BIMODAL HEARING BENEFITS

Many cochlear implant (CI) recipients achieve high levels of speech understanding in quiet, yet their performance decreases in more challenging listening situations involving background noise. This is thought to be due, in part, to the limited coding of voice pitch via electrical stimulation, impairing the ability to distinguish between competing voices. For many recipients, supplementing CI electrical stimulation with acoustic input from the contralateral (non-implanted) ear has been shown to provide improved hearing outcomes over a CI alone.
Combining input from electrical and acoustic modalities is referred to as bimodal hearing.

Recipients who utilise acoustic input on the side of the CI via a receiver attached to their sound processor (sometimes referred to as ‘Hybrid hearing’) or those who receive bilateral cochlear implants, may also achieve better speech understanding in noise compared to using a CI alone.8,9

The benefits of bimodal hearing are well-documented in comprehensive reviews of published literature.9,10 To summarise, speech understanding in quiet and noise may be enhanced by restoring access to bilateral and binaural cues such as those arising from head shadow and redundancy.11-17 Enhanced sound quality and music appreciation14, 18-21 along with improved localisation ability16,22 and reduced listening effort;12,23-26 have also been reported with bimodal stimulation. These benefits are largely attributed to the additional spectral-temporal information provided via acoustic hearing that is complementary to the spectral information provided by electrical stimulation of the implant.27-29 Furthermore, continued use of a hearing aid may alleviate the negative impact of auditory deprivation in the non-implanted ear,22 and also suppress tinnitus.30

Bimodal hearing benefits:
- Improved hearing in quiet and noise
- Better sound and music quality
- Superior sound localisation
- Improved ease of listening
- Prevention of auditory deprivation
- Tinnitus masking

BIMODAL CANDIDACY

Many unilaterally implanted CI recipients have some acoustic hearing present in their non-implanted ear, providing an opportunity to combine bimodal inputs to optimise overall listening performance. Acoustic frequencies up to approximately 500 Hz have been shown to be most effective at enhancing speech recognition when combined with a cochlear implant. While some recipients may show bimodal benefit with limited acoustic thresholds in the non-implanted ear, published literature suggests that the benefit provided by amplification reduces when low-frequency audiometric thresholds exceed 70 dB HL.33-36

An ideal candidate for bimodal fitting has usable acoustic hearing in the contralateral ear and obtains measurable bimodal benefit in terms of clinical performance and sound quality. In determining candidacy, it is recommended to also consider the potential for gaining benefit from bilateral cochlear implantation. Although bimodal and bilateral device fittings both provide substantial benefits,7 there are substantial differences. For example, speech recognition benefits in spatially separated speech in noise and localisation ability of bilaterally implanted listeners, is often greater than that shown for bimodal users. This is due, in part, to greater effectiveness of the head shadow and improved symmetry of binaural cues for bilaterally implanted users.

BIMODAL FITTING GUIDE

Current literature suggests there is no single ‘best’ bimodal fitting approach,6 and given the known variability inherent amongst CI recipients, a fitting method that considers the individual preferences of each bimodal recipient should be considered in achieving a favourable outcome.

Electrical and acoustic hearing differ substantially, so in most cases optimising the sound processor and hearing aid individually will be sufficient to provide substantial bimodal benefit for recipients.

A recommended fitting approach for recipients using a Cochlear™ Nucleus® sound processor with a contralateral ReSound hearing aid, is summarised below. This flow can be adapted for any hearing aid brand. The rationale supporting this workflow is detailed in the next section on bimodal research outcomes.
Simplified bimodal workflow

1. Fit CI sound processor using standard procedures (for audibility, comfort and sound quality)

2. Fit hearing aid to target and verify with real ear insertion gain where available

3. Activate both devices and fine tune the hearing aid settings for preferred loudness and sound quality based on recipient feedback

4. Via the hearing aid software, adjust the default mixing ratio for wireless accessories to ‘6dB’

Bimodal fitting is complete

Bimodal device settings

<table>
<thead>
<tr>
<th>Nucleus Sound Processor</th>
<th>GN ReSound Hearing Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1: SCAN</td>
<td>P1: All Around, Soft Switching</td>
</tr>
<tr>
<td>P2: Custom</td>
<td>P2: All Around, Omni*</td>
</tr>
<tr>
<td></td>
<td>NAL-NL2 prescription (^3)</td>
</tr>
<tr>
<td>User preferred settings for comfort and sound quality</td>
<td>User preferred settings for comfort and sound quality</td>
</tr>
<tr>
<td>Accessory mixing ratio 2:1</td>
<td>Accessory mixing ratio 2:1</td>
</tr>
</tbody>
</table>

* For other hearing aid brands, select the default P1 program and then select an omni-directional program for P2.

