INTRODUCTION

The importance that early auditory stimulation has on the infant’s plastic brain with regard to optimal listening and language development is well-known.\(^1\)\(^2\) During the first year of life, infants with normal hearing start to pay attention to the acoustic features of the speech they are surrounded by. They also develop phonology and acquire the statistical patterns that are important for word segmentation.\(^3\)

Children with congenital hearing loss are now identified earlier because of universal hearing screening programmes for newborn infants.\(^4\) The recommended practice for newborn infants with hearing
impairment is to be screened before 1 month of age, diagnosed before 3 months and provided with suitable hearing aids and family-centred interventions no later than 6 months. This is often referred to as the 1-3-6 policy. However, children born with severe-to-profound hearing loss derive little benefit from conventional hearing aids when it comes to listening and preverbal skills. Cochlear implants provide electrical stimulation, support the auditory system and ensure that sound reaches the infant’s auditory cortex. If cochlear implants are not provided during the first year of life, infants with severe-to-profound hearing loss will miss out on this important period of auditory and language learning.

Three systematic reviews and one shorter review have been conducted to evaluate the effects of cochlear implants in early childhood. These concluded that providing implants at a younger age led to better spoken language acquisition and speech recognition. However, the evidence for the possible additional benefits of providing implants before a child has reached the age of one year needs to be strengthened. A systematic review by Bruijnzeel et al compared children implanted before 12 months and at 12-24 months and two further cohort studies have been published since then. All three studies demonstrated that implants in infancy led to better linguistic outcomes.

It is common to provide implants before the child is one year of age in Australia and many European countries, but the American Food and Drug Administration has not yet approved implants before a child’s first birthday. This is despite existing universal hearing screening programmes for newborn infants in the country and current evidence supporting implants at an earlier age. Other countries need to implement universal newborn hearing screening programmes worldwide before they can start to provide infants with cochlear implants. Previous studies have shown that children who are receiving cochlear implants after their first birthday struggle with the pace of spoken language development, compared with age-matched children with normal hearing. Our hypothesis was that children who received cochlear implants during their first year of life would develop language at a more appropriate age-related rate than children implanted at later ages. We also believed they would be more likely to experience the long-term benefits. Infants with severe-to-profound hearing loss have received cochlear implants at the Hearing Implant Centre at the Karolinska University Hospital in Stockholm, Sweden, since 2002. The varied ages at the time of surgery allowed us to analyse the effect of early age of implantation in children with severe-to-profound congenital hearing loss.

The primary aim of the present study was to investigate whether providing cochlear implants at 5-11 months of age had a stronger positive influence on spoken language development and speech recognition than at 12-29 months of age. Secondly, we wanted to compare children implanted before 9 months of age and between 9 and 11 months. The final aim was to examine whether the medical risks associated with surgery were greater in younger patients.

2 | PATIENTS AND METHODS

Our cohort was children who had undergone unilateral or bilateral cochlear implant surgery from January 1, 2002 to December 31, 2013 at the Hearing Implant Centre, Karolinska University Hospital, Stockholm, Sweden. They were all included in a standardised follow-up programme that investigated how their speech recognition and spoken language abilities developed. All the participating families had received some family-centred intervention, like auditory-verbal therapy or individual parental guidance with a more auditory-oral approach. However, the frequency and intensity of these intervention actions varied, for unknown reasons.

The children came from different parts of the country and were assessed before implantation and during regular follow-up visits to the Hearing Implant Centre. The post-operative evaluations were performed at 1 and 6 months after surgery and then every 6 months until the children reached the age of four. They were then assessed on an annual basis until they were 17.
Between 2002 and 2013, 193 children aged between 5 months and 2.5 years received cochlear implants. After we applied the exclusion criteria, (Figure 1) the cohort consisted of 103 (52 boys) children aged 4.3-16.0 years who were followed up for a mean of 10.0 ± 3.7 (range 4.7-16.0) years. The main reasons for excluding children were that the first language spoken by the parents at home was not Swedish (n = 28) and cognitive delays (n = 19). The characteristics of the cohort are presented in Table 1.

The study cohort was analysed with respect to the children's chronological age at the time of their first cochlear implant surgery. We compared the language performances of the children who had surgery at 5-11 and 12-29 months of age and also compared those who had surgery at 5-8 months and 9-11 months.

