An approach for determining individual frequency allocation map in cochlear implant users using cochlea CT-scans

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Background

It is well known that cochlear implants (CI) have a good track record in restoring hearing functions. However, the perception with state-of-the-art CI systems is significantly distorted in acoustic situations containing multiple talkers and music

Previous studies have shown the importance of the **frequency allocation map (FAM)** for better sound perception with CI stimulation (Saadoun et al. 2022). Finding an optimum FAM may be even more crucial for bimodal CI patients where acoustic- and electric-frequency information should be ideally tonotopically aligned between the two ears.

Abstract

We have designed an approach in which we generate five individualized CT-scan-based FAMs.

For each FAM some acceptance criteria are calculated based on (Lambriks et al. 2020) and (Di Maro et al. 2022) to see if enough electrodes are assigned to some pre-defined frequency regions.

Our approach presents the FAMs to expert audiologists and researchers, who can then use the acceptance criteria to choose the most appropriate FAM for their patient, for both clinical and research purposes.

Methodology

Our method generates **five different CT-based FAMs from the tonotopic map of the patient**. Additionally, the default FAM proposed by Oticon Medical GMCI fitting software (non-CT-based) is proposed as the sixth FAM. The proposed FAMs may be modified slightly (by jittering or deletion of a frequency band) as the bandwidth of each channel (electrode) should be a multiple number of 125 Hz. Experts may calculate the tonotopic maps manually or automatically (e.g., with Oticon Medical **Nautilus software**, (Margeta et al 2022)) from the individualized CT scans.

FAM1: Matching the tonotopic map

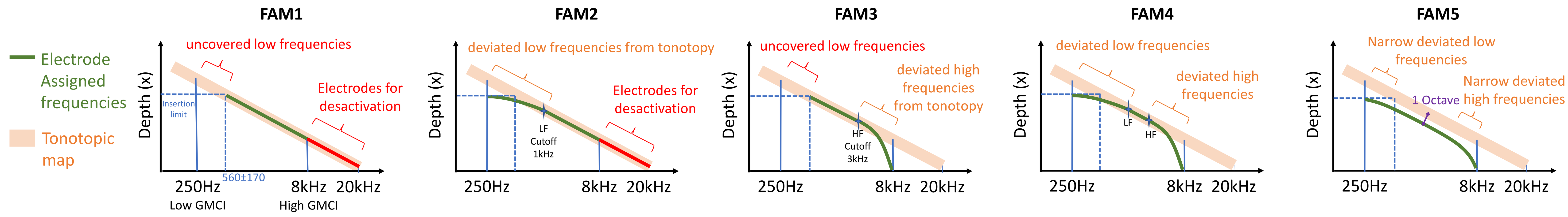
- FAM1 fully matches the tonotopic map of the inserted electrodes in the cochlea. Note that in FAM1 the lowest frequency band is a function of the electrode array insertion depth. Additionally, a few basal electrodes may need to be deactivated as the maximum tonotopic frequency passes over the Nyquist frequency of the audio samples in the cochlear implant sound processor.

FAM2-FAM4: LF, HF, LF-HF Hybrid maps

- FAM2 introduces a low-frequency cutoff frequency below which the center frequencies of the electrodes linearly deviate from the tonotopic map to approach the GMCI map (i.e., the Oticon Medical default map).
- FAM3 does the same but based on a high-frequency deviation.
- FAM4 combines FAM2 and FAM3 methods to compensate for the limitations of FAM1, but at the expense of more deviation from the tonotopic map at low and high frequencies.

