Bimodal Hearing

A guide to fitting

Hear now. And always

Cochlear™

Contents

Background

Hearing Aids Complement Cochlear Implants: Binaural Benefits

Teresa YC Ching, PhD; Paula Incerti, M Aud; Mandy Hill; Jane Brew

This article summarizes empirical evidence on the binaural benefits that can be derived from wearing a hearing aid with a cochlear implant (bimodal hearing devices), and discusses issues associated with clinical management of adults and children.

A person who has severe to profound hearing losses in both ears but wears a cochlear implant in only one ear may experience considerable hearing deficits in localization and speech intelligibility. The ability to localise sounds is highly dependent on being able to perceive sounds in both ears. When the low-frequencies are clearly audible in both ears, the brain can make use of the differences in time and intensity of sounds reaching the two ears to locate where a sound comes from on the horizontal plane. When sounds are inaudible in one ear, localization becomes very difficult (Byrne, Noble and LePage, 1992; Byrne and Noble, 1998). Reduced localization may lead to reduced safety, and difficulties in social functioning when understanding speech is reliant on lipreading.

Further, listening with two ears enables a person to understand more when speech occurs in background noise. This is because binaural processes related to head diffraction, binaural squelch, and binaural redundancy facilitate speech perception (Dillon, 2001). Due to the physical size of the head, a sound on the right side of the head will reach the right ear a bit sooner than it will reach the left ear. It will also be slightly louder in the right than in the left ear. This head diffraction effect will enhance speech intelligibility in noise when speech and noise come from different sides of the head, because the brain can selectively attend to the ear with a better signal-to-noise ratio (SNR) for understanding speech. Even when the same signal and noise reach both ears, the brain can combine both inputs to produce more salient central representations of the speech signal than if only input from one ear is available (binaural redundancy). The brain can also make use of the inter-aural time differences to partially reduce the deleterious effect of noise (binaural squelch).

For unilateral cochlear implant users who have residual hearing in the non-implanted ear, it is possible to provide binaural hearing by fitting a hearing aid to that ear. There is increasing evidence on the binaural benefits that are possible with the use of bimodal hearing devices.

Speech Intelligibility

Many studies have measured the speech perceptual abilities of people who use cochlear implants and hearing aids. The following summarizes the data according to those that evaluated binaural redundancy, and others that assessed head diffraction effects and binaural squelch effects.

Binaural Redundancy

When speech and noise were presented from the same loudspeaker positioned at a fixed distance in front of the subject, the signal-to-noise ratio is similar at both ears. In this test situation, binaural/bimodal hearing is still superior to monaural hearing with CI alone, as long as the hearing aid causes speech in any frequency range to be audible. Figure 1a,b summarises the sentence perception data reported in previous literature for adults (Shallop et al, 1992; Dooley et al, 1994; Blamey et al, 1997; Armstrong et al, 1997; Tyler et al, 2002; Syms III & Wicklesberg, 2003; Ching et al, 2004; Hamzavi et al, 2004) and for children (Simon-McCandless, 2000; Ching et al, 2001; Ching et al, submitted). Results from listening in quiet (Figure 1a) and in noise (Figure 1b) are shown, with averaged results from each study represented by a data point. Greater binaural/bimodal advantage is evident for speech perception in noise than in quiet.

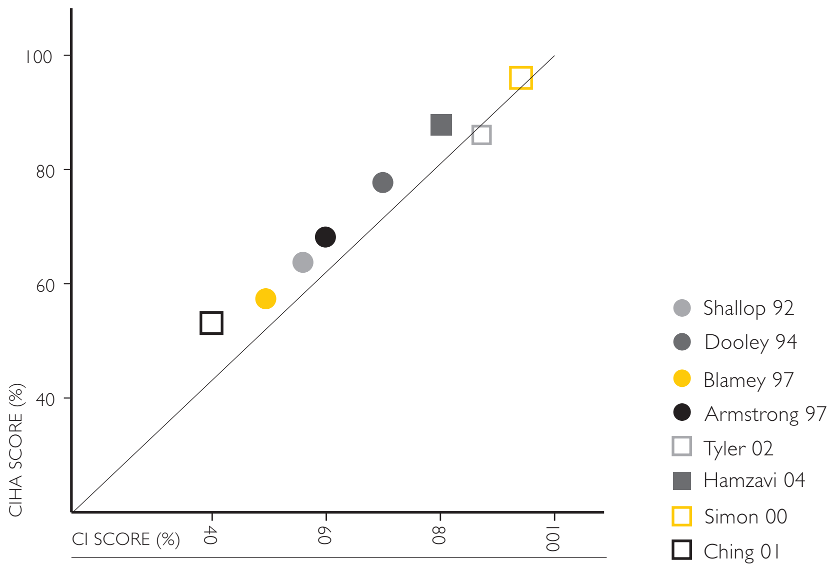


Figure 1a. SENTENCES IN QUIET

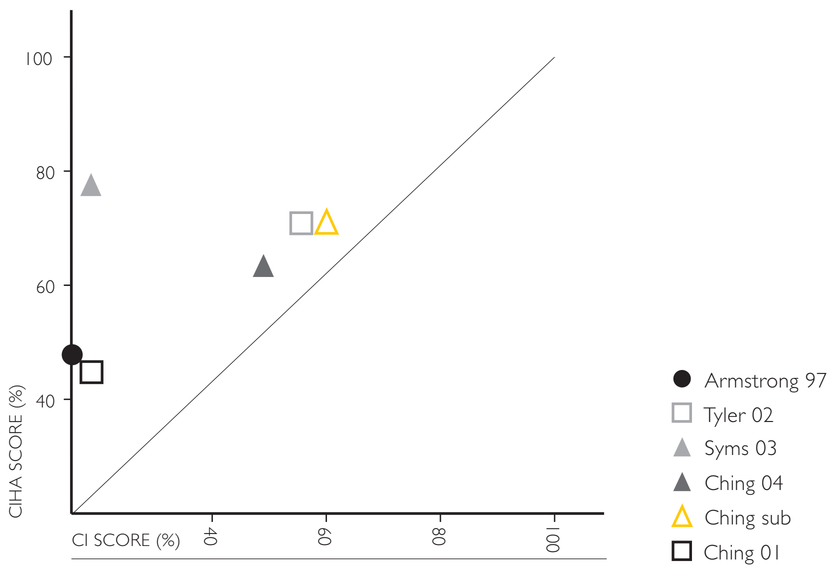


Figure 1b. SENTENCES IN NOISE

Figure 1. Sentence perception in quiet and in noise from spatially co-incident sources (1a and 1b), and sentence perception in noise from spatially separated sources (1c) are shown. Percent correct scores for cochlear implant alone (CI) are presented in relation to those for cochlear implant and hearing aid (CIHA). Each data point shows the averaged results from one study. The filled symbols are for adults and the open symbols are for children. The diagonal line represents no improvement of the CIHA condition over the CI condition.

