Prelinguistic Vocal Development in Young Cochlear Implant Recipients and Typically Developing Infants: Year 1 of Robust Hearing Experience

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This investigation examined the time course and sequence of prelinguistic vocal development during the first year of cochlear implant (CI) experience. Thirteen children who were implanted between 8 and 35 months and 11 typically developing (TD) infants participated in this longitudinal study. Adult–child play interactions were video- and audio-recorded at trimonthly intervals for each group, and child utterances were classified into categories representing progressively more mature productions: Precanonical Vocalizations, Basic Canonical Syllables, and Advanced Form vocalizations. Young CI recipients met the 20% criterion for establishment of the Basic Canonical Syllables and Advanced Forms levels with fewer months of robust hearing experience than the TD infants. Most CI recipients followed the sequence of development predicted by the Stark Assessment of Early Vocal Development—Revised. The relatively rapid progress of the CI children suggests that an earlier period of auditory deprivation did not have negative consequences for prelinguistic vocal development. It also supports the notion that young CI recipients comparatively advanced maturity facilitated expeditious auditory-guided speech development.

Prelinguistic vocal development has been characterized as a process consists of overlapping levels of speech production ability in which non–speech-like vocalizations decrease in frequency as adult-like vocalizations emerge and become increasingly common (Koopmans-van Beinum & van der Stelt, 1986; Nathani, Ertmer, & Stark, 2006; Oller, 1980; Stark, 1980; Zlatin, 1975). Advancements in prelinguistic vocal development (hereafter called "vocal development") are considered foundational for acquiring a mature phonological system (Vihman, Macken, Miller, Simmons, & Miller, 1985). Such advancements are also likely to be among the first observable indications of improved hearing sensitivity in deaf children who receive cochlear implants (CIs) as infants or toddlers. The current longitudinal study assessed the effects CI experience on the time course and sequence of vocal development in 13 children who received CIs between 8 and 35 months of age. Typically developing (TD) infants served as controls to determine whether the CI recipients required more, similar, or fewer-than-typical months of robust hearing experience (i.e., auditory access to speech at conversational intensity levels; Ertmer & Inniger, 2009) to reach vocal development milestones.

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Vocal Development in Children Who Are TD

Several classification systems have been developed to characterize the types of vocalizations that infants who are TD produce before they acquire mature speech patterns. These systems show remarkable similarities in the kinds of vocalizations, ages of emergence for various kinds of vocalizations, and number of developmental levels observed during the first 2 years of life (Koopmans-van Beinum & van der Stelt, 1986; Nathani et al., 2006; Oller, 1980; Roug, Landberg, & Lundberg, 1989; Stark, 1980; see Ertmer & Nathan Iyer, 2010; Oller, 2000; and Vihman, 1996, for reviews). A classification system based on the work of Rachel Stark was selected for use in the current study because it has been previously applied with both children who are TD and those with hearing losses.

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The original version of this system was described by Stark in 1980 and was refined and named the Stark Assessment of Early Vocal Development by Nathani, Ertmer & Stark (2006). The most current version—the Stark Assessment of Early Vocal Development—Revised (SAEVD-R)—was recently shown to be a reliable and valid measure of vocal development in TD children (Nathani et al., 2006). Table 1 provides an overview this system. A comprehensive description of the five levels of the SAEVD-R and operational definitions for 23 kinds of vocalizations were originally presented in a study of TD infants (Nathani et al., 2006). The main findings of this study are summarized next.

Nathani et al. (2006) validated the SAEVD-R in a mixed design (cross-sectional and longitudinal) study of 30 TD infants in six age ranges: 0–2, 3–5, 6–8, 9–12, 13–15, and 16–20 months. Five characteristics of typical vocal development were identified: (a) vocalizations from SAEVD-R levels 1, 2, and 3 (i.e., Reflexive, Control of Phonation, and Expansion levels, respectively) were dominant for infants <9 months but decreased in frequency as more mature productions emerged; (b) vocalizations from levels 3, 4, and 5 (i.e., Expansion, Basic Canonical Syllables [BCS], and Advanced Forms [AF], respectively) became dominant after 9 months of age; (c) Level 3 vocalizations (mainly vowels and vowel-like productions) were the most frequently produced type of vocalization from 3 to 15 months of age; (d) Level 4 vocalizations increased greatly between 9 and 12 months; and (e) AF showed a sizable increase only in the oldest age group (16–20 months). These results were consistent with many aspects of previously proposed models of vocal development (see Vihman, 1996, for review). However, the SAEVD-R also extended these earlier models by demonstrating the sizable increase in Advanced Form vocalizations between 16 and 20 months of age. Taken together, the findings showed that the SAEVD-R is a viable tool for assessing progress toward mature speech patterns across the first 2 years of life.

The current investigation employed a modified, three-level version of the SAEVD-R. In the "Consolidated SAEVD-R," vocalizations from SAEVD-R levels 1–3 are combined into a single Precanonical (PC) level. The first three SAEVD-R levels were merged because vocalizations from each are commonly produced by both TD children and those with severe-profound hearing loss who use hearing aids (Ertmer & Mellon, 2001; Iyer & Oller, 2008; Oller, Eilers, Bull, & Carney, 1985; Stoel-Gammon & Otomo, 1986). Thus, classifying vocalizations into SAEVD-R levels 1, 2, or 3 separately provides very limited information about the effects of CI-aided hearing on the time course of vocal development. Vocalizations from levels 4 (BCS) and 5 (AF) are unchanged and included as separate levels in the Consolidated SAEVD-R. Because of its reduced number of levels, the Consolidated SAEVD-R has improved potential for reliable use in research and

Table 1 Levels of the Stark Assessment of Early Vocal Development-Revised, ages of expected emergence for each level, and examples of vocalization types emerging at each level (Nathani et al., 2006)

SAEVD-R Levels	Age of Emergence (months)	Example Vocalization Types
Level 1. Reflexive vocalizations	0–2	Crying, vegetative (coughs, hiccups), grunts (quasi-resonant nuclei)
Level 2. Control of Phonation	1–4	Primitive vowel-like sounds with poor vocal quality (fully resonant nuclei), "goos", closants (e.g., clicks, smacks, trills)
Level 3. Expansion	3–8	Squeals, vowels and vowel-like productions, consonants, marginal babbling[a]
Level 4. Basic Canonical Syllables	5–10	Consonant-vowel syllables with rapid transitions (e.g., CV, CVCV, CVCVCV), whispered vocalizations
Level 5. Advance Forms	9–18[b]	Closed syllables (CVC), CCV syllables, diphthongs, VC syllables, jargon[c]

[a]A series of primitive and slowly combined consonant and vowel-like productions.
[b]The ages in this table are based on children from English-speaking homes. Age of emergence for some Advance Form vocalization types may differ across languages (Vihman, 1993).
[c]More than two CV syllables containing at least two different consonant and vowel types and the presence of changes in intonation or stress pattern during the series (e.g., [gagadidbu] with rising intonation pattern).

clinical situations as compared to the five-level SAEVD-R.

