Effect of Age at Cochlear Implantation on Auditory Skill Development in Infants and Toddlers

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Objectives: To investigate the effect of age at cochlear implantation on the auditory development of children younger than 3 years and to compare these children's auditory development with that of peers with normal hearing.

Design: Using a repeated-measures paradigm, auditory skill development was evaluated before and 3, 6, and 12 months after implantation. Data were compared with previously published data from cohorts with normal hearing.

Participants: One hundred seven hearing-impaired children (age range, 12-36 months) who received a cochlear implant during clinical trials in North America.

Main Outcome Measure: Auditory skill development was assessed using the Infant-Toddler Meaningful Auditory Integration Scale, a tool that provides a quantitative measure in children as young as newborns.

Results: Infants and toddlers who receive implants show rapid improvement in auditory skills during the first year of device use regardless of age at implantation, although younger children achieve higher scores. Children who undergo implantation at a younger age acquire auditory skills nearer to those of their peers with normal hearing at a younger age. The mean rate of acquisition of auditory skills is similar to that of infants and toddlers with normal hearing regardless of age at implantation.

Conclusion: Performing implantation in children with profound hearing loss at the youngest age possible allows the best opportunity for them to acquire communication skills that approximate those of their peers with normal hearing.

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Recent research indicates that early identification and intervention have a significant positive effect on communication development in very young hearing-impaired children. For example, Yoshinaga-Itano et al. found that infants whose hearing losses were identified and who were fit with hearing aids before 6 months of age demonstrated significantly better language scores than children identified after 6 months of age. In another study, Moeller evaluated vocabulary and verbal reasoning skills in a group of 112 children with hearing loss who were enrolled at various ages in a comprehensive intervention program. At 5 years of age, children who had been enrolled before 11 months of age demonstrated significantly better vocabulary and verbal reasoning skills than children enrolled after 11 months of age. Similarly, a positive relationship has been shown between early age at implantation and enhanced cochlear implant (CI) performance in children.

There is little information, however, concerning the effect of age at implantation on meaningful listening skills in children as young as 12 months who undergo implantation. Evaluating device benefit in these young children poses significant challenges. First, they have short attention spans and variable levels of compliance. Second, they present with limited skills in understanding and using language. Third, few clinically useful measures exist to evaluate auditory development in infants and toddlers, regardless of whether they have impaired or normal hearing.

The objectives of this study were (1) to investigate the effect of age at implantation on the auditory development of children who undergo implantation before age 3 years and (2) to compare the auditory development of these young children with that of peers with normal hearing (NH). The auditory capabilities of the children who received implants and those with NH were assessed and compared using the Infant-Toddler Meaningful Auditory Inte-
Auditory skills were assessed using the IT-MAIS. The IT-MAIS was developed and standardized as an assessment tool of auditory skill development in children. The test is a structured interview schedule that queries parents about their child’s spontaneous listening behaviors in everyday situations. The IT-MAIS is not a questionnaire in which parents are asked direct questions regarding their child’s auditory behavior. Rather, the test uses interview elicitation techniques similar to those used with the Vineland Adaptive Behavior Scales. Assessment measures like the Vineland are widely used in developmental psychology and are accepted as reliable tools. One of the advantages of structured interview tools is that clinicians may obtain information about behavior without requiring a young child’s compliance or attention. Another advantage is that information about behavior is independent of the language used. In the case of the IT-MAIS, the auditory behaviors evaluated are universal and represent developmental milestones.

In the IT-MAIS, 10 questions are posed to parents that sample 3 different areas of auditory skill development. These include changes in vocalization associated with device use (questions 1 and 2), alerting to sounds in everyday environments (questions 3, 4, 5, and 6), and deriving meaning from sound (questions 7, 8, 9, and 10). Using information provided by the parent, the examiner scores each question based on the frequency of occurrence of a target behavior. Scores for each question range from 0 (“never demonstrates the behavior”) to 4 (“always demonstrates the behavior”). The highest possible score on the IT-MAIS is 40 (10 questions × maximum score of 4).

PROCEDURES

Parents of children who use implants were administered the IT-MAIS 4 times: before implantation (based on their child’s use of hearing aids) and 3, 6, and 12 months after implantation. Clinical staff at each child’s cochlear implantation center conducted the test. To ensure consistency of test administration and standardization of parent responses, the IT-MAIS protocol contains numerous written probes to which clinicians must adhere. In addition, all clinicians had received prior training in the administration of the test, further reducing interexaminer variability. Each child’s IT-MAIS score at each test interval was converted to a percentage correct score (total score/40 × 100).

For data analysis, subjects with implants were divided into 3 groups based on age at implantation. Group 1 (n = 45) consisted of children who underwent implantation between 12 and 18 months of age. Group 2 (n = 32) consisted of children who underwent implantation between 19 and 23 months of age. Group 3 (n = 30) consisted of children who underwent implantation between 24 and 36 months of age (Table). The IT-MAIS scores from each group were compared with scores that were obtained from the parents of 109 children with NH aged 5 to 36 months (mean age, 12.5 months). The distribution of NH children by age was as follows: 52% were younger than 12 months, 23% were 12 to 18 months old, 10% were 19 to 23 months old, and 15% were 24 to 36 months old. Parents of these NH subjects were administered a translated version of the IT-MAIS in Hebrew (n = 68) or Arabic (n = 41).

The primary aim of the study was to compare the effect of age at implantation on auditory skill development and performance. Figure 1 shows the mean performance on the IT-MAIS for the 3 groups of children before and 3 and 6 months after implantation (12-month data were omitted from this first analysis because of the small sample size). The mean IT-MAIS scores for all 3 groups of subjects were near zero before implantation but improved rapidly over time with increased use of the device. There were no differences in mean scores over time between the 2 earliest groups who received implants (groups 1 and 2), whereas the mean scores for group 3 are lower than scores for groups 1 and 2.

