BIAP Recommendation 06/18:

Bimodal stimulation: hearing-aid fitting in combination with a cochlear implant

General foreword

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Introduction

Bimodal fitting involves the simultaneous use of electrical and acoustic stimulation in separate ears (combining a hearing aid and cochlear implant), necessitating intricate system integration. This recommendation highlights the advantages of bimodal stimulation, particularly in the context of binaural processing and cortical map reorganization.

Scope

In this recommendation are discussed the implications of this strategy, the benefits and limitations in cases of bimodal stimulation to obtain the best audibility.

Recommendation

1. The meaning of 'bimodal' stimulation and how it works

In cases of bimodal stimulation, one sound source will be perceived by two different modalities: **acoustic** and **electrical**. The brain will have to process both inputs of auditory information with visual, motor and somatosensory cues to elaborate only one auditory object.

Receiving two versions of the same sound signal poses challenges in terms of intensity, temporal and spectral resolution, requiring intra- and inter-hemispheric plasticity. The more both ears are stimulated, the more audibility can be reached over the whole frequency range, as the brain is capable of integrating information from different stimulations.

2. Benefits of bimodal stimulation

Bimodal stimulation provides the advantage of binaural hearing abilities, limits the constraint of auditory deprivation and may improve the quality of life in general.

The bimodal benefit varies for different patient profiles, depending on several factors, such as previous hearing aid use, residual hearing, age, comorbidities, medical and rehabilitation issues etc. However, the aim is to improve the extended dimensions of speech and environmental sound perception for adults and children compared with unilateral CI alone.

The expected bimodal benefit is approximately 10 to 20% for speech recognition in quiet, and 10 to over 30% for both speech recognition in overall noise and in spatially separated noise (Holder et al., 2022).

Optimised bimodal stimulation includes a chance of enhancing the fusion of binaural cues by using Interaural Level Differences (ILD) and Time Differences (ITD) (Francart and McDermott, 2013) including:

- the Head Shadow effect: contralateral attenuation and Signal-to Noise improvement of up to 15 dB
- the Summation effect: enhancement of 6 dB to 10 dB for sounds >30 dB SL
- Enhanced Speech Understanding in Noisy Environments and the Binaural Squelch effect.
- Sound Localisation (Pieper et al, 2022)

Additionally, bimodal hearing reproduces temporal fine structures more accurately than CI alone. This offers:

- more natural and acceptable sound quality
- benefits for speech and music
- less listening effort (Bess and Hornsby, 2014)
- enhanced interpretation of meaning in speech and emotions in voice

Despite the different stimulations, these varied inputs can complement each other, especially when the importance of implementing measurements throughout the process is understood.

3. Candidates

To decide in favour of bimodal stimulation, the degree of hearing loss, the length of time of sensory deprivation and the presence of comorbidities are aspects that need to be considered, as they can facilitate or hinder this process.

From 70 to 80% of CI-users (adults and children) with bilateral severe or profound hearing loss can benefit from bimodal stimulation. Bimodal stimulation can provide benefits even with poor residual hearing and for a short period of time. Until the implantation of the second ear, use of hearing aids (HA) can improve the audibility up to 250 Hz. (Gifford & Dorman, 2019; Moberly et al, 2022)

Most CI patients with hearing thresholds better than 90 dB HL may show some benefit from a HA in the non-implanted ear. However, if bimodal benefit is not demonstrated, a second CI should be considered (Holder et al, 2022).

In bilateral profound hearing loss, and particularly in children, patients will benefit from bilateral implantation. In the case of asymmetric hearing loss with usable residual hearing in the better ear, bimodal stimulation is recommended.

4. <u>Challenges</u>

The main challenge of bimodal fitting is achieving binaural interaction, since without this the two ears act as two almost independent receivers. The interdependent acoustic dimensions (frequency, latency and level) must be addressed in this process.

A reduction of interaural mismatch in frequency and latency improves binaural fusion. This fusion is expected to improve localisation and possibly improve masking release, but some concepts, such as loudness balancing, have to be revisited, and a more involved fitting process anticipated.

