

Using the Observer-Based Psychophysical Procedure to Assess Localization Acuity in Toddlers Who Use Bilateral Cochlear Implants

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Hypothesis: Localization acuity will emerge in deaf children who receive bilateral cochlear implants (BI-CIs) before the age of 3 years but not in age-matched children who use a single device.

Background: There is a growing clinical trend in which infants with severe-to-profound sensorineural hearing loss are receiving BI-CIs by 3 years. Although there is general agreement that better communicative and educational outcomes are achieved when the first implant is provided at a young age, there are few behavioral data showing the functional benefits of providing infants with BI-CIs. One potential benefit of BI-CIs is improved localization acuity, which develops within the first few years of life.

Methods: Two groups of children with chronological ages ranging from 26 to 36 months participated: 1) children with normal hearing ($n = 8$) and 2) children with severe-to-profound sensorineural hearing loss ($n = 18$). Of the children who are deaf, 10 used BI-CIs, and 8 used unilateral cochlear implants. Localiza-

tion acuity was measured with a single interval 2-alternative-forced choice right/left discrimination task, and minimum audible angles were computed at a performance level of 80% correct. Behavioral data were collected using the observer-based psychophysical procedure.

Results: Preliminary results show that the observer-based psychophysical procedure is a feasible method to measure localization acuity in children with normal hearing and in deaf children with cochlear implants and that localization acuity is emerging in toddlers with BI-CIs but not yet in toddlers with unilateral cochlear implants.

Conclusion: These data are among the first to show localization acuity in young children who use BI-CIs. **Key Words:** Bilateral cochlear implants—Cochlear implants—Localization acuity—Minimum audible angle—Observer-based psychophysical method.

Otol Neurotol 29:235–239, 2008.

Cochlear implants (CIs) are prosthetic devices that provide auditory input to individuals who are deaf. Recently, there has been a clinical trend to provide these individuals with bilateral CIs (BI-CIs; 1 for each ear) either simultaneously or with varying amounts of time between the activation of the 2 devices. This trend has been extended to deaf infants, with the impetus being to promote the development of binaural processes at a

time when the infant's brain is highly plastic. In many instances, these children are receiving bilateral input by 3 years.

Studies with adults and older children have shown that, on average, patients with BI-CIs have improved speech understanding in noise and improved sound localization (1–3). There are very few behavioral data, however, showing the functional benefits of BI-CIs in young children. The purpose of this study was to assess localization acuity in a population of toddlers (children younger than 3 yr) who either use BI-CIs or unilateral CIs (U-CIs). To assess localization acuity in these young children, the observer-based psychophysical procedure (4) was used. Minimal audible angle (MAA; smallest difference in angle between 2 sound sources that can be reliably discriminated [5]) was measured. The study tested the hypothesis that MAAs will be smaller (better) in toddlers who use BI-CIs compared with toddlers who listen with a single device (U-CI).

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This study was supported by NIH NIDCD R21DC006642 (R. Y. L.), NIH NIDCD F32DC008452 (T. M. G.-C.), Cochlear Americas for sponsoring participation of a subset of children with cochlear implants.

Financial Disclosure: In the past year, Dr. Ruth Litovsky has served as a paid consultant to Cochlear America and was reimbursed for time spent on a speaking engagement and preparing a "white paper."

MATERIALS AND METHODS

Participants

Participants consisted of 2 groups of children with chronological ages ranging from 26 to 36 months. One group of 18 toddlers had severe-to-profound bilateral sensorineural hearing loss. In this group, 10 participants used BI-CIs, and 8 participants used a U-CI. For additional demographics of the participants, see Table 1. A second (control) group of 8 normal-hearing (NH), typically developing toddlers also participated.

Stimuli

Stimuli were the spondaic words “baseball” and “birthday,” recorded with a male voice at a sampling rate of 44 kHz and stored as WAV files. On each trial, 1 word was randomly chosen and repeated 3 times (e.g., “baseball, baseball, baseball”). In the “fixed” condition, the stimulus level was 60 dB SPL. In the intensity-rove (“roved”) condition, the stimulus level was randomly varied over an 8-dB range (60 ± 4 dB SPL) to minimize the availability of overall monaural level cues that are present when sound intensity is fixed (6).

