

# Effectiveness and efficiency of a dedicated bimodal fitting formula

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## Abstract

The population of unilateral cochlear implant (CI) users with aidable residual hearing in the contralateral ear is continuously growing. Aiding the contralateral ear with a hearing aid has been shown to provide substantial benefit regarding speech intelligibility in quiet and in noise, sound quality, localization ability and listening effort. In this study, a dedicated hearing aid with the accompanying fitting prescription, tailored to the needs of bimodal listeners was evaluated in nine bimodal CI users. Speech intelligibility scores in noise revealed on-par performance of the dedicated bimodal fitting compared to the clinical standard prescription. 78% of the bimodal CI users preferred the dedicated bimodal fitting over the clinical standard. The minimal subject-specific fine-tuning effort required during the dedicated bimodal fitting process emphasizes the clinical efficiency.

## Introduction

With expanding inclusion criteria for cochlear implantation,<sup>1</sup> the number of cochlear implant (CI) users with residual acoustic

hearing in the contralateral ear is increasing. Aiding the contralateral ear with a hearing aid has been shown to provide substantial benefit regarding for example speech intelligibility in quiet,<sup>2,3</sup> and in noise,<sup>2-6</sup> sound quality,<sup>3,7</sup> localization ability<sup>2,5,6</sup> and listening effort.<sup>3</sup> Such benefits can generally be obtained using any hearing aid appropriate for the individual contralateral hearing loss, fitted according to the clinical practice independent of the CI.

To further improve bimodal hearing, a dedicated bimodal system has been developed: the Naida Link bimodal system consisting of a Naida CI sound processor and a Naida Link hearing aid. The accompanying fitting formula (Adaptive Phonak Digital Bimodal, APDB),<sup>8</sup> takes into account the specific characteristics of bimodal listening. While traditional hearing aid fitting aims at optimizing speech intelligibility with the hearing aid alone by maximizing audibility of the entire frequency spectrum, in bimodal CI users, the CI ear often dominates speech intelligibility,<sup>5</sup> especially if the contralateral hearing loss is severe to profound. To optimally complement listening with the CI, which by design, codes the higher frequency regions fundamental to speech intelligibility, the APDB fitting formula therefore emphasizes audibility of low frequency sounds which carry temporal fine-structure information to support speech understanding in noise. To improve balanced sound perception, the loudness growth functions are aligned between the CI and hearing aid and the slow-acting automatic gain control (AGC) of the CI is implemented in the hearing aid. Veugen *et al.*<sup>9</sup> have shown the alignment of the hearing aid to the CI to be beneficial. Speech intelligibility in single competing talker noise was improved by matching the AGC characteristics of the hearing aid to the CI. Additionally, the matched AGC was preferred to a standard hearing aid AGC in a subjective preference task. This study investigates subjective preference and speech intelligibility in noise in bimodal CI users upgraded to the Naida Link hearing aid. Speech intelligibility with the CI alone is compared to speech intelligibility in the bimodal listening configuration. Additionally, results are compared between traditional hearing aid fitting using DSLv5 and dedicated bimodal fitting using the APDB fitting formula. Moreover, the efficiency of this new prescription is investigated by analyzing the amount of fine-tuning required to achieve an individually optimal setting.

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## Materials and Methods

### Subjects

Nine experienced unilateral adult cochlear implant users participated in the study. All subjects were post-lingually deafened and had moderate to severe hearing loss in the contralateral ear. Detailed subject demographics can be found in Table 1.

## Devices and fitting

The Naída Link hearing aid is available in two configurations: Naída Link UltraPower (UP) and Naída Link Receiver-in-the-Canal (RIC). The Naída Link UP offers a maximum output power of 142 dB SPL and maximum gain of 82 dB (2cc coupler) in the frequency range of <100 up to 4,900 Hz. The Naída Link RIC offers a maximum output power of 126 dB SPL and maximum gain of 55 dB (2cc coupler) in the frequency range of <100 up to 6,200 Hz. To fit the Naída Link hearing aids, a dedicated fitting formula was developed: the APDB fitting formula. By aligning the behavior of the contralateral hearing aid to the Naída CI regarding frequency response, loudness growth functions, and AGC characteristics, the APDB fitting formula aims at optimally complementing hearing with the Naída CI rather than optimizing hearing with the hearing aid alone. Different from traditional hearing aid fitting approaches, the APDB fitting formula reduces gain in dead regions identified from the audiogram, typically at high frequencies and emphasizes audibility of low frequencies. Loudness growth is aligned to the Naída CI by implementing the input-output function of the CI in the hearing aid. The Naída CI dual-loop AGC is applied to the hearing aid side to align dynamic behavior across ears. The Naída CI employs a slow-acting compression circuit with a very high compression ratio (1:12) to map environmental sounds onto the most comfortable level while preserving temporal envelope cues in order to optimally use the small dynamic range of the electrically stimulated auditory nerve.

