The variable, that has been found to be highly negatively correlated with speech intelligibility, is degree of hearing loss (Boothroyd 1984; Smith 1975). Profoundly hearing impaired children demonstrate a high level of variation in speech intelligibility: with a consistently found average of merely 20%, with individual scores ranging from 0% to roughly 80% (Smith 1975; Monsen 1978). Typical Gold HA users have 72–81% intelligibility, Silver HA users 20% (Osberger et al. 1993; Osberger et al. 1994; Robbins et al. 1995), and Bronze HA users or typical CI-candidates only 3–7%. After receiving a CI (after the age of 5 years) and using the device for about 2–3 years, the average intelligibility scores increase to 15–18%, a score comparable to that of Silver HA users, but still markedly lower than that of Gold HA users. Cochlear implantation before the age of 5 years, however, resulted in BIT levels comparable to those of Gold HA users (i.e. 80%) after 4–6 years of implant use (Tobey et al. 2000). The overview table (Table 1) also shows that higher intelligibility scores are reported when listeners who are familiar with the speech of children with hearing impairment served as judges (Dawson et al. 1995a).

When using single words as speech material instead of sentences to assess intelligibility (Mondain, Sillon, Vieu, Lanvin, Reuillard-Artieres, Tobey, & Uziel 1997), the findings seem to indicate that children with CI are more intelligible when uttering short sentences than isolated words, similar to normally hearing children.

CI children implanted at an average age of 4.3 years, and tested by means of the intelligibility rating scale SIR (Allen et al. 1998; O'Donoghue et al. 1999) were shown to reach category 2 (unintelligible connected speech with some single words identifiable) one to two years after implantation, category 3 (intelligible connected speech to a listener who concentrated and read lips) 3 to 4 years after CI, and on average category 4 (intelligible speech to a listener with a little experience of deaf speech) five years after implantation.

4.4 Lexical development

Two commonly used vocabulary tests are the *Peabody Picture Vocabulary Test* (PPVT) for receptive vocabulary and the *Expressive One-Word Picture Vocabulary Test* (EOWPVT) for expressive vocabulary. Similar to the general language test RDLS (described in Section 3.1), the raw scores on these tests are converted to age-equivalent scores based on normative tables for normally hearing subjects and to vocabulary rates.

Several studies (Boothroyd, Geers, & Moog 1991; Dawson, Blamey, Dettman, Barker, & Clark 1995b; Geers & Moog 1994) have documented that the rate of lexical development of deaf children was only a fraction of the average rate in normally hearing children, viz. 0.33–0.63. Hence, CI candidates have a substantial vocabulary delay before implantation, but after implantation they have been shown to develop vocabulary skills significantly faster than their peers without implants (Kuo & Gibson 2000; Dawson et al. 1995b; El-Hakim, Levasseur, Papsin, Panesar, Mount, Stevens, & Harrison 2001; Geers & Moog 1994). Receptive and expressive vocabulary rates between 0.71 and 1.1 were found for CI children implanted between 3 and 9 years of age, a pace not significantly different from normally hearing children.

Sometimes, even higher than normal rates were found (Bollard, Chute, Popp, & Parisier 1999; Kuo & Gibson 2000; Kirk et al. 2000). In the study of Bollard et al. (1999), for instance, the children showed a mean vocabulary age of 12.4 months before implantation (at a chronological age of 36 months). At the end of 18 months of implant use, they reached a mean vocabulary age of 55 months and had equaled their hearing peers in vocabulary acquisition. Thus, the initial gap between chronological age and vocabulary age before implantation did not increase (and even decreased) after children started using the device, as it would have if they had not received CI at all.

