ROLE OF INFANT VOCAL DEVELOPMENT IN CANDIDACY FOR AND EFFICACY OF COCHLEAR IMPLANTATION

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Previous research has documented the importance of audition in the development of typical infant vocalization. Of particular interest is the development of canonical babbling, which is related to mastery of the timing elements of speech. Children with severe to profound hearing loss who use hearing aids have demonstrated both delayed and deviant canonical babbling. The vocal development of 12 children has been followed as they have been considered for cochlear implantation. Nine of these children have undergone implantation, and 5 of these children have been followed for more than 1 year after implantation. On average, canonical babbling emerged at 6.5 months after implantation. The time frame in which some children developed words was accelerated in terms of length of auditory experience as compared with normal-hearing peers. Mature oral-motor development is likely the primary contributing factor in this time course. One child who received a cochlear implant began to babble with hearing aids. It is not known whether normal canonical babbling is sufficient evidence on which to base candidacy decisions; however, our data suggest that children who produce canonical babbling maintain and build upon those skills after implantation.

KEY WORDS — canonical babbling, cochlear implant, hearing aid, vocal development.

Children with bilateral severe to profound sensorineural hearing loss as young as 12 months of age are now being considered candidates for cochlear implantation. The current candidacy guidelines for children for US Food and Drug Administration–approved devices stipulate that children must also show little or no benefit from amplification and show limited development of auditory skills.[1] This lower age at which parents can choose implantation for their child presents new challenges to professionals who work with these children to document their candidacy by the child's first birthday. Although electrophysiological and behavioral test measures for infants can quantify the degree of hearing loss, it remains a challenge to document whether a child can use his or her aided residual hearing to develop speech, language, and auditory skills. Linguistic skills vary widely at this age, not only in children with hearing loss, but even in normal-hearing children.

The use of infant vocal behaviors as one tool in the determination of implant candidacy and efficacy is currently being investigated. A number of researchers have documented the normal stages of vocal development observed in hearing children. The stages of normal infant vocal development include reflexive, vegetative, and cry vocalizations from birth to 3 months of age; precanonical vocalizations, such as vowel attempts, emerging around 4 months of age; and canonical syllables or true babbling, occurring between 7 and 9 months of age in normal-hearing children.[2,3] Canonical babbling is characterized by true consonant-vowel repetitions with regular timing between the consonant and vowel portions of the syllable. The timing elements of canonical babbling are believed to form the foundation of speech timing in fluent conversational speech. In addition, work by Oller et al[3,4] has documented that the canonical babbling of children with severe to profound hearing losses differs significantly from that of normal-hearing children in a number of specific ways. First, the onset of the babbling is much later than that of normal-hearing children, the variety of phonemes used is reduced, the volume of babbling is reduced, and, most importantly, the timing elements between the consonant and the vowel are significantly longer than those of normal-hearing children.[3,4]

Thus, children's vocalizations studied during cochlear implant candidacy and after implantation may provide information on which to judge candidacy for implantation and predict outcomes. Specific questions addressed by our research program include 1) What type and quantity of vocalizations constitute "minimal progress" in auditory and speech skills, which are requisite to implantation? 2) What is the course of infant vocal development after implantation? and 3) What is the interaction between vocal

