

# Babbling Complexity and Its Relationship to Speech and Language Outcomes in Children With Cochlear Implants

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**Objective:** To investigate if babbling complexity in early childhood is related to speech and language outcomes in later childhood in children with cochlear implants (CIs).

**Study Design:** Retrospective.

**Setting:** Tertiary care hospital.

**Patients:** Nineteen infants with CIs participated.

**Intervention:** Infants received multichannel CIs.

**Main Outcome Measures:** Infant vocal recordings were taken during pre- and post-CI visits up to 13 months post-CI. Vocalizations were measured using a scoring system that takes into account the phonetic complexity of infant vocalizations. Outcome variables included articulation and language measures

collected at 4 years of age. Data were analyzed using correlational and regression analyses.

**Results:** For infants with at least 6 to 9 months of CI experience, the phonetic complexity of babbling is significantly correlated with receptive vocabulary, articulation abilities, and global language skills at 4 years of age.

**Conclusion:** The phonetic complexity of prelinguistic vocalizations is related to later speech and language outcomes in children with CIs. This information may be valuable in terms of tracking progress in pediatric CI users. **Key Words:** Cochlear implants—Pediatrics—Speech/language outcomes. *Otol Neurotol* 00:00-00, 2007.

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The primary purpose of the study was to determine if prelinguistic vocalizations can predict later speech and language outcomes in children with prelingual deafness who use cochlear implants (CIs).

## Vocal Development in Children With Normal Hearing

Most researchers and professionals evaluate early vocal development in terms of a stage model (1). Using the model described by Oller (1), vocal development in the first year of life consists of 4 stages: phonation (0–2 mo), primitive articulation (1–4 mo), expansion (3–8 mo), and canonical (5–10 mo). The phonation stage is characterized by quasivowels, which are produced with normal phonation but do not have the acoustic qualities of adultlike vowels. In

the primitive articulation stage, infants pair quasivowels with consonant-like sounds. The expansion stage involves the production of raspberries, squeals, yells, and more vowel-like sounds. In the canonical stage, infants begin producing well-formed consonant-vowel sequences that match the timing characteristics of mature syllables. Stoel-Gammon (2) suggested that atypical babbling might predict delayed acquisition of meaningful speech and language. She used Mean Babbling Level (MBL), a scoring system that takes into account the phonetic complexity of babbling, to analyze speech samples for typically developing infants. Two of the infants demonstrated atypical babbling patterns and delays in the onset of meaningful speech. Stoel-Gammon concluded that atypical babbling patterns could signal slow linguistic growth in young children.

## Vocal Development in Children Who Are Deaf or Hard of Hearing

Early literature on vocal development in infants with hearing loss focused on describing prelinguistic vocalizations in relation to children with normal hearing. For example, Oller and Eilers (3) found that the onset of canonical babbling was significantly delayed

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in infants with hearing loss, relative to hearing infants. This research was later extended to children with CIs. Bass-Ringdahl (4) evaluated the onset of canonical babble in 13 infants pre- and post-CI. She found that once children received a critical level of audibility (as quantified by the Speech Intelligibility Index), the onset of canonical babble followed patterns typical of children with normal hearing. Ertmer and Mellon (5) and Ertmer et al. (6) conducted detailed analyses of vocal production in children with CIs. He found that 1 child showed an increase in canonical vocalizations after 5 months of CI use. A second child demonstrated less rapid progress, producing primarily precanonical vocalizations during the first year of CI use. These results suggest that there may be variability in the rate of vocal development across pediatric CI recipients.

Wallace et al. (7) and Moeller et al. (8) examined the relationship between prelinguistic vocalizations and later speech outcomes in children with hearing loss. Wallace et al. (7) found no significant correlations between babbling complexity, as measured by MBL, and later speech skills. Methodological issues, including nonstandardized administration of the protocol, could explain the findings, however. For example, some of the participants were tested as young as 5 months, before the expected onset of canonical babbling in normal-hearing infants, and some had significant motor and/or cognitive delays. Moeller et al. (8) found different results in a group of 12 infants with hearing loss, in that prelinguistic vocalizations were significantly correlated with later articulation measures. Further research is needed in children with CIs to clarify these discrepant findings.