Head Diffraction

The effect of head diffraction has been measured by presenting speech and noise from spatially separated sources in two studies for adult listeners (Tyler et al, 2002; Ching et al, 2004) and one study for child listeners (Ching et al, submitted). Data on the mean cochlear implant (CI) and cochlear implant and hearing aid (CIHA) scores reported in these studies are shown in Figure 1c, with each data point representing averaged results from one study.

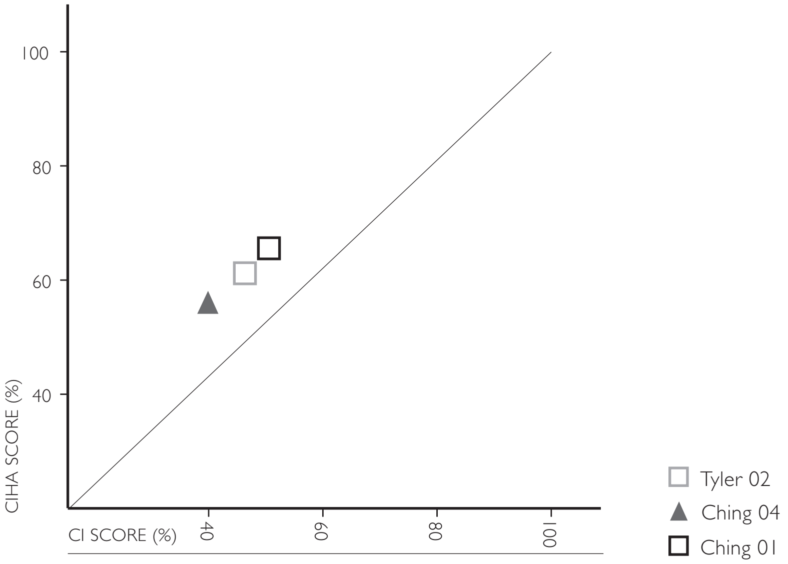


Figure 1c. SENTENCES IN NOISE
Dichotic Listening

Both adults and children understood sentences better in noise when using CIHA compared to CI alone in the dichotic listening condition. These results were obtained when speech was presented nearer to the hearing aid side, and noise was presented nearer to the cochlear implant side. The hearing aid would of course not lead to any benefit, or may even be detrimental to speech perception, if speech were to come from the side nearer the cochlear implant and noise from the side nearer the hearing aid (as described in Tyler et al, 2002).

Access to head diffraction differences is possible only if the hearing aid causes the mid- or high-frequency parts of speech to be clearly audible. It follows that benefits due to head diffraction effects may be compromised when the residual hearing in the ear aided with a hearing aid is limited to very low frequencies, and when the hearing aid fitting does not provide clear audibility at frequencies where there is functional hearing.

The speech results from both adults and children shown in Figure 1 support the fitting of a hearing aid to the non-implanted ear of unilateral cochlear implant recipients.

Binaural Squelch

People who use current bimodal hearing devices are not able to make use of binaural squelch for speech perception if the degree of hearing loss in the non-implanted ear is severe or profound. This is supported by direct research into the ability of hearing-impaired listeners to make use of inter-aural time delay for perceiving sentences in speech-shaped noise (Ching et al, in preparation). The study concluded that whereas normal hearing listeners and moderately hearing-impaired listeners using bilateral hearing aids perceived sentences better when the noise was delayed in one ear relative to the other than when it was not delayed, the same was not observed for listeners with more severe hearing losses, irrespective of whether they used bilateral hearing aids or bimodal hearing devices. The finding is consistent with a previous study on hearing-impaired listeners showing that the ability to use inter-aural time differences decreases as hearing loss increases, and that masking release is negligible for hearing losses exceeding 50 dB HL (Jerger et al, 1984). Even if bimodal hearing devices users have moderate degrees of hearing loss in the non-implanted ear, their access to binaural squelch will be limited by the extent to which the cochlear implant preserves fine timing information.

Localization Advantages

A few studies have examined the sound localization ability of unilateral cochlear implant child users (Ching et al, 2000; Ching et al, 2001; Ching et al, submitted) and adult users (Tyler et al, 2002; Ching et al, 2004). Measurement methods varied in detail, but such variations do not alter the two general findings that localization ability is poor for unilateral cochlear implant users, and that the ability is improved when a hearing aid is worn with a cochlear implant. Figure 2 shows mean results summarized from the three studies on children and one study on adults that reported rms localization errors. (Tyler et al, 2002 gives a percentage correct score rather than rms error for 3 adults tested using an array of two loudspeakers.) The data on adults were drawn from Ching et al (2004) in which an array of 11 loudspeakers (a 180° arc, with loudspeakers at 18° apart) were used and pink noise pulses were presented at 65 dB SPL from one of the loudspeakers at random. The subjects responded by identifying the loudspeaker from which the noise originated. Data from two of the studies on children used the same test method (Ching et al, 2000; Ching et al, 2001), and data from one study was based on an array of 5 loudspeakers at 30° apart. Performance was scored as rms error between the source and the response loudspeakers, expressed as degrees.

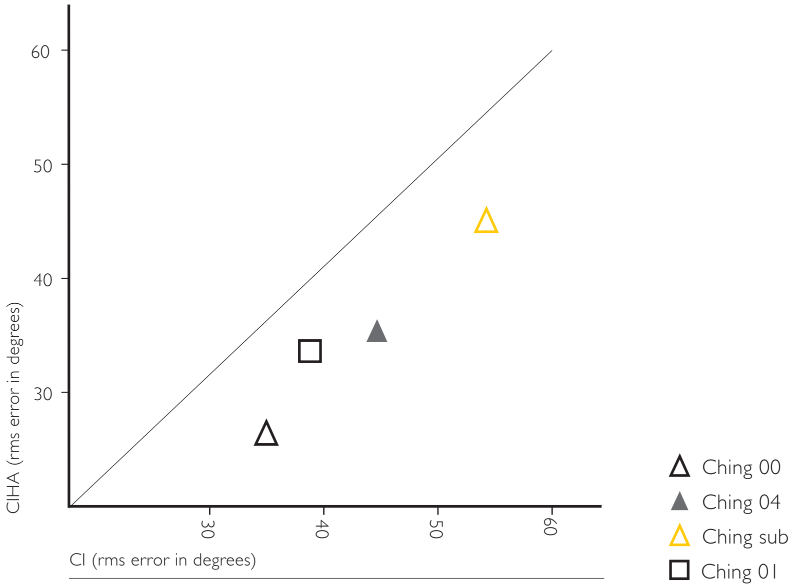


Figure 2. HORIZONTAL LOCALIZATION

Horizontal localization with cochlear implant alone (CI) compared to cochlear implant with hearing aid (CIHA). Each data point represents averaged rms error score from one study, expressed in terms of degrees. The filled symbols are for adults, and the open symbols are for children. The diagonal line represents no improvement of the CIHA condition over the CI condition.