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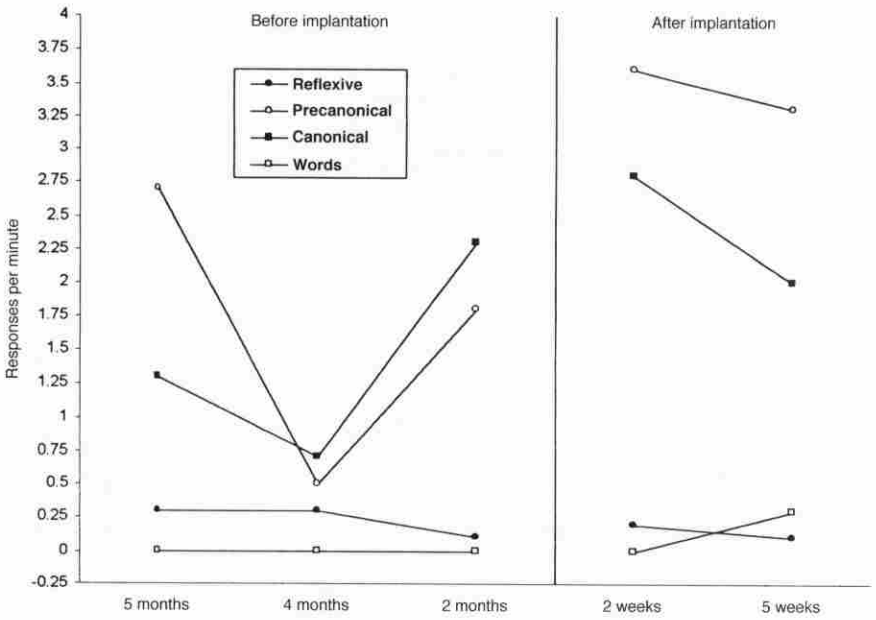

Fig 1. Responses per minute for male patient for 4 vocalization types: reflexive, precanonical, canonical, and words. Time of implant stimulation is indicated by vertical line.

development before implantation and the development of speech after implantation?

METHOD

Participants. Twelve children who were considered candidates for implantation were enrolled in this preliminary study. Five of the children underwent implantation and have been followed for at least 1 year after implantation. All of the children received a Nucleus 24M cochlear implant between 18 and 20 months of age. None of the children had surgical complications that would be indicative of possible poor performance with the device. All of the children received aural rehabilitation services through their local educational agency in Iowa, which used a simultaneous communication approach, as well as performing auditory training.

Protocol. Each child was scheduled to be seen at monthly intervals before and after cochlear implantation, but the actual time between visits varied between 1 and 3 months for some of the children. Video and digital tape recordings were obtained with the child, a parent, and an examiner interacting with favorite toys and books, bubbles, and specific toys in an elicited speech task. This speech task, developed by the first author, was composed of 15 age-appropriate words sampling the entire vowel quadrilateral and age-appropriate consonants. Although it was not expected that the children would initially produce the words, it was felt that consistent exposure to the words and objects would lead to the ability to participate in the task. This task was developed to serve the needs of the research project until the children were old enough to participate in the current speech protocol (sentence imitation and story retell tasks).

The data were classified into 4 vocalization categories: reflexive vocalizations, precanonical babbling, canonical babbling, and words. Interobserver agreement between 2 coders on 20% of the data was obtained. Ten-minute segments of data were coded independently by 2 transcribers. The types of vocalizations were identified in an ongoing time sequence, and interobserver agreement was calculated by a point-by-point comparison of each instance of vocal behavior. For the reliability measures completed, interobserver agreement averaged 90% for the identification of reflexive vocalizations, 87% for the identification of precanonical vocalizations, and 87% for canonical babbling. A portion of the segments identified as canonical babbling were analyzed acoustically to verify the presence of canonical babbling according to the criteria of Oller et al.[3,4] Specifically, the timing of the second formant frequency transition between consonant release and the nucleus of the vowel could not exceed 120 ms for the segment to be considered normal canonical babbling.

RESULTS

For the 12 children who have developed canonical babbling, the average age of onset was 6.5 months after implantation. Four of the 5 children who have had their implant for more than 1 year began using words by 12 months. None of those children showed canonical babbling in the candidacy phase. Acoustic analysis confirmed that the babbling occurred in normal rhythmic intervals and met the timing criteria to be considered normal; however, there was a reduced variety of phonemes produced and a reduced number of canonical babbling occurrences in the sample. For the sake of brevity, we discuss here 2 children

