

## Should Children Who Wear a Cochlear Implant in One Ear Use a Hearing Aid in the Opposite Ear?

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### Introduction

People who can hear with both ears understand speech better in noisy environments and locate where sounds come from better than those who hear with only one ear. Hearing-impaired children are, therefore, generally fitted with two hearing aids so that they could benefit from hearing binaurally. Children who use a cochlear implant in one ear and no amplification in the opposite ear are, however, deprived of these advantages. If the non-implanted ear were left unaided for too long, its ability to process speech would decrease (Gelfand and Silman 1993; Gatehouse 1992). Although the residual hearing in the ear is often useable for acoustic amplification, there has been little consideration of fitting a hearing aid to the non-implanted ear. Clinicians and professionals who work with children had uncertainties about how to fit, and whether it is beneficial to do so. Does a hearing aid need to be adjusted differently depending on whether a cochlear implant or a hearing aid is worn in the other ear? Does the use of a hearing aid interfere with the use of a cochlear implant? Can a child integrate information from an acoustic input and an electrical input to obtain binaural benefits? Would these benefits, if any, be affected by the implant processing strategy? Does a period of discontinued hearing aid use after implantation prevent a child from deriving hearing aid benefit? In this paper, we will address these questions by reviewing some recent work at the National Acoustic Laboratories in Australia.

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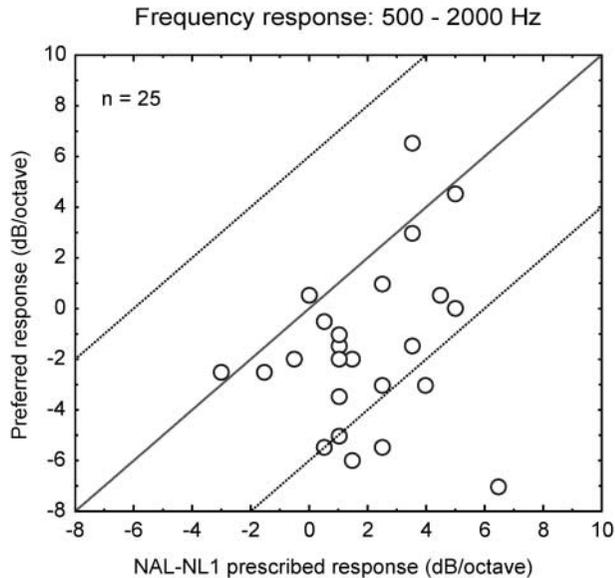
### Does a Hearing Aid Need to be Adjusted Differently When Used with a Cochlear Implant?

We determined the hearing aid requirements of 25 children who wear a cochlear implant and a hearing aid in contralateral ears using a procedure that involved judgments of speech intelligibility and loudness, as described in detail in Ching, Psarros, Hill, Dillon and Incerti (2001a). The average hearing thresholds of the children in the non-implanted ear at 500 Hz, 1000 Hz, and 2000 Hz were 95 dB HL, 103 dB HL, and 113 dB HL respectively. Eight of the children did not have measurable thresholds at 2000 Hz and above (audiometer limit = 120 dB HL).

Briefly, a paired-comparisons test was used to find the frequency response that was best for understanding speech. The children wore a hearing aid in one ear, and listened to a story presented audiovisually. They compared speech amplified using the NAL-NL1 prescription (Dillon 1999) with speech amplified with either more or less high-frequency emphasis than the prescription, and chose the frequency response that was best for understanding speech.

To find the overall gain required by the children, speech was presented first to the ear with a cochlear implant and then to the ear with a hearing aid. The children were required to compare the loudness of speech between ears, and judge whether speech sounded louder in one ear. The overall gain of the hearing aid was adjusted using a bracketing method until speech was judged to sound equally loud in both ears.