Another measure on the lexical level is the type/token ratio (TTR), used in the studies of Szagun (2000) (studying German-learning children) and Ertmer, Strong and Sadagopan (2003). This is a measure of vocabulary diversity based on the ratio of different words (types) to the total number of words (tokens) in a sample. We have to take into account, however, that the TTR is function of the number of tokens in the language sample: samples containing larger numbers of tokens give lower values for TTR and vice versa. Although the TTR's of CI children were quite similar to the ratios for normally hearing children when considering hearing age (i.e. number of months after implantation), the TTR's were based on far fewer word types and tokens per sample than normally hearing children. For instance, normally hearing German-learning children had a vocabulary of approximately 400 word tokens at 29.5 months of age, in contrast to approximately 250 word tokens for the CI group at 18.5 months after implantation (or at 30 months chronological age) (Szagun 2001). In addition, a number of studies (Coerts, Baker, van den Broek, & Brokx 1996; Szagun 2000) agreed that CI children had a marked preference for content words over function words both before and after implantation. This could be a result of their impaired hearing, as content words can receive stress and are therefore perceptually more salient than function words, which are normally unstressed.

4.5 Morphosyntactic development

Mean Length of Utterance (MLU) measured in morphemes is commonly used as a general indicator of grammatical progress. In a number of studies (Szagun 1997; Szagun 2000; Szagun 2001; Coerts et al. 1996; Ertmer et al. 2003; Spencer, Tye-Murray, & Tomblin 1998; Coerts & Mills 1994), MLU was calculated on spontaneous speech samples of CI children. Although every study demonstrated an increase in MLU after implantation, the results across studies showed great diversity, and among CI children the variability was large: some CI children progressed as rapidly as normally hearing children, others were much slower in their morphologic and syntactic development. Table 2 demonstrates these substantial differences in MLU results across studies.

Although it is difficult to compare MLU over different languages, all investigators agree that CI children make progress in combining morphemes, but the intersubject variability appears to be very large. In addition, the data show that CI children acquire the morphosyntax of their language more slowly than normally hearing children with a considerable delay in MLU in compar-

Table 2. Overview of MLU results in CI children acquiring English (E), German (G) or Dutch (D).

Mean age at implantation	Number of months after CI	Mean MLU	Study
1;8	42	2.57	Ertmer et al. 2003 (E)
2;3	18	≤ 1.50–3.25	Szagun 2000 (G)
2;6	24	4.30	Szagun 1997 (G)
2;5	32	3.50	Szagun 2001 (G)
3;1	18	4.80 (in words)	Bollard et al. 1999 (E)
3;4	42	2.70	Szagun 1997 (G)
5;0	18	1.69–1.87	Coerts et al. 1996 (D)
5;4	18	> 4.00	Coerts & Mills 1994 (D)
5;7	46	2.55–8.96	Spencer et al. 1998 (E)

ison with normally hearing children. Many CI children (implanted at a mean age of 2.4 years) remain at the stage of two-word utterances (i.e. MLU of ≤ 2.25) after several years of implant use, while most normally hearing children reach the stage of complex grammar (i.e. MLU of > 4.00) by the age of 3 years (Szagun 2001).

The MLU is a rather general and quantitative measure, and more detailed qualitative analysis of the morphosyntactic development in CI children can be done (Coerts et al. 1996; Szagun 2000; Szagun 1997; Spencer et al. 1998; Svirsky, Stallings, Lento, Ying, & Leonard 2002). Such studies have shown that English-learning CI children acquire plural formation on nouns earlier and more easily than the regular past tense marker on main verbs (Svirsky et al. 2002; Spencer et al. 1998), similar to normally hearing children. With respect to case and gender marking in German (Szagun 2000), most CI children acquire the nominative case of the definite (/der/, /die/, /das/) and indefinite (/ein/, /eine/, /ein/) articles. However, accusative forms are rare and dative forms absent. Additionally, the CI children acquire more definite forms when these are used in pronominal function than in article function.