CI technology has had a profound impact on intervention and outcomes for children with profound hearing loss. Research suggests that implantation at younger ages results in better outcomes (9). This has led to an increasing number of children receiving CIs before 24 months of age. Literature on vocal development in children with CIs has centered around documenting the emergence of pre- and post-canonical utterances (5,6). Few have examined the predictive validity of measuring early phonetic abilities in children with CIs, despite a need for more measures of prelinguistic skills in this population. The present study evaluates the relationship between prelinguistic vocalizations and later linguistic outcomes in children with CIs. We hypothesize a predictive relationship between babbling complexity at younger ages and speech and language skills at older ages, consistent with previous findings in children with normal hearing (2).

## MATERIALS AND METHODS

### Participants

Nineteen children (9 female subjects) diagnosed with severe-to-profound sensorineural hearing loss participated. All participants were born to hearing parents. Initial CI stimulation was between 11 and 27 months of age (mean, 18.21;

standard deviation, 4.21). These children were selected from a larger longitudinal cohort of pediatric CI recipients because they had received a CI before 30 months of age and had at least 12 months of CI experience.

American English was the primary spoken language in each family's home. All children's cognitive abilities seemed to be within normal limits in accordance with the Bayley Scales of Infant Development-II "Mental" subscale (10). All children had no known visual abnormalities or motor delays, with the exception of 1 research participant (RP 18) who showed mild motor delays. Table 1 describes participant demographic characteristics.

### Vocal Recording

Participants were video- and audio-recorded using a wireless microphone (Telex FMR-500). All data were recorded using a Marantz solid-state digital audio recorder. The investigator and the child's primary caregiver interacted with the child in a quiet testing room. The investigator followed a similar protocol across participants, presenting a consistent set of age-appropriate toys. Data were collected at both pre- and post-CI visits. Although attempts were made to keep recording sessions consistent both within and across participants, the amount of data collected varied because of participant factors (e.g., fatigue and missed appointments) or experimenter factors (e.g., equipment failure).

### MBL Scoring

Speech samples were analyzed using Adobe Audition 1.5 software (Adobe Systems Incorporated, San Jose, CA, USA). The first author transcribed all of the speech samples. The speech samples were coded using MBL, based on criteria described by Stoel-Gammon (2). An utterance was described as a vocalization if the examiner judged it to be nonmeaningful and speechlike, contained a vocalic or consonant element, and was produced with an egressive airstream. Nonmeaningful vocalizations were any utterances that could not be identified as a meaningful lexical item. Speechlike utterances were

TABLE 1. Demographic characteristics of participants

RP#	Sex	Etiology	Age at HA fit (mo)	Age at IS (mo)	PTA (4F) dBHL best ear preimplant
RP 1	Female	Unknown	21	27	107.8
RP 2	Female	Unknown	3	20	115
RP 3	Male	Unknown	6	20	88.3
RP 4	Female	Connexin 26	12	16	106.6
RP 5	Male	Unknown	3	20	110.6
RP 6	Male	CMV	4	14	118.1
RP 7	Female	Unknown	9	19	111.6
RP 8	Female	Unknown	14	19	114.4
RP 9	Female	Unknown	17	24	105
RP 10	Male	Unknown	4	11	117.1
RP 11	Female	Hereditary	4	13	120
RP 12	Female	Unknown	2	14	120
RP 13	Male	Hereditary	4	15	91.9
RP 14	Male	Ototoxicity	18	19	100.3
RP 15	Male	Unknown	14	20	111.6
RP 16	Male	Unknown	20	25	113.1
RP 17	Female	Mondini	10	18	98.8
RP 18	Male	Unknown	12	18	117.5
RP 19	Male	Connexin 26	5	14	100.6

HA indicates hearing aid; IS, initial stimulation with cochlear implant; PTA 4F, pure-tone average at 500, 1000, 2000, and 4000 Hz.

vocalizations that could not be classified as vegetative sounds (crying, coughing, laughing, and grunting). Utterance boundaries were determined by 2 seconds of uninterrupted silence after vocalization. A maximum of 50 utterances of each sample was included for analysis. Recordings had to contain a minimum of 30 utterances to be included in the data set.

Utterances were assigned to levels depending on their phonetic content and syllable structure. The 3 levels had the following definitions: 1) Level 1—vowel, syllabic consonant, consonant-vowel or vowel-consonant combination in which the manner of articulation for the consonant is a glide or glottal; 2) Level 2—consonant-vowel or vowel-consonant combination in which the consonant is a true consonant (not a glide or glottal; the vocalization can contain repetitive sequences of sounds, but the place and/or manner of the consonant cannot change, except in voicing features); and 3) Level 3—consonant-vowel or vowel-consonant combinations in which the consonants are true consonants and the place and/or manner of articulation change at least once within the breath group.