Prior hearing aid experience is important, so users fit previously with other prescriptions (such as DSL\(^4\)) may prefer to retain that prescription for their bimodal fitting.

Not all recipients will prefer loudness to be balanced across the modalities so set levels according to user preferred settings.

Avoid limiting high frequency amplification in the hearing aid to maximise binaural and acoustic cues.

If further bimodal optimisation is desired, please refer to the advanced bimodal parameter optimisation on page 8.

Adjusting the accessory mixing levels applies 6 dB attenuation of the hearing aid microphone relative to the accessories so the mixing ratio for accessories is consistent across devices (2:1). The Cochlear MiniMicrophone 2/2+ uses this recommended level as the default, so does not require adjustment via the hearing aid software.
10 STEPS TO BIMODAL FITTING WITH AVENTA SOFTWARE

Step 1
Program the CI using standard fitting procedures with clinical programming software. Optimise the MAP as necessary.

Step 2
Write the MAP/s to the sound processor saving the two default program settings of P1 SCAN and P2 Custom.

Step 3
Using the Aventa software, connect a GN ReSound hearing aid. Select Patient Information then the Start Tab and adjust the following hearing aid settings:
• Under Experience Level, select Experience-Non Linear. This provides the closest match to the selected prescription.
• Under Frequent Environments, select two programs (P1, P2) both set to the All-Around configuration.

Step 4
Select AutoFit to connect to the hearing aid, set the initial fit gain and feature settings, optionally calibrate digital feedback suppression, then save information to the database and hearing instrument (as per the Aventa fitting software flow).

Step 5
Under Fitting Menu, select Adjust Fitting Target Rule and select the NAL-NL2 prescription.

Step 6
Under Advanced Features in the Tools menu, select the following hearing aid settings:
• For P1, choose the Soft Switching default for microphone directionality to match SCAN in the sound processor.
• For P2, select Omni. This uses a fixed omni-directional microphone setting which is similar to the Custom program in the sound processor. This is also the preferred setting to perform verification of the fitting using real-ear measures.
• All other Advanced Features are recommended to be maintained at the default settings.

Step 7
Under Tools menu, select the gain adjustment function to verify the hearing aid fitting.
• Real Ear Insertion Gain is recommended to verify the hearing aid fitting, however fit to simulated gain targets if real ear verification is not available.
• Use P2 to complete verification with the omni-directional microphone setting to avoid attenuation if the recipient looks away from the speaker during the test.
• Adjust the hearing aid gain to meet the prescribed targets as closely as possible.

Step 8
With the CI sound processor on (at user-preferred settings), fine tune the hearing aid settings for loudness comfort based on recipient feedback and preference.
• Speak to the recipient at a conversational speech level and modify the hearing aid gain and frequency response based on sound quality and loudness preferences for listening with both devices. (Research suggests that for many users, minimal gain adjustment will be required to obtain good acceptance of the hearing aid and cochlear implant signals in combination.)
• Check comfort with loud impulsive sounds (such as hand clapping), and adjust MPO if required.

Step 9
From the All-Around tab, select Autorelate to copy the gain settings from P2 to P1 in the hearing aid.

Step 10
Check whether bimodal pairing to wireless accessories is desired, and if so, make the recommended adjustments to the microphone streaming balance sliders. Follow clinical instructions for pairing bimodal hearing devices to Nucleus wireless accessories.
BIMODAL RESEARCH FINDINGS

Two recent clinical investigations conducted by the Australian HEARing Co-operative Research Centre in Melbourne assessed the suitability and acceptance of the simplified bimodal fitting workflow detailed earlier in this discussion guide. The first study examined two different approaches to loudness balancing the hearing aid and cochlear implant sound processor, while the second study assessed take-home acceptance and satisfaction following use of the complete bimodal fitting workflow with a group of experienced bimodal listeners. Study results are summarised below.