The above-mentioned studies explain the morphological acquisition order by the degree of perceptual salience of the grammatical cues. For example, regular past tense in English is marked by the addition of a final /t/ or /d/, both characterized by a brief burst and formant transition lasting a few tens of milliseconds. In contrast, the noun plurals are marked by the addition of a final /s/ or /z/. These phonemes have a much longer duration than the bursts associated with a final /t/ or /d/. Therefore, Svirsky et al. (2002) assumed that the morphological marker for plurals was perceptually more prominent to the CI users than the marker for past tense. Similarly, Szagun (2000) predicted that CI children would have problems acquiring inflectional morphemes on unstressed function words, such as articles. German case inflection, for instance, occurs mainly on articles, so she expected CI children to have particular problems in acquiring case inflection, which was confirmed by the results. The CI children perform nearly as well as normally hearing children in acquiring noun plurals and verb inflectional morphology on the main verb (viz. infinitive /en/, third person singular, imperative singular, past particle, first person singular, in this order). However, they acquire substantially less forms of the definite and indefinite articles, particularly case-inflected forms, since articles do not receive stress. The fact that the children acquire more forms of the definite article when used pronominally is an additional evidence for the effect of perceptual salience.

These suggestions made by Svirsky et al. (2002) and Szagun (2000) call for cross-linguistic research to investigate the possible universality of the factor of perceptual prominence in the development of grammar.

4.6 Pragmatic development

4.6.1 *Communicative behaviors*

Important features of (preverbal) interaction in children include the ability to distribute attention between the parent and objects of communication (which occurs at around 4 to 6 months of age in normally hearing children, when the child begins to follow the parent's line of gaze), the ability of turn-taking by gesture and by vocalization, and the awareness of the appropriate time to take a turn (Bruner 1983).

Methods to quantify these features in young children have been developed by Tait and colleagues (Tait 1993; Tait & Lutman 1994; Lutman & Tait 1995; Tait, Lutman, & Robinson 2000). Transcribed recordings of conversations are scored according to a detailed written protocol. The turns taken are identified and classified as vocal (VTT or vocal turn taking) or gestural (GTT) according to whether they are taken using voice or silent gesture or sign. If turns contain elements that cannot be predicted from the adult's preceding turn, they are further classified as showing autonomy (vocal VA, or gestural GA), including contradicting the adult, introducing new topics or information, joking, or asking questions. A child who is not yet using words can nevertheless exercise vocal autonomy, for example by vocalizing strongly to attract attention. When a turn is taken vocally without simultaneous eye contact between the child and the adult, it is classified as a non-looking turn (NLT). Finally, the percentage of

A: You went to tea with Susie, didn't you! ↓

C: Linda house, Linda.

A: Wasn't Linda there? ↓ Wasn't she? Was Pamela

C: (shakes head)

A: there? ↓ I know, you're Susie's friend. Was

C: I Susie friend.

A: Pamela there? ↓

C: Pamela school.

Figure 2. Transcript of a conversational interaction between adult (A) and child (C). Arrows indicate turn-taking by the child, dotted and solid lines indicate eye contact (see text). The arrows mark 4 occasions when the child takes a conversational turn: 3 of these turns are vocal and 1 gestural (shown in brackets); the first turn is a non-looking turn; 3 of the 4 turns show autonomy, by introducing new information (adopted from Tait 1993).

the total number of adult's syllables for which the child is looking at the adult is calculated (eye contact or EC).

Figure 2 illustrates the scoring. The transcript shows the adult's (A) and the child's (C) contributions presented in parallel. Arrows (↓) mark the child's opportunity for a conversational turn. The eye contact is added to the transcript as a dotted line just under the adult's words (or part of words) for which the child is looking at the adult, and as a continuous line under the words for which the child is not looking at the adult.