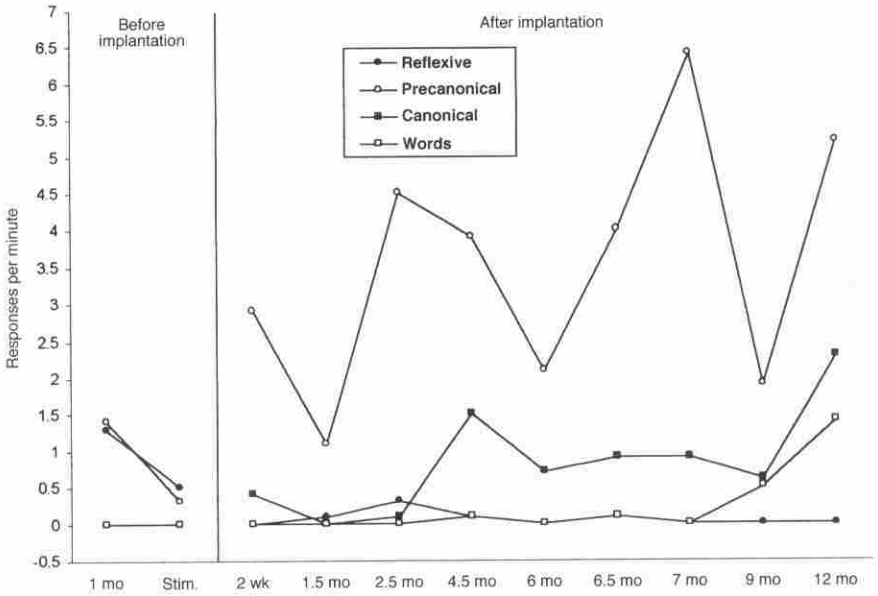

Fig 2. Responses per minute for female patient for 4 vocalization types: reflexive, precanonical, canonical, and words. Time of implant stimulation is indicated by vertical line. Recording was made on day of stimulation (Stim.) but before activation of device.

whose results illustrate interesting trends observed in the data. Figures 1 and 2 illustrate the rate of use of the different types of vocal development over time; however, the y-axis on the two Figures does not utilize the same scale. One of the characteristics of infants is their variability of behavior from one session to the next; therefore, overall trends of development are of interest. One child presented with asymmetric hearing loss and underwent implantation in his poorer ear. The benefit he received from amplification in the better ear was sufficient for him to develop canonical babbling before he received a cochlear implant. As illustrated in Fig 1, after only 5 weeks of implant use, his precanonical vocalization rate increased, while his canonical babbling rate remained relatively constant, over that time period. It appeared that he demonstrated continued and uninterrupted development of canonical babbling despite the introduction of new auditory input. Additional data will need to be gathered and analyzed to understand the interaction between the child's preimplantation speech skills and his development over time. In Fig 2, the rate of responses for the 4 vocalization types is shown for another child. She presented with a very low rate of both reflexive and precanonical vocalizations during the preimplantation phase. After implantation, there was an immediate and dramatic rise in precanonical vocalizations, with canonical syllables emerging 4.5 months after implantation and words emerging 12 months after implantation. This child is more typical of an implant candidate who had virtually no residual hearing before implantation.

DISCUSSION

The results of this preliminary study suggest that children who are considered as implant candidates present with differing stages of vocal development during candidacy for the device. It is unclear at this time whether canonical babbling during candidacy for implantation should or should not be considered "minimal progress" in the development of speech and auditory skills. It would be premature to suggest that a child who had developed the normal timing features of canonical babbling should not be considered a candidate for cochlear implantation during infancy. Conversely, it also is unclear whether that child would be considered an excellent candidate, because the device would support the continued development of those prerequisite speech skills. Continued study is needed to answer this question. Regarding our second question on the course of vocal development, we do have evidence to suggest that the implant leads to increased precanonical vocalizations, with canonical vocalizations emerging an average of 6.5 months after implantation. For all of the children, the implant allowed them the necessary auditory experience to develop normal timing of canonical babbling, an essential skill in speech development, and 4 of the 5 children who have more than 1 year of experience with the device have developed words by 12 months after implantation. The course of vocal development was consistent with the stages of development seen in normal-hearing children. Regarding the interaction between vocal development and the implant, the male patient described above was able to transfer preimplantation canonical babbling skills to the postimplantation phase. Our data on this child are limited, and further research will continue to address this potential interaction effect. We do not yet know whether these skills will lead to even faster or more normal speech acquisition over time.

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