Novel Approaches to Investigating Binaural Processing in Bilateral Cochlear Implants Using Neural Processing and Psychophysical Measures

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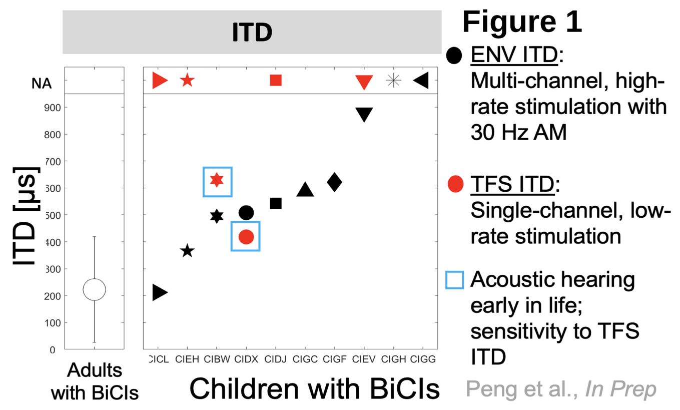
INTRODUCTION

- Sound localization depends on binaural cues: interaural time differences (ITDs) at low frequencies and interaural level differences (ILDs) at high frequencies[1]. Low-frequency ITDs are conveyed by temporal fine structure (TFS), while high-frequency ITDs can be transmitted through slow envelope (ENV) modulation[2].
- Typically-hearing (TH) listeners exhibit high sensitivity to both TFS- and ENV-ITDs. In contrast, bilateral cochlear implant (BiCI) users show reduced ITD sensitivity due to limitations in temporal precision of CI processors[3].
- Previous work has demonstrated that children with BiCIs can detect ENV-ITDs, but only those with early acoustic hearing experience are sensitive to TFS-ITDs[4–5].



- However, neural encoding of TFS- and ENV-ITDs in TH individuals remains underexplored, especially that comparable to CI listening.
- In this phase of the study, we investigate neural processing of TFS- and ENV-ITD in TH adults by simulating a single-electrode stimulation in CIs, as well as in BiCI users.

OBJECTIVES

1. Examine how task demands (active discrimination vs. passive listening) influence neural processing of binaural cues, including the impact of auditory attention on cue encoding across auditory processing stages.
2. Investigate how TFS- and ENV-ITD cues are differentially processed and whether attention enhances cortical representations of these cues.
3. Link behavioral just-noticeable differences (JNDs) with active cortical discrimination (P300) to identify neural biomarkers for binaural sensitivity and perceptual performance.

METHODS

Participants:

- TH: N = 5 (mean age(SD): 21.8 years (1.64))
- BiCI: N = 1 (47 years of age, unknown etiology)

Ear	Age of onset of hearing loss	Age at CI activation	Implant	Electrode tested	Bilateral CI usage
Left	3 years (HA use since 5 years of age)	33 years	CI512	12	12 years
Right		35 years	CI422	12	

Stimuli:

- Short-duration click trains[6] to reduce CI artifact for TFS (100 pps)[7,8] and ENV (4000 pps, 125 Hz AM)[9] ITDs.
- For TH, stimuli embedded in notched noise to limit excitation spread and simulate restricted, CI-like excitation patterns.