Setup

Figure 1 shows a schematic diagram of the experimental setup. All measures were conducted in a 9×10 -foot sound booth with reverberation time (RT_{60}) of 200 ms. Digitally matched loudspeakers (Cambridge Soundworks) were mounted on a custom-made arc spanning ± 70 degrees and were placed at intervals of 10 degrees for large angles and 2.5 degrees for small angles. Two side monitors, mounted 45 degrees to the right and left of center underneath the arc, provided video reinforcement. A camera, placed at 0 degrees, provided video feed into the observation side of the test booth (not shown), which was used by an observer to monitor the participant’s behavior.

Participants sat either on their caregivers’ lap or alone on a chair, in the center of the room, with the head approximately 1.5 m from the loudspeakers. Caregivers and research assistants

in the test booth used earphones, which provided a diotic presentation of the stimulus on each trial, to eliminate any tester bias during the experiment.

Procedure

The experiment consisted of a right-left discrimination task. This is a single-interval 2-alternative-forced choice task in which the listener needs to determine if the target stimulus was presented on the right or left with either fixed or varying angular separations. Behavioral responses were measured using the observer-based psychophysical procedure (4). This method is commonly used in infant psychoacoustics and has proven to be accurate in determining auditory sensitivity (7,8). For this study, the procedure was modified slightly so that localization acuity could be assessed. On each trial, an observer, who was located in the observation room and unaware of the stimulus location, watched the toddler’s behavior via video feed. The observer signaled the computer to randomly present a stimulus on the right or left when the child was quiet and looking forward (with the aid of the research assistant in the booth). After the stimulus presentation, the observer made a decision regarding the stimulus location (right or left) by watching the child’s responses (e.g., head turn, eye widening, and shift in gaze). If the observer chose the correct side of presentation, the child’s response was reinforced by the activation of a video on the side of stimulus presentation.

For the group of NH listeners, the speaker array spanned ± 50 degrees, with speakers at the following angles: ± 2.5 , ± 5 , ± 10 , ± 20 , ± 30 , ± 40 , and ± 50 degrees. This configuration was chosen after pilot testing revealed that 10-degree speaker separations resulted in ceiling effects at smaller angles. For toddlers with CIs, initial testing began with a speaker array spanning ± 70 degrees, with 10-degree speaker separations. If the toddlers’ performance reached asymptote at 10 degrees with this configuration, the experiment was repeated with the ± 50 -degree speaker array used for the NH toddlers. Each adaptive track began at the largest angular displacement.

TABLE 1. Demographics of toddlers who use cochlear implants

Participant (sex)	Etiology	Age of first CI (mo)	Age of second CI (mo)	Age at visit (mo)	Device (ear)
Unilateral					
CICC (M)	Connexin 26	15		36	N24 implant, Sprint processor (left)
CICE (M)	Connexin 26 and 30	10.5		30	HiRes implant, Auria processor (right)
CICI (M)	Unknown etiology	14.5		36	Pulsar implant, Tempo processor (right)
CICJ (M)	Connexin 26	10		35	HiRes implant, PSP processor (right)
CICL (M)	Connexin 26	16		27	Freedom implant, Freedom processor (right)
CICM (M)	Connexin 26	13		36	HiRes implant, PSP processor (right)
CICN (F)	Connexin 26	15.5		32.5	Freedom implant, Freedom processor (right)
CICQ (M)	Usher syndrome Type 1	26.5		31	Freedom implant, Freedom processor (right)
Bilateral					
CIBV (M)	Connexin 26 and 30	17	24	29	Hires implant, PSP processor (B)
CIBX (M)	Waardenburg syndrome	10	12	31.5	N24 implant, Sprint processor (B)
CICA (M)	Unknown etiology	29	29	35	Pulsar implant, Tempo processor (B)
CICB (F)	Connexin 26	11	25	31	N24 implant, Sprint processor (right) Freedom implant, Freedom processor (left)
CICF (F)	Bacterial meningitis at 1 mo	17	28	34.5	Freedom implant, Freedom processor (B)
CICG (M)	Connexin 26	13	20.5	27	C40+ implant, Tempo processor (right) Pulsar implant, Tempo processor (left)
CICH (M)	Unknown etiology	11	12	27	Pulsar implant, Tempo processor (B)
CICK (M)	Connexin 26	13	15.5	28.5	HiRes implant, PSP processor (B)
CICO (M)	Connexin 26	13	25	31	Freedom implant, Freedom processor (B)
CICP (F)	Connexin 26	13	20	26.5	Freedom implant, Freedom processor (B)

M indicates male; F, female; B, bilateral.

