Lateralization Performance With "Channel Specific" Mixed Rate Stimulation Strategy Using the CCi-Mobile Research Processor

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Introduction: spatial hearing is poor with bilateral cochlear implants (BiCIs).

- **CIs have restored hearing for over 1 million individuals with severe to profound hearing loss [1].**
- **However, CIs don't fully restore hearing abilities: spatial hearing, for example, which requires 2 ears, is poor even with BiCIs, as shown in Figure 1.** ITD: interaural time difference, one of spatial hearing cues.

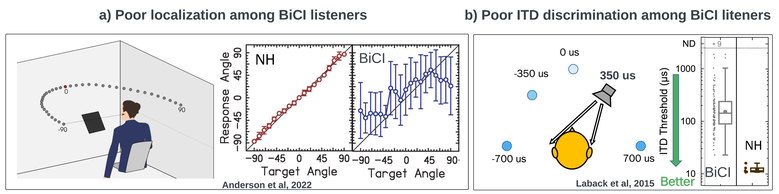


Figure 1. Comparison of spatial hearing measures between normal hearing (NH) and BiCi listeners. a) stimulus: pink noise b) stimulus: unmodulated tones. Note that for BiCI listeners, the stimulus was constant amplitude pulse train. References: [2, 3].

The following factors contribute to poor spatial hearing in BiCIs.

- ***External processors are not synchronized.*** Encoding of ITD is difficult with pulses from two sides not being synchronized.
- ***High stimulation rate is adopted for all electrodes in clinic.*** Low rate is needed for ITD sensitivity while high rate is important for speech intelligibility.
- ***There is interaural mismatch between implants:*** 1) Asymmetric insertion depth 2) Different lengths in electrode arrays 3) Asymmetric neural health 4) Different electrode-nerve interface

"Mixed rate" strategy running on synchronized research processors could improve spatial hearing but so far results have been mixed.

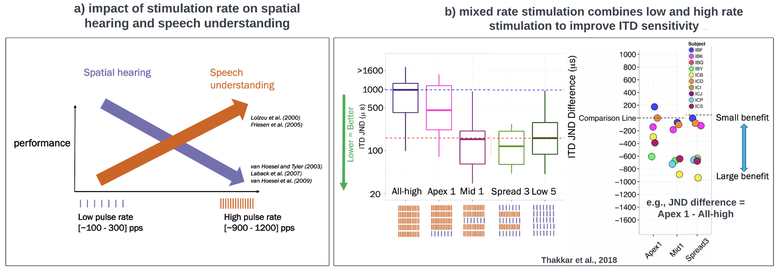


Figure 2. a) ***Most clinical strategies use high rate stimulation to preserve speech intelligibility***, stimulus: constant amplitude pulse train. b) [left], stimulus: constant amplitude pulse train; introduction of low-rate stimulation (purple pulses) improves ITD sensitivity. [right] the comparison between the mixed rate and all-high strategies: negative values indicate improvements with mixed rate strategy. ***Not all participants benefit from mixed rate strategy.*** References: [4--9].

Hypothesis: some BiCI listeners gained little benefit from "mixed rate" strategy because low-rate ITD information was presented at a region with large asymmetry across ears (hence poor sensitivity to ITD, the last of the three limitations listed above).

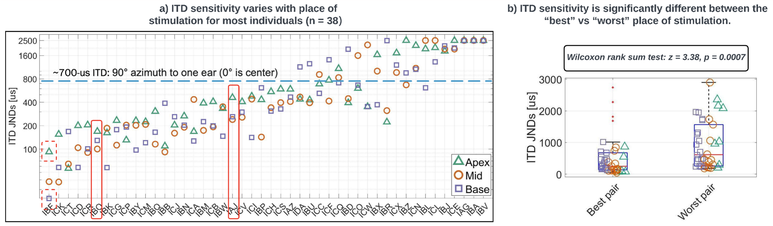
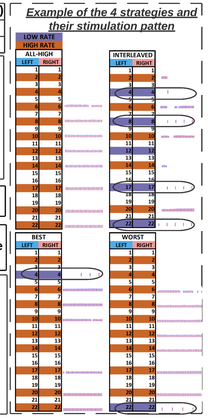


Figure 3. Stimulus: constant amplitude pulse train. The dataset used to produce these figures was published in Thakkar et al, 2020 [10]. Subject IBO and IAJ, circled in subfigure a), returned and participated in this study.