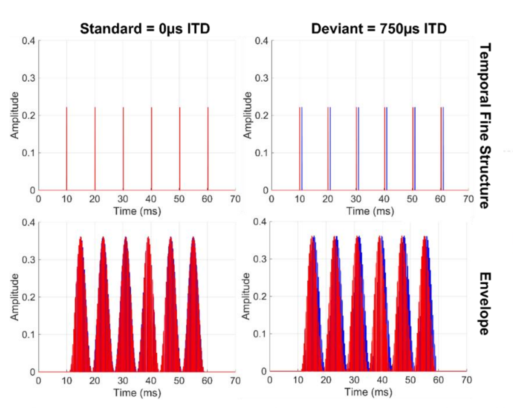


Figure 2: *TFS- and ENV-ITD stimuli*

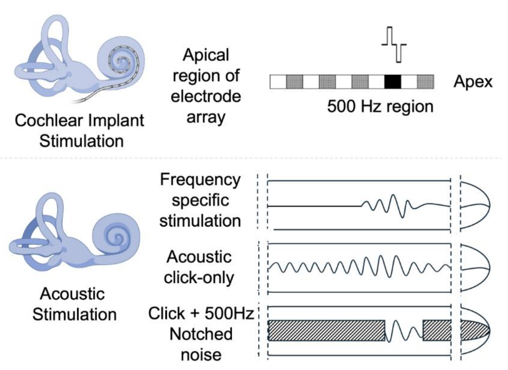


Figure 3: *Simulating Single electrode stimulation in TH*

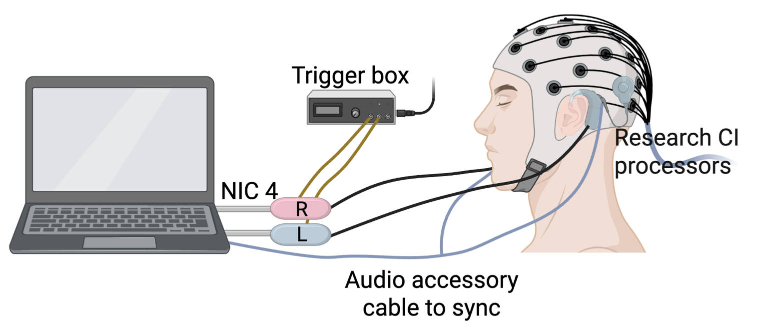


Figure 4: *Direct stimulation set up for BiCI users.*

METHODS

Psychophysical Just-Noticeable-Difference Experiment

- ITD JNDs provide a measure of accuracy and threshold for binaural cue processing.
- ITD cue magnitudes (10, 20, 40, 80, 140, 200, 400, 750 µs) were tested 20x per side, using a method of constant stimuli.
- A logistic sigmoid was fit to the data using psignifit MATLAB toolbox (v3)[10], and a threshold at 70.1% correct was considered as JND.

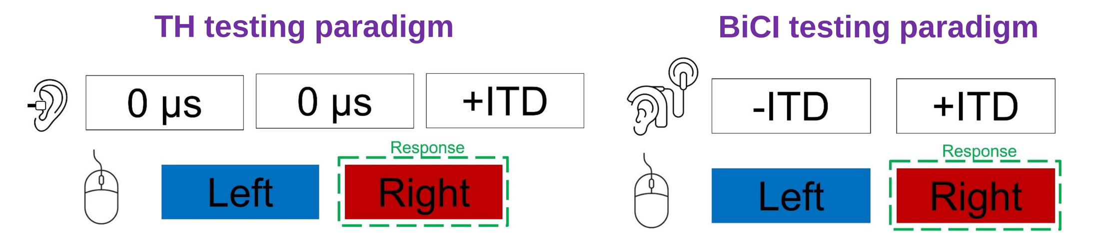


Figure 5: *Example of 3 interval and 2 interval, 2 alternate forced choice JND task.*

Electrophysiological Experiments

- Participants listened (passive control) or actively responded (active oddball) to changes between standard (ITD=0µs) and deviant (ITD=750µs) stimuli.
- Obligatory and active attentive responses were recorded using a 64-channel EEG system (Compumedics Neuroscan Synamps II amplifier and Curry9 v9.0.2).

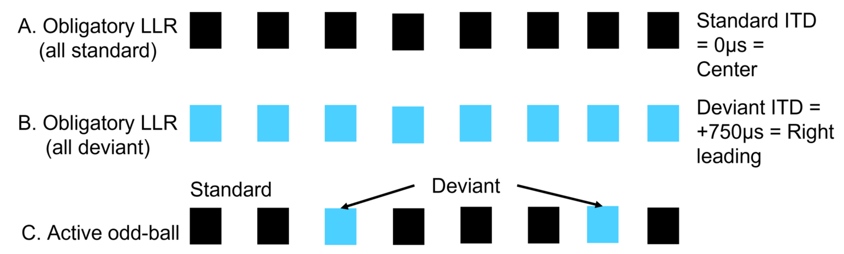


Figure 6: *Different recording paradigms of obligatory and active oddball tasks.*