Most of the children had used hearing aids on a trial period for at least 2 months before their first cochlear implant surgery. The ear with the most impaired hearing was operated on first, and the hearing aid was continuously used on the ear with better hearing. If the ear with the cochlear implant outperformed the ear with the hearing aid over time, with regard to speech recognition, cochlear implant surgery was also recommended for the remaining ear. All the children in this study had severe-to-profound hearing loss and scored zero or one point on the Reynell Developmental Language Scales, third edition (Reynell scales).

2.1 | The implants and bilateral considerations

The cochlear implants were programmed by two of the authors (FA, ME) and four other experienced engineers at the Hearing Implant Centre. Electrical stimulation levels were based on behavioural responses and the following objective measures: electrically evoked compound actions potentials, intraoperatively recorded stapedius reflex thresholds and electrically elicited auditory brainstem responses. Of the 103 children, 98 had bilateral cochlear implants: 70 underwent a two-stage sequential bilateral implantation and 28 children had a one-stage bilateral implantation. Of the remaining five children, four benefitted from a hearing aid on the contralateral ear and in one child, the second ear was not suitable for a cochlear implant for medical reasons.

We used implants from MED-EL for 95 of the children, and eight children had implants from Cochlear Ltd. All children with bilateral cochlear implants were fitted with implants from the same company. The families were allowed to choose between the two brands, and the majority felt that the MED-EL was more user-friendly, mainly because the behind-the-ear device was smaller.

2.2 | Language development and speech recognition

Language data were measured by two of the authors (UL and EÖ) and three other certified speech and language pathologists at the Hearing Implant Centre. The assessment tools we chose described different language and listening abilities over time: language understanding, receptive and expressive vocabulary, speech intelligibility and speech recognition.

Language understanding was evaluated with the Reynell scales, which has been shown to evaluate receptive and expressive language ability in 1074 children aged 0-7 years. A validated and adapted Swedish version of the comprehension section of the Reynell scales was used in the current study. The Swedish norm study showed that the Reynell scales results for 122 children aged 2.5-3.4 years were comparable to results for 182 age-matched English children. Because the data showed similar results in both linguistic contexts, but the age range was more limited in the Swedish norm study, we decided to use the validated English data to compare our children, who were followed with Reynell scales over time. The language understanding test was performed before the first cochlear implantation and then at 6, 12, 24, 36 and 48 months after the first cochlear implant was fitted.

We used the Peabody Picture Vocabulary Test, Third Edition (Peabody test) to evaluate receptive vocabulary. The test has been translated into Swedish and is considered to be valid in a Swedish linguistic context. It has been evaluated, and norms were developed for 154 Swedish children aged six and 12 years. However, the Swedish norms were not reliable and we decided to use American norm data, which covered a broader age range. The Peabody test is a closed-set word knowledge test. The subject chooses from four pictures for every item described by the examiner. The receptive vocabulary was initially assessed 18 months after...
the first implant was fitted and then at 12-month intervals until the child was 16 years of age.

Expressive vocabulary was evaluated using the Boston Naming Test (Boston test), which can be used for both adults and children. The test has been validated, and Swedish norms have been developed for 111 adults, 152 children aged 6-15 years, and 28 children aged 3-4 years. It is an open-set test that asks the child to name 60 pictures, with an increasing degree of difficulty. The tester is not allowed to provide the child with clues, and similar words are counted as correct only if they are closely related to the target word, for example synonyms or subordinated words.

The first and second editions of the Speech Intelligibility Rating Scales were used to determine the children’s speech intelligibility in real-life situations. This scale was originally developed for use in children with hearing impairment, and the reliability was tested by Allen et al in 54 children aged 1.4-10 years with cochlear implants. The second edition of the intelligibility scale is a five-level rating scale, which ranges from recognisable spoken words to connected speech that is intelligible to all listeners. Edition one had six levels, but levels three and four were combined to create a scale that was similar to the second edition. In our study, speech intelligibility was rated by a speech and language pathologist at the Hearing Implant Centre before the first cochlear implant. Subsequent assessments were then carried out after 6 months, 12 months and then every 12 months until the child reached level five. The speech intelligibility rating has not been validated in Swedish children with hearing impairment, but it was translated into Swedish and used at the Hearing Implant Centre.