Figure 1 shows the frequency response slope



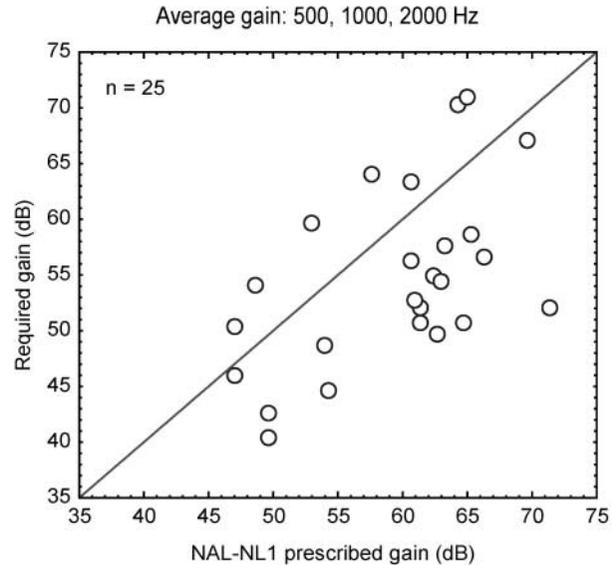
**Figure 1.** Preferred frequency response in relation to the NAL-NL1 prescribed frequency response. Frequency response slope from 500 to 2000 Hz is expressed in terms of dB/octave. The diagonal line shows complete agreement, and the broken lines on either side represent  $\pm 6$  dB/octave.

(500–2000 Hz) found to be best for understanding speech compared to the NAL-NL1 prescription for 25 children.

Eighty percent (20) of the children preferred a frequency response that was within  $\pm 6$  dB/octave of the NAL-NL1 prescription. The remaining found a frequency response that had less high-frequency emphasis than the prescription to be better for understanding speech. On average, the preferred gain at 500 Hz was not significantly different from the prescription ( $p > 0.05$ ), but the preferred gain at 1000 Hz and 2000 Hz was significantly less than the prescribed gain ( $p < 0.05$ ).

Figure 2 shows the three-frequency-average (500, 1000, 2000 Hz) gain required by the children compared to the NAL-NL1 prescription. The children's required gain was on average 4 dB less than the prescribed gain ( $p < 0.05$ ).

These results suggest that the NAL-NL1 prescription can be used to prescribe a hearing aid for a child who also uses a cochlear implant in the other ear. The prescription provides suitable amounts of gain at low and high frequencies for 80% of the children tested, and 20% required less high-frequency gain. Using any other procedure that prescribes greater high-frequency emphasis than the NAL-NL1



**Figure 2.** Required gain averaged over 500, 1000, and 2000 Hz in relation to the NAL-NL1 prescribed gain. The diagonal line shows complete agreement.

would result in providing too much high-frequency gain to an even greater proportion of children. The individual variability shown in the preferred frequency response and required overall gain indicates that it is beneficial to evaluate and fine-tune a hearing aid according to the needs of the individual child.