Vocal Development in Children With Hearing Loss

In contrast to the steady progress noted for TD children, children with bilateral, prelingual, severe-to-profound hearing losses who use hearing aids commonly exhibit delayed and incomplete vocal development. Their deficits include restricted formant frequency range in vowel-like productions (Kent, Osberger, Netsell, & Hustedde, 1987); smaller than typical phonetic and syllable shape inventories (Stark, 1983; Stoel-Gammon, 1988; Stoel-Gammon & Otomo, 1986), late onset, and low canonical babbling ratio (Oller & Eilers, 1988); and a lack of jargon (see Table 1 for definition; Stark, 1983). It should be remembered, however, that infants and toddlers with hearing losses vocalize as frequently as those with normal hearing (e.g., Clement, 2004; Moeller et al., 2007; Nathani, Oller, & Neal, 2007; Iyer & Oller, 2008). For the most part, however, their productions are dominated by vocalizations that emerge early in life: grunts, squeals, cries, and isolated vowel-like sounds (Oller et al., 1985; Stoel-Gammon & Otomo, 1986; Iyer & Oller, 2008). Thus, developmental delays become apparent at ages when speech-like vocalizations (i.e., those found at the BCS and AF levels) typically emerge.

Several investigations have shown that the emergence and frequency of canonical syllables or "babbling" is delayed in children with hearing loss compared to children who are TD (Eilers & Oller, 1994; Koopmans-van Beinum, Clement, & van der Dikkenberg-Pot, 2001; Oller & Eilers, 1988). These studies indicated that the acquisition of rapidly produced consonant–vowel (CV) combinations is negatively impacted by hearing loss. However, when given speech intervention and time for maturation, children with severe-profound hearing loss who use hearing aids—and even a child with congenital absence of cochleas (Lynch, Oller, & Steffens, 1989)—have learned to combine consonants and vowels rapidly to produce babbling (Oller & Eilers, 1988). Thus, canonical syllables (e.g., [ma] [du]) or babbled syllable strings (e.g., [bababa]) might be acquired through a combination of visual cues (i.e. lip movements for bilabial consonants), improved speech–motor coordination through speech intervention and maturation, as well as through improved hearing sensitivity via hearing aids or CIs.

Influence of CI Experience on Vocal Development

Newborn hearing screening has made it possible for children with hearing losses to be identified during the first month of life, fit with hearing aids soon after, and—if appropriate candidates—given CIs during first, second, or third years of life. As a result, young CI recipients begin to experience robust hearing within an age range when extensive gains in vocal development and spoken language are typically made.

Recent studies suggest that children who receive CIs by their third birthdays can make significant progress in vocal development during the first year of device use. Their advancements have been measured in the emergence of speech-like vocalizations, gains in phonetic diversity, and the establishment of new levels of vocal development. An early case study by McCaffery, Davis, MacNeilage, and von Hapsburg (1999) found that a child who was implanted at 25 months substantially increased both consonant and vowel inventories and the variety of vocalizations she produced within 9 months of CI activation. Ertmer and Mellon (2001) reported that a child who was implanted at 19 months (Hannah) established BCS and AF (previously called postcanonical vocalizations) within 5 months of CI activation—the latter achievement occurring with fewer-than-typical months of robust hearing experience. Hannah also acquired 10 consonants and nearly all English vowels during her first 12 months of CI use (Ertmer, 2001; Ertmer & Mellon, 2001).

Several multichild studies have also documented post-implantation relatively rapid progress. Using an elicitation technique, Moore and Bass-Ringdahl (2002) found that nine young CI recipients (18–20 months at implant) began to produce canonical syllables after average of 6.5 months of CI experience. Spontaneous speech samples from the young CI recipients followed by Schauwers, Gillis, Daemers, De Beuklaer, and Govaerts (2004) showed an onset of new babbling behaviors with even fewer months of robust hearing: within 1–4 months after implantation. Like the previously cited case studies, the production of canonical syllables was achieved with typical or fewer-than-typical months of robust hearing experience via a CI.

A more complex picture emerged in a recent study by Ertmer, Young, and Nathani (2007) that employed the SAEVD-R. Seven young recipients (implanted between 10 and 35 months of age) who were enrolled in oral communication, parent–infant programs showed a variety of abilities prior to and during the course of this longitudinal study. Three participants had already established the BCS level at $\geq$20% (criterion previously applied by Oller & Eilers, 1988; Ertmer & Mellon, 2001) prior to implantation at 28, 30, and 36 months old. In contrast, four children who were implanted before 28 months had not established the BCS level prior to implant activation. Three of the latter group established the BCS level after approximately 6 months of CI experience; the remaining child (implanted at 10 months) required 17 months of CI experience and showed an unexpected sequence of development by establishing the AF level 5 months *before* the BCS level. Thus, the BCS level was established prior to implantation in the older participants who had very limited access to speech through hearing aids and with fewer-than-typical months of robust hearing by all but the youngest participant. These diverse observations suggest that the production of canonical syllables may not be an indicator of CI benefit for some relatively older CI recipients. They also suggest that the onset and increased frequency of CV syllable production after implantation may be a sign that improved hearing is guiding speech development in children who have not reached the BCS level before implantation.

Regarding the time course for establishing AF, none of the children in the Ertmer et al. (2007) study had established the AF level prior to receiving their CIs. This preliminary finding suggests that establishing these kinds of vocalizations requires robust access to speech at conversational intensity levels. Further, six of the seven established the AF level within 11 months of CI experience—substantially less than the 16–20 months of robust hearing experience observed in TD children (Nathani et al., 2006). The only child who had not established the AF level after 24 months of CI use was found to have secondary learning difficulties in addition to hearing loss. Taken together, these individual profiles indicate that advancement to the AF level was facilitated by CI use and that young CI recipients can establish this level with fewer-than-typical months of robust hearing experience.

In sum, the young CI recipients studied by Ertmer et al. (2007) exhibited different levels of vocal development before implantation and required different amounts of robust hearing experience to establish the BCS and AF levels with their CIs. However, they often made these advancements with fewer-than-typical months of robust hearing experience than seen in the Nathani et al. (2006) investigation. The diversity of these findings highlights the need to further determine the time course and sequence of vocal development in larger numbers of young CI recipients. Such estimates require direct comparisons with TD children that are not currently available in the literature. This article addressed these needs by examining vocal development in 13 young CI recipients and comparing the time course and sequence of their advancements with those of 11 TD infants.