Speech recognition data were collected by several certified audiologists who were specially trained to work with children. The tests were performed in an audiometric test room that met ISO 382. Speech recognition was measured in a sound field without any competing sound sources. The test consisted of 25 monosyllabic Swedish words that were phonemically balanced and presented at 65 decibels of sound pressure level by a male voice. The outcome was the proportion of correctly repeated words. The result that we included in the analysis was the maximum result from the measurements performed from seven to nine years of age (8.47 ± 0.8 years). The rationale for choosing this age was that implanted children tend to reach asymptote at around seven years of equivalent linguistic capability.

2.3 | Evaluating complications

All children were monitored at the Hearing Implant Centre for complications related to the surgery and for risks associated with the implant, as part of the clinical follow-up protocol.

2.4 | Statistical analyses

Validated norm data for language understanding, receptive and expressive vocabulary allowed us to determine the language age of each child. A within-subject linear regression analysis of language age versus chronological age was then performed. When a child had results from two or more sessions, the linear ordinary least square regression was calculated, yielding the rate and delay. This was based on the slope and intercept of the linear regression, where the intercept was interpreted as the delay extrapolated to birth.

The children were divided into different groups depending on their age at the time of their first surgical procedure, and the mean of the individual regression lines was calculated to illustrate the respective group data. In addition, the individual regression line made it possible to estimate the children’s equivalent language age at a specific chronological age. This method was used to analyse each test at the median age of testing (age e). This was four years of age for the Reynell scales, six years of age for the Peabody test and eight years of age for the Swedish Medical Research Council’s paediatric assessment scales.
years for the Boston test data. Coefficients $\beta$ were extracted from the linear regression: 
$$y_i = \beta_0 + \beta_1 x_i + \epsilon_i,$$
where $y_i$ was the result in developmental age, $x_i$ was the age at testing and the index $i$ denotes the child. The following formula estimated the performance at age $e$ for a specific test: 
$$E = \beta_0 + \beta_1 e.$$ See Figure 2 for an example of the estimation.

This enabled us to estimate the language development rate and the language delay, so that we could determine the language age for each child at a fixed chronological age. If the child was only tested once, and if that test was within 6 months before or after the age of estimation, that score was used. These estimations were used as dependent variables when we analysed the effect of the age at first cochlear implantation. Square-root transformation was needed to achieve normal distribution of the growth variable. The delay variable was treated with non-parametric tests.

The age when the individual child reached the highest score of five on the Speech Intelligibility Rating was calculated as a function of the age at the time of the first implant. The speech recognition data were transformed to rationalised arcsine units (rau) before the statistical analyses to normalise the distribution of the data.²⁶

### 2.5 Ethics

The study was approved by the regional ethical review board of the Karolinska University Hospital (number 2013/1127-31/2). Informed consent was not needed from the parents as the data were from the regular follow-up visits after cochlear implant surgery.

### 3 RESULTS

#### 3.1 Language understanding

The Reynell scales were used to measure language understanding. Children implanted at 5-11 months of age exhibited a significantly

| First cochlear implant | Reynell | Peabody | Boston |
|------------------------|---------|---------|--------|
| 5-8 mo                 | 1.05 ± 0.36 | 3.95 ± 0.93 | 6.71 ± 1.54 |
| 9-11 mo                | 1.15 ± 0.37 | 3.8 ± 0.95 | 6.83 ± 1.15 |
| 12-17 mo               | 1.1 ± 0.37  | 3.01 ± 0.79 | 6.48 ± 1.34 |
| 18-23 mo               | 0.97 ± 0.37 | 3.41 ± 0.64 | 6.4 ± 1.34  |
| 24-29 mo               | 0.91 ± 0.37 | 3.16 ± 0.69 | 6.4 ± 1.34  |
| All                    | 1.03 ± 0.33 | 3.5 ¥ ± 0.89 | 5.7 ± 1.56 |

Note: Growth and delay, slope and intercept from the linear regression and estimation from each child and test presented as mean ± standard deviation. Reynell = Reynell Scales (language understanding); Peabody = Peabody test (receptive vocabulary); Boston = Boston test (questionnaire); Age at Intell level 5 = chronological age when the child's Speech intelligibility is rated as level 5 (highest level).
higher mean development rate to those implanted at 12-29 months, as shown in Table 2 (slope 1.1 versus 0.96, \(t = 2.0, P < .05\)).