Methods

Participant	Age at testing (years)	Age at 1st implant (years)	Age at 2nd implant (years)
IBO	58	42	45
IAJ	77	51	58

Example of the 4 strategies and their stimulation patten



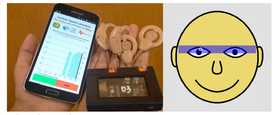
Step 1

Direct stimulation **(RF generator: to bypass clinical processors) was used to measure threshold and most comfortable stimulation levels to create the MAPs for *ALL-HIGH* and *INTERLEAVED* strategies (see on the right).**
1) *ALL-HIGH*: all 10 pairs of electrodes (in colors) were stimulated at 1000 pulses per second (pps)(in orange).
2) *INTERLEAVED*: every other pair was stimulated at 125 pps, shown in purple. The actual stimulation is next to the MAPs.

Step 2 ***Direct stimulation*** **was used to measure ITD sensitivity (left, right discrimination, see Figure 1, b) at 125 pps, on those 5 low-rate electrode pairs in the INTERLEAVED strategy.**

Step 3 **The pair with the best ITD sensitivity was selected to deliver low-rate stimulation in the *"BEST"* strategy, and the pair with worst ITD sensitivity was used to create the MAP for the *"WORST"* strategy.** ***The "BEST" and "WORST" pairs vary from individual to individual.***

Step 4



Ghosh et al., 2022

Subjects were asked to indicate the perceived location of the stimulus on the purple bar (i.e., lateralization). The lateralization was tested on *CCi-MOBILE* (portable research processors) with 2 types of stimulus in quiet: 1) *complex tone* 2) *CNC word*. *The lateralization performance was compared among 4 stimulation strategies.*

Figure 4. Refer to [11] for details on CCi-MOBILE. ***Would the "BEST" strategy tailored for each subject make sure that EVERYONE benefits from the mixed rate strategy?***

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- **Special thanks to Shelly Godar for assisting with many aspects of this study.**

Results

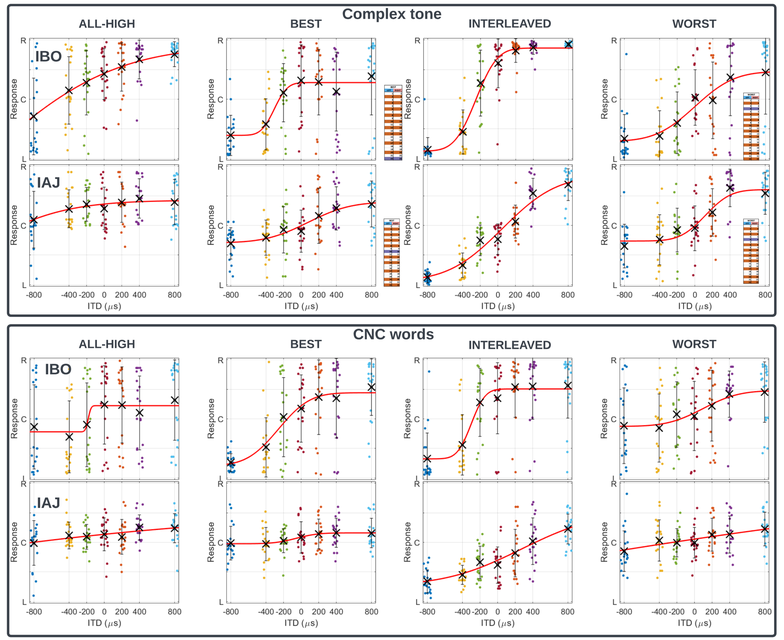

Figure 5. x axis is stimulus ITDs; y axis is response location: C(Center), R(Right), L(Left). Each dot is a response. Big x is mean, error bar is 1 std.

Discussion

- **ITD sensitivity "predicts" the benefit from "mixed rate" strategies (combine Figure 3 and results).**
- **For IBO, the BEST strategy is slightly better than the WORST strategy, when the stimulus is word.**
- **INTERLEAVED strategy resulted in the best lateralization performance overall for both subjects.**
- **Both subjects performed better with complex tone, compared to word (speech) stimulus.**

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