These empirical results show that binaural interaction occurs with an implant and a hearing aid, and that both children and adults were able to make use of bimodal hearing to improve their localisation ability compared to the use of a cochlear implant alone.

Functional Performance in Everyday Life

Several studies have reported anecdotal comments from users of bimodal hearing devices about the superiority of wearing a cochlear implant with a hearing aid in everyday life, compared to the use of a cochlear implant alone. The comments from adults (Armstrong et al, 1997; Blamey et al, 1997; Tyler et al, 2002; Syms III & Wickesberg, 2003; Ching et al, 2004) and children (Simons-McCandless & Shelton, 2000) or parents of children (Ching et al, 2000; Ching et al, 2001; Ching et al, submitted) are summarized in Table 1. Adults' preference for using bimodal hearing devices appears to be dominated by the 'naturalness' of music, quality of speech and environmental sounds, and 'clarity' and 'distinctiveness' of people's voices. Parents commented on the children's improved social functioning abilities when using bimodal hearing devices due to increased ease of communication and enhanced confidence. Both adults and children commented on increased directional hearing, sense of security, and of sounds being perceived in the middle rather than in one ear.

a. Adult

	N	**Adult**
Armstrong et al, 1997	12	• more "natural" sound • sound is heard in both ears rather than through the implant alone • own voice quality is improved • a "full communication potential" is available
Blamey et al, 1997	50	• hear sounds in both ears rather than on one side • "naturalness" of overall percept
Tyler et al, 2002	3	• hearing aid picks up additional information, gives 'clarified' hearing • feels more comfortable hearing sounds in both ears • gets more directional sound • hearing aid adds a little to more hearing level, while my cochlear implant gives me the word and voice clarity.
SymsIII & Wickesberg, 2003	6	• better localization • better sound quality
Ching et al, 2004	21	• adds more 'brilliance' to people's voices • enjoy music more • identify speaker in a group • easier to listen to speech in shops and restaurants • gives a "better balance" • more confident in everyday life
Hamzavi et al, 2004	7	• some directional hearing • more speech-like sound quality

b. Child

	N	Child
Simons-McCandless & Shelton, 2000	4	• speech appears to be heard in the middle of his head rather than in one ear • provide added security if either were to stop working during a school day • prefers sound quality and localization ability with the use of both devices worn together
Ching et al, 2001	11	• initiate more conversation • understand more of what's being said • require less repetition • more willing to converse with unfamiliar persons • more confident in shops
Ching et al, 2000	5	• children generally functioned better in everyday life
Ching et al, 2002	7	• picks up other people's conversation • speaks more clearly
Ching et al, submitted	18	• imitate voice and intonation better • can localize sounds better • more spontaneous and responsive in conversations • doesn't mishear as much • can recognise songs on the radio • can distinguish between environmental sounds • can distinguish between people's voices • more confident with friends • participates more actively in games • enjoys jokes more • more talkative • more attentive • less repetition required

Four studies have used structured interviews based on questionnaires to solicit the information in a systematic way. The advantage in everyday life was quantified by comparing questionnaire scores between the CIHA and the CI conditions, based on real-life experiences over a period of one week for each condition. Figure 3 summarizes the data from adults (Ching et al, 2004) and children (Ching et al, 2000; Ching et al, 2001; Ching et al, submitted), with the mean result from each study represented by a data point. Functional performance is better with CIHA than with CI alone, both for adults and for children.

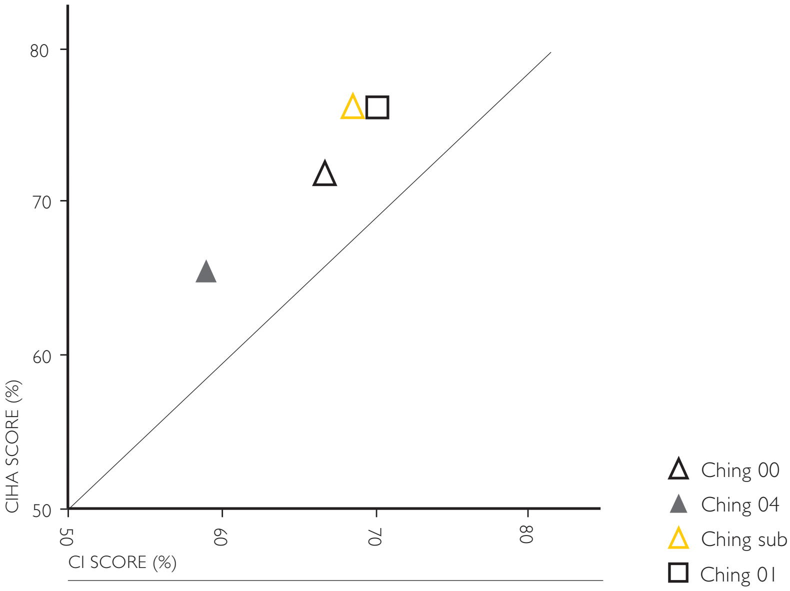


Figure 3. FUNCTIONAL PERFORMANCE

Functional performance with cochlear implant alone (CI) compared to cochlear implant with hearing aid (CIHA). Each data point represents averaged questionnaire scores in percentage terms. Results from children are based on parents' questionnaire scores, and results from adults are based on the adults' questionnaire scores.

In order to find out whether the children and adults who were fitted with a hearing aid due to their participation in a research study were wearing a hearing aid with a cochlear implant a year afterwards, we mailed out a questionnaire to all local participants (18 adults and 13 children) and conducted a telephone interview based on the questionnaire. The questionnaire included 4 questions on usage (how often did the subject use a cochlear implant and a hearing aid; a cochlear implant alone; which was the preferred amplification mode, and how much was the preferred mode better than the alternative mode); and 12 questions on preferences in a range of specific situations (talking to family/friends in quiet, in transport, in noise, recognising someone calling from behind and/or at a distance, watching TV or movie, listening to music, localizing sounds, detecting/ recognising sounds in the environment; and for children, communication in the classroom and in the playground were included).