Children implanted after their first birthday had a delay in language understanding that was present throughout the whole time-span that the Reynell scales covered. We used these scales to measure language understanding until 48 months after the child's first cochlear implantation (Figure 3).

At 4 years of age, the children who received their first implant at 5-11 months, performed close to the norm data, but the children who had their first implant at 12-29 months were a mean of 9 months behind (3.9 ± 0.9 versus 3.2 ± 0.7, \(t = 4.4, P < .0001\)). The four-year estimated language development age exhibited a significant correlation with age at implantation of −0.77 (\(r^2 = .23, P < .001\)) (Figure 4).

The second aim was to explore whether children implanted at 5-8 months had better outcomes than children implanted at 9-11 months. The children with surgery at 5-8 months did not show any significant difference in language understanding, with regard to the growth rate or delay, compared with the norm data. The \(t\) test for the slope was \(t = 0.83, P = .4\) and for the delay was \(t = -1.46, P = .16\). In addition, language development over time, as measured by the Reynell scales results at different ages, did not differ from the expected development for children with normal hearing. However, infants who underwent surgery at 9-11 months for the first time showed a significant delay in their language understanding development, with a mean of 9.6 months, extrapolated to time of birth (\(t = -2.4, P = .026\)). However, they caught up with a mean language understanding development of 1.15, which was faster than the norm data, according to the one-sided \(t\) test (1.9, \(P < .05\)). The data for each child with regression are shown in Figure S1.

### 3.2 | Receptive vocabulary

The average regression for the Peabody test (Table 2) revealed significantly larger delays and higher development growth rates compared with the norm data, according to the \(t\) test and Wilcoxon rank sum test. The slope was 1.43 versus one (\(t = 6.13, P = .001\)), and delay was −3 versus zero years (\(V = 194, P = .001\)).

No significant differences were found between first surgery at 5-8 months and 9-11 months in terms of developmental growth rate or delay. The six-year estimation revealed a significant correlation between the age at the time of the first cochlear implantation and receptive vocabulary of −1.3 (\(r^2 = .23; P < .001\)). This suggested that a one-year delay in surgery, on average, caused a delay of 1.3 years delay in receptive vocabulary at 6 years of age (Figure 5).

Children who received their first implant at 5-11 months showed a performance of 6.4 ± 1.4 years of language equivalent age, somewhat ahead of the validated norm performance (\(P < .05\)). At 12-29, the respective statistics were 5.1 ± 1.4 years of language equivalent age (\(t = 4.3, P < .0001\)).
Children who received an implant before their first birthday did not show any benefits of even earlier surgery, with regard to their growth rate, delay or six-year estimation. The data for each child are presented in Figure S2.

3.3 | Expressive vocabulary

Expressive vocabulary was measured using the Boston test. Based on the eight-year estimation, surgery before the child’s first birthday was beneficial, according to the t test. For first surgery at 5-11 months, it was 9.2 ± 3 years and for first surgery at 12-29 months, it was 6.7 ± 3 years (t = 3.36, P < .05). Infants implanted before their first birthday did not show any significant subgroup differences, according to the t test. At 5-8 months, it was 10.0 ± 4.4 and at 9-11 months it was 8.3 ± 2.3 (t = 1.4, P = .18). However, a linear regression analysis revealed a significant correlation between the child’s age at the time of the first cochlear implant and their expressive vocabulary, namely − 2.6 (r² = .21, P < .001). The data for each child are shown in Figure S3.

3.4 | Speech intelligibility

The correlation between the age when the first cochlear implant surgery was performed and the age when the patient attained the

| First cochlear implant | Reynell (%) | Peabody (%) | Boston (%) | Speech (%) | Intell (%) |
|------------------------|-------------|-------------|------------|------------|-----------|
| 5-8 mo                 | 0 (0)       | 11 (42)     | 13 (50)    | 13 (50)    | 5 (19)    |
| 9-11 mo                | 0 (0)       | 4 (18)      | 10 (45)    | 13 (59)    | 3 (14)    |
| 5-11 mo combined       | 0 (0)       | 15 (31)     | 23 (48)    | 26 (54)    | 8 (17)    |
| 12-17 mo               | 1 (4)       | 8 (32)      | 8 (32)     | 13 (52)    | 7 (28)    |
| 18-23 mo               | 0 (0)       | 2 (12)      | 1 (6)      | 5 (29)     | 3 (18)    |
| 24-29 mo               | 1 (8)       | 3 (23)      | 3 (23)     | 6 (46)     | 1 (8)     |
| 12-29 mo combined      | 2 (4)       | 13 (24)     | 12 (22)    | 24 (44)    | 11 (20)   |
| All                    | 2 (2)       | 28 (27)     | 23 (22)    | 50 (49)    | 19 (18)   |