Currently HA + CI devices are not often fitted together and mostly they are developed independently of one another, which leads, e.g., to synchronisation problems.

The challenges in bimodal fitting involve:

- **Spectral** distortion (place mismatch-electrode allocation). In the process of amplifying sound waves through a hearing aid, there is a clear relationship between the exact position of stimulation on the basilar membrane and the corresponding frequency. For electrically stimulated sound, the location depends on the mapping of the limited array of electrodes. This results in a lack of frequency specificity in the cochlea for the same sound, which sometimes may also overlap (Francart & McDermott 2013).

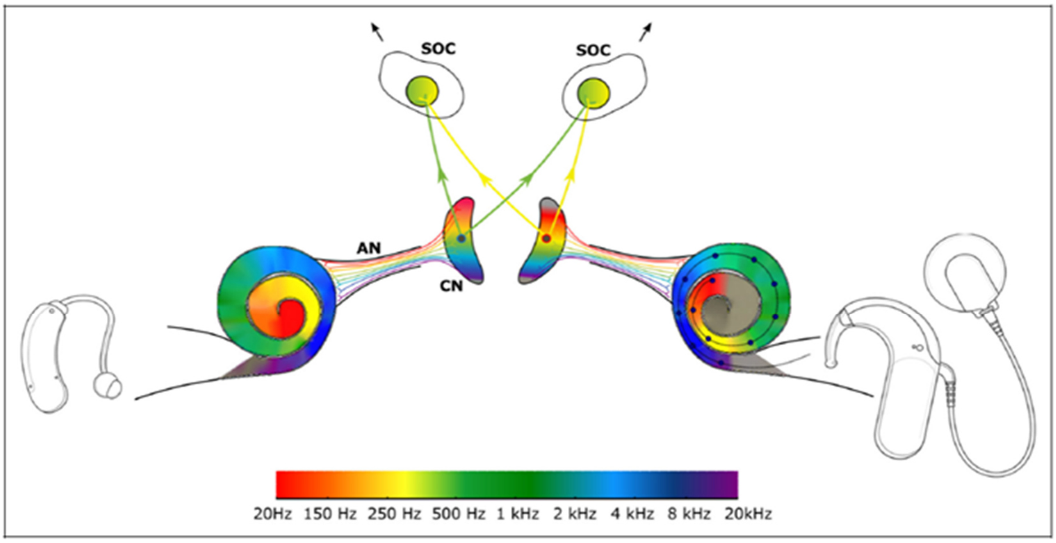

Figure 3. Frequency mismatch in bimodal ci. A binaural neuron in the SOC is innervated from identical cochlear positions and therefore from different frequency bands, as indicated by the different colors. AN: auditory nerve, CN: cochlear nucleus, SOC: superior olivary complex.

Figure 1: Frequency mismatch (Pieper et al, 2022)

- **Time** of synchronisation (latency): the difference in milliseconds between the CI and the HA responses. In hearing aids, the soundwave needs time to reach the auditory nerve, unlike with cochlear implants where the auditory nerve is stimulated instantly (Francart & McDermott 2013).