Fourteen adults (78%) continued to use a hearing aid with an implant for at least 30 hours a week, two did not wear a hearing aid and were considering a second implant, and two had subsequently received a second cochlear implant. Ten children (77%) continued to use a hearing aid with a cochlear implant. One child ceased wearing a hearing aid with a cochlear implant some time after her participation in the study, despite her indication that using bimodal hearing devices was 'a lot better' than using a cochlear implant alone. This child was referred to her audiologist for follow-up counselling and management. One adolescent has not continued to wear a hearing aid now that he relies on his FM system that works with his implant only. One adolescent replied by mail because he could not communicate effectively over the phone. He uses a hearing aid alone, and doesn't use his cochlear implant with his hearing aid because it aggravates the noise problem he encounters in his work environment.

Four adults and the parents of twelve children completed the entire questionnaire on rating the relative efficacy of bimodal hearing devices in a range of situations. Figure 4 shows the overall preference in relation to the preference averaged across specific situations. All except two children rated CIHA to be better than CI overall, and that rating was consistent with the ratings based on a range of situations in real life. The situations in which a hearing aid complements a cochlear implant most effectively for children are 'talking to the teacher and to classmates in the classroom'; 'talking to friends in the playground'; 'recognising the caller when he or she called from behind'; 'communicating with family or friends in a bus/train/car'; and 'localising sounds'. One child commented especially on being able to hear better with both devices during dancing classes, and another commented on being able to hear the radio better when he used both devices.

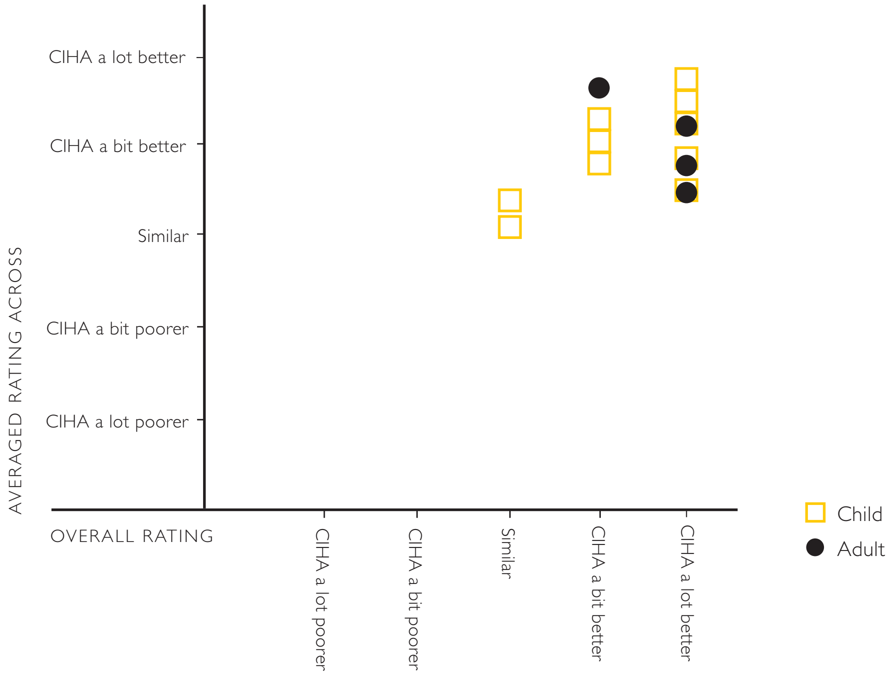


Figure 4. PREFERENCE JUDGMENTS

The overall preference scores in relation to the preferences averaged across 12 specific everyday life situations for adults (filled symbols) and children (open symbols).

All four adults continued to wear a hearing aid with a cochlear implant. Not only did they confirm that there were small improvements in understanding speech when 'talking to family and friends in quiet and in noise' and 'watching a movie or TV', but they also attested to the greater benefits associated with 'listening to music'; 'localising sounds'; 'recognising sounds and voices in the environment'; and 'recognising who called when someone called from a distance and/or from behind'. The adults also explained that they selectively used bimodal hearing devices in certain situations, but a cochlear implant alone in some other situations. For instance, one adult commented that she would turn her hearing aid off in noisy social situations when she wanted to listen to the friend on the side nearer her cochlear implant. Another commented that he would not wear his hearing aid when he rode his motor bike so as to cut down on wind noise.

These results from the follow-up study, albeit from a very small sample, confirmed the contribution of a contralateral hearing aid to a unilateral cochlear implant in some everyday life situations, but also revealed that individual management strategies are required to encourage the effective use of binaural amplification, especially for children.

Clinical Issues

Pre-implant and post-implant counseling

There is no direct evidence to indicate that people who received pre-implant counseling on the use of bimodal hearing are more likely to continue using a hearing aid after implantation. Indeed, a survey of 71 adults who received unilateral cochlear implants at the Melbourne implant clinic (Cowan & Chin-Lenn, 2003) revealed that 53 (75%) continued to use a hearing aid in the non-implanted ear immediately after implantation although no specific counseling on bimodal hearing was provided. They rated bimodal hearing for speech in noise and localization to be significantly better than using a cochlear implant alone. Of the 53 adults, 51% had their hearing aids fine-tuned to facilitate bimodal hearing. It may be surmised that the remaining 26 users may derive greater binaural benefits if their hearing aids were fine-tuned with their cochlear implants. For children, clinicians customarily discouraged hearing aid use after implantation (Simon-McCandless & Shelton, 2000). Fortunately, this practice is changing as an increasing number of children who receive unilateral cochlear implants have functional residual hearing in the non-implanted ear, and evidence is accumulating to indicate that the contralateral hearing aid complements the cochlear implant. Although there is no systematic data on the role of counseling, experience in practical management of children at the Sydney Cochlear Implant Centre supports the value of counseling for parents, teachers, and children (if applicable), and the implementation of individual management strategies in facilitating the use of a hearing aid with a cochlear implant for children (Ching et al, 2003).

Hearing aid fitting and fine-tuning

We recommend selecting a hearing aid using the NAL-RP prescription, in keeping with the empirical evidence showing that the prescription is appropriate on average. Individual fine-tuning can be carried out 2-4 weeks after fitting using a systematic procedure to check that the hearing aid frequency response is best for speech intelligibility, and that the gain for low-level inputs and high-level inputs (or compression ratio) of the hearing aid provide a loudness sensation that is similar to that provided by the cochlear implant. If an individual requires modifications in frequency response and/or gain, the procedure gives clear indications of how changes need to be made. Balancing the loudness between ears is essential for listening comfort, and could make the difference of a child using a hearing aid or not.

FM system

When a binaural FM system with independently adjustable gain for each ear is fitted to a child user of bimodal hearing devices, the child would not be expected to gain any advantages from head diffraction or binaural squelch in those circumstances where the FM system is actually used. However, the child would be able to derive the advantage arising from binaural redundancy.