In contrast, traditional hearing aid prescription families such as DSL (for review Seewald *et al.*)<sup>10</sup> or NAL<sup>11,12</sup> maximize audibility of sounds across the entire spectrum, especially those frequencies crucial to speech intelligibility (1-4 kHz) and apply fast-acting multi-channel AGCs.

In this study, the Naída Link UP hearing aid was used in combination with a Naída CI Q70 processor. The Naída Link hearing aid was fitted either with the APDB fitting formula or with a traditional hearing aid fitting formula, DSLv5, a well-established clinical standard prescription.

## Test material

Speech intelligibility was measured using the Italian matrix sentence test<sup>13</sup> in the international female fluctuating masker (IFFM) noise to mimic a cocktail party environment. The Italian Matrix sentence test consist of a set of 50 words, combined into arbitrary sentences of the structure: Name Verb Numeral Noun Adjective, with ten alternatives for each position. To create the

IFFM noise, the pause duration in the International Speech Test Signal (ISTS)<sup>14</sup> is reduced to 250 ms and the order of the speech segments composing the ISTS is varied.<sup>15</sup> Speech and noise were presented from the front. The noise level was fixed at 55 dB while the speech level was varied adaptively to determine the speech reception threshold (SRT). At the beginning of each study appointment, subjects were presented with two test lists to avoid training effects during the test session.

Subjective preference was determined using the experimenter's voice as stimulus. Response choices were *APDB preferred*, *DSL preferred* and *no preference*.

## Measurement schedule

Subjects were invited to two study appointments. At the first appointment, speech intelligibility in noise was tested using the CI alone. All subjects were then fitted with a Naída Link UP hearing aid. Fitting was performed once using the APDB fitting formula without subject-specific optimizations and once using the DSLv5 fitting formula without subject-specific optimizations. The APDB fitting was then fine-tuned for each subject in preparation for a chronic trial phase of two to four weeks, during which subjects used the Naída Link UP hearing aid fitted with the APDB fitting formula in their everyday lives. All necessary adjustments were recorded. At the second study appointment, after the chronic trial phase, speech intelligibility in noise was measured in the bimodal listening configuration using the APDB (without fine-tuning) and DSLv5 fitting formula. The test order was alternated between subjects with subjects 1, 3, 5, 7 and 9 tested using the APDB fitting first and subjects 2, 4, 6, and 8 tested using the DSLv5 fitting first. The first study appointment lasted approximately 50 minutes while the second study appointment lasted approximately 65 minutes. The first and second authors of the study supervised all study procedures and the same audiologist performed them.

## Ethics

The study design and subject recruitment were in accordance with local ethics committee requirements.

## Statistical analysis

Statistical analyses were performed using Statistica 12 (TIBCO Software Inc., Palo Alto, USA) with a level of significance set at 0.05. Main effect of device configuration was determined using Friedman ANOVA. Post-hoc analysis was performed using Wilcoxon-signed rank tests. Bonferroni corrections for multiple comparisons were applied.

**Table 1. Detailed subject demographics.**

ID	Age (yrs)	Etiology	Age at diagnosis/duration of deafness before implantation (yrs)	Duration of CI use (months)	PTA (dB HL)	Previous hearing aid
S01	75	Progressive HL	62/12	12	96	Siemens Pure
S02	78	Otosclerosis	35/41	24	45	Endo Amplifon
S03	73	Meniere's	65/7	10	48	N/A
S04	51	Progressive HL	34/16	15	76	Phonak Audeo
S05	61	Progressive HL	52/5	36	95	Oticon Swift 70
S06	73	Progressive HL	50/23	6	50	Endo Amplifon
S07	55	Progressive HL	17/37	10	86	Intertone Rite
S08	63	Meniere's	40/22	8	61	N/A
S09	66	Progressive HL	48/17	6	81	Oticon Acto Pro