Three research questions were addressed in the current study. First, do young CI recipients and TD infants require comparable amounts of robust hearing experience to establish the BCS and AF levels? For children with hearing loss, the amount of robust hearing is considered equivalent to months of CI use. For TD infants, it is considered equivalent to chronological age. To make this comparison, it is necessary to examine TD infants and toddlers who are actually in the early stages of vocal development rather than age-peers of young CI recipients. It is recognized that comparing relatively older CI recipients with younger TD infants and toddlers is uneven because the former group is more mature than the latter group in numerous ways (e.g., neurological, physiological, cognitive, and social development) at the start of the study. Mindful of these developmental differences, the purpose of comparing the two groups is to determine whether young CI recipients require more, approximately the same, or fewer months of robust hearing experience to make advancements in vocal development. Outcomes of this comparison are needed to assess the effectiveness of the CI signal for early speech development and to provide a sense of whether young CI recipients might “catch-up” or remain delayed in speech development relative to children who have normal hearing.

The second question asked: How many months of robust hearing experience are required to establish the speech-like BCS and AF levels after implantation? Answers to this question can provide a basis for assessing the efficiency with which young CI recipients make gains in vocal development and can be clinically useful for determining whether children are making adequate progress during the first year of CI use.

The third question asked: Do young CI recipients follow the sequence of vocal development predicted by the SAEVD-R (i.e., establishing the PC, then BCS, and then AF levels)? As mentioned above, six children studied by Ertmer et al. (2007) followed the sequence predicted by the SAEVD-R, whereas the youngest child in the study (implanted at 10 months) established the AF level before the BCS level. Further study is needed to determine how consistently the predicted progression is followed by other young CI recipients.

In addition to their clinical applications, exploration of these research questions will contribute to understanding the role of audition in speech development and the effects of a preimplant period of auditory deprivation on spoken language learning. As discussed above, the role of audition becomes evident as children begin to produce the mature, speech-like vocalizations that would not be obtained without robust hearing: those of the AF level. The impact of auditory deprivation on early speech development can be inferred by examining the rate at which speech-like vocalizations from the BCS and AF levels are established. Previous research suggests that post-implantation advancements in vocal development will require fewer-than-typical months of robust hearing experience. Replication of this finding would support the notion that an early period of auditory deprivation does not negatively impact auditory-guided speech development at the prelinguistic level.

Methods

Participants

Two groups of children participated in the study. Originally, the CI group consisted of 6 boys and 10 girls. Each child had a bilateral, severe-to-profound hearing loss and received a CI between 8 and 35 months of age ($M = 20.59$ months), with activation within 1 month postsurgery. All were enrolled in parent–infant programs at oral communication programs in the Midwestern United States. The children entered the study once it was determined that they had received their devices before 36 months of age, that English was the only language spoken in the home, and that their parents were willing to participate. The children were accepted consecutively based on availability. They were enrolled without regard to gender as it has been shown to have little influence on vocal development in children who are TD (Lynch, Oller, Steffens, & Budder, 1995). Three children were enrolled but eventually excluded from the current report because they were identified as having speech motor difficulties, behaviors related to Autism Spectrum Disorders, or developmental motor delays associated with hypotonia, in addition to hearing losses. As a result, four boys and nine girls were included in the current analysis. Of these children, several had bilateral implants: two had bilateral CIs at the time of enrollment and one added a second CI during the course of the study. Eight of the children were enrolled in the study prior to or shortly after receiving their devices. These children contributed a preimplant sample ($n = 2$), an "early" sample (within 2 months of implantation; $n = 6$), or both ($n = 1$). The remaining children were not available for participation until close to their third month of CI experience. Table 2 contains background and audiometric information for the CI recipients.

Seven boys and five girls who were TD entered the study at 6 months of age. Because the CI group was not controlled for gender, and previous studies of TD children (Lynch et al., 1995) have not found gender effects in prelinguistic vocal development, no restrictions were put on gender for the children in the TD group. The ages of the TD children permitted comparison with the CI group after 6, 9, and 12 months of robust hearing experience. All the children in the TD group had passed hearing screenings soon after birth and were reported by their parents to have no developmental delays at the start of the study. One child was eventually diagnosed as having a speech delay and a low vocabulary at 24 months of age. Her data were excluded from the current analysis. The remaining children (seven boys and four girls) exhibited no

Table 2 Background and audiometric information for children in the CI group

Child	Gender	HL identified (months)	Age at first CI activation (months)	Age at second CI activation (months)	Etiology	Device (Processing strategy)	Pre-CI thresholds (unaided better ear-dB HL)	Mean CI-aided thresholds (SF or better ear) 6–12 mo (dB HL)	NISP
Unilateral CI									
ABHO	F	NHS	27		Unknown	PSP (HiRes-P)	89	18.75	48
ANLO	F	12	30		Unknown/ family history	Freedom (ACE)	Aided 78; NR >4k	30	18
DAST	M	11	21		Malformed cochlea	Freedom (ACE)	76; NR >4k	18	44
GIAI	F	NHS	13		Unknown	Freedom (ACE)	100	23	66
JAES	M	NHS	16		Unknown	PSP (HiRes-P)	Bilateral profound[b]	13	20
JAWE	F	NHS	19		Connexin 26	PSP and Harmony (HiRes-P)	Mod-severe to profound[c]	21	40
JOIR	M	NHS	12		Unknown	Freedom (ACE)	106	20	25
JORO	F	NHS	36		Unknown	Freedom (ACE)	96; NR >2k	26	16
OLHE	F	NHS	25		Unknown/ dysplasia[d]	Freedom (ACE)	80	38	66
OWJO	M	NHS	9		Unknown	Freedom (ACE)	NR	19	72
Bilateral CI									
CAST	F	NHS	13	19	Unknown	Freedom (ACE[e])	NR ABR	30	30
JOLO	F	13	21	21	Unknown	Freedom (ACE)	94	28	48
MAMA	F	13	18	20	Unknown	Freedom (ACE)	100	25	12
M			20.00	18.13				23.83	38.9
SD			7.83	4.17				6.61	20.6

Note. CI, cochlear implant; SF, sound field; NISP, Nittrouer Index of Social Position (Nittrouer, & Burton, 2005); PSP, Platinum Series Sound Processor; HiRes, HiResolution; ACE, Advanced Combinational Encoder; NR, no response to pure- or warble tones; ABR, Auditory Brainstem Response; and NHS, Newborn Hearing Screening.
[a]JORO was identified with a mild bilateral loss by ABR testing at 1 month, bilateral mild to severe loss at 19 months, and a moderately severe to profound loss (right ear) with a severe to profound hearing loss (left ear) at 20 months of age.
[b]No audiogram on file; hearing loss reported as “bilateral profound.”
[c]No actual audiogram on file; hearing loss reported as “moderately severe to profound.”
[d]Bulbous deformity on apical turns bilaterally.
[e]Sound field.

developmental delays during the course of the study and contributed samples at each scheduled interval.