The second aim of the study was to compare auditory skill development in children who use implants with that of NH children of the same chronological age. To make these comparisons, individual IT-MAIS scores for each of the 3 CI groups were plotted with IT-MAIS data.
obtained from the 109 NH children (Figures 2, 3, and 4). For simplicity, only the mean±2 SE values are plotted for the NH children. For the 3 CI groups, individual data are shown before and 3, 6, and 12 months after implantation. Because children entered this study in a staggered manner, limited data are available for subjects at the 12-month interval after implantation. Therefore, data at this interval should be interpreted cautiously. Each CI group’s data were fit with exponential functions, as shown in Figures 2, 3, and 4 for groups 1, 2, and 3, respectively.

Rapid improvement in IT-MAIS scores over time is evident for all 3 age groups following implantation. For the youngest children (group 1), the data could be fit by an exponential curve ($r=0.82$, $P<.01$), as seen in Figure 2. Notably, 70% of the variance in group 1 data was attributable to implant use (as indicated by months after implantation), and more than two thirds of the children fell within the normal distribution of IT-MAIS scores after 6 and 12 months of implant experience. A few of them reached the normal range after only 3 months of listening with the implant.

Results for the group 2 children, who underwent implantation between 19 and 23 months of age, are plotted in Figure 3. These data also could be fit by an exponential curve ($r=0.80$, $P<.01$), and 65% of the variance was attributable to CI use. About one third of the children fell within the normal distribution of IT-MAIS scores after 6 and 12 months of implant experience. In contrast to groups 1 and 2, the IT-MAIS scores from group 3 children, who underwent implantation between 24 and 36 months, showed such great variability that the data could not be predicted by duration of CI use in any systematic way (Figure 4). Moreover, almost all group 3 scores continued to fall below the NH range after 6 and 12 months of CI use.

Figure 5 shows the mean data from the 3 groups of children plotted as a function of hearing age. Hearing
age reflects months of implant use and chronological age for the NH children. The mean scores indicate that the children who use implants acquired auditory skills at a rate similar to that of NH children, independent of age at implantation. However, as is evident in Figures 2, 3, and 4, there is large intersubject variability.

Three main findings emerge from this study. First, mean IT-MAIS scores from infants and toddlers who use implants indicate rapid improvement in auditory skills during the first year of device use regardless of age at implantation, although younger children achieve higher scores. Second, children who undergo implantation at a younger age attain auditory skills nearer to those of their NH peers at a younger age, as measured on the IT-MAIS. When children receive CIs at an older age, factors other than implant use begin to affect their ability to achieve auditory milestones. Third, the mean rate of acquisition of auditory skills is similar to that of NH infants and toddlers regardless of age at implantation.

Specifically, mean IT-MAIS scores show that the 2 groups of children who received implants before age 2 years had significantly faster rates of progress and higher scores than the children who received implants between 2 and 3 years of age. However, there were no significant differences in mean IT-MAIS scores between the 2 youngest groups. At first glance, a comparison of the mean data suggests that there is no advantage to performing implantation in a child at 12 to 18 months of age, as opposed to performing implantation at 19 to 24 months of age. The rate of auditory skill acquisition is the same. However, when IT-MAIS scores from group 1 and group 2 children are compared with those of NH infants and toddlers, a distinction emerges between the 2 youngest groups. Specifically, the youngest group 1 children achieved IT-MAIS scores within the normal range...
at earlier intervals after implantation (and thus younger ages) than children in group 2. Similarly, children in group 2 achieved auditory milestones at earlier ages than children in group 3.

What advantage might there be to the attainment of auditory milestones at ages closest to those achieved by NH children? There are 3 primary advantages. First, the goal of any intervention is for the child to master skills as close as possible to the time that he or she is biologically intended to do so, taking advantage of developmental “windows” of opportunity. This results in developmental synchrony. Second, our primary interest in the development of auditory skills is the fact that such skills form the foundation for spoken language competence. Therefore, delayed auditory development leads to delayed language skills. Although we did not assess language in this study directly, recent evidence suggests similar age-at-implantation effects on language that were found in this study on auditory development. Third, mastery of any developmental skill depends on cumulative practice: the more delayed the age of acquisition of a skill, the farther behind children are in the amount of cumulative practice they have had to perfect that skill. For example, a third grader who is a nonreader may be given intensive, concentrated reading instruction and score on tests at the third-grade reading level after intervention. However, that child has missed out on hundreds of hours of cumulative reading practice that other students have had by third grade. Such practice is essential for building language and cognitive and experiential knowledge and for attaining automaticity of skills. We would argue that the same holds true for cumulative auditory practice in children with CIs.

The data from this study are based on parent-report. Parent-report data, when collected under careful, controlled conditions, have been shown to be valid and reliable. In fact, previous work showed a strong correlation between MAIS scores and speech perception scores on the Phonetically Balanced Kindergarten Test. The behaviors tracked on the IT-MAIS are similar to those on the MAIS, with modifications in the response criteria to be developmentally appropriate for young children. Parent-report data should be viewed as only one measure of implant benefit. Further work is needed to correlate parent-report data with data obtained via other measures in this population of young children.

In summary, children younger than age 3 years undergoing implantation demonstrated impressive auditory skill development during the first year of device use. These data suggest that performing implantation in children with profound hearing loss at the youngest age possible allows the best opportunity for them to acquire communication skills that approximate those of their NH peers.

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