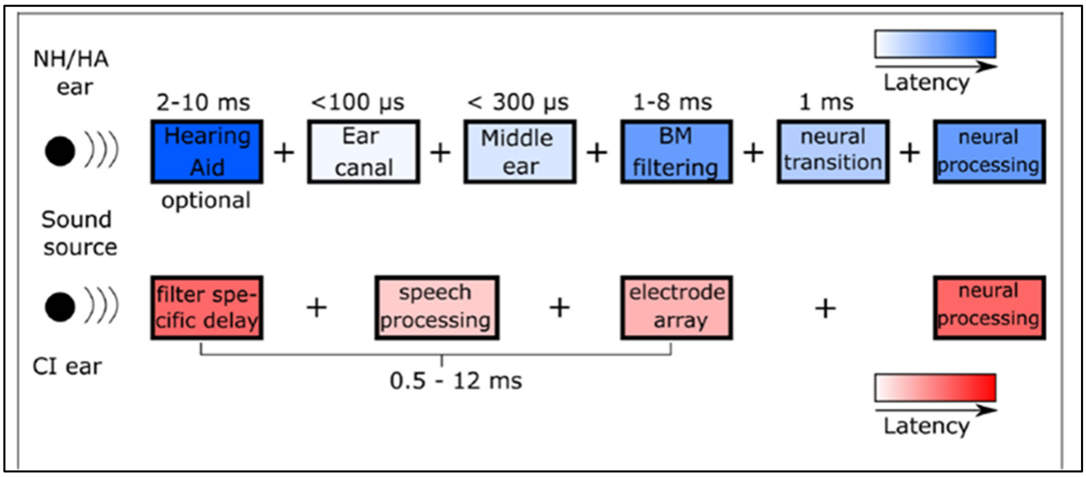

Figure 2: Time difference (Pieper et al, 2022)

- **Loudness growth (level):** the difference in loudness perception over the dynamic range with the hearing aid and the CI. The challenge in fitting the hearing aid is to reach the same loudness perception for conversational levels (Francart & McDermott 2013).

- **Level balancing** between the HA and the CI is not always possible, so loudness differences remain and hinder sound localisation, meaning that the patient may not perceive frontal sound as coming from the front.

5. Selection of the hearing aid

Owing to the aspects mentioned above, we recommend that the hearing-aid adjustments and the CI mapping be done at the same place at the same time.

Some cochlear implant (CI) companies have started collaborating with hearing aid manufacturers to improve how both devices work together as a unified system. These efforts aim to enhance the user experience by addressing challenges such as synchronising sound timing, balancing loudness perception, and enabling seamless connectivity with remote technologies. However, this level of integration is not yet standard across all manufacturers, and approaches may vary depending on the company.

The audiologist will preferably choose a hearing aid that is compatible with the CI. Another possibility is to select a CI that is compatible with the hearing aid for experienced users. These decisions must be made in agreement with the user after counselling.

The CI companies that do not have this partnership with the HA industry provide the possibility of adjusting the time constants of the CI, by simply feeding the software with the trademark, type and model of the HA used in the contralateral side, so that the CI automatically fits the corresponding characteristics as closely as possible.

If a compatible hearing aid cannot be selected, considering the importance of time of synchronisation in bimodal stimulation, audiologists should select HAs with advanced signal processing.

It is important to understand that the adjustment process takes time. Patients are often used to a certain sound quality that they have experienced for many years. Introducing new settings can feel unfamiliar or even unpleasant at first. The brain needs time to adapt to the new way of hearing. Fitting is a gradual process involving multiple follow-up visits and patient feedback.

It is recommended to focus on optimising the CI first, and to consider adjustments to the hearing aid later in the fitting process.

There are specific clinical recommendations to guide HA selection and fitting with regard to the following:

HA Audibility

Real-ear verification of the aided response should be the standard of care when fitting the HA, since adequate audibility is essential for HA benefit. No clear evidence has been found on how certain choices in HA fitting formulae contribute to optimal bimodal performance. Clinicians should perform real-ear verification of HA audibility as prescribed by a validated fitting formula, such as the National Acoustic Laboratories' Nonlinear Fitting Procedure (NAL NL 2/NL 3) or Desired Sensation Level (DSL-5). See BIAP Recommendation 06/11 Annex 2.

For a manufacturer-specific HA fitting formula specifically designed for the use with a CI processor for adults, careful verification is advised.

HA Bandwidth

The decision to use full or restricted bandwidth will depend on the presence of cochlear dead regions. If there is evidence of dead regions (hearing threshold ≥ 80dB HL) the HA could be programmed to use full and restricted bandwidths in two different programs. When restricting bandwidth, gain is not provided to frequencies where thresholds exceed 80 dB HL. Using both subjective preference and aided speech recognition assessments with recorded stimuli will allow comparison of the effectiveness of each strategy and selection of the most useful one.