This type of analysis has shown that three measures (VTT, VA, and NLT) increase substantially within the first year after implantation in children implanted at a mean age of 3.3 years (Tait 1993; Tait & Lutman 1994). Vocal turns increase to 80–90% of all turns taken at 6–12 months post CI, and autonomy and non-looking turns reach approximately 50% of all turns taken at 3–6 months post CI. This is very similar to the results of Gold/Silver hearing aid users: both groups show increased ability to contribute vocally in conversation, and to make these vocalizations even without looking at the adult speaker. Bronze hearing aid users in contrast, do not develop this ability: they show a substantial increase in GTT and GA. These latter measures decrease for the

CI group. In other words, CI candidates resemble Bronze hearing aid users in their preference for gestural modes of communication, but after implantation, they rapidly move towards the vocal and auditory modes as seen in the Silver and Gold group and they may even exceed them. The remaining measure, EC, tends to increase slightly for all groups, but this appears to be a very idiosyncratic measure with very large variation. As a group, the CI children have a lower level of EC, relative to the Gold/Silver HA group, which may indicate that watching the speaker is less important for implantees.

4.6.2 *Narratives*

A narrative can be defined as a discourse form in which at least two different events are described so that the relationship between them (temporal, causal, contrastive) becomes clear. It is expected to contain an introduction and an organized sequence of events that leads to a logical conclusion. The development of narrative skills relies largely on incidental learning, resulting from repeated exposure to a number of different types of story forms. Deaf children are reported to have difficulties in developing the narrative structures, clearly because of their limited access to verbal information and thus to incidental learning (Yoshinaga-Itano & Snyder 1985; Griffith, Ripich, & Dastoli 1990; King & Quigley 1985; Marschark, Mouradian, & Halas 1994; Klecan-Aker & Blondeau 1990). In consequence, they produce fewer propositions, shorter or incomplete sentences with less structural variability, they omit adverbs and conjunctions, and have difficulty with evaluative elements. The narrative ability in 8-to-9-year-old CI children (implanted at a mean age of 3,5 years) was assessed by asking them to tell a story after viewing an eight-picture sequence story (Crosson & Geers 2000 and Crosson & Geers 2001). Each utterance was coded for type of narrative structure: (1) *orientations* (which provide the setting of the narrative), (2) *complicating actions* (which refer to a chronologically ordered event), (3) *evaluations* (which provide the characters' reactions to events), or (4) *resolutions* (which occur after the high point, resolving the action). In addition, the use of conjunctions and referents (such as nominals, pronouns, modifiers) was analyzed as measure of cohesion. The results showed a correlation between the narrative ability of the CI children after 4 to 6 years of implant use with the speech perception. Children with more auditory benefit from their cochlear implant use fewer orientations (30% in comparison with 46% in "poor perceivers"), more evaluations (28% in comparison with 19% in "poor perceivers"), and are more likely to recruit both coordinating and temporal conjunctions to link semantic relations in their narratives. Thus, these "good perceivers" structure their stories in a more normal pattern (i.e.

22% orientations and 30% evaluations) than below-average speech perceivers. And although their use of subordinate conjunctions may be not as well developed as in hearing children, it is significantly above that of deaf children with below-average auditory benefit of their implant. In addition is shown that good narrative ability adds to reading comprehension scores, supporting the importance of narrative skills to academic achievement.

5. Factors affecting language outcomes in CI children

One the most consistent findings reported in studies on pediatric CI is the large variability and individual differences in outcome performance observed on a wide range of language measures. Some children do very well with their implants, and other children do poorly. At present, a good understanding or explanation for these large individual differences does not exist, but several factors have already been identified that are responsible for the variation in performance, and will be described in this section.

5.1 Age at implantation

Evidence exists that children who receive a CI at a younger age do better on a range of language measures than children who are implanted at an older age. In general, early implantation increases the likelihood to obtain age-appropriate language skills.

With regard to the onset of babbling, Schauwers et al. (2004) showed that it takes a median of 1 month of auditory exposure to start babbling, regardless of the age at implantation. However, since babbling in normally hearing children starts at a mean age of 8 months, early cochlear implantation is mandatory to have the child babbling at a normal age. This was the case for the two youngest CI subjects (implanted at 5 and 7 months of age), who started babbling at 8 and 10 months of age, and who thus took their first steps to a normal speech and language development at a normal chronological age.