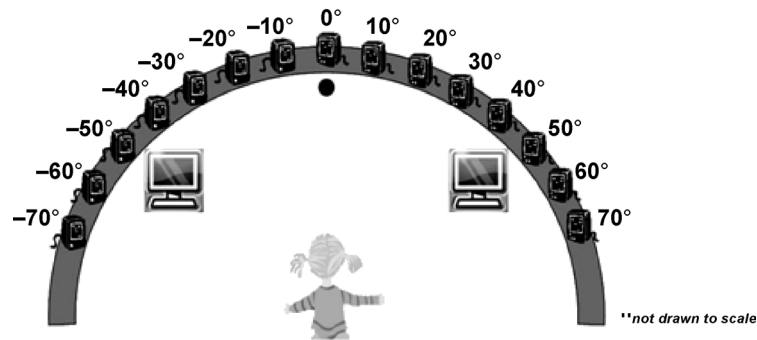


FIG. 1. Experimental setup.

The objective of this task was to determine the MAA, which is traditionally defined as the smallest difference in angle between 2 sound sources that can be reliably discriminated (5). Data were collected using a 3-down/1-up adaptive method to vary the angular separation between the right and left locations from trial to trial. Decisions regarding the step size leading to larger or smaller angular separations were based on Parameter Estimation by Sequential Testing (PEST) rules as used in previous studies of this sort (9,10). Each adaptive track was terminated once 5 reversals were reached or sooner if participants became fussy or uncooperative.

Tucker-Davis Technologies System III (RP2, PM2, AP2), with a PC host, was responsible for stimulus presentation, varying the source direction (right or left) randomly, and for changing the angle of presentation. Software for stimulus presentation and data collection was written in Matlab.

Data Analysis

For each adaptive track, MAA was computed using the Matlab psignifit toolbox (version 2.5.41), applying the methods described by Wichmann and Hill (11,12). A logistic function was fit to all data points from each experimental run for each participant, using a constrained maximum likelihood algorithm. MAA was computed at the point on the psychometric function where performance was 80% correct. Because this method requires minimal performance of 80% correct at 1 angular dis-

placement, MAA could not be determined for toddlers who did not achieve this level of accuracy. For example, none of the toddlers with U-CIs scored 80% or greater at any angle; therefore, their MAAs could not be calculated, and their data are not reported below. In addition, because of the small sample size reported, statistical comparisons were not conducted. Data shown in Figure 3 represent group means ± 1 standard deviation.

RESULTS

Figure 2 illustrates 4 examples of adaptive tracks to illustrate the variability in performance among the participants. In Figures 2A (NH toddler) and B (listener with BI-CIs), the adaptive algorithm for each listener quickly descended to small angles, and 5 reversals were completed. In Figure 2C (listener with BI-CIs), the adaptive algorithm quickly descended to small angles (10–20 degrees) but then ascended toward larger angles. Finally, Figure 2D (listener with U-CI) illustrates an adaptive track that was representative of listeners who did not score greater than or equal to 80% correct at any angle.