Note: Missing data defined as less than two test points or when one test was performed but it was more than 6 mo away from the estimated age for Reynell = Reynell scales (language understanding); Peabody = Peabody test (receptive vocabulary); Boston = Boston test (expressive vocabulary); Speech = Speech recognition; Intell = Speech intelligibility (lack of age at maximum speech intelligibility rating).
highest score of five for speech intelligibility was significant (1.8, \( r^2 = .28; P < .05 \)). Children implanted at 5-8 months reached the maximum level at a mean age of 4.2 ± 1.2 years, which was slightly more than 1 year earlier than for the infants implanted at 9-11 months, which was 5.3 ± 2.1 (t = -2.1, P < .05).

3.5 | Speech recognition

The median speech recognition was 84% (range 48%-100%) with a first quartile value of 76% and a third quartile value of 92%. There was no correlation between the age at implantation and speech recognition (F[1,48] = 1.526, \( r^2 = -.01, P = .22 \)).

3.6 | Complications after surgery

No severe anaesthesia or surgical complications were reported in the cohort, including meningitis or wound infections. Post-operative problems were rare and only occurred in 8/103 patients. They included transient seroma on the implant housing and pain or wounds at the surgical sites. There was no correlation between complications and the age at surgery, according to Fisher’s exact test: \( P = .47 \) for 5-11 months compared with 12-29 months and \( P = .36 \) for 5-8 compared with 9-11 months.

3.7 | Compliance

Some of the children did not co-operate with the tests and any missing values are noted in Table 3.

4 | DISCUSSION

The current study demonstrated that children who had their first cochlear implant surgery before 9 months of age were able to acquire spoken language abilities more rapidly (Figure 3). However, the age at the time of the first implant made no difference with regard to speech recognition. The rate of complications among infants was low and similar to the complication rates for cochlear implant surgery in older children. These results indicate that cochlear implant surgery is safe for infants and preferable from a language development perspective. Children with cochlear implants do not develop normal hearing, and their hearing limitations are lifelong. This makes it even more important to provide these children with early auditory input, which will increase the possibility of them benefiting from good spoken language development.

The language development in children fitted with their first cochlear implant below 9 months of age did not differ from norm data at 4 years of age. The way that they acquired spoken language at such a fast rate revealed the remarkable capacity of the infant brain. Within a short period of time they were able to move from very limited auditory input, or none, to a language outcome that was comparable to children with normal hearing. This finding was in line with previous research that showed that the auditory system must be stimulated during infancy to retain normal function.\(^1\,2\,27\,28\)

In contrast, children implanted at 18-29 months did not close the gap with the norm data. This is important because a prolonged period of auditory deprivation leads to worse prerequisites for typical linguistic development.\(^1\,2\)

Our study results showed good agreement with Leigh et al,\(^29\) who studied the receptive language growth rate and language delay in children with cochlear implants. The language growth rate was not conclusive in itself, but the growth rate, combined with the language delay, was a valuable measure and showed reliable results over time.

Having an initial language delay in infancy seems to have a negative impact on future development, but we don't yet understand how this delay might affect a child’s language capacity later in life. Early language delay may also affect how the parents and other caregivers communicate with the child. For example, they may use more simplified language and fewer synonyms, which is not a good strategy, especially for children with hearing impairment.\(^30\)

4.1 | Strengths and limitations

A strength of this study was that it used data gathered from several time points over a long follow-up period and that it was all obtained from the same Hearing Implant Centre. This contrasts with other studies that, for example, only examined receptive vocabulary at one specific age point.\(^31\,32\) The long follow-up data showed that many children who received their first cochlear implants at 12-18 months had relatively low scores on the receptive vocabulary test when they were younger. Interestingly, several of them closed the gap in their early school years. One possible explanation for this finding could be an increased knowledge of vocabulary over time, because of rich language stimulation by sensitive caregivers. The finding could also be explained by children expanding their vocabulary because of their own reading capacity.\(^30\,33\)

It is possible to influence the age when children with severe -to -profound hearing loss are fitted with their first cochlear implants, unlike other variables that influence spoken language outcomes.