After assignment of utterances to 1 of the 3 levels, MBL was calculated for the entire sample, using the following equation:

$$\text{MBL} = \frac{(\sum a + 2\sum b + 3\sum c)}{(\sum a + \sum b + \sum c)}$$

where a = Level 1 utterances, b = Level 2 utterances, and c = Level 3 utterances.

This calculation resulted in a score ranging from 1.0 to 3.0, with 1.0 representing the least amount of phonetic complexity and 3.0 representing the greatest amount of phonetic complexity.

### Language Measures

Language measures included the Minnesota Child Development Inventory (MCDI) (11), the Peabody Picture Vocabulary Test—Third Edition (PPVT-III) (12), and the Goldman-Fristoe Test of Articulation—Second Edition (GFTA-2) (13).

The MCDI is a parent-report inventory that assesses a broad range of developmental milestones from 6 months to 6 years of age. Parents indicated if behaviors do or do not apply to their child by circling “yes” or “no” on designated forms. The Expressive Language (MCDI Exp) and Comprehension-Conceptual (MCDI Rec) subscales were included in the present analysis. The Expressive Language subscale examines global expressive language and the Comprehension-Conceptual subscale examines global receptive language. During data collection, parents indicated whether the target behavior was produced by using voice, sign, or both. Voice-only responses were included because we were primarily interested in the development of spoken receptive and expressive language.

The MCDI yields age-equivalent scores. We calculated language quotient (LQ) scores by dividing the age-equivalent scores by the child’s chronological age to control for language differences across participants as a function of age. LQ scores that equal 1.0 indicate language performance consistent with what is expected for an individual’s chronological age. LQ scores below 1.0 indicate delayed language performance, relative to chronological age, and LQ scores above 1.0 indicate language performance that is advanced relative to chronological age.

The PPVT-III is a standardized measure of receptive vocabulary skills appropriate for children aged 2 years, 6 months to adulthood. The examiner names 1 of 4 pictures per plate, and the child points to one of the pictures. It was administered through speech only to prevent score inflation because of the iconicity of some signs. The measure yields a standard score.

The GFTA-2 is a standardized articulation measure. Children label picture plates to test consonant accuracy in initial, medial, and final positions. The measure yields a standard score.

### Procedure

Repeated measures were collected for each child at pre- and post-CI visits. The participants constituted a clinical population, and appointments were occasionally cancelled because of adverse weather or illness; thus, the number of assessments varied across children. MBL scores were averaged within designated time intervals: preimplant to initial stimulation; 2-week, 1-month, and 2-month post-CI; 3-, 4-, and 5-month post-CI; 6-, 7-, 8-, and 9-month post-CI; and 10-, 11-, 12-, and 13-month post-CI.

Parents completed an MCDI each time the child participated in the testing session. The GFTA-2 and PPVT-III test administration began at ages 2 years and 2 years, 6 months, respectively. We included language measures collected at approximately 4 years of age in the present data analysis.

### Statistical Analysis

Spearman rank order correlational analyses were calculated to determine the strength of the association between average MBL scores at any of the 5 time intervals, age at initial stimulation (Age IS), and/or the pre-CI 4-frequency pure-tone average (PTA 4F, calculated as the average of thresholds at 500, 1000, 2000, and 4000 Hz) to later speech and language outcomes (MCDI Exp and Rec LQ scores and GFTA-2 and PPVT-III standard scores). Spearman correlations were chosen because some of the data did not meet normality assumptions, and therefore, Spearman correlations represented the most conservative correlations. After the Spearman correlations, regression models were run, and partial correlations were determined for variables found to have significant relationships to the outcome measures.

### Interobserver Agreement

Three research assistants (RAs) transcribed and scored sessions to assess interobserver agreement for MBL. All 3 RAs had completed an undergraduate course in phonetics and were competent at transcribing speech. They each underwent training with the MBL scoring system before completing agreement coding. The RAs reviewed approximately 15% of each participant’s sessions. MBL scores were compared with those of the first author. The average interobserver agreement for MBL agreement was 88% (range, 80–100%).