Information was gathered to determine whether there were significant differences in socioeconomic status between the CI and TD groups. This was accomplished by using the Nittrouer Index of Social Position (NISP; Nittrouer & Burton, 2005; see Table 2), an interview that yields a score based on parental educational levels and occupations. The NISP procedure was modified slightly to accommodate single parent families following procedures used by Nittrouer (personal communication, February, 2008). Comparisons revealed that the TD group had greater NISP scores ($M = 68.27$) than the CI group ($M = 38.85$), $t\ (22) = -3.53$, $p = 0.002$. Although socioeconomic status has been shown to have little impact on babbling development (Oller, Eilers, Basinger, Steffens, & Urbano, 1995), awareness of social status may be important for considering between-group differences if the CI children show delays in vocal development relative to those of the TD children.

Research Design and Data Collection

A longitudinal research design was used to examine the time course and sequence of vocal development in the CI and TD groups. Twenty-minute video and audio recordings of adult–child play interactions were made prior to implantation, within 2 months of CI activation (early session) and at 3, 6, 9, and 12 months postimplant activation. Children in the TD group were recorded when they were 6, 9, and 12 months old. Recordings were not made at 3 months for TD group because it was expected that the *establishment* of the BCS and AF levels (i.e., ≥20% of a sample) would be observed after 6 months of age (Nathani et al., 2006). The typical age range of *emergence* (i.e., the age at which children *begin* to produce a particular type of vocalization) for vocalization from these levels is 5–10 months and 16–20 months of age, respectively (Nathani et al., 2006).

Video and audio recordings were made with Sony mini-DVD camcorders (model number DCR-DVD405) coupled with Bluetooth wireless microphones. The microphones were worn in fitted, front vest pockets to ensure a consistent microphone–mouth distance of less than 4 inches. Recordings were made by each child's early interventionist (EI) so that all adults in the recording session were familiar to the child. In cases where parents or guardians of CI children were unable to attend a scheduled recording session the child interacted with their EI (15%) or a daycare provider (4%). When parents or guardians were involved (81% of sessions), almost all sessions involved mothers (97%). Recordings for 12 of the CI children were made at the child's intervention center; recordings for the remaining child (CAST) were made in her home. Mothers were involved in all the recording sessions for the TD children. These sessions were conducted in a playroom setting in the first author's laboratory. Children in both groups played with items from a standard set of books, puzzles, dolls, and toys during each session.

Data Analysis

Video and audio recordings of 81 parent–child interaction sessions were reviewed by research assistants so that child utterances could parsed from DVDs and saved as separate digital soundfiles on a computer. An utterance was defined as a vocalization or group of vocalizations separated from all others by either audible ingressive breaths or by listener intuitions about utterance boundaries that are often indicated by a silence of 1 sec or longer (Ertmer & Nathan Iyer, 2010; Lynch et al., 1989; Stark, 1980). Only protophone vocalizations (i.e., those that are precursors of speech, Oller, 2000) were analyzed. Fixed signal vocalizations such as crying and laughter and vegetative sounds such as sneezing, burping, and hiccups were not saved as sound files because they do not become more speech-like with age. At least 50 utterances containing protophones were parsed from 84% of the sessions. Each parsed sound file was assigned a special code representing the child, the interval of the sample, and the number of the utterance within the sample (e.g., third of 50 utterances). This coding system ensured that the listener–judges who classified child utterances from the soundfiles were blind to the children's hearing status (CI or normal) and the interval at which the recording was made. The listener–judges were graduate students in Speech-language Pathology or Audiology who had completed coursework in Phonetics and had been trained to use the SAEVD-R. Soundfiles alone were used to classify vocalizations because video recordings can provide information about the presence or absence of a CI, age, and social communication that might influence judgments of vocalization types.

The operational definitions of the SAEVD-R (Nathani et al., 2006) were used to classify child utterances. Because children's utterances often contained more than one kind of vocalization, they were classified according to the most advanced vocalization type within the utterance. For example, an utterance that contained an isolated vowel, a squeal, and a CV syllable would be classified at the BCS level because the CV was the most advanced type of vocalization within the utterance.

Once vocalization types were identified using SAEVD-R operational definitions, utterances were classified into one of three broader categories from the Consolidated SAEVD-R: PC, BCS, or AF. Using the Consolidated SAEVD-R, vocalization types from SAEVD-R levels 1–3 were classified as PC vocalizations when they lacked vowels and true consonants in combination with rapid transitions between them (Ertmer et al., 2007). Examples of PC vocalizations include grunts, squeals, and isolated vowels. Nathani et al. (2006) demonstrated that PC vocalizations are dominant before 8 months of age and decrease in frequency during the second year of life in TD children. PC vocalizations are produced by deaf and hearing infants alike, and the frequency of these vocalizations does not appear to be affected by hearing status (Ertmer & Mellon, 2001; Ertmer et al., 2007).

Utterances were classified as BCS when they were produced with normal phonation and had at least one CV combination with a rapid transition (Oller & Lynch, 1992). Nathani et al. (2006) demonstrated that BCS vocalizations (e.g., CV, CVCVCV syllables) begin to emerge around 5 months of age and increase substantially after 9 months of age, accounting for approximately 40% of children's output by 20 months of age. Deaf children have shown delays in the emergence and establishment of BCS compared to children who are developing typically (e.g., Oller & Eilers, 1988).

Finally, AF have the canonical characteristics of BCS but are later emerging and more phonetically and prosodically complex. Examples include closed syllables such as VC, CVC, and CCV syllables, diphthongs, and jargon. AF vocalizations typically begin to emerge after 9 months and increase to approximately 20% of children's utterances between 16 and 20 months of age (Nathani et al., 2006).

The first 50 consecutive child utterances, or all available utterances from sessions yielding less than 50 utterances, that were adequate in intensity and without excessive background noise or talk-over were classified from each session. Utterances of poor audio quality were discarded and replaced with the next consecutive utterance of acceptable quality.

Reliability

A total of 3,908 utterances were classified into the PC, BCS, or AF categories for the CI and TD groups combined. Approximately 20% (797 utterances) of these were reclassified to assess intraclassifier and interclassifier reliability. Cohen's Kappa was calculated to determine how well the original and second classifications agreed with each other. A Kappa of .97 was determined for intra-classifier agreement and a Kappa of .86 was found for inter-classifier agreement. Kappa values of greater than .75 have been characterized as excellent agreement by Fleiss (1981).