Although there is an international policy protocol that encourages early intervention after universal newborn hearing screening, it is not always followed. In addition, some children are lost to follow-up for other reasons. The practical finding of the current study is that it is crucial to identify all infants with hearing issues at an early stage, in order to avoid unnecessary language delays.\(^4\,5\)

There is a need to implement universal newborn hearing screening in more countries and to speed up the evaluation process. We would also encourage organisations like the US Food and Drug Administration to reconsider their current criteria for age at implantation. Unless changes are made, most children will not be able to receive cochlear implants before they reach 12 months of age.\(^5\)

We agree with Yoshinaga-Itano et al,\(^34\) who have suggested a new 1-2-3 policy: screening at 1 month, diagnosis at 2 months and fitting hearing aids at 3 months and with cochlear implant surgery from 5 months.\(^5\,34\) Our study provides further knowledge on how
important very early cochlear implant interventions are for deaf infants and that early surgery needs to become more widespread. 7

The lack of an age-matched control group with normal hearing children was a limitation, and there was some missing data. Data issues are inevitable in clinical studies, but they do limit the interpretation of the results.

Spoken language understanding, speech intelligibility and the size of a child’s expressive and receptive vocabulary only represent some parts of the language domain. Future studies should also investigate more complex and underlying linguistic abilities, in relation to the age when cochlear implants are fitted. Multilingual cohorts and children with other diagnoses, in addition to deafness, were not represented in the study. Socio-economic status level and the amount of language intervention was not considered, but may have had an influence on the language results.

5 | CONCLUSION

Fitting cochlear implants before a child’s first birthday was crucial for spoken language development at 6 years of age. Infants who received their implants before nine months had an even more age-typical language profile. The medical risks associated with cochlear implant surgery under nine months were no greater than for children who were older when they had cochlear implant surgery.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