## RESULTS

Spearman correlation coefficients were calculated between MBL scores averaged within the 5 time intervals, Age IS, PTA (4F), and the outcome measures (Table 2). MCDI Exp LQs were significantly correlated with MBL scores at 6 to 9 months post-CI and 10 to 13 months post-CI ( $r = 0.646$ ,  $p < 0.01$ ;  $r = 0.556$ ,  $p < 0.05$ , respectively) and Age IS ( $r = -0.510$ ,  $p < 0.05$ ). MCDI Rec LQs were significantly correlated with MBL scores

**TABLE 2.** Spearman rank correlation coefficients between interval Mean Babbling Level scores, precochlear implant hearing sensitivity, age at initial stimulation, and speech and language outcome measures

Outcome measure	Pre-CI/IS	2 wk, 2 mo post-CI	3–5 mo post-CI	6–9 mo post-CI	10–13 mo post-CI	PTA (4F) pre-CI	Age at IS
MCDI Exp LQ	0.340 (n = 13)	0.297 (n = 11)	0.383 (n = 16)	0.646 <sup>a</sup> (n = 18)	0.556 <sup>b</sup> (n = 17)	-0.022 (n = 18)	-0.510 <sup>b</sup> (n = 18)
MCDI Rec LQ	0.364 (n = 12)	0.101 (n = 11)	0.358 (n = 16)	0.676 <sup>a</sup> (n = 18)	0.643 <sup>a</sup> (n = 17)	-0.065 (n = 18)	-0.343 (n = 18)
GFTA SS	0.495 (n = 13)	0.423 (n = 12)	0.317 (n = 16)	0.504 <sup>b</sup> (n = 19)	0.322 (n = 18)	-0.154 (n = 19)	-0.408 (n = 19)
PPVT SS	0.309 (n = 12)	-0.085 (n = 11)	0.336 (n = 15)	0.674 <sup>a</sup> (n = 17)	0.450 (n = 16)	-0.032 (n = 17)	-0.415 (n = 17)

<sup>a</sup> $p < 0.01$ .<sup>b</sup> $p < 0.05$ .

Age IS indicates age at initial stimulation; GFTA SS, Goldman-Fristoe Test of Articulation standard score; MCDI Exp LQ, Minnesota Child Development Inventory expressive language quotient; MCDI Rec LQ, Minnesota Child Development Inventory receptive language quotient; PPVT SS, Peabody Picture Vocabulary Test standard score; PTA 4F, 4-frequency pure-tone average.

at 6 to 9 months post-CI and 10 to 13 months post-CI ( $r = 0.676$ ,  $p < 0.01$ ;  $r = 0.643$ ;  $p < 0.01$ , respectively). GFTA-2 standard scores were significantly correlated with MBL scores at 6 to 9 months post-CI ( $r = 0.504$ ;  $p < 0.05$ ). PPVT-III standard scores were significantly correlated with MBL scores at 6 to 9 months post-CI ( $r = 0.674$ ;  $p < 0.01$ ). The variables found to contribute significantly to the outcome measures used in this study were MBL (at 6–9 and 10–13 months post-CI) and Age IS. Furthermore, Age IS was only significantly correlated to MCDI Exp. Because MBL at 6 to 9 months post-CI was consistently and highly (14) correlated with the outcome measures, MBL at 6 to 9 months post-CI and Age IS were entered into regression models to determine the significance of their contributions to the outcome measures when the contribution of each was taken into account (Table 3). When Age IS is inserted into the models, the partial correlation between MBL at 6 to 9 months post-CI and all 4 outcome measures remains highly significant at  $p$  values consistently less than 0.01. The partial correlations of Age IS to the outcome measures of MCDI Exp and GFTA also remain significant with  $p$  values of less than 0.05. The results support the hypothesis that there is a significant relationship between babbling complexity at younger ages and speech and language skills at older ages for children with CIs. The results also support that the earlier children receive CIs (represented by Age IS), the higher their achievement on certain measures of language and articulation (MCDI Exp and GFTA).

In an effort to investigate contributing factors to post-CI MBL, Spearman correlations were calculated between preimplant hearing sensitivity (PTA 4F) and MBL. PTA 4F was significantly and negatively correlated with MBL measured at pre-CI/IS, at 3 to 5 months post-CI and 6 to 9 months post-CI ( $r = -0.553$ ,  $r = -0.514$ ,  $r = -0.503$ , respectively, with  $p$  values  $< 0.05$ ).

## DISCUSSION

The current study has important clinical implications. The results indicate that prelinguistic vocalizations are an important prognostic indicator for later speech and language development in children with CIs. Specifically, MBL collected at 6 to 9 months post-CI is

consistently predictive of global language, receptive vocabulary, and articulation abilities by 4 years of age. Given the decreasing age at which children are receiving CIs, it is valuable for audiologists and speech-language pathologists to have reliable and valid clinical tools for tracking progress and predicting later outcomes. Low MBL scores (around 1.0) by 6 months of CI use may indicate a need for the audiologist to make changes to the child's MAP. A lack of progress in MBL scores may also indicate a need for increasing speech-language services.