Statistical Analyses

A linear mixed longitudinal model was used to analyze the data. CI participant samples from 3, 6, 9, and 12 months post-CI activation and TD samples from 6, 9, and 12 months of age were analyzed. Three children missed recording sessions due to illness, scheduling problems, or family relocation. Raw scores consisted of the number of child utterances that were classified at the PC, BCS, and AF levels for each recording session. A maximum of 50 utterances were examined for each session, with approximately 16% of the sessions having less than 50 utterances produced (M = 39 classifiable utterances; *range* = 14–49 utterances). Raw scores were converted to percentages because of differences in the total number of utterances per session. The main effects of Group (CI vs. TD) and Time (post-implant Months 3, 6, 9, and 12 for CI group; CA of 6, 9, and 12 months for TD group) were examined through a linear mixed model ANOVA with arcsine transform of the percentage data. Group served as the between-subjects factor and Time as the within-subjects factor. Separate analyses were completed for PC, BCS, and AF vocalizations.

Results

Precanonical Vocalizations

Figure 1 presents the mean percentage of PC vocalizations from the 3, 6, 9, and 12 months postactivation intervals when the majority of CI users contributed samples. Limited data were obtained at the preimplant and "early" sessions. These can be found in Table 3. Percentages for the TD children at Months 6, 9, and 12 are also presented in Figure 1. From this

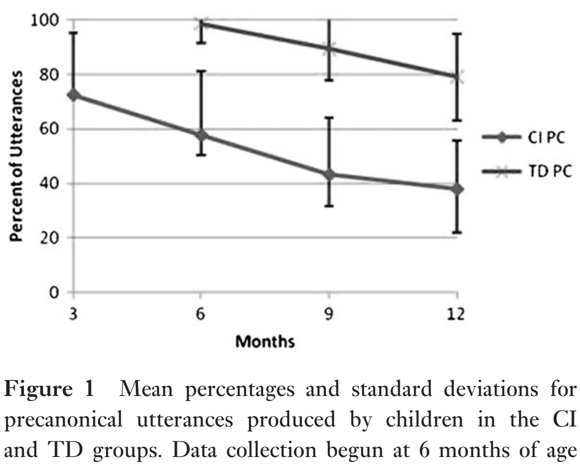

Figure 1 Mean percentages and standard deviations for precanonical utterances produced by children in the CI and TD groups. Data collection begun at 6 months of age for TD children.

Table 3 Percentages of vocalizations from each Consolidated SAEVD-R level during each sampling interval

Child (age at activation)	Precanonical						Basic Canonical Syllables						Advanced Forms					
	Pre	Early	3	6	9	12	Pre	Early	3	6	9	12	Pre	Early	3	6	9	12
OWJO (9)		100	94	71	58	34		0	4	29	30	40		0	2	0	12	26
JOIR (12)	100	100	88	68	18	16	0	0	9	30	44	36	0	0	3	2	38	48
CAST (13)			54	20	28	38			42	78	66	34			4	2	6	28
GIAI (13)		76	84	80	92	28		14	14	6	6	42		10	2	14	2	30
JAES (16)			98	76		83			2	16		17			0	8		0
MAMA (18)			68	58	36	46			30	36	54	38			2	6	10	16
JAWE (19)		76	68		36	28		18	12		30	64		6	20		34	8
JOLO (21)		96	70	92	48	52		4	30	8	32	36		0	0	0	20	12
DAST (21)	92		84	48	32	34	8		8	38	30	24	0		8	14	38	42
OLHE (25)		28	24	28	24	36		68	64	44	52	28		4	12	28	24	36
ABHO (27)			38	46	26	16			38	46	16	26			24	8	58	58
ANLO (30)			90	74					10	24					0	2		
JORO (36)		30	50	26	44	40		36	38	38	40	34		34	12	36	16	26
M (20.00)	96.00	72.29	70.00	57.28	40.18	37.58	4.00	20.00	23.15	32.72	36.36	34.92	0.00	7.71	6.82	10.00	23.45	27.50
SD (7.83)	5.66	31.29	22.88	23.56	20.7	17.81	5.66	24.68	18.67	19.37	17.27	11.69	0.00	12.19	7.94	11.47	16.95	16.93

Note. Empty cells indicate that the child was unavailable.

figure, it can be seen that both groups showed decreased percentages of PC vocalizations over time. PC utterances comprised 70% of the CI group's utterances at 3 months postactivation and decreased to 57%, 40%, and 38% in Months 6, 9, and 12, respectively. Mean percentages for the TD group decreased from 96% at 6 months of age to 86% and 76% by 12 months.

Following arcsine transformation of the percentage data, ANOVA revealed significant main effects for Group $F(1, 24) = 53.56$, $p < .0001$ and Time $F(3, 52.7) = 15.76$, $p < .00001$ There were no significant interactions $F(2, 52.71) = 1.10$, $p = .34$. Post hoc between-group comparisons revealed that the means for the CI group were lower than those of the TD group after 6 months $t(58.53) = -6.3$, adjusted $p < .001$, 9 months $t(59.9) = -5.48$, adjusted $p < .001$, and 12 months $t(58.42) = -4.6$, adjusted $p < .001$, of robust hearing experience. Post hoc within-group comparisons found no differences in the percentages of PC utterances between Months 3 and 6 and Months 6 and 9 for the CI group (alpha $p = .05$). In contrast, Months 9 $t(53.4) = 3.97$, adjusted $p < .001$, and 12 $t(52.86) = 4.82$, adjusted $p < .0001$, had lower percentages of PC utterances than Month 3. A similar pattern was noted within the TD group: no differences in the mean percentages were found for Months 6 versus 9 or 9 versus 12, but significantly lower percentages were found for Months 6 versus 12 $t(52.5) = 4.61$, adjusted $p < .0001$.

These data show that the CI group produced a lower percentage of PC utterances than TD children with comparable months of robust hearing experience. Both groups made significant decreases in the percentages of these early-emerging vocalization types from the beginning of the study until the end of 1 year of robust hearing. These trends represent progress toward more mature productions, with the CI group making greater reductions of non–speech-like vocalizations than seen for the TD infants.