Auditory experience

A clinical question remained as to whether one should fit a hearing aid to a child or adult who did not continue to wear a hearing aid after receiving a unilateral cochlear implant for some years. Previous evidence on bimodal hearing benefits have mostly been based on results from subjects that habitually used a hearing aid with a cochlear implant, with some suggestion that people who did not habitually use bimodal hearing derived less benefit (Armstrong et al, 1997). In contrast, recent research that compared the performance of adults and children who habitually wore a hearing aid with a cochlear implant to those who did not (Ching et al, 2004; Ching et al, submitted) provide evidence that binaural benefits are possible for both groups of subjects after a short period of familiarisation with the two devices. After fitting a hearing aid to the non-implanted ear, both groups were given a familiarisation period of 4-8 weeks before evaluation. The results clearly indicated that both groups derived binaural benefits from bimodal hearing compared to using a cochlear implant alone. We therefore recommend fitting a hearing aid to the non-implanted ear of children or adults who discontinued hearing-aid use after implantation.

Disadvantage

Notwithstanding the accumulating evidence in support of the use of bimodal hearing devices, there may be some people who have deficits in binaural processing such that better performance is obtained with a unilateral device than with bilateral devices (this phenomenon has been observed for hearing aid wearers – see for example, Jerger et al, 1993). Evidence for withdrawing hearing aid amplification for a unilateral cochlear implant recipient would include consistent and prolonged rejection of the hearing aid after the clinician has made every effort to fine-tune the fitting, as well as poorer speech test results when using bimodal hearing than when using a cochlear implant alone. For young children, parental reports showing that the child functions better with a cochlear implant alone during trial periods of a few days with the implant alone would also constitute evidence when a systematic method of evaluation is adopted.

Concluding Remarks

Binaural processes operate only when sounds are audible in both ears, and this paper has summarized research evidence showing that binaural benefits in speech, localization, and functional performance are possible with the use of bimodal hearing devices. Fitting a hearing aid to a recipient of unilateral cochlear implants can help to improve the quality of life of the recipient and family. Wearing a hearing aid also eliminates the negative impact of auditory deprivation in the non-implanted ear. Other tangible advantages arising from the use of bimodal hearing devices include having access to directional microphones in both ears that will enhance speech perception in noise (Ricketts, 2002); enhanced sound quality (Balfour & Hawkins, 1992; Simon-McCandless & Shelton, 2000; Ching et al, 2003; 2004); masking tinnitus in both ears (Brooks & Bulmer, 1981); and having one device available when the other is not. Unless there is a clear indication that bimodal device use is counter-productive, we recommend that bimodal stimulation be the standard practice for clinical management of children and adults who receive unilateral cochlear implants.

References

Armstrong M, Peg P, James C, Blamey P: Speech perception in noise with implant and hearing aid. *Am J Otol* 1997; 18: S140-S141.

Balfour P, Hawkins D: A comparison of sound quality judgments for monaural and binaural hearing aid processed stimuli. *Ear Hear* 1992: 13(5): 331-339.

Brooks D, Bulmer D: Survey of binaural hearing aid users. *Ear Hear* 1981: 2: 220-224.

Blamey P, Armstrong M, James C: Cochear implants, hearing aids, or both together? In GM Clark (ed) *Cochlear Implants* (273-277). Bologna: Monduzzi Editore.

Byrne D, Noble W, LePage B: Effects of long-term bilateral and unilateral fitting of different hearing aid types on the ability to locate sounds. *J Am Acad Audiol* 1992; 3: 369-382.

Byrne D, Noble W: Optimizing sound localization with hearing aids. *Trends Amp* 1998; 3(2): 51-73.

Ching TYC, Psarros C, Hill M, Dillon H, Incerti P: Should children who use cochlear implants wear hearing aids in the opposite ear? *Ear Hear* 2001; 22: 365-380

Ching TYC, Psarros C, Incerti P, Hill M: Management of children using cochlear implants and hearing aids. *Volta Rev* 2003; 103(1): 39-57.

Ching TYC, Incerti P, Hill M: Binaural benefits for adults who use hearing aids and cochlear implants in opposite ears. *Ear Hear* 2004; 25: 9-21.

Ching TYC, Hill M, Brew J, Incerti P, Priolo S, Rushbrook E, Forsythe L : The effect of auditory experience on speech perception, localization, and functional performance of children who use cochlear implants and hearing aids in opposite ears. (*Int J Audiol*, submitted).

Ching TYC, Psarros C, Hill M: Hearing aid use with the Nucleus 24 cochlear implant system for children who switched from the SPEAK to the ACE strategy. *Aus NZ J Audiol* 2000; 22: 123-132.

Cowan R, Chin-Lenn J: 'Bimodal hearing aid use' - using a cochlear implant and hearing aid effectively. Presented at the 4th APSCI, Taipei, 2003.

Dillon H: *Hearing Aids*. Thieme, 2001.

Dooley GJ, Blamey PJ, Seligman PM, Alcantara JI, Clark GM, Shallop JK, Arndt P, Heller JW, Menapace CM: Combined electrical and acoustical stimulation using a bimodal prosthesis. *Arch Otolaryng Head Neck Surg* 1993; 119: 55-60.

Hamzavi J, Pok SM, Gstoettner W, Baumgartner W-D: Speech perception with a cochlear implant used in conjunction with a hearing aid in the opposite ear. *Inter J Audiol* 2004; 43: 61-65.

Jerger J, Silman S, Lew H, Chmiel R: Case studies in binaural interference: converging evidence from behavioural and electrophysiologic measures. *J Am Acad Audiol* 1993; 4(2): 122-131.

Jerger J, Brown D, Smith S: Effect of peripheral hearing loss on the MLD. *Arch Otolaryngol* 1984; 110: 290-296.

Shallop JK, Arndt PL, Turnacliff KA: Expanded indications for cochlear implantation: perceptual results in seven adults with residual hearing. *J Sp Lang Path Audiol* 1992; 16: 141-148.

Simons-McCandless M, Shelton C: Cochlear implants and hearing instruments: do they mix? *Hear Rev* 2000; Nov: 38-48.

Syms III CA, Wickesberg J: Concurrent use of cochlear implants and hearing aids. In Kubo T, Takahashi Y, Iwaki T. (ed) *Cochlear Implants*; 2001: Kugler Publ, The Hague, The Netherlands.

Tyler RS, Parkinson AJ, Wilson BS, Witt S, Preece JP, Noble W: Patients utilizing a hearing aid and a cochlear implant: speech perception and localization. *Ear Hear* 2002; 23: 98-105.