Frequency Lowering (FL) Technology

There is no evidence for the added value of FL in bimodal fitting (Holder et al, 2022). If the user is familiar with FL, audiologists should provide both conditions and let the patient compare and select the best option. For this the use of speech sound perception tests is recommended. Be aware that over time the situation may change, as the improved audibility provided by the implant may require different adjustments.

Automatic Gain Control (AGC) Match

Be aware that AGC in hearing aids is different from the AGC setting of the CI. At the time of writing this recommendation, the matched AGC system is available in one CI/HA system from a specific manufacturer (e.g. Advanced Bionics Naida CI processor and Phonak Link HA). Currently, there is insufficient evidence to support specific recommendations (Holder et al, 2022; Gifford,2019).

Loudness Balance

HA and CI should be optimised by loudness balancing of sounds originating between the ears; ideally, the patient should perceive all frontal sources from the front.

Loudness balancing is typically performed by adjusting the HA gain to match perceived loudness of the CI, although this is not always possible owing to gain requirements. The current systematic review suggests starting with the base HA prescriptive formula targets, verifying the HA fitting via probe microphone measures, then adjusting accordingly.

Enhancing the low frequencies in the hearing aid can be helpful to balance loudness perception. The use of loudness scaling (e.g. with contour Test – later explained) is a feasible tool to help set the balance between the instruments.

When applicable, the volume control can also be used by patients to moderate loudness matching in real-world environments.

Subjective preference and aided speech recognition assessments are both recommended to ensure that bimodal listeners achieve their maximal hearing potential.

Use of Hearing Assistive Technology Systems (HATS) see BIAP Rec 06/16 - 07/7.

A way to improve hearing in demanding listening situations is the use of HATS to enhance the application of any noise reduction algorithm. HATS in the bimodal situation, connected to both the CI and the HA, provides additional benefit compared with the use of the system with the CI or the HA alone. It is recommended to use a system compatible with both devices simultaneously. (Both the CI processor and the HA microphones must be activated and programmed in a 1:1 or 50/50 gain setting to guarantee environmental inputs along with the speaker signal transmitted through the wireless system).

Connectivity for streaming

When applicable, connectivity should be enabled in both devices simultaneously.

Directionality

The choice of a microphone configuration in a bimodal setup may differ from the default settings, and further evaluation of different settings in individual patients is required to determine the optimal choice.

Matching different automatic programs

It is recommended to synchronise automatic programs on both devices as effectively as possible. This is only possible when CI and HA work together in synchrony.

General remarks

Keep in mind that there is no universal setting that works for everyone. Each individual has unique hearing needs and preferences, so device configurations must be tailored accordingly. Personalisation is key to achieving optimal outcomes - what works well for one person may be ineffective or even counterproductive for another.

6. Validation: Recommended Audiometric Assessments for Optimising Bimodal Fitting

To ensure optimal performance and user satisfaction in bimodal hearing (combining a hearing aid and cochlear implant), the following assessments are proposed:

- ***Speech Audiometry (Monaural vs. Bimodal) in Quiet and Noise***

Compare monaural (HA and CI separately) with bimodal performance. Bimodal results should be at least equal to or better than the best monaural outcome.

- ***Loudness Scaling (Monaural)***

Use tests such as the Contour Test for loudness perception (Cox et al., 1997) or another loudness scaling test. Perception of soft and loud sounds should be nearly equivalent for both ears.

- Sound Localisation (Post-Training)

Localisation remains one of the more challenging aspects of bimodal hearing. Structured training is essential to achieve meaningful improvement.

- ***Subjective Benefit Questionnaires***

Administer validated questionnaires to assess perceived benefit and satisfaction with bimodal hearing.

- ***Listening Fatigue Questionnaires***

Evaluate fatigue using tools such as the Vanderbilt Fatigue Scales VFS-A or VFS-PED to understand the cognitive load associated with bimodal listening.

7. Conclusion

Many aspects must be considered in bimodal fitting. To achieve an optimal outcome (where the patient is satisfied with the settings of both systems and where the integration at the brain level is maximised) the fitting of the HA and the CI should be performed by the same experienced professional at the same place.

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