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REFERENCES

1. Kuhl PK. Early language acquisition: cracking the speech code. Nat Rev Neurosci. 2004;5(11):831-843.
2. Kral A, Sharma A. Developmental neuroplasticity after cochlear implantation. Trends Neurosci. 2012;35(2):111-122.
3. Pelucchi B, Hay JF, Saffran JR. Statistical learning in a natural language by 8-month-old infants. Child Dev. 2009;80(3):674-685.
4. Ching T, Dillon H, Button L, et al. Age at intervention for permanent hearing loss and 5-year language outcomes. Pediatrics. 2017;140(3):e20164274.
5. American Academy of Pediatrics JCoIH. Year 2007 position statement: Principles and guidelines for early hearing detection and intervention programs. Pediatrics. 2007;120(4):898-921.
6. Korver A, Smith R, Van Camp G, et al. Congenital hearing loss. Nat Rev Dis Primers. 2017;12(3):16094.
7. Bruijnzeel H, Draaisma K, van Grootel R, Stegeman I, Topsakal V, Grolman W. Systematic review on surgical outcomes and hearing preservation for cochlear implantation in children and adults. Otolaryngol Head Neck Surg. 2016;154(4):586-596.
8. Lund E. Vocabulary knowledge of children with cochlear implants: a meta-analysis. J Deaf Stud Deaf Educ. 2016;21(2):107-121.
9. Vlastarakos PV, Proikas K, Papacharalampous G, Exadaktylou I, Mochlioulis G, Nikolopoulos TP. Cochlear implantation under the first year of age—the outcomes. A critical systematic review and meta-analysis. Int J Pediatr Otorhinolaryngol. 2010;74(2):119-126.
10. McKinney S. Cochlear implantation in children under 12 months of age. Curr Opin Otolaryngol Head Neck Surg. 2017;25(5):400-404.
11. Dettman SJ, Dowell RC, Choo D, et al. Long-term communication outcomes for children receiving cochlear implants younger than 12 months: a multicenter study. Otol Neurotol. 2016;37(2):e82-95.
12. Cupples L, Ching T, Button L, et al. Spoken language and everyday functioning in 5-year-old children using hearing aids or cochlear implants. Int J Audiol. 2018;57(2):S55-S69.
13. Colletti L, Mandala M, Zoccanette L, Shannon RV, Colletti V. Infants versus older children fitted with cochlear implants: performance over 10 years. Int J Pediatr Otorhinolaryngol. 2011;75(4):504-509.
14. Edwards S, Garman M, Hughes A, Letts C, Sinka I. The Reynell Developmental Language Scales (RDLS III). Berkshire, UK: NFER-Nelson Publishing Company Ltd; 1997.
15. Lloyd M, Dunn LM, Dunn DM. Peabody picture vocabulary test, 3rd edn. Circle Pines, MN: American Guidance Service; 1997.
16. Kaplan E, Goodglass H, Weintraub S. The Boston naming test, 2nd edn. Philadelphia, PA: Lea & Febiger; 1983.
17. Tallberg IM. The Boston Naming Test in Swedish: normative data. Brain Lang. 2005;94(Suppl 1):19-31.
18. Allen C, Nikolopoulos TP, Dyar D, O’Donoghue GM. Reliability of a rating scale for measuring speech intelligibility after pediatric cochlear implantation. Otol Neurotol. 2001;22(5):631-633.
19. Linden G, Fant G. Swedish word material for speech audiometry and articulation tests. Acta Otolaryngol Suppl. 1954;116:189-204.
20. Eriksson L, Grundström P. Reynell Developmental Language Scales III, språkförståelsedelen. Översättning och normering, samt studie över sambandet mellan testresultat och föräldrars utbildningsnivå [Degree university, Speech and language department. Swedish; 2000.
21. Fyrborg Å, Gustavsson I, Lunddäv E. PPVT-III 97 Form III A. Översättning och bearbetning, [Degree project]: University of Gothenburg, Speech and language department. Swedish; 2001.
22. Edvik A, Grohp VP. Picture Vocabulary Test - svensk normering av passiv ordförråd hos försökeläran samt elever i åk 3 och 6, [Degree project]: Karolinska Institutet, CLINTEC, Speech and language department. Swedish; 2001.
23. Brusewitz K, Tallberg I-M. The Boston naming test and Swedish children: normative data and response analysis. Eur J Dev Psychol. 2010;7(2):265-280.
24. Westlin M. Strategier vid bildbenämning: En explorativ studie av 3-4 åringars ordförråd, [Degree project]: Karolinska Institutet, CLINTEC, Speech and language department. Swedish; 2007.
25. Blamey PJ, Sarant JZ, Paatsch LE, et al. Relationships among speech perception, production, language, hearing loss, and age in children with impaired hearing. J Speech Lang Hear Res. 2001;44(2):264-285.
26. Studebaker GA. A “rationalized” arcsine transform. J Speech Hear Res. 1985;28(3):455–462.
27. Gordon KA, Wong DD, Valero J, Jewell SF, Yoo P, Papsin BC. Use it or lose it? Lessons learned from the developing brains of children who are deaf and use cochlear implants to hear. Brain Topogr. 2011;24(3–4):204–219.
28. Kral A, Kronenberger WG, Pisoni DB, O’Donoghue GM. Neurocognitive factors in sensory restoration of early deafness: a connectome model. Lancet Neurol. 2016;15(6):610–621.
29. Leigh J, Dettman S, Dowell R, Briggs R. Communication development in children who receive a cochlear implant by 12 months of age. Otol Neurotol. 2013;34(3):443–450.
30. Cruz I, Quittner AL, Marker C, DesJardin JL, Team C. Identification of effective strategies to promote language in deaf children with cochlear implants. Child Dev. 2013;84(2):543–559.
31. Bavin EL, Sarant J, Leigh G, Prendergast L, Busby P, Peterson C. Children with cochlear implants in infancy: predictors of early vocabulary. Int J Lang Commun Disord. 2018;53(4):788–798.
32. Nicholas JG, Geers AE. Spoken language benefits of extending cochlear implant candidacy below 12 months of age. Otol Neurotol. 2013;34(3):532–538.
33. Nittouer S, Muir M, Tietgens K, Moberly AC, Lowenstein JH. Development of Phonological, Lexical, and Syntactic Abilities in Children With Cochlear Implants Across the Elementary Grades. J Speech Lang Hear Res. 2018;61(10):2561–2577.
34. Yoshinaga-Itano C, Sedey AL, Wiggin M, Chung W. Early Hearing Detection and Vocabulary of Children With Hearing Loss. Pediatrics. 2017;140(22):e20162964.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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