Two secondary findings, although not the focus of this study, indicate that pre-CI hearing sensitivity and age at initial stimulation also play important roles in the development of babbling in children with CIs. Clinically, the relationship of pre-CI audibility to the development of babbling highlights the need for optimization

**TABLE 3.** Regression models for the contribution of Mean Babbling Level at 6 to 9 months post-CI and Age IS to the outcome measures of Peabody Picture Vocabulary Test–Third Edition, Goldman-Fristoe Test of Articulation–Second Edition, and Minnesota Child Development Inventory Expressive and Receptive

Variable	Coefficient (SD)	$t$ test	$p$	Partial correlation
Regression model PPVT-III (n = 17, $R^2 = 0.576$ )				
MBL 6–9	50.59 (13.60)	3.72	0.002	0.705
Age IS	-1.92 (1.13)	-1.69	0.113	0.412
Regression model GFTA-2 (n = 19, $R^2 = 0.434$ )				
MBL 6–9	43.30 (15.71)	2.76	0.014	0.567
Age IS	-2.47 (1.15)	-2.15	0.047	0.474
Regression model MCDI Exp (n = 18, $R^2 = 0.681$ )				
MBL 6–9	0.447 (0.086)	5.17	0.0001	0.800
Age IS	-0.014 (0.006)	-2.29	0.037	0.509
Regression model MCDI Rec (n = 18, $R^2 = 0.652$ )				
MBL 6–9	0.608 (0.123)	4.93	0.0002	0.786
Age IS	-0.018 (0.009)	-1.96	0.069	0.451

Age IS indicates age at initial stimulation; GFTA-2, Goldman-Fristoe Test of Articulation–Second Edition; MBL 6–9, Mean Babbling Level at 6 to 9 months; MCDI, Minnesota Child Development Inventory; PPVT-III, Peabody Picture Vocabulary Test–Third Edition; SD, standard deviation.

of the pre-CI hearing aid fitting. From a clinical standpoint, the findings indicate that pre-CI hearing sensitivity and earlier ages of implantation “feed” into post-CI babbling development and post-CI babbling development “feeds” into later linguistic development. Therefore, one may speculate that to maximize post-CI speech and language development, cochlear implantation should take place at younger rather than older ages, audibility should be optimized pre-CI, and babbling development should be tracked with a particular emphasis placed on MBL at 6 to 9 months post-CI. Future research is needed to address the relationships between these complex variables. A multiple-regression path analysis would clarify the degree to which pre-CI audibility and age at initial stimulation influence the phonetic complexity of babbling, and how these multiple factors influence later speech and language outcomes.

These data clarify a discrepancy in previous literature on vocal development in children with hearing loss. Wallace et al. (7) concluded that prelinguistic vocalizations are not related to later speech development after failing to find a correlation between MBL scores and articulation scores after age 5 in a group of children with moderate-to-profound hearing losses. Moeller et al. (8) found a significant correlation between MBL scores (termed syllable structure level) and later articulation skills. The present findings are consistent with the results of Moeller et al. (8), in that the phonetic complexity of babbling (when examined at 6–9 months post-CI) was consistently related to later speech measures. These results also expand on these previous findings, in that babbling (when examined at 6–9 months post-CI) was consistently related to global receptive and expressive language, as well as receptive vocabulary. The finding that post-CI MBL scores were more strongly correlated with language scores than speech production scores is surprising and counterintuitive because it would be expected that vocal production would be more strongly related to performance on articulatory than vocabulary/global language measures. The results may support general probabilistic models of phonology, which propose a general cognitive mechanism linking knowledge of sound structure and the lexicon as described by Munson et al. (15). Children with stable phonological representations (i.e., those producing complex canonical babbling) are more adept at forming links between unfamiliar strings of sounds and semantic representations. Further research with a larger study sample is needed to elucidate these intriguing findings.

The present study was a preliminary investigation involving the relationship between the phonetic complexity of babbling and later speech and language outcomes in children with CIs. There are many directions for possible future research. The first step would be to

increase the sample size of our CI population, which would permit us to conduct additional statistical analyses, such as the regression-based path analysis previously mentioned. In addition, we would like to include a normal-hearing control group, which would allow us to compare vocal development in hearing children and children with CIs, as well as provide further evidence for the predictive validity of measures of early phonetic abilities. Finally, other future directions for research might include examining MBL in relation to concurrent audibility measures with the CI, type of intervention, and age at identification of hearing loss.

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