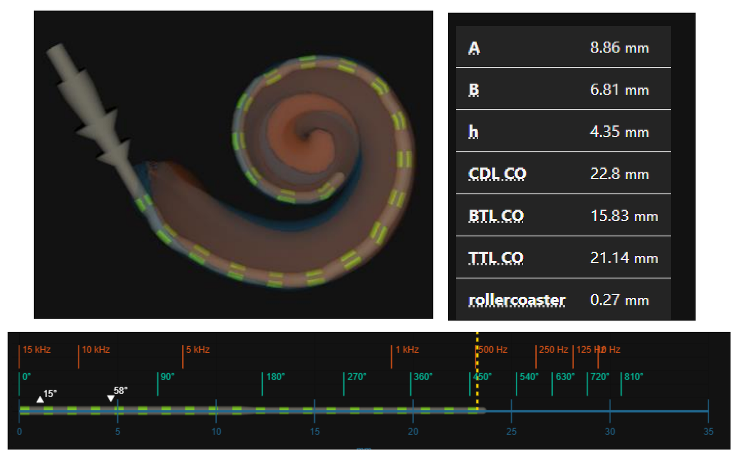
FAM5: Parallel to tonotopic

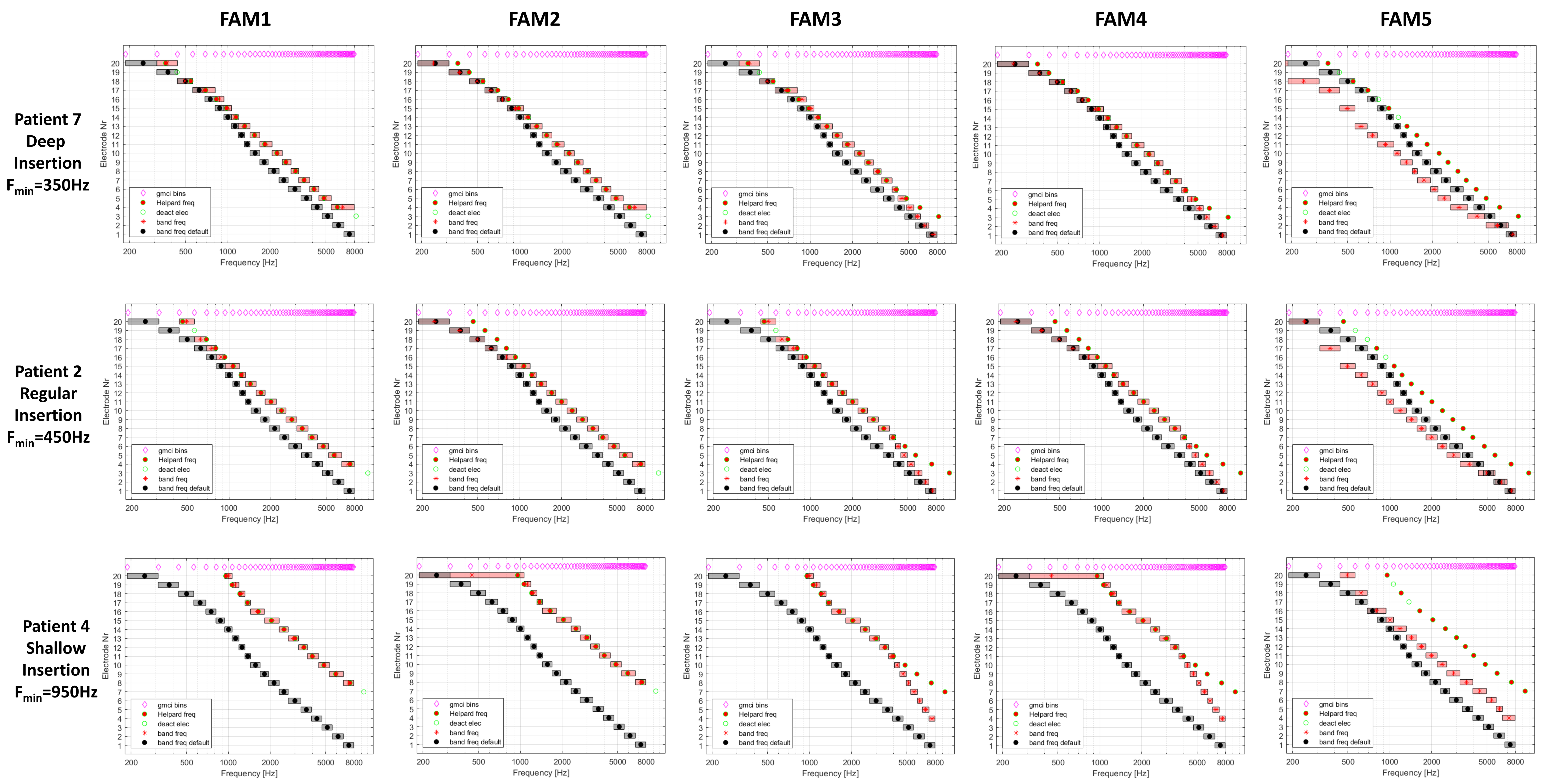
- FAM5 is designed to have a quasi-constant shift from the tonotopic map, and therefore preserves the slope or curvature of the tonotopic map. The shift can be set to a fixed value (e.g., 1 Octave) or can be determined by an optimization method, where a cost function penalizes any curvature dissimilarity between the two maps when putting the lower/upper frequency boundaries of FAM and GMCI at the same level.



Results

We applied our FAM design approach to 10 bimodal CI patients.
The tonotopic frequencies derived from CT-scans were provided by the Hannover Medical School (MHH) under the framework of the BiMoFuse project funded by the Demant Foundation.
Tonotopic maps were calculated manually. For future studies, these maps can be automatically obtained using Nautilus software (Margeta et al. 2022) as shown below.





- The lowest and highest tonotopic frequencies measured were 560±170 and 14900±890 Hz, respectively.
- In GMCI minimum and maximum frequencies are set to 250 and 7312 Hz, respectively.
- FAM1 and FAM3 do not include apical frequencies below 560 Hz (in average).
- Typically, two to three basal electrodes have to be deactivated in FAM1 and FAM2.
- FAM4 introduced an average deviation of 1.16 and 1.03 octaves between tonotopic and the allocated map at the lowest and highest GMCI frequencies, respectively.
- In FAM5, the average optimum shift was determined to be about -0.7 octave. Setting this value to -1 octave (to maintain harmonic relationships in both ears) required deactivation of 1 to 2 apical electrodes in the electrode arrays.

References

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Di Maro et al., Eur. Arch. ORL 2022, doi: 10.1007/s00405-021-07245-y

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