How to fit bimodally

Optimising a contralateral hearing aid for a cochlear-implant user

T Ching, National Acoustic Laboratories, Australia
www.nal.gov.au

The NAL- NL 1 procedure has been shown to be an optimal starting point for fitting hearing aids to children and adults who wear cochlear implants in the opposite ear. It is therefore recommended that the hearing aid be selected initially by using the NAL-NL1 prescription, with targets verified using real-ear measurement.

Research has shown that it is beneficial to optimise the hearing aid by fine-tuning it according to individual needs. On average, children who have had their hearing aids optimised with their cochlear implants perceived speech better in noise, localised better, and functioned better in everyday life than when they wore their cochlear implants alone or their implants with unadjusted hearing aids. (Ching, Psarros, Hill, Dillon and Incerti, Ear Hear 22, 365-380, 2001; Ching, Psarros, Incerti and Hill, The Volta Review 103, 39-57, 2003).

Hearing aid optimisation can be carried out soon after a stable MAP for the cochlear implant is established. Before optimisation, the patient needs to have used the hearing aid for at least a few hours a day for a few weeks.

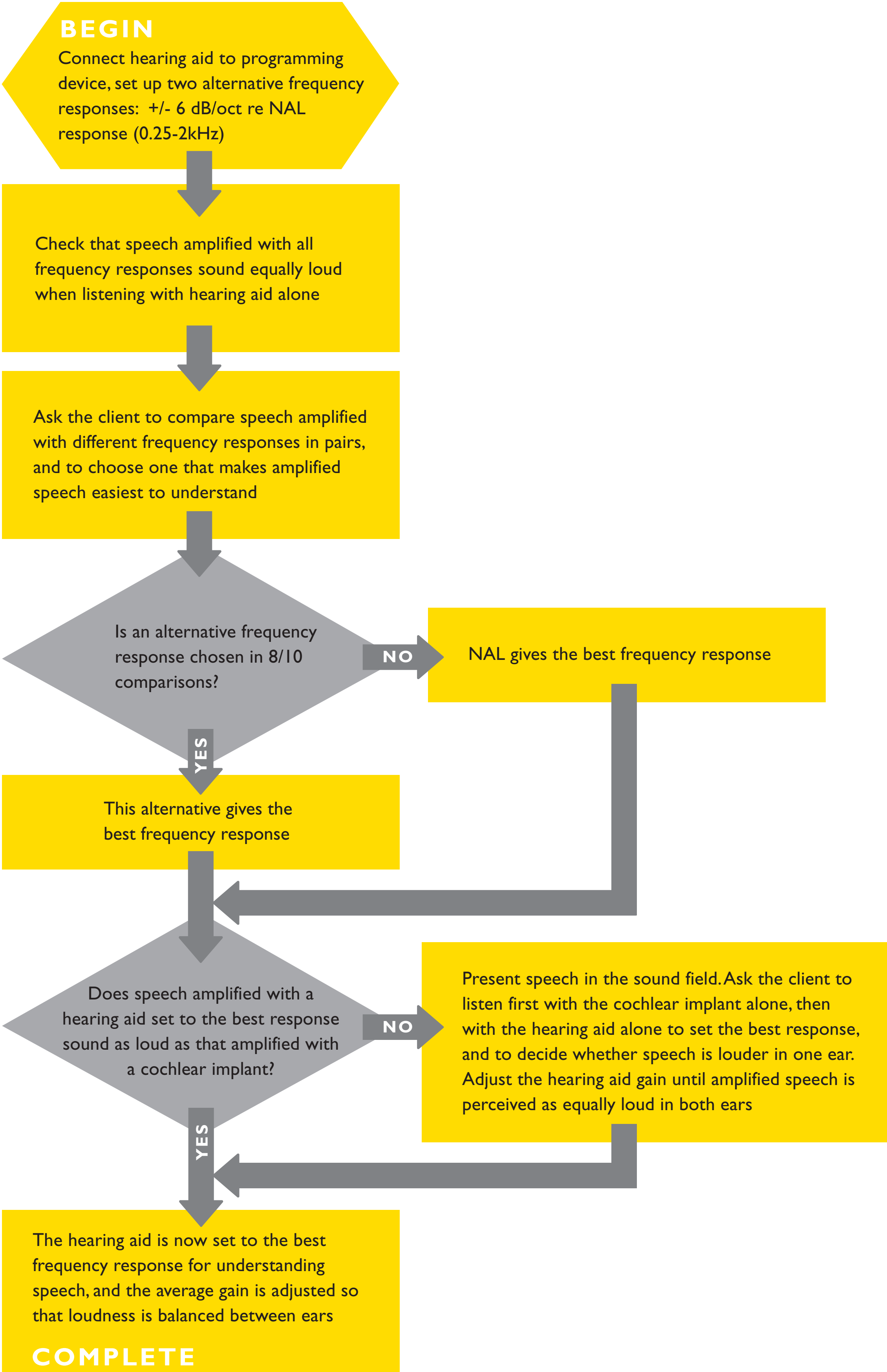
There are two parts to the hearing aid optimisation procedure. For both parts, the patient wears a hearing aid that is connected to a programming device. The first part aims to determine the best frequency response for understanding speech. This involves doing a paired-comparisons test while the patient listens to continuous speech. For children, more reliable results can be obtained with audio-visual presentation than with auditory alone presentation of speech (Ching, Hill, Birtles, Beecham, Aus & NZ J Audiol 21, 51-63, 1999). The patient wears a hearing aid that is connected to a programming device. The NAL-NL1 frequency response, and alternative frequency responses that either provides a nominally 6 dB/octave boost (250 – 2000 Hz) or a 6 dB/octave cut relative to the NAL-NL1 frequency response are set up within the fitting software. Often, somewhat smaller variations will be all that can be achieved in the hearing aid. A recorded story is then presented at conversational level, and the patient listens to the story first using one frequency response, then a second frequency response, and then decides which one is better for understanding the story. Each alternative is compared with the NAL response for a number of times until a significant preference is obtained. The cochlear implant is switched off during this test.

The second part aims to equate the loudness of speech in the ear with a hearing aid to that in the ear with a cochlear implant. This involves the patient listening to the story using the preferred frequency response in the hearing aid, and then using the cochlear implant. The patient compares the loudness in both ears, and decides whether speech amplified with the hearing aid is louder, softer, or similar to speech amplified with the cochlear implant. The hearing aid gain is then adjusted until the child finds both sides to be similar in loudness. For linear hearing aids, this test is carried out for an average input level. For non-linear hearing aids, this test can be carried out at more than one input level, and the compression characteristics of the hearing aid can be adjusted accordingly.