Basic Canonical Syllables

Figure 2 contains the mean percentages of BCS utterances at the same intervals represented in Figure 1. On average, the CI group had established

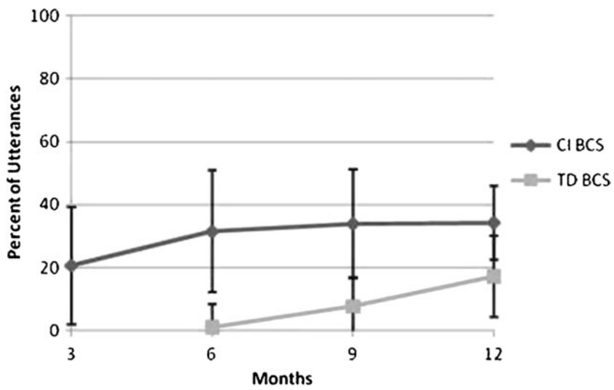

Figure 2 Mean percentages and standard deviations for basic canonical syllable utterances produced by children in the CI and TD groups. Data collection begun at 6 months of age for TD children.

the BCS level at 23% after 3 months of robust hearing and further increased the proportion of these speech-like syllables to between 32% and 36% during the remaining months. In contrast, the TD group produced few BCS utterances at 6 months before increasing percentages to almost 20% after 12 months of robust hearing.

Following arcsine transformation, ANOVA revealed main effects for Group $F(1, 26.5) = 39.08$, $p < .0001$ and for Time $F(3, 53.5) = 6.4$, $p = .0008$ with significant Group × Time interactions $F(2, 53.52) = 4.41$, $p < .017$. Post hoc between-group comparisons revealed that the CI group produced a greater percentage of BCS utterances than the TD group at 6 months $t(67.77) = 6.21$, adjusted $p < .0001$, and 9 months $t(68.41) = 4.18$, adjusted $p < .0001$, but not at 12 months.

Regarding post hoc testing for within-group comparisons, significant differences were not observed across the months for the CI group. In contrast, the TD group produced higher percentages of BCS utterances in Month 9 than Month 6 $t(52.67) = -2.51$, adjusted $p < .0395$, and in Month 12 compared to Month 6 $t(52.67) = 4.54$, adjusted $p < .0001$. These data show that on average, the CI group exceeded the 20% criterion for establishment of the BCS level after 3 months of CI use and during each of the following months. The TD group's first approximated the 20% level (mean ~18%) at 12 months. This score was highly similar to that documented for other TD infants using the SAEVD-R (Nathani et al., 2006).

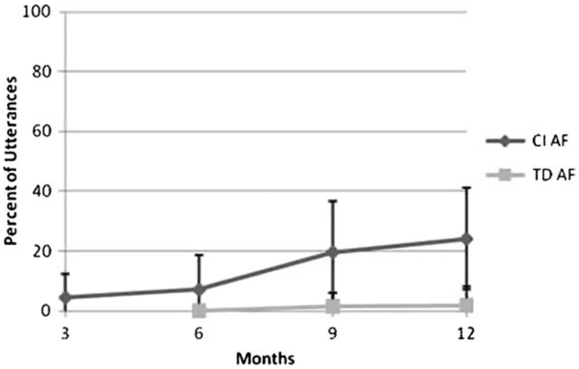

Figure 3 Mean percentages and standard deviations for Advanced Form utterances produced by children in the CI and TD groups. Data collection begun at 6 months of age for TD children.

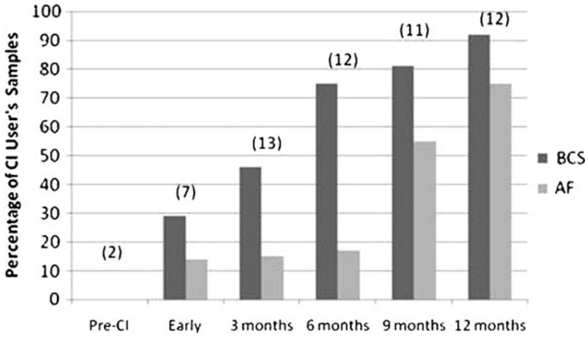

Figure 4 Percentage of CI participants meeting or exceeding the 20% criterion for establishment of Basic Canonical Syllables and Advanced Forms at each sampling interval (number of samples per interval).

Advanced Forms

Figure 3 shows that the proportions of AF utterances at each month were relatively low in comparison to those from the PC and BCS levels. The CI group produced few AF utterances until meeting the 20% criterion for establishment after 9 months of robust hearing experience. A slight increase was apparent at the 12-month interval. In contrast, the TD group produced very few AF vocalizations at any interval. Main effects of Group $F(1, 25.57) = 34.3$, $p < .0001$ and Time $F(3, 53.28) = 11.43$, $p < .000$ were again noted whereas a Group × Time interaction was not significant. Post hoc testing revealed that the CI group produced greater percentages of AF utterances than the TD group at 6 months $t(61.77) = 3.29$, adjusted $p < .0018$, at 9 months $t(62.97) = 4.40$, adjusted $p < .0001$, and 12 months $t(1, 61.65) = 5.10$, adjusted $p < .0001$.

Within-group post hoc testing for the main effect of Time revealed that there were no meaningful differences between the 3- and 6-month or the 9- and 12-month scores for the CI group. However, significantly greater percentages of AF utterances were noted for Month 9 versus both Month 3 $t(54.03) = -3.97$, adjusted $p < .0012$, and versus Month 6 $t(54.79) = -2.99$, adjusted $p < .0215$. Likewise, greater percentages of AF vocalizations were produced in the 12 month session than in Month 3 $t(53.44) = -4.98$, adjusted $p < .0001$, and Month 6 $t(54.12) = -3.95$, adjusted $p < .0013$. No differences were noted for the TD group across the 6-, 9-, and 12-month intervals. Mean scores indicate that the CI group required between 6 and 9 months of robust hearing experience to establish the AF level at 20%. Based on previous research, the TD group would be expected to establish the AF level between 16 and 20 months of age (Nathani et al., 2006). Mean scores for the CI group suggest that they followed the sequence of development previously noted for TD infants and toddlers (i.e., establishing BCS before AF; Nathani et al., 2006). However, a closer look at individual CI users provides a clearer picture of time-line for establishing the BCS and AF levels.

Individual Scores of CI Recipients

Figure 4 illustrates the percentage of individual CI users who established the BCS and AF levels at the intervals examined. From this figure, it can be seen that prior to implantation, neither of the two samples met criterion for either level. A steady increase in the number of children who established the BCS level can be seen as percentages increase from 29% at 3 months to 92% at 12 months. Increases in the number of CI users establishing the AF level are delayed by comparison: <17% of the children had established the AF level at the early and 3- and 6-month intervals. A large increase to 55% was noted at 9 months and followed by a further increase to 75% of the children after 1 year of CI use. Thus, individual scores reveal that the majority of young CI recipients had established the BCS level by 6 months and the AF level by 9 months. In addition to clarifying the time-course for establishing speech-like vocalizations, these data support the notion that most of the children followed the sequence of development predicted by the SAEVD-R by establishing BCS before AF.