Only few studies addressed other linguistic domains as a function of age at implantation, and the findings are not unequivocal. But it has to be noted that most reports focused on children who were implanted late in terms of linguistic development. Implantation beyond the age of 2 or 4 years may be too late for a number of speech developmental features. Some investigators found more improvements in segmental speech aspects in the younger CI groups (i.e. implanted before 5–9! years of age) (Kirk & Hill-Brown 1985; Tobey et al. 1991a;

Tye-Murray et al. 1995; Grogan et al. 1995; Tobey et al. 1991b), while others (Blamey et al. 2001) found no evidence of significant differences in the production of vowels and consonants in a group of CI children implanted between 2 and 5 years of age.

With regard to intelligibility scores using the McGarr or BIT sentence tests, implantation before the age of 5 years yields 48–55% scores, compared to 15–18% when implanted after 5 years of age (Dawson et al. 1995a; Osberger et al. 1994)! The intelligibility also seems to improve faster when implanted at a young age (before 5 years) (Tye-Murray et al. 1995), as do the receptive and expressive language measures (by means of the RDLS) (Kirk et al. 2000; Kirk et al. 2002; Hammes et al. 2002; Kuo & Gibson 2000). On the other hand, no such age benefit was found for vocabulary growth (Miyamoto et al. 1999; El-Hakim et al. 2001; Dawson et al. 1995b) and only a weak benefit for the measure MLU (Szagun 2001). With regard to communicative behavior, autonomous vocal or gestural turn-takings are significantly higher in earlier-implanted children (in the range of 2–5 years) (Tait et al. 2000).

Two interesting factors have been postulated to contribute to this alleged age benefit. First, cochlear implantation at very young ages facilitates the natural ability of young children to learn incidentally, an ability that decreases with age. Older children depend more on didactic instruction and it has been shown that this method is less effective for true language mastery than incidental learning (Robbins et al. 1999). Secondly, early auditory stimulation through a CI contributes to more normal maturation of the auditory pathways. Electrophysiological measures (of the auditory cortex) have suggested a maturational delay in implanted children that approximates the period of auditory deprivation prior to implantation (Robinson 1998). As a consequence, this maturational delay will be smaller in children implanted at younger ages.

5.2 Educational approaches

Geers (2002) and Geers, Brenner, Nicholas, Uchanski, Tye-Murray and Tobey (2002) performed a large-scale study to investigate factors contributing to auditory, speech, language, and reading outcomes after 4 to 6 years of CI use in 136 children with prelingual deafness (all aged 8–9 years at the time of testing). The careful analysis focused on the identification of the educational factors most conducive to maximum implant benefit. It turned out that the educational variables accounted for approximately 12% of the variance in outcome after implantation. The primary rehabilitative factor associated with performance outcome was educational emphasis on oral communication (OC). This was more important than any other rehabilitative factor examined, including classroom placement (public or private, special education or mainstream), amount of therapy, experience of the therapist, and parent participation in therapy. This is in line with other studies that have shown that implanted children who were immersed in OC environments tend to develop much better expressive language (in terms of vocabulary, segmental content and intelligibility) than implanted children who were placed in total communication (TC) programs (which imply the integration of spoken and signed language) (Robbins et al. 1997; Miyamoto et al. 1999; Robbins et al. 1999; Svirsky et al. 2000a; Kirk et al. 2002; Cullington, Hodges, Butts, Dolan-Ash, & Balkany 2000; Osberger et al. 1994; Tobey et al. 2000; Osberger et al. 1993; Chin 2002 and Chin 2003). On the other hand, receptive language skills are not significantly different for OC and TC children (Cullington et al. 2000; Dawson et al. 1995b).

An obvious explanation for the discrepancy in expressive language abilities between OC and TC children could relate to the nature and extent of the language to which the children are exposed. Whereas oral children with hearing parents are exposed to spoken communication throughout the day, it is often the case that children who use TC have a more limited exposure to language. Many caregivers of children who use total communication are learning signed language at the same time as their child, thus offering an impoverished model to the child. Furthermore, it is often the case that only a limited number of people in the child's environment know or are learning signs. It may be that the linguistic environment of many children who use TC is impoverished in comparison to that of OC children and of normally hearing peers. However, this issue needs further study.