Study Method

Participants

Seventeen experienced bimodal adult users were recruited from the Royal Victorian Eye and Ear Hospital CI clinic. The average age of the subject group was 69 years (ranging from 52 to 83 years). All subjects had post-lingual hearing loss. The average period of CI device use was 5.3 years (ranging from 0.8 to 11.5 years). Subjects were implanted with a Nucleus Profile Series, Nucleus CI24RE, or Nucleus CI422 Cochlear Implant. The audiometric hearing thresholds for the non-implanted ear are shown in Figure 1 for each subject. One subject did not have any measurable hearing at 2000 and 4000 Hz and this is indicated by a value of 125 dB at those frequencies. A range of hearing aid devices from five manufacturers were used by subjects prior to study commencement (Phonak - Extra 311AZ, Naida, Exelia Art P); Siemens - Explorer 500P, Motion, Pure, Orion); Oticon - Syncho, Sumo, VM9; Unitron Max ESP; and Widex RIC).

Device Fitting

All subjects were fit with a Nucleus 6 (CP900 series) Sound Processor on their implanted side. 16 of 17 subjects (94%) used the default SCAN program (with automatic sensitivity control-ASC, Adaptive Dynamic Range Optimisation-ADRO, Wind noise reduction-WNR) and Noise Reduction-SNR-NR), while the remaining subject used a custom program with individualised user settings (ADRO and Whisper).

The hearing aids fitted to the contralateral ear were either a ReSound LiNX\textsuperscript{TM} 2, or (in cases of severe-to-profound hearing loss) a ReSound ENZO\textsuperscript{TM} 2. The NAL-NL2 prescription was used as the basis for hearing aid fitting, and the match-to-targets validated using real ear insertion gain with the Siemens Unity hearing aid measurement system and ISTS (International Speech Test Signal).\textsuperscript{39} Gain adjustments were applied with an aim to match the prescribed gain to within 5 dB of the prescription at each of the signal levels of 50, 65 and 80 dB SPL. Most gain differences between the actual and target responses were within 5 dB SPL of target, with matching the 65 dB SPL target given precedence. Nine of 17 subjects (53%) were under-fitted at 4000 Hz at each of the signal levels due to hearing thresholds being greater than 80 dB HL. This was deemed acceptable given matching exactly to target is of lower priority with profound levels of hearing loss because of the limited amplification benefits.\textsuperscript{40}

Figure 1: Individual unaided audiometric thresholds in the non-implanted ear.
STUDY 1: COMPARISON OF LOUDNESS BALANCING METHODS

Procedure

A comparison was made between two loudness balancing approaches which varied according to the signal type (broadband or frequency-specific) and presentation level (single or multiple level) used. The first balancing procedure (BP1) utilised female continuous discourse presented at 65 dB SPL, with gain adjustments applied to that signal only. The second balancing procedure (BP2) used the ISTS signal filtered into low-frequency (< 500 Hz), mid-frequency (∼ 500 Hz and > 1000 Hz) and high-frequency (> 1000 Hz) components delivered at multiple presentation levels (55, 65 and 75 dB SPL). With this method, the hearing aid gain was adjusted in response to subject reports for each frequency band and level. Where thresholds for a particular frequency band were poorer than 90 dB HL, that frequency range was not used for the balancing. The order of presentation of the frequency range and levels was: (1) 65 dB SPL using low, mid then high frequency components, (2) low, mid and high-frequency filtered signals at 55 dB SPL, and (3) low, mid and high-frequency filtered signals at 75 dB SPL. A final check at 65 dB SPL with each of the low, mid and high-frequency signals was then performed to ensure balance at 65 dB SPL had not been compromised by adjustments made to 55 and 75 dB SPL signal levels.

For each loudness balancing method, the signal type was presented in the free-field from directly in front of the listener, and gain adjustments from the NAL-NL2 prescription were applied by the clinician until loudness balance was reported. Loudness balance was determined subjectively by judging when the combined sound heard from both the hearing aid and sound processor was perceived as centred in the head. For each subject, real ear insertion gain frequency responses for each loudness balancing procedure was measured and the 3-frequency average gain (using 500, 1000 and 2000 Hz) was compared to the prescribed 3-frequency average gain. For the one subject who had no measurable hearing at 2000 Hz, the frequencies of 500 and 1000 Hz were used to calculate average gain.