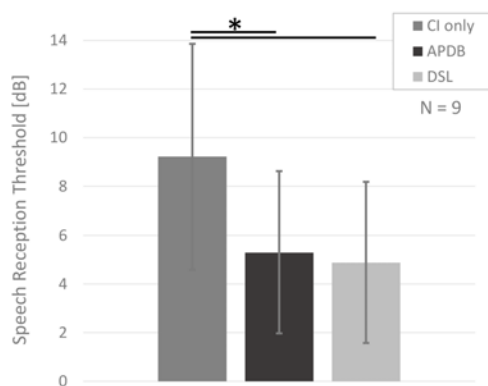
CI, cochlear implant; PTA, pure tone average; N/A: not applicable; dB, decibel; HL, hearing level.

## Results

Mean SRTs in IFFM noise, measured at a noise level of 55 dB using the three different device configurations are presented in Figure 1. All nine subjects completed the measurements. Friedman ANOVA revealed a statistically significant effect of the tested device configuration ( $\chi^2(2)=12.40$ ,  $P=0.002$ ). Performance when listening with the bimodal system fitted with either the APDB or DSLv5 fitting formula was statistically significantly better than listening with the CI alone by on average  $3.9\pm 3.4$  dB ( $Z=2.52$ ;  $P=0.035$ ) and  $4.3\pm 2.9$  dB ( $Z=2.67$ ;  $P=0.023$ ) respectively. There was no statistically significant difference in performance between the two fitting formulae ( $Z=0.30$ ;  $P=2.301$ ). Results of the individual fine-tuning of the APDB fitting formula for the chronic trial phase as well as the preference test conducted at appointment 2 are presented in Figure 2. Only minimal subject-specific fine-tuning of the APDB fitting was required for the chronic trial (Figure 2A): six subjects required overall level adjustments achieved with a maximum of three clicks, one subject required a bandwidth limitation and two subjects did not require any fine-tuning. No mitigations against acoustic feedback were required. At the end of the second study appointment, seven out of nine subjects (78%) preferred the APDB fitting over the DSLv5 fitting (Figure 2B). Reasons for preferring APDB included higher clarity of speech as well as the DSL fitting being perceived as too loud.

## Discussion

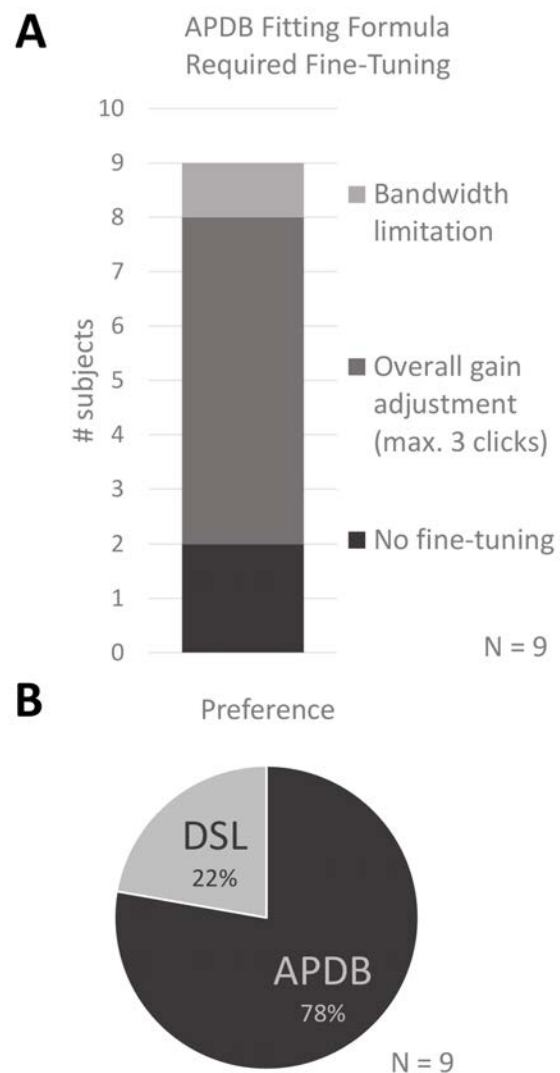
This study compared speech intelligibility in noise in bimodal listeners between the CI only listening condition and two bimodal listening conditions, differing in the fitting formula used to fit the HA. All nine subjects included in this study were able to complete speech intelligibility measurements in IFFM noise using the Italian matrix sentence test.<sup>13</sup> When tested with the CI alone and in both bimodal listening conditions (APDB and DSLv5 fitting), the