Additional Post Hoc Analysis

The percentages of the three kinds of vocalizations (PC, BCS, and AF) were compared between children with bilateral CIs and those with unilateral CIs at each sampling interval. No significant differences were noted for any of these comparisons (alpha = .05), indicating that the percentages of vocalizations from each category at each interval were not significantly different for children with one versus two CIs.

Discussion

The Time-course of Vocal Development Following Cochlear Implantation

The following discussion is organized to examine performance of the CI and TD groups at each of the three levels of the Consolidated SAEVD-R. Within each of these sections, group comparisons are used to discuss the amount of robust hearing experience needed to establish each level. Individual scores will be used to estimate the time course for establishing the BCS and AF levels after CI activation. Finally, a combination of group and individual data will be used to determine the sequence of vocal development following cochlear implantation.

Precanonical Vocalizations

Previous research has shown that PC vocalizations gradually decrease as speech-like vocalizations become more common in TD children (Nathani et al., 2006; Oller, 1980, 2000). Although both groups of children showed this tendency, the CI children produced fewer PC vocalizations than the TD children at each interval (Figure 1). CI users decreased PC vocalizations from a high of approximately 70% at 3-months postactivation to less than 40% after 1 year of CI use. Thus, the majority of their vocalizations were speech-like after 1 year of robust hearing with a CI. These group findings are consistent with case studies that found decreases in PC vocalizations soon after implantation at a young age (Ertmer & Mellon, 2001; Ertmer et al., 2007). The TD children, in contrast, produced PC vocalizations almost exclusively at 6 months and continued to produce them at moderately high levels (M = 80%) as 1-year-olds. In summary, children in the CI group reduced the frequency of non–speech-like vocalizations more rapidly than children in the TD group who had comparable amounts of robust hearing experience.

Regarding individual performances, Table 3 shows that two children (OLHE and JORO) had relatively low proportions of PC vocalizations soon after implantation. Although preimplant data are unavailable, their scores suggest that they had decreased PC vocalizations substantially before receiving their CIs. As Table 2 shows, JORO experienced a progressive hearing loss before implantation at 35 months of age. Thus, her auditory experiences via hearing aids might have enabled her to make advancements prior to enrolling in the study. OLHE also produced relatively low amounts of PC vocalizations during the early session. Her subsequent sessions showed that BCS vocalizations were in the majority during the early and 3-month sessions. Although OLHE did not have a progressive hearing loss, her unaided hearing levels were within the mid-severe range (PTA of 80 dB HL), rather than the profound range of hearing loss. Thus, she likely had more access to some features of conversational-intensity speech via hearing aids than most other CI recipients. Access to these features might have enabled her to increase production of canonical syllables, thereby decreasing PC vocalizations. In addition, because JORO and OLHE were among the oldest children to receive CIs, they had participated in intervention services longer than the younger recipients. It is possible that the interaction between preimplant hearing experiences and intervention might have facilitated their relatively advanced status near the start of the study. The remaining CI recipients showed comparatively high levels of PC vocalizations during preimplant and early sessions and gradual decreases across the first year of device use.

Basic Canonical Syllables

The establishment of canonical syllables or “babbling” at the 20% level is a hallmark of vocal development (Oller, 2000; Oller & Eilers, 1988; Nathani et al.,

Table 4 Percentages of vocalizations at each consolidated SAEVD-R level during each sampling interval for TD children

	Precanonical			Basic Canonical Syllables			Advanced Forms		
Child	6	9	12	6	9	12	6	9	12
COKU	96	89	84	2	11	16	2	0	0
FACO	76	92	94	24	8	6	0	0	0
HOWA	100	76.9	46	0	15.4	44	0	7.7	10
ISIL	100	64	86	0	32	14	0	4	0
LIRO	100	100	100	0	0	0	0	0	0
OLHA	100	90	62	0	10	32	0	0	6
PARI	100	100	84	0	0	16	0	0	0
SASN	98	96	72	0	4	22	2	0	6
SYNE	100	87.10	62.1	0	6.45	34.5	0	6.45	3.4
TRTO	91	85.42	80	9	6.25	20	0	8.33	0
WIAB	98	70	68	2	18	12	0	12	20
M	96.27	86.40	76.19	3.36	10.10	19.68	0.36	3.50	4.13
SD	7.27	11.73	15.85	7.35	9.19	12.89	0.81	4.42	6.29

Note. All the children were 6 months old at the start of the study.

2006). As the mean scores in Figure 2 reveal, the CI group first established the BCS level at the early interval and their mean scores exceeded 20% for all following intervals. However, a closer look at Table 3 reveals considerable individual differences. Neither child from the preimplant interval (JOIR or DAST) had reached the 20% level for BCS. At the Early interval, it is apparent that JORO's and OLHE's relatively high scores lifted the group mean to the 20% level; the remaining scores did not exceed 18% at the early interval. As mentioned previously, the relatively high scores of JORO and OLHE suggest that the production of canonical syllables might have been facilitated by preimplant hearing experiences and participation in intervention. A look at individual scores for Month 3 reveals that 6 of 13 children had reached the 20% criteria for establishing the BCS level; 9 of 11 had done so by 9 months; and all but one child (JAES) had established the BCS level at 12 months. Based on individual performances, the majority of young CI recipients had established the BCS level with 9 or fewer months of robust hearing experience (see Figure 4).

Figure 2 also shows that the TD group had not established the BCS level by 12 months of age. The mean score at this interval (19%) is very similar to the 18% documented in other TD children who were between 9 and 12 months of age (Nathani et al., 2006). Table 4 shows that one TD child had reached the 20% level by 6 months (FACO) and one by 9 months (ISIL). A total of five TD children had established the BCS level by 12 months. Taken together, group and individual data show that the CI recipients required fewer months of robust hearing to establish the BCS level than the TD children, although the CI and TD groups did not differ in the percentages of BCS vocalizations at the 12-month interval.

Advanced Forms

None of the young CI recipients in the Ertmer et al. (2007) study had established the AF level prior to receiving a CI. Similarly, neither of the two children who contributed preimplant samples in the current study had established this level before implantation. Further, of the seven children who contributed "early" samples, only JORO met establishment criteria for the AF level. Again, her score of 34% suggests that preimplant hearing and intervention experiences had better positioned her to acquire and establish AF vocalizations after activation. The other child with relatively high BCS scores at the early session, OLHE, did not establish the AF level until she had 6 months of CI experience. Her profile suggests that preimplant hearing experiences were not robust enough to establish the highest level of the Consolidated SAEVD-R prior to implantation.