Speech perception and localisation ability were compared for the two loudness balancing approaches using the bimodal condition. Speech perception was measured for 14 /17 subjects using the AUSTin adaptive speech perception test (ASPT) presented at 65 dB SPL in adaptive four-talker babble noise. The adaptive test determines each subject’s speech reception threshold (SRT), defined as the point at which 50% of morphemes are correctly identified. Both speech and noise were presented from a loudspeaker in front of the listener (S0N0; co-located noise). Two lists of sentences were presented for each condition and the order of testing was counter-balanced across subjects. Localisation ability was assessed for 15/17 subjects using a 13 speaker array in 180 degree configuration in the horizontal plane. Pink noise bursts were presented randomly from one of the 13 loudspeakers, with a total of 80 stimuli presented per condition. The maximum presentation level was 68 dB SPL and loudness was randomly jittered by up to 8 dB steps of 1 dB SPL.

Results

Figures 2a and 2b show the average preferred real ear insertion gain for each subject that was reported to give bimodal balance (on the y-axis), relative to the corresponding prescribed real ear insertion gain (on the x-axis) at 65dB SPL. The solid lines indicate the +/- 5 dB gain range from the prescribed response. For BP1 (discourse), the preferred gain for 88% of subjects was within 5 dB of the NAL-NL2 prescription at 65 dB SPL. For BP2 (ISTS), the preferred gain for 82% of subjects was within 5 dB of the NAL-NL2 prescription at 65 dB SPL. 76 and 64% of subjects preferred a 3-FA gain within 5 dB of the prescription at presentation levels of 50 and 80 dB SPL respectively.

Figures 2a (top) showing BP1 (Discourse, 65 dB) and 2b (bottom) showing BP2 (ISTS, multiple level and frequency adjustment). The solid lines indicate the +/- 5 dB gain range from the prescribed response.
Speech perception and localisation results are summarised in Figures 3a and 3b for each of the loudness balancing approaches. Lower SRT values and RMS error indicate better performance (shown as lower values on the y-axis). Analysis using a two-tailed paired t-test revealed no significant difference in SRT between the two loudness balancing approaches. Grouped mean SRT values were -3.6 dB and -3.3 dB for BP1 (discourse) and BP2 (ISTS) respectively.

Since localisation data were not normally distributed, analysis was conducted using the Wilcoxon Signed-Rank Test. No significant difference was observed between the two loudness balancing approaches (Z=0.245, P=0.839). Grouped median RMS error were 41.1 degrees for BP1 (discourse) and 36.8 degrees for the BP2 (ISTS).

Conclusion
Findings from this study suggest that the relatively simple loudness balancing approach (BP1) can be successfully applied within a bimodal fitting workflow and that a more complex procedure that utilises frequency-specific signals and adjustments at multiple-signal levels (BP2) does not appear to provide additional clinical advantage. The majority of subjects required minimal adjustment from the prescribed NAL-NL2 gain in order to perceive bimodal loudness balance, regardless of the balancing procedure used. There was no significant difference in speech perception in noise or localisation ability between the approaches.
STUDY 2: ACCEPTANCE OF A SIMPLIFIED BIMODAL FITTING WORKFLOW

Procedure

A simplified loudness balancing technique (described earlier), was incorporated into a bimodal clinical fitting workflow. Following fitting of a ReSound LiNX29 or ENZO29 hearing aid with their sound processor using this workflow, subjects were provided with a minimum of two weeks take home experience. They were asked to compare their overall satisfaction with the hearing aid and sound processor in combination, against the bimodal hearing using their own hearing aid fit prior to enrolment into the study. Responses were captured via a questionnaire using a five point Likert scale with the following categories of response 'Very Satisfied, Somewhat Satisfied, Neither Satisfied nor Dissatisfied, Somewhat Dissatisfied and Very Dissatisfied.'

Detailed analysis of subjective feedback was conducted to explore the potential fine-tuning refinements that might improve user satisfaction with the bimodal fitting workflow.

Results

Results are shown in Figure 4. 16 of 17 subjects were satisfied with the bimodal fitting obtained using the simplified workflow, which in some instances included individualised fine-tuning. Over 70% of the subjects rated being 'Very Satisfied' with the fitting, with a further 23.5% rating being 'Somewhat Satisfied'. One subject reported being 'Neither Satisfied nor Dissatisfied' with the fitting, and none of the subjects reported being 'Somewhat' or 'Very Dissatisfied.'

Analysis of the fine-tuning adjustments indicated that:

- Three subjects preferred the hearing aid to be louder than the sound processor, rather than being equally balanced bimodally. Fine-tuning adjustments based on subjective feedback improved the sound quality and satisfaction level for those subjects.