It is desirable to perform both tests, but if there are practical limitations, it is still worth doing only the loudness balancing test so that sounds are equally loud in both ears. In our experience, the optimisation results in variation in gain more often than in frequency response, and can make the difference of a child wearing or not wearing a hearing aid in the contralateral ear.

Further information can be obtained from the NAL website: **www.nal.gov.au**

How to optimize a contralateral hearing aid for a cochlear implant user



Prior to the hearing aid fine-tuning, ensure that an accurate fitting is achieved following these steps:

1. Assess hearing threshold levels
2. Select a hearing aid using an NAL prescription
3. Verify the fitting by insertion gain measurement
4. Check the saturated sound pressure level (OSPL90) to ensure listening comfort.

The client should be wearing the hearing aid with their cochlear implant for at least a few hours per day for 2 to 4 weeks to become familiarised with the hearing aid.

Hearing Aid Fine-tuning Procedure

This procedure should be carried out after the fitting parameters of the cochlear implant are stabilised.

You will need a TV monitor, a video or disc player, an audiometer, an amplifier and a loudspeaker connected as shown below:

Part 1:
Frequency response

Goal:
To determine the frequency response that is best for understanding speech using a paired comparisons task.

Steps:

1. Connect a hearing aid to the programming device, and set up the NAL response and two alternative frequency responses with different degrees of high and low frequency emphasis (nominally 6 dB/octave cut or boost between 250 and 2000Hz relative to the NAL prescription). Use the Alternative Frequency Response Worksheet (page 19) to calculate the required responses and set these up in the hearing aid using a 2cc coupler. Ensure that any adaptive parameters, such as noise reduction or feedback suppression are switched off.
2. Present recorded speech audio-visually or auditory alone at 65 dB SPL in the sound field, measured at a distance of one metre from the client's position. Activate the NAL response in the hearing aid. Instruct the client to listen to speech with the hearing aid alone (cochlear implant turned off) and judge the loudness of the amplified speech. Use the Instructions for Most Comfortable Level (page 20) and Loudness Judgement Scale (page 21). Adjust the gain if necessary to achieve a comfortable rating.
3. Repeat step 2 for the two alternative frequency responses.
4. Next, instruct the client to compare speech presented at 65 dBSPL amplified through their hearing aid with the NAL response and one of the alternative responses. Introduce the response presented first as 'A' and the second response as 'B'. It is helpful to give the client a card or switch box labelled with 'A' and 'B' as a visual representation of the two responses. Instruct the client to choose the response that is easiest to understand. If they can't decide, play both responses again. Use the Instructions for Paired Comparisons (page 22).
5. Present recorded speech at 65dB SPL and activate the frequency responses in pairs using a randomised order (as in the randomisation lists on page 25) such that each alternative is compared with the NAL response four times.
6. Record the client's responses and follow the instructions on the Paired Comparisons Score Sheet (page 23) until a preferred response is obtained.

Paired comparisons

Alternative frequency response worksheet

Name ____ Date of birth __________________

Address ____ Clinician ________________________

To obtain targets for alternative frequency responses, insert NAL gain for each frequency and add the gain adjustment values. The adjustment values are based on the required variations in response slope and empirical data on gain changes to maintain comfortable listening level for each alternative response.

Record the achieved gains for each frequency response.

Low Frequency Boost

Frequency	**250Hz**	**500Hz**	**1000Hz**	**2000Hz**	**4000Hz**
NAL gain					
+ gain adjustment	7	4	0	-6	-12
= Target					
Achieved					

Low Frequency Cut

Frequency	**250Hz**	**500Hz**	**1000Hz**	**2000Hz**	**4000Hz**
NAL gain					
+ gain adjustment	-11	-5	-1	5	8
= Target					
Achieved					

Instructions

Most comfortable listening level

I am going to play a story. Listen to the story and show me on the scale whether it is too loud, comfortable or too soft.

Loudness Judgement Scale

Too loud

Comfortable

Too soft

Instructions

Paired comparisons

I want you to listen to a story. Listen to A for a while, and then listen to B for a while. Then, I want you to tell me which one is easier to understand. Is A better, or is B better?

Paired comparisons

Score sheet

Name ______________________ Date ____________

Clinic ______________ D.O.B. ____________ Ear: R/L ____________

Stage 1. Compare the NAL response with each alternative 4 times.
Record the number of times a frequency response is preferred:

	NAL	+6dB/oct	-6dB/oct
A			
B			
TOTAL			

Excluding NAL, are any of the totals 2 or more?

☐ No. This evaluation is complete. The NAL response is the preferred response.

☐ Yes. Retain responses having a score of 2 or more.
Discard other responses and cross out the discared response on this score sheet.

Stage 2. Compare the NAL response with each remaining alternative 4 times.
Record the number of times a frequency response is preferred:

	NAL	+6dB/oct	-6dB/oct
A			
B			
TOTAL			
Combined TOTAL: Stages 1 + 2			

Excluding NAL, are any of the combined totals (1+2) 6 or more?

☐ No. Evaluation is complete. The NAL response is the preferred response.

☐ Yes. Is that total 7 or more?
- ☐ No. Retain the response having a total of 6.
- ☐ Yes. That is the selected response.

Stage 3. Compare the NAL response with the remaining alternative 4 times.
Record the number of times a frequency response is preferred:

	NAL	+6dB/oct	-6dB/oct
A			
B			
TOTAL			
Combined TOTAL: Stages 1 + 2+ 3			

Excluding NAL, are any of the combined totals (1+2+3) 10 or more?

☐ No. Evaluation is complete. The NAL response is the preferred response.

☐ Yes. That is the preferred response.
It is significantly better than the NAL response for speech intelligibility.

Result of paired comparisons test:

The selected response for speech intelligibility is ____

The measured hearing aid gain (insertion/functional/2cc coupler) for this response:

Frequency	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Gain					

Randomisation lists

Here are some lists of frequency response combinations that can be used for paired comparisons.

Randomisation 1

A	B
Low boost	NAL
NAL	Low boost
NAL	Low cut
Low cut	NAL
NAL	Low cut
NAL	Low boost
Low cut	NAL
Low boost	NAL

Randomisation 2

A	B
Low cut	NAL
NAL	Low cut
NAL	Low boost
NAL	Low cut
Low boost	NAL
Low cut	NAL
NAL	Low boost
Low boost	NAL

Randomisation 3

A	B
NAL	Low boost
Low boost	NAL
NAL	Low cut
NAL	Low boost
Low cut	NAL
Low boost	NAL
NAL	Low cut
Low cut	NAL

Part 2:
Gain

Goal:

To adjust hearing aid gain so that speech is perceived as equally loud in both ears using a loudness balancing test.