## Does a Hearing Aid Interfere with a Cochlear Implant?

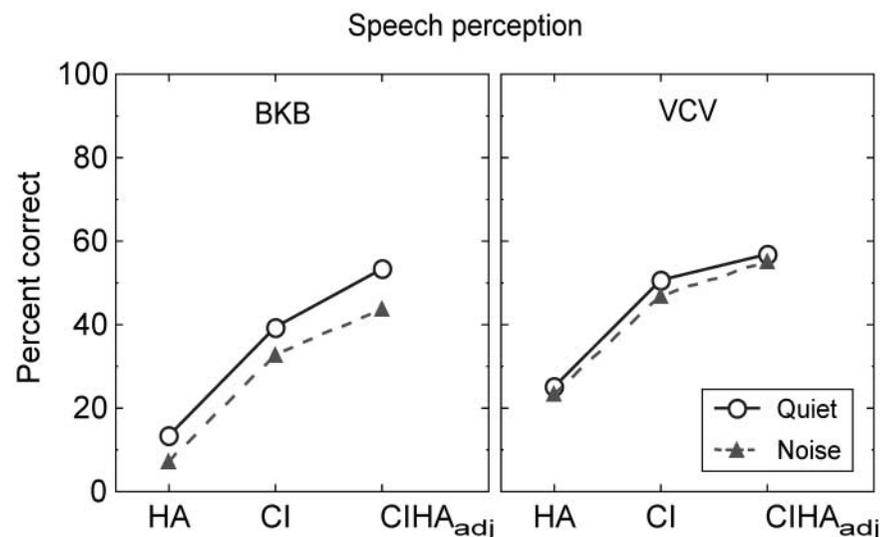
A major concern for fitting a hearing aid to a child with an unilateral cochlear implant is that the acoustic input and the electrical input might not integrate to form a percept, thereby leading to interference. Ching et al. (2001a) examined whether the use of a hearing aid with a cochlear implant interfered with speech perception in a diotic listening condition where the same acoustic signal was presented to both ears. Eleven children who used either a Nucleus 22 or a Nucleus 24 cochlear implant system programmed with the SPEAK strategy in one ear were evaluated. Each child also wore a Bernafon AF120 behind-the-ear hearing aid in the contralateral ear. The hearing aid was adjusted using the procedure described above after a stable implant MAP was established. The children were presented with speech and babble noise from the same loudspeaker positioned at  $0^\circ$  azimuth at a distance of one meter. They were asked to repeat

BKB sentences (Bench and Doyle 1979) and nonsense syllables presented both in quiet and in 4-talker babble noise at a signal-to-noise ratio of 10 dB. Performance was measured when the children used hearing aids alone, cochlear implants alone, and cochlear implants with adjusted hearing aids. Figure 3 shows the mean speech perception results. The children perceived sentences better when using a cochlear implant with a hearing aid compared to using a cochlear implant alone both in quiet and in noise. Evidently, there was no hearing aid interference with the cochlear implant. Analysis of the consonant confusion based on responses to nonsense syllables in terms of relative information transmitted did not support any instance of confusion either. Not only was there no degradation in performance in the binaural condition compared to the monaural condition, there was an increase in manner information transmission in quiet, and an increase in voicing and manner information transmission in noise. The speech results indicated that no interference occurred in the diotic listening condition, and that the children were able to integrate an acoustic input with an electrical input to derive benefits due to binaural redundancy (Dillon 2001). Speech perception improved both for listening in quiet and in noise even when the same speech and noise mixture is available at each ear.

### Are There Advantages of Binaural/Bimodal Amplification Under Real-Life Dichotic Listening Situations?

The benefit from binaural hearing under dichotic listening conditions can be even greater than that in a diotic condition due to head diffraction effects. When inputs are received in both ears, a child can benefit from using information provided to the ear with a better signal-to-noise ratio. Ching et al. (2001a) reported that children obtained benefits in horizontal localization and functional performance in real-life when using cochlear implants with hearing aids. Horizontal localization was measured using an array of eleven loudspeakers spanning a range of 180° at ear level. Noise bursts were presented from a randomly chosen loudspeaker, and the children had to identify the source loudspeaker. When the children were using cochlear implants with hearing aids, they made significantly less errors than when they used cochlear implants alone ( $p < 0.05$ ). The mean number of errors was reduced from 37 for the monaural condition to 30 for the binaural condition.

Functional performance in real-life was assessed using a structured interview of the parents based on a



**Figure 3.** Mean percent correct for 11 children when aided with hearing aid alone (HA), cochlear implant alone (CI), and cochlear implant with hearing aid (CIHA). The left panel shows sentence scores (BKB), and right panel shows consonant scores (VCV). Circles represent results in quiet, and triangles represent results in noise.

questionnaire. The parents were required to observe their child's performance in a range of real-life situations over a week during which the child used either a cochlear implant alone, or a cochlear implant with a hearing aid. None of the parents judged their child to be functioning poorer when wearing a cochlear implant with a hearing aid compared to wearing a cochlear implant alone. On average, the questionnaire score for the binaural condition was significantly better than the monaural condition ( $p < 0.05$ ). The mean difference score between the two aided conditions was 7%. Parents also commented that the children participated more actively in conversations and were more confident in conversing with unfamiliar persons.