For the CI group, the mean proportion of AF vocalizations first exceeded the 20% criterion for establishment in Month 9 (23.4%) and increased slightly in Month 12 (27.5%). The percentages in Table 3 show that 7 of 12 children reached the 20% level within 9 months of CI activation and that 10 children did so within 12 months. Two children (JAES and MAMA) did not establish the AF level during the first year of CI experience. Their profiles indicate that some young CI recipients require more than 1 year of robust hearing to establish this level. A third child, JAES, did not contribute samples after the 6-month interval, and so it is not possible to determine how much robust hearing experience was needed to establish the AF level. In summary, group and individual data converge to indicate that the establishment of the AF level can be expected within 12 months of CI activation in most cases (Figure 4). Possible factors that might lead to slower or more rapid establishment will be discussed below.

As Figure 3 shows, children in the TD group produced very few AF vocalizations between 6 and 12 months of age. Thus, even when JORO's early score is removed from the CI group, it is apparent that the AF level was established by young CI recipients with fewer months of robust hearing than in the TD group. The CI children's more-rapid-than-typical progress suggests that auditory deprivation did not have a negative impact on vocal development and that improved audition played a key role in establishing the highest level of vocal development. In fact, Establishment of the AF level appears to be the clearest indicator—given the variability for the establishment of the BCS level—of auditory-guided speech development in young CI recipients.

The findings of the current investigation are in general agreement with previous studies showing more rapid-than-typical progress in vocal development following CI activation (Ertmer & Mellon, 2001; Ertmer et al., 2007; McCaffery et al., 1999; Moore & Bass-Ringdahl, 2002; Schauwers et al., 2004). Why might young CI recipients make advancements in vocal development with less robust hearing experience than children who are TD? In attempting to understand this phenomenon, it has been proposed that young CI recipient's relatively greater maturity at the introduction of robust hearing affords them an advantage for vocal development (Ertmer & Mellon, 2001; Ertmer et al., 2007). That is, their relatively advanced neurological, cognitive, social, and motor maturity enables them to perceive the phonetic, timing, and structural (i.e., syllable shapes) characteristics of mature speech models and incorporate them in their own productions more readily than younger TD children.

The "advanced maturity" hypothesis also implies that children who receive CIs at very young ages would require greater amounts of robust hearing experience to complete vocal development than those implanted at relatively older ages. This contention was supported by an earlier study showing that older recipients completed the process of vocal development sooner after implantation than younger recipients (Ertmer et al., 2007). Data from the current study are insufficient for determining the time course for completing the process of vocal development (criteria: establishment of the BCS and AF levels and reduction of the percentages of PC vocalizations to minority status; Ertmer et al., 2007). As a result, this possibility must wait to be explored until the current participants have completed their second year of CI experience.

The influence of children's intervention programs must also be considered in addition to their improved hearing sensitivity and relative maturity. Each of the CI users was enrolled in a parent–infant intervention program after their hearing losses were identified. Such programs have a family-centered approach in which parents learn how to stimulate listening, communication, and language development throughout the day. Four children who were implanted at 24 months or older (i.e., ABHO, ANLO, JORO, and OLHE) also entered an Oral preschool program during the study, at approximately 3;0. Their preschools also focused on the development of listening, speech production, and spoken language. Taken together, the gains observed in this study are likely due to the combination of improved access to conversational speech models via CIs, children's readiness to modify their own vocalizations through exposure to adult speech models and auditory feedback, and the intensive intervention efforts of parents and clinicians.

Finally, it is worth noting that the relatively lower NISP scores of the CI group did not appear to negatively impact the time-course for reaching the BCS or AF levels. This finding is in general agreement with an earlier study that found little effect of socioeconomic status on vocal development in TD children (Oller et al., 1995).

Sequence of Vocal Development

Several findings support the notion that BCS vocalizations emerged and became established before AF vocalizations in young CI recipients. First, group data show that the BCS level—but not the AF level—was established by four of seven children who gave samples during the early session (i.e., within 2 months of activation; Figure 4). After that point, BCS mean scores consistently exceeded establishment levels for the CI group. Second, the majority of children (9/13) had established the BCS level by 6 months of device experience. In contrast, means for AF vocalizations did not exceed 20% until after 9 months of CI experience, and it was not until Month 9 that the majority of the CI group (7/11 available samples) had met or exceeded establishment criterion at least once. Finally, the percentages of BCS vocalizations exceeded AF vocalizations at every interval, suggesting that the former were more readily acquired and produced than the latter. However, two young CI recipients first established the BCS and AF levels within in the same sample. It is not possible to determine whether these levels were established in the expected sequence or in reverse order between Months 9 and 12 (GIAI) or between activation and the 3-month session (ABHO). One child (JAWE) first established the AF level during the 3-month session and then the BCS level during the 9-month session. Data were not available for her 6-month session. Thus, although there were exceptions, the majority of young CI recipients and trends in group data followed the sequence of vocal development predicted by the SAEVD-R.

Limitations and Future Directions

Several limitations should be kept in mind when interpreting the current findings. Ideally, preactivation samples would have been collected for each participant. Having preactivation samples would have provided a baseline of vocal development via hearing aids. Unfortunately, this was not possible due to delays between parent's decision to pursue a CI at a medical center and children's enrollment in the oral education programs where children were recruited. Another limitation concerns variability in children's samples. Specifically, some levels were established (exceeded 20%) during at a given interval but did not reach establishment criterion at the next interval. This phenomenon occurred less often for the BCS level (only 2 of 12 children) than for the AF level (3 of 6 children who had established AFs by Month 9 or before). Session to session variability has been shown to be a common phenomenon in TD children (Tomasello & Stahl, 2004). It is likely that young CI recipients vary in the types of vocalizations produced across sessions as well. More frequent sampling might have provided a clearer picture of the consistency of children's vocalization patterns and clarified the sequence of vocal development in the two children who first established both the BCS and AF levels in the same session. Lastly, it is important to remember that other spoken language abilities (e.g., morphology and syntax) might not show a rapid rate of acquisition despite expedient gains in vocal development (Ertmer, Strong, & Sadagopan, 2003).

In summary, the main findings of the current investigation are in agreement with previous studies showing that children with CIs make gains in vocal development with fewer-than-typical months of robust hearing experience. They also provide estimates of the time-course for reaching the BCS and AF levels and suggest that auditory deprivation at a young age did not negatively impact early speech development. The essential nature of robust hearing for acquiring the diverse syllable shapes and vocalizations of the AF level was also verified. Our on-going research will continue to examine vocal development, early phonological development, and expressive vocabulary gains through the first 2 years of CI experience.

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Conflicts of Interest

No conflicts of interest were reported.

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