**Figure 1.** Results of the adaptive Italian matrix sentence test in 55dB international female fluctuating masker noise. Speech reception thresholds in noise measured with the cochlear implant (CI) alone, in bimodal listening mode fitted with the Adaptive Phonak Digital Bimodal (APDB) fitting formula and in bimodal listening mode fitted with the DSLv5 formula. Bars represent mean speech reception thresholds, error bars denote standard deviation. Statistically significant differences are denoted by bars and asterisk.

resulting SRTs showed a large inter-subject variability of up to 15.8 dB (CI only). The variability in SRT outcomes seen here is larger than what was reported by *e.g.* Hey *et al.*<sup>16</sup> using similar speech material in stationary speech-shaped noise. In part, the higher variability seen here may be attributed to the subjects not being familiar with the matrix speech material from the clinical routine. However, previous research has also shown the variability of SRT results to depend on characteristics of the interfering noise with fluctuating noise, such as the IFFM noise used here, producing larger variability than stationary noise maskers.<sup>17</sup> Therefore, the high variability in the reported SRT results may be attributed to the fluctuating interfering noise.

The bimodal benefit obtained by the addition of the contralateral hearing aid also showed considerable inter-subject variability of 11.8 dB and 9.9 dB for the APDB and DSLv5 fitting, respectively. This variability is comparable to the approximately 12 dB variability in bimodal benefit reported by Firszt *et al.*<sup>6</sup> for speech in R-SPACE noise. The large variability can mainly be attributed to the performance of S09, who achieves 11.8 dB (APDB) and 10.6 dB (DSLv5) bimodal benefit, with all other subjects receiving less



**Figure 2.** Results of the individual fine-tuning of the Adaptive Phonak Digital Bimodal (APDB) fitting formula (A) and the subject preference between APDB and DSL (B).

than 6 dB bimodal benefit in either fitting condition.

The average bimodal benefit found in  $S_0N_0$  in this study cohort amounted to  $3.9 \pm 3.4$  dB and  $4.3 \pm 2.9$  dB for the APDB and DSLv5 fitting, respectively. These results are comparable to the  $4.2 \pm 0.9$  dB reported by Devocht *et al.*<sup>3</sup> using comparable speech material in the same test setup. Morera *et al.*<sup>2</sup> used different speech material in the same test setup and reported 3dB bimodal benefit.

Comparing speech intelligibility in noise, no significant difference was found between the APDB fitting and DSLv5 fitting conditions. Speech intelligibility using the APDB fitting formula without subject-specific fine-tuning was on par with DSLv5, an established clinical standard prescription, albeit without subject specific fine-tuning as would be applied in the clinical routine. At typical speech levels of approximately 65 dB, both fitting formulae prescribe similar gains, therefore similar performance with both formulae can be expected. For all subjects in the study cohort, only minimal fine-tuning was required for the APDB fitting formula to achieve an individually optimum setting. Compared to traditional hearing aid fitting, which is often an intricate process involving detailed, patient-specific adjustments,<sup>18</sup> the straightforward fitting procedure of the APDB fitting formula greatly reduces the time and effort required of the audiologist, allowing efficient hearing aid fitting without compromising patient satisfaction as demonstrated by the large majority of the subjects preferring the APDB fitting over the DSLv5 fitting.

Compared to the DSLv5 fitting, the APDB fitting prescribes up to 16 dB less gain at high input levels and only slightly more gain at soft levels between 500 Hz and 2 kHz. This difference in gain prescription is a likely reason for the majority of subjects preferring the APDB fitting. One of the most cited reasons for this preference was DSL being perceived as too loud.

In this study, only a relatively small number of subjects could be included and only one spatial test condition was evaluated. Additionally, the time to acclimatize to the new hearing aid fitting was limited to two to four weeks. Especially for the two subjects without previous hearing aid experience, S03 and S08, this acclimatization period may not have been sufficient. Nevertheless, the results obtained within this study fall well within the range of previously reported outcomes.

## Conclusions

Cochlear implant users with aidable acoustic hearing in the contralateral ear benefit from bimodal listening, regardless of the fitting formula used to fit the contralateral hearing aid. The APDB fitting formula provides the same level of speech intelligibility in noise as the established DSLv5 fitting formula while at the same time minimizing the time and effort required for fitting. The majority of subjects prefer the APDB fitting over DSLv5.

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