The speech results reported in Ching et al. (2001a) are consistent with those reported in previous literature (Simon-McCandless and Shelton 2000; Chmiel, Clark, Jerger, Jenkins and Freeman 1995) indicating that some binaural benefits in speech perception can be obtained. Horizontal localization was not assessed in any of the previous studies on children (and adults) with cochlear implants. This is nonetheless an important auditory skill that enables a person to alert to the source of sounds that can be cause for alarm, and to turn to a talker in a group situation where conversation switches from one talker to another. Without audibility in both ears, this skill is severely degraded. Ching et al. (2001a) showed that children performed at chance level when they used cochlear implants alone, but some were able to use the 'distorted' inter-aural cues for locating sounds on a horizontal plane when they also wore hearing aids.

An important dimension in assessing binaural effects is whether binaural hearing benefited aural/oral function in everyday life communicative situations. Test arrangements in a laboratory can at best simulate some conditions in real life, and the benefits measured in the controlled setting may or may not transfer to real-life situations. Ching et al. (2001a), and Ching, Psarros and Hill (2001b) reported that parents' systematic observations of their children's performance indicated that the children functioned more effectively in a variety of communicative situations experienced in real life when they were aided binaurally than monaurally. This suggests that the children were able to integrate and utilise information from an acoustic and an electrical input.

## **Is Hearing Aid Benefit Affected by the Implant Processing Strategy?**

Previous research on hearing aid benefit for children who use cochlear implants has primarily been based on users of the Nucleus 22 cochlear implant system programmed with the Multipeak or the SPEAK strategy (Chmiel et al. 1995; Simon-McCandless and Shelton 2000; Ching et al. 2001a). Advances in cochlear implant technology and processing strategy have led to the implementation of the ACE strategy in the Nucleus 24 system. The theoretical advantage of the ACE over the SPEAK strategy has been attested by speech perceptual measures of adults (Arndt, Staller, Arcaroli, Hines and Ebinger 1999), and to a lesser extent, children (Psarros et al. in press). Whether this means that children who use the ACE strategy received so much more information than the SPEAK strategy as to render the use of a hearing aid ineffectual was investigated by Ching et al. (2001b).

Speech perception, localization, and parents' observations of children's functional performance in everyday life were assessed for five children who switched from the SPEAK to the ACE strategy. Hearing aid benefit was quantified by calculating the difference scores between cochlear implant and hearing aid condition and cochlear implant alone condition for each implant processing strategy. Results indicated that the speech scores for the implant and hearing aid condition were either similar to or better than those for the implant alone condition, irrespective of which implant strategy the children were using. On average, there was an increase in the reception of information pertaining to consonant voicing and manner of articulation when a hearing aid was used with an implant, both for the SPEAK and the ACE implant strategy. Hearing aid benefit in horizontal localization was indicated for four of the five children tested. The parents also rated the children to be functioning better in real-life when they were aided binaurally than monaurally. Clearly, the children benefited from using a hearing aid in the contralateral ear, regardless of whether they used the SPEAK or the ACE strategy in the cochlear implant system.

## Does Discontinued Hearing Aid Use After Implantation Prevent a Child from Deriving Binaural Benefit from a Hearing Aid Fitted Retrospectively?