Steps:

1. Present recorded speech in the sound field at 65dB SPL while the client listens with their cochlear implant alone. Using the Loudness Judgement Scale (page 27), check that the client rates the speech as comfortable. If they do not, the cochlear implant map will need to be checked before continuing with this procedure.

2. Connect the hearing aid to a programming device and select the preferred frequency response from the Paired Comparisons procedure.

   If the hearing aid is non-linear with adjustable compression parameters, go straight to step 4.

3. If the hearing aid is linear, present recorded speech at 65dB SPL. Ask the client to listen to the speech first with their Cochlear Implant alone, remember how loud it is, and then listen with their hearing aid alone. Instruct the client to indicate whether the hearing aid sounds louder, the same or softer than the cochlear implant. Use the Instructions (page 28) and the Loudness Balancing Scale (page 29).

   Adjust the hearing aid gain adaptively until the client rates the loudness to be the same in both ears. Record the required gain level on the Loudness Balancing score sheet (page 30) Ensure that you achieve the same gain level 2 out of 3 times. Go to step 6.

4. If the hearing aid is non-linear, present continuous speech at 55 dBSPL. Ask the client to listen to the speech first with their Cochlear Implant alone, remember how loud it is, and then listen with their hearing aid alone. Instruct the client to indicate whether the hearing aid sounds louder, the same or softer than the cochlear implant. Use the Instructions (page 28) and the Loudness Balancing Scale (page 29).

   Adjust the overall gain of the hearing aid adaptively until the client rates the loudness of speech in the hearing aid to be the same as that in the implanted ear. Record the required gain level on the Loudness Balancing Score sheet (page 30). Repeat until you achieve the same gain level 2 out of 3 times.

5. Next, present continuous speech at 80 dBSPL. Adjust the compression ratio until the client rates the loudness of speech in the hearing aid to be the same as that in the implanted ear. If the hearing aid has more than one channel, adjust the ratio by the same amount in each channel. If the compression ratio is not adjustable, adjust the compression threshold instead (don't adjust both). Record the required compression parameter on the Loudness Balancing score sheet (page 30).

6. Switch on the cochlear implant and the hearing aid, play speech at 65dBSPL, check that the client rates the speech as comfortable, using the Loudness Judgement Scale (page 27).

Loudness Judgement Scale

Too loud

Comfortable

Too soft

Instructions

Loudness balancing

I want you to listen to a story with your cochlear implant, and remember how loud it is. Then I want you to listen with your hearing aid, and show me using the scale whether it is louder, the same, or softer than your cochlear implant.

Loudness Balancing Scale

Louder

Same

Softer

Loudness Balancing

Score sheet

Name ______________________________ Date ______________

D.O.B. __________ Clinic ________________ Tester ____________________

	Gain at 55dBSPL	Compression Parameters at 80dBSPL
1		
2		
3		
TOTAL		
MEAN		

Frequently asked questions

Q.1 How long does the fine tuning procedure take?

On average, it takes about an hour for both adults and children.

Q.2 What if I cannot achieve a 6 dB/octave cut or boost between 250 and 2000Hz relative to the NAL prescription?

You may be limited by the practical constraints of the hearing aid but try to get as close as possible to the target levels for the alternative frequency responses as calculated on the worksheet. Even if these target levels are not achieved, the alternative can still be used providing that the client perceives the alternative response as sounding different from the NAL response.

If there is less than 3dB/octave variation between one of the alternatives and the NAL response, do not use this alternative in the paired comparisons test.

Q.3 The manufacturer's fitting software I'm using does not have the option of paired comparisons. How can I switch easily between the frequency responses?

Most programmable hearing aids will allow you to set at least 2 programs you can switch between.

If you are unable to set all 3 responses at once in order to perform fully randomized comparisons, perform all the comparisons between NAL and one of the alternatives (eg/boost) first, then recall a saved hearing aid setting which consists of the NAL and the other alternative (eg/cut) to perform those comparisons. Randomize the order of presentation as much as possible.

Q.4 Does it matter what speech material I use for this procedure?

Recorded speech material should be used at all times. The content of the material should be suited to the level of speech understanding of the client. Ideally, the recording should be shaped to match the long term average speech spectrum (LTASS).

You can contact the National Acoustic Laboratories to obtain a copy of an audio-visual recording of a children's story. For adults, the continuous discourse on the NAL CD can be used.

Q.5 What about the switch box used in paired comparisons procedure on the video? I don't have one of those.

The switch box used in the video has a 2-position switch labeled as A and B respectively. The switch is not connected to the programming device and does not change the setting in the hearing aid. It is used to give a visual representation of the 2 alternatives, A and B. The Audiologist activates a frequency response in the hearing aid via the fitting software and indicates to the client by relating the sound to the switch position A or B. The switch box is not an essential part of the procedure. A card marked with A and B would serve the same purpose as the switch box.

Q.6 What is the youngest age at which a child is able to perform the evaluation procedure?

The ability to make comparisons as required in this procedure is usually demonstrated from approximately 6 years of age. Research has shown that the NAL procedure prescribes an appropriate frequency response slope on average so always match the NAL targets in the initial fitting.

When the child can make reliable loudness judgments but is unable to attend for the whole procedure, balance the loudness between the ears for an average input level of 65dB SPL. The same is applicable for clients who may have a limited attention span.

This section will be updated on the NAL website: **www.nal.gov.au**

www.cochlear.com

Cochlear Ltd (ABN 96 002 618 073) 14 Mars Road, Lane Cove NSW 2066, Australia Tel: 61 2 9428 6555 Fax: 61 2 9428 6352
Cochlear Americas 400 Inverness Parkway, Suite 400, Englewood CO 80112, USA Tel: 1 303 790 9010 Fax: 1 303 792 9025 Toll Free: 1 800 523 5798
Cochlear Europe Ltd 22-24 Worple Road, Wimbledon, London SW19 4DD, United Kingdom Tel: 44 0 20 8879 4900 Fax: 44 0 20 8946 9066
Cochlear AG European Headquarters, Margarethenstrasse 47, CH-4053 Basel, Switzerland Tel: 41 61 205 0404 Fax: 41 61 205 0405
Cochlear GmbH Karl-Wiechert-Allee 76A, D-30625 Hannover, Germany Tel: 49 511 542 770 Fax: 49 511 542 7770
Nihon Cochlear Co Ltd Ochanomizu-Motomachi Bldg, 2-3-7 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan Tel: 81 3 3817 0241 Fax: 81 3 3817 0245
Cochlear (HK) Ltd 21F Shun Ho Tower, 24-30 Ice House Street, Central, Hong Kong Tel: 852 2530 5773 Fax: 852 2530 5183

Cochlear™

N30495F ISS1 MAY04