- Two subjects had a frequency-gain response in their own hearing aid that differed substantially from the NAL-NL2 prescription at the time of enrolment into the study. For one subject the NAL-NL2 prescription resulted in less gain being applied in the low frequencies than their prior fitting, and for the second subject there was more gain provided when using NAL-NL2 in the higher frequencies than they had previously experienced. On the study questionnaires, these subjects reported being 'Somewhat Satisfied' with the workflow fitting, and may have benefited from further fine-tuning of the loaner hearing aid to more closely match the preferred settings in their own hearing aids.

- One subject who reported being 'Neither Satisfied nor Dissatisfied' experienced feedback problems during take home use of the device. This may have been resolved by changing from a dome to a more occluding custom ear mould fitting, but the subject declined a further fitting appointment.

Conclusion

Results are shown in Figure 4. 16 of 17 subjects were The majority of subjects in this study were Satisfied or very Satisfied with the bimodal fitting achieved using the proposed fitting approach. Further fine-tuning based on individual preference and subjective feedback is likely to optimise the fitting further, and improve satisfaction and acceptance.
**BIMODAL CLINICAL CONSIDERATIONS**

1. **How long after CI activation should I perform the bimodal fitting?**

   In general, bimodal fitting is recommended as soon as possible after cochlear implant activation if a recipient has been habitually wearing a contralateral hearing aid prior to surgery. This will provide immediate access to bimodal hearing benefits and assist with the acclimatisation to the novel sound of the cochlear implant in the opposite ear. Recipients who have discontinued wearing a contralateral hearing aid post CI activation have been shown to regain bimodal benefits a few weeks after they have been refit and acclimated to the bimodal condition.9

2. **Are prescriptions other than NAL-NL2 suitable for use in bimodal fittings?**

   The NAL-NL2 hearing aid prescription has been shown to provide suitable frequency response and gain characteristics for bimodal listeners37, and is designed to maximise speech intelligibility whilst ensuring the overall loudness of speech at any level does not exceed that perceived by normal hearing listeners40. However prior hearing aid experience is an important consideration, so users (especially children) who were previously fit with other prescriptions such as DSL (Desired Sensation Level38) may prefer to retain those prescription and gain parameters for their bimodal fitting.

3. **Which advanced bimodal parameters can I optimise?**

   Adjustments to the following advanced clinical parameters may be explored for non-routine fittings:

   - **Change the slope of the gain curve in the hearing aid.** Trialling a low-frequency boost or cut program might result in improved sound quality for some bimodal listeners.23,37

   - **Limit high-frequency amplification in the hearing aid if cochlear ‘dead regions’ are confirmed.** Avoid amplification to cochlear dead regions (identified by use of the TEN or SWPTC tests)43-44 to benefit speech understanding and improve sound quality.45 In the absence of identification of a dead region, retaining high-frequency amplification (or wide band fitting) is generally preferred over applying a boost or cut to preserve head shadow advantage and interaural level differences46 (ILDs), as well as horizontal localisation ability. Increase the C-SPL setting in the sound processor to match loudness. Increasing the C-SPL setting from 65 to 75 may assist in matching loudness at signal intensity levels above 65 dB SPL. The C-SPL parameter defines the upper signal intensity at which the fast component of the Automatic Gain Control is activated in the sound processor. Note that the Q-value will be automatically adjusted to compensate for the expanded electrical dynamic range requiring a global C-level programming increase of approximately 15-20% of the electrical dynamic range to ensure overall loudness is maintained in the modified program.]

4. **What should I do if no bimodal benefit is measured or a decrement is shown?**

   Over time, a recipient may derive more benefit from their CI than the contralateral hearing aid, however it is important to encourage ongoing use of both devices for optimal hearing ability. Conventional speech perception testing may not be sufficiently sensitive to demonstrate significant bimodal benefit, therefore consider measures of patient satisfaction in real world noise situations when assessing bimodal fitting outcomes. If contralateral hearing thresholds deteriorate to diminish perceived bimodal benefit, or a patient presents with a true bimodal performance decrement, consider candidacy for bilateral cochlear implantation.
REFERENCES


3. Zhang T, Dorman MF, Spahr A. Information from the voice fundamental frequency (F0) region accounts for the majority of the benefit when acoustic stimulation is added to electric stimulation. Ear and hearing. 2010 Feb;31(1):63.


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