Past practice in managing children with unilateral cochlear implantation discouraged the use of a hearing aid in the non-implanted ear. It was reasoned that a child needed a cochlear implant because a hearing aid failed to deliver useful information to the child. Furthermore, it was speculated that an acoustic signal in the non-implanted ear would interfere with the electrical signal provided by the implant. Now that audiometric selection criteria for cochlear implantation have changed, more children with unilateral cochlear implants have useful residual hearing in the non-implanted ear. Emerging research evidence has led to a better understanding of potential hearing aid benefit for implant users. These have led to modifications in current management practice for children (Psarros, Ching and Hill in review), and children who have unilateral implants are encouraged to wear a hearing aid in the non-implanted ear. Procedures and strategies are also implemented to facilitate integration of information from both ears. However, older children who were implanted some years ago had discontinued hearing aid use after implantation. Our current study aimed to examine whether these children could derive benefits from a hearing aid fitted retrospectively to the non-implanted ear.

### Subjects

Seven children aged between 7 and 9 years participated in this study. They used a Nucleus 22 or Nucleus 24 cochlear implant system programmed with the SPEAK or the ACE strategy, and had stable implant MAPs. After implantation, all children ceased to wear a hearing aid in the non-implanted ear, and hearing was no longer monitored in the unaided ear. At the commencement of the study, the

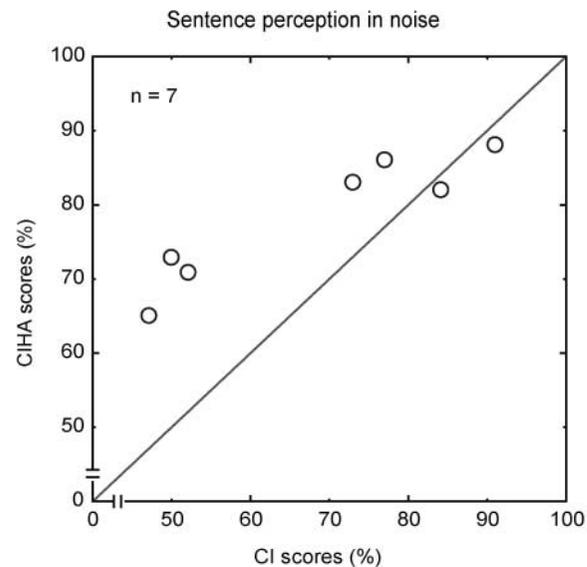
period of hearing aid non-use for these children ranged from four to six years. The hearing thresholds in the non-implanted ear are shown in table 1.

### Hearing Aid Fitting and Adjustment

A Bernafon AF120 behind-the-ear hearing aid was fitted to each child according to the NAL-NL1 prescription (Dillon 1999). The children were encouraged to gradually increase hearing aid usage with cochlear implant until they were using both devices for at least six hours a day. About a month after the fitting, each child's hearing aid was optimised using the procedures described previously.

### Assessment of Hearing Aid Interference in Diotic Listening

A test of speech perception in noise was used to assess whether the use of a hearing aid interfered



**Figure 4.** Individual sentence scores in percent correct for implant and hearing aid (CIHA) in relation to implant alone (CI) for 7 children.

**Table 1.** Mean hearing threshold level (HTL), standard deviation (SD), and Range of HTL for 7 children.

Frequency (Hz)	250	500	1000	2000	4000
HTL	85	99	102	109	109
SD	19	15	10	17	18
Range	55–110	70–115	85–110	80–125	75–125

with the use of a cochlear implant. Speech and babble noise were presented from the same loudspeaker placed in front of a child at a distance of one meter. BKB sentences were presented at 70 dB SPL, and babble noise was presented at a signal-to-noise ratio of 10 dB. On average, scores increased from 68% for the monaural condition to 78% for the binaural condition. Figure 4 shows the individual speech scores obtained with implant alone, and with implant and hearing aid. Five children scored higher in the binaural than in the implant alone condition, and the remaining two scored equally well for both conditions. No evidence of interference was indicated.