5.3 Implant characteristics

Approximately 24% of the variance in outcome of implantation (speech perception, speech production, spoken language, simultaneous language, and reading) can be predicted by device-specific features (Geers 2002 and Geers et al. 2002) such as coding strategies, the number of active electrodes, the extent of the dynamic range and loudness growth.

5.4 Child characteristics

The most important child-related predictor of cochlear implant outcome seems to be good nonverbal intelligence (Geers 2002; Geers et al. 2002). Once this variable was held constant, other features like age at implantation and age at onset of deafness did not contribute significantly to speech perception and speech production skill levels measured at ages 8–9 after 5.5 years of implant use! Family-related features like family size and parent's education did not seem to provide a particular (dis)advantage. All child and family characteristics together (and thus primarily IQ) accounted for 18% of the outcome variance after implantation in this study.

5.5 Level of pre-operative hearing

Children with more residual hearing prior to implantation show better achievements than children with less residual hearing. Szagun (2001) found that pre-operative hearing correlates significantly with linguistic growth in MLU (assessed by means of spontaneous language samples) and with vocabulary growth (assessed by parental report), accounting for 53% and 42% of the variability respectively. In other words, better pre-operative hearing is associated with more rapid growth in grammar and vocabulary. These correlations are much stronger than the ones for age at implantation (for children implanted between 14–46 months). Similarly, El-Hakim et al. (2001) demonstrated that residual hearing is the only significant predictive factor for expressive vocabulary performance on the EOWPVT test for children implanted at approximately 5 years of age.

5.6 Length of CI experience

Longitudinal studies of CI children (Tomblin et al. 1999) reported that length of implant use, rather than chronological age, is the principal factor accounting for the variance in the performance on syntactic tests of children with cochlear implants. That is, deaf children with CI experience have better English grammar than those without CI experience and the more CI experience the better the grammar. The use of morphological inflected endings, studied by Spencer et al. (1998), is not related to the age of the CI children, but to the length of CI experience. The investigators particularly found significant correlations between CI experience and use of third person singular tense and total bound morphemes used. These findings suggest that use of English inflected endings may be less affected by maturation and aging, and more by auditory input.

5.7 Speech perception

Children with better speech perception tend to include more English inflected endings within conversation (Spencer et al. 1998). Furthermore, open-set speech perception scores, as assessed by Moog and Geers (1999), correlate significantly with scores on measures of speech production, language, and reading. With regard to narratives, Crosson and Geers (2001) revealed a significant difference between good speech perceivers and poor speech perceivers in narrative structure and cohesion. The narrative structure of the good perceivers is similar to that of normally hearing children and different from that of poor perceivers, in that it includes less orientations (which provide the setting of the narrative) and more evaluations (which provide the characters' reactions to events). The CI children with better speech perception also use more conjunctions and more referents, which are both signs of cohesion in a narrative.