The adaptive tracks in Figure 2 were used to estimate each listener’s MMA (see Methods) when 80% correct

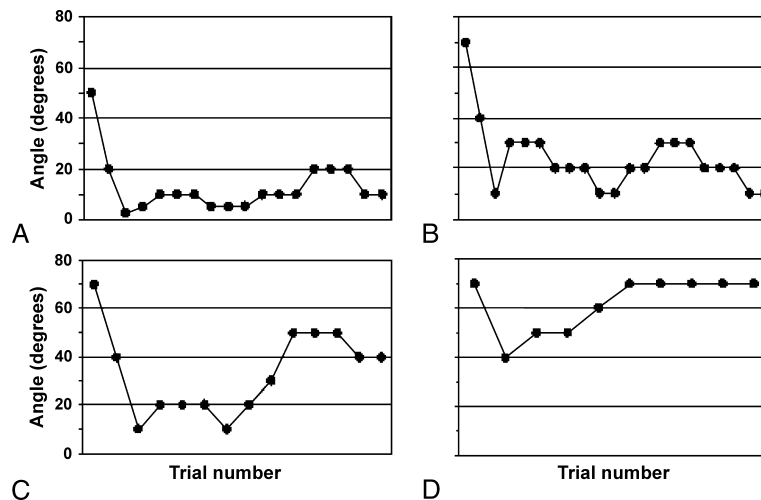


FIG. 2. Examples of adaptive tracks. The side of presentation was collapsed across all angles and plotted as a function of trial. Adaptive tracks are shown for a toddler with NH (A), toddlers with BI-CIs (B and C), and a toddler with a U-CI (D).

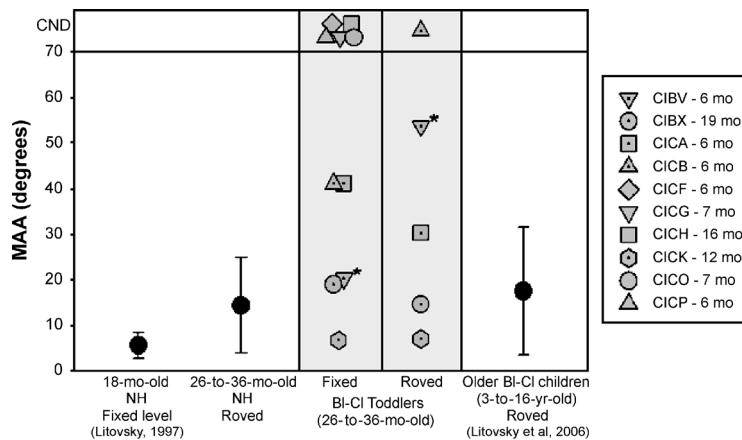


FIG. 3. Localization acuity is emerging in some toddlers with BI-CIs. Means ± 1 standard deviation are shown. Asterisks indicate that only 3 reversals were used to estimate MAA for this participant. CND, could not be determined. Time indicated in the legend represents the duration of experience with BI-CIs.

was achieved for at least 1 angle. Figure 3 illustrates the estimated MAAs of 4 groups of children (from left to right): 1) for comparison, NH 18-month-old children who completed the task with a fixed-level stimulus (9); 2) NH 26- to 36-month-old children who completed the task with intensity roving (this study); 3) deaf toddlers with BI-CIs (shaded gray area) who completed the task with a fixed-level stimulus and a subset of these children who repeated the task with intensity roving; and 4) for comparison, a group of older children with BI-CIs (13). When compared with their NH peers, the group of children with BI-CIs show large intersubject variability in performance, which is a common feature among individuals who use CIs (2,13–15). It is important to highlight, however, that 3 toddlers with BI-CIs seem to have age-appropriate localization acuity, both in the fixed-level and intensity-rove conditions.

DISCUSSION

Observer-Based Psychophysical Procedure

The first main result of this study is that the observer-based psychophysical procedure is a feasible method to assess localization acuity both in toddlers with NH and toddlers with CIs. Although this method was designed for infants, it proved to be quite successful for use with slightly older toddlers when using age-appropriate reinforcement. The observer-based psychophysical procedure holds much promise in the evaluation of infants and toddlers with CIs, especially because objective behavioral data from these children are lacking. For example, this method has recently been used to measure psychometric functions for detection in even younger children who use CIs (16).

Toddlers With Bilateral CIs

The second result of this study, which addresses our initial hypothesis, is that localization acuity seems to be emerging in half ($n = 5$) of the children who use BI-CIs, with 3 children approaching age-appropriate performance.