### Assessment of Binaural Benefits in Dichotic Listening

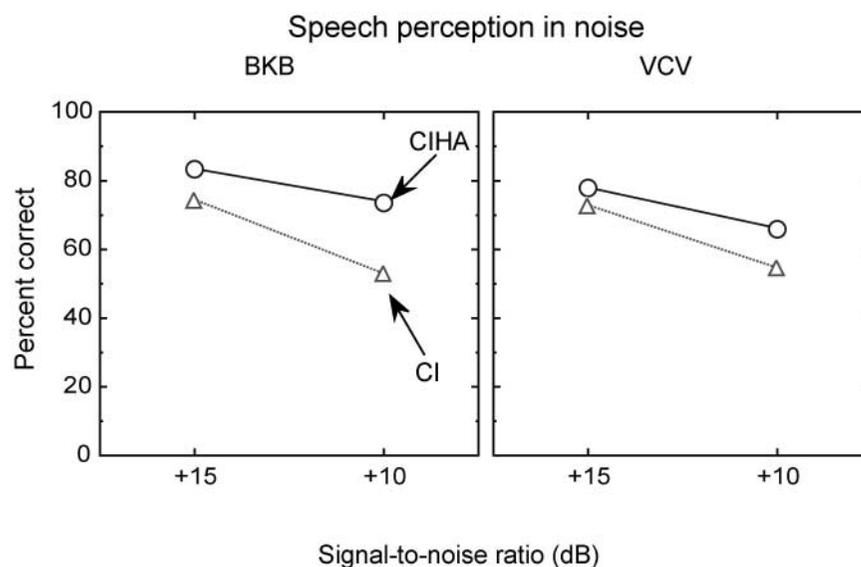
Speech perception, horizontal localization, and functional performance of each child were assessed when the child wore a cochlear implant alone, and a cochlear implant with a hearing aid.

Sentence perception and consonant recognition were measured in babble noise. Speech and babble noise were presented from separate loudspeakers located at  $\pm 60^\circ$  azimuth. Speech was always presented on the side where the child wore a hearing aid, and noise on the side where the child wore a cochlear implant. Performance was measured at signal-to-

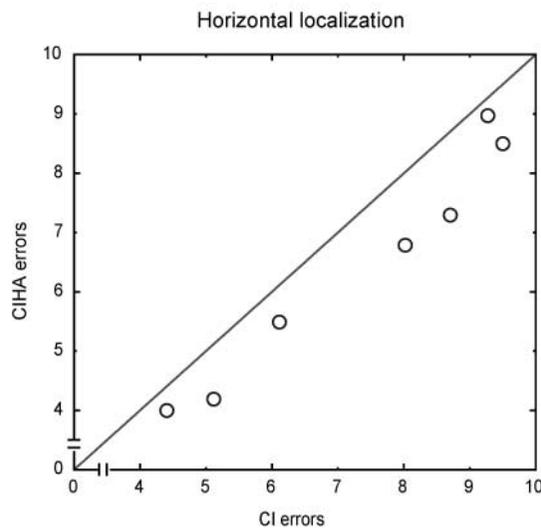
noise ratios of 15 dB and 10 dB. Figure 5 shows the mean speech scores for the two aided conditions. On average, the speech scores for the binaural condition were significantly better than the monaural condition ( $p < 0.05$ ). The improvement was greater at the more adverse signal-to-noise ratio.

Horizontal localization was measured using an array of five loudspeakers spanning a range of  $120^\circ$  placed at a distance of one meter from the subject position. Pink noise bursts were presented from each loudspeaker at random, and the child was required to identify the source loudspeaker. On average, the difference was significant ( $p < 0.05$ ) although the effect was small (mean difference between the number of errors for the monaural and the binaural conditions is one). Figure 6 shows the individual results indicating a reduction in localization errors for five children when they wore hearing aids with cochlear implants than when they wore cochlear implants alone. Two children performed at chance level (number of errors = 8) for both aided conditions.