5.8 Higher-level cognitive factors

Pisoni, Cleary, Geers and Tobey (1999) believe that individual variation in performance of CI children be related to processing information at more central levels of analysis that reflect the operation of cognitive processes such as perception, attention, learning, and memory. They criticize studies that focus on demographic variables and traditional outcome measures, because these measures of performance are argued to be the final "product" of a large number of complex sensory, perceptual, cognitive processes that may be responsible for the observed variation among CI users. Instead, Pisoni et al. (1999) prefer to focus on "processes" that lead to a final response, on the underlying mechanisms used to perceive and produce spoken language. A series of correlational analyses on test scores (of speech perception, language comprehension, spoken word recognition, receptive vocabulary, receptive and expressive language development, and speech intelligibility) in "Star" CI children (i.e. who scored in the upper 20% on an open-set speech perception test), and "Controls" (i.e. who scored in the lower 20% on an open-set speech perception test) suggested that the exceptionally good performance of the "Stars" might be due to their superior abilities to process spoken language, specifically, to perceive, encode, and retrieve phonological representations of spoken words from lexical memory and use these representations in a variety of different language processing tasks, especially tasks that depend on vocal learning and phonological processing. Secondly, Pisoni et al. (1999) reported correlations between measures of working memory, in which digit span was assessed, and four sets of outcome measures, namely speech perception, speech production, language, and reading. Moderate to high correlations were found between forward auditory digit span and each of the 4 outcome measures. This suggests the presence of a common source of variance related to working memory, viz. the encoding and rehearsal of phonological representations of spoken words. The performance differences among CI children can be due to the operation of a subcomponent of working memory known as the "phonological loop", which is responsible for the rehearsal and maintenance of the phonological representations of spoken words in memory. The authors also suggest that rehearsal speed in working memory may be one of the factors that distinguished good CI users from poorer ones. The additional correlation between digit span and communication mode suggests that early auditory experience in oral-only programs may have specific effects on working memory capacity: OC children have significantly longer digit spans than TC children. With these findings, Pisoni et al. (1999) want to emphasize that traditional outcome measures are not adequate to assess these underlying processes and may be unable to detect and measure important central cognitive factors as sources of variance.

6. Conclusion

Cochlear implantation is a major event in the life of a deaf-born child and it is likely to have a significant impact on his/her further development. Although impressive amounts of data have been reported to date, the interpretation remains difficult. This is mainly due to the fact that almost every element in this field is in full evolution, jeopardizing the comparability of data. The technology of implantation has gone through important steps of amelioration, our insights in the early speech and language development have evolved substantially, universal neonatal screening programs have realized early detection of hearing impairment, early intervention has become possible and the indications for cochlear implantation have extended towards low ages. On top of that, we are dealing with children in full development and it is difficult to know for sure whether an evolution in such a child is to be attributed to the intervention or to the natural development.

Notwithstanding these difficulties, the available data show clear evidence of the significant impact of cochlear implantation on the speech and language development of the child. Congenitally deaf children develop delays in almost all aspects of their linguistic evolution. After implantation, the rate of development tends to normalize. This is demonstrated by overall measures of the receptive and productive speech development and also by more specific linguistic measures. The phonology shows a significant increase in the percentage of correct consonant and vowel production and an increase to a near to normal phonetic inventory. The intelligibility of the child's words increases, as does his or her lexical development. Also the morphosyntax benefits from implantation, although this issue seems to remain difficult and most implanted children seem to dwell at the stage of 2-word utterances for a long time. This also seems to be the case for the pragmatic development, where benefits are seen but they seem to be subject to ceiling effects. Ceiling effects are very important and to date, it is insufficiently clear to which extend they exist in this domain. Indeed, cochlear implantation may speed up the development to near to normal rates, but a crucial question remains whether the delays, as they have been built up prior to implantation, are reversible and will disappear. So far, in most aspects of the linguistic development, this seems NOT to be the case. On the other hand, it cannot be overemphasized that almost all available data are from children who received their implant between 2 and 5 years of age, ages that can be considered late in terms of linguistic development. One could anticipate by extrapolation that earlier implantation would imply smaller delays to start with, and thus better outcomes. Age at implantation has been shown to be a significant predictive factor, but not the only one. The outcome also depends to a great extend on technological features (like speech coding strategies), on the educational setting and on the cognitive skills of the child.

Above all, and probably the quintessence of the whole issue, is the awareness that the developmental path of a child, not only in linguistic terms, depends largely on the natural ability of a child to learn incidentally rather than by didactic instruction, as mentioned by Robbins et al. (1999). From a developmental point of view, the linguistic acquisitions of a deaf child may teach us how far we can get with didactic instruction, and what its limit is. Cochlear implants, by restoring hearing, may restore the facility of incidental learning and the earlier this is done, the better it may be for the child.