The other 5 children with BI-CIs, however, did not score above 80% correct on this task, even at the largest angle tested (70 degrees); most of these children had only 6 to 7 months of bilateral exposure (except for CICH, see below). Although these data are preliminary, they suggest that a predictor of performance will be duration of BI-CI use, with children who have longer exposure to bilateral input performing better. If this is true, then we would expect MAAs to continue to decrease, or improve, over time (indicating the maturity of localization skills) in these children, especially since spatial hearing continues to develop throughout the first 5 to 7 years of life (9).

The participants with the greatest amount of bilateral experience (CIBX and CICK) performed somewhat better in both the fixed and roved conditions than the listeners with only 6 to 7 months of bilateral use. It is interesting to note that 1 participant with more than 12 months of BI-CI experience (CICH) could not perform the task above chance levels. This child is different from CIBX and CICK in that his CI microphones were placed on his shoulders, whereas CIBX and CICK had microphone placements at or near their ears. This preliminary finding raises the hypothesis that microphone placement may influence the extent to which spatial hearing will develop in children who use BI-CIs. These data suggest that participants who have processor microphones in the most natural position (at or near the ears) may outperform listeners with processor microphones located away from the ears. Although this hypothesis would be consistent with the contribution of the head (and head motion) to sound localization skills, a more extensive investigation of this issue is necessary.

The Effect of Intensity Roving

The third result of this study relates to the effect of intensity-roved stimuli. The purpose of intensity roving is to minimize overall level cues that can be used to identify source locations when the intensity level is fixed (6). In the present study, roving had a variable effect on performance in children with BI-CIs. In 3 of 5 listeners who

completed the fixed and roved conditions, MAAs were either unchanged or slightly better in the roved condition. It is important to note that these listeners (CIBX, CICA, and CICK) were among the children who had the smallest interval between the activation of their 2 implants (0–2 mo); thus, they had very little exposure to unilateral input. The other 2 listeners (CIBV and CICB), who had 7 to 14 months of experience with a single device before receiving their second implant, performed more poorly in the roved condition. Taken together, these data suggest that the ability to use interaural cues may be expedited in children who have more experience with their BI-CIs or who have a smaller interval between receiving their first and second implants.

The effect of intensity rove was also seen in the NH toddlers. As seen in Figure 3, performance of the NH 26- to 36-month-old children, who completed the task with intensity roving, is slightly poorer than that of the 18-month-old children from Litovsky (9), in which roving was not used. These data are consistent with the idea that the task is more difficult for toddlers when intensity roving is implemented. In addition, the larger variability within the group of 26- to 36-month-old NH children would be consistent with a skill that is most likely still emerging at this age (17).

SUMMARY

Although only half of the participants with BI-CIs had measurable MAAs, none of the children using a U-CI could perform the right-left discrimination task above chance. This suggests that bilateral input, even through 2 CI processors that are not coordinated, can promote development of spatial hearing at a young age. The difference in performance between the BI-CIs and U-CI groups cannot be attributed to differences in chronological age or total length of hearing experience because the children in the U-CI group were at a slight advantage in each category.

One possible problem in using the adaptive version of the right-left discrimination task is that the performance of these listeners may have been underestimated because of factors such as fatigue, inattentiveness, and/or confusion about the task (18). These factors may contribute to the inconsistent responses seen in Figure 2C. One possible solution to this problem is to increase reliability by using a method of constant stimuli at fixed angular displacements. This modified adaptive method allows a larger number of trials to be completed at each angle, can be tailored to each participant because decisions about what angles to measure are based on previous performance at larger or smaller angular displacements, and has been used previously in older children with BI-CIs (3,13). Although there is a greater potential for habituation in listeners with this modified adaptive method, it may provide a secondary means by which localization acuity can be assessed (and thus incorporate within-subject test reliability).

In summary, we have illustrated a method that can be used to measure acuity of spatial hearing in young BI-CI users. With the steadily decreasing age at which children are receiving BI-CIs, this approach could also be extended to even younger populations of infants and listeners that are difficult to test.

Acknowledgments: The authors thank all of the families who participated in this project. The authors also thank Dasika Vasant for helpful discussions regarding experimental methods; Gongqiang Yu for software development; and Shelly Godar, Susan Richmond, Molly Bergsbaken, Tanya Jensen, and Kristie Henslin for assistance in data collection.

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