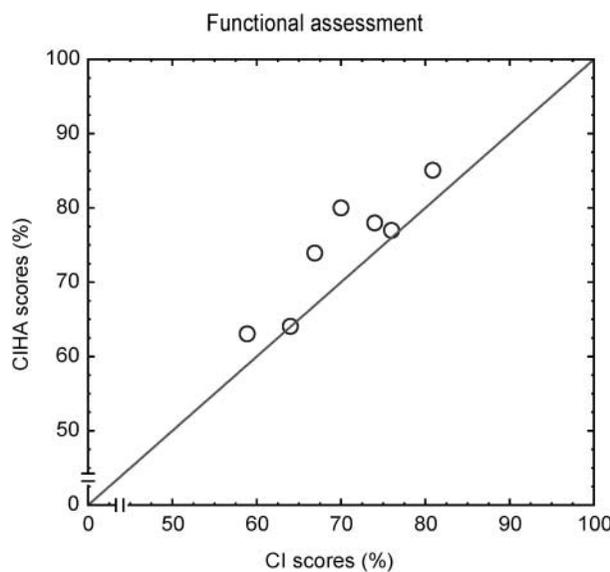
Functional performance was evaluated by systematic observations of the children's aural/oral function in different communicative situations in real life. The children wore cochlear implants alone, and cochlear implants with hearing aids, each for a week. During this time, the parents recorded their child's performance using a questionnaire. The parents were



**Figure 5.** Mean percent correct for 7 children when listening to sentences (BKB) and consonants (VCV) presented at 15 dB and 10 dB signal-to-noise ratios. Circles represent implant and hearing aid (CIHA), and triangles represent implant alone (CI) scores.



**Figure 6.** Individual localization errors for implant and hearing aid (CIHA) compared to implant alone (CI). The diagonal line shows complete agreement.



**Figure 7.** Individual questionnaire scores for implant and hearing aid (CIHA) compared to implant alone (CI). The diagonal line shows complete agreement.

interviewed at the end of each trial period. The individual questionnaire scores are shown in figure 7.

The scores are generally similar or higher for the implant and hearing aid condition than for the implant alone condition. The mean difference was

significant ( $p < 0.05$ ) although the effect was small. Some of the binaural advantages that parents reported include an increased alertness to environmental sounds, better speech perception in quiet and in noise, as well as clearer speech production. One parent also noticed that her child was able to pick up other people's conversations when she wore a hearing aid with a cochlear implant, whereas she was unable to do so when she used a cochlear implant alone. None reported any observable disadvantages arising from the children's use of binaural amplification.

All children demonstrated binaural benefits in at least one of the measures. These preliminary results suggest that hearing aid use should be encouraged, even for children who have discontinued hearing aid use after implantation.

## Summary and Conclusion

In summary, the NAL-NL1 prescribes an appropriate gain-frequency response for 80% of the children who wear cochlear implants with hearing aids, and the remaining children preferred a frequency response that had less high-frequency emphasis than the NAL-NL1 prescription. Individual hearing aid adjustment with a cochlear implant can be implemented to optimise hearing for each child.

There is no indication that the use of a hearing aid and a cochlear implant leads to interference or confusion. This is true of children who continue to use hearing aids after implantation, as well as children who discontinued hearing aid use but were refitted with a hearing aid between four to six years after implantation.

Binaural benefits in speech perception, localization, and aural/oral function in real life can be obtained, both for children who have and have not continued to use hearing aids after implantation. Benefits can be obtained regardless of whether the children were using the SPEAK or the ACE strategy in their cochlear implants.

Therefore, children with unilateral cochlear implants should not be deprived of the benefits of binaural hearing by being denied amplification in the non-implanted ear. Prospective implant candidates should be counselled of the potential benefits of continual hearing aid use in the non-implanted ear. Management programmes for children with cochlear implants should incorporate guidelines and procedures for encouraging and facilitating the use of hearing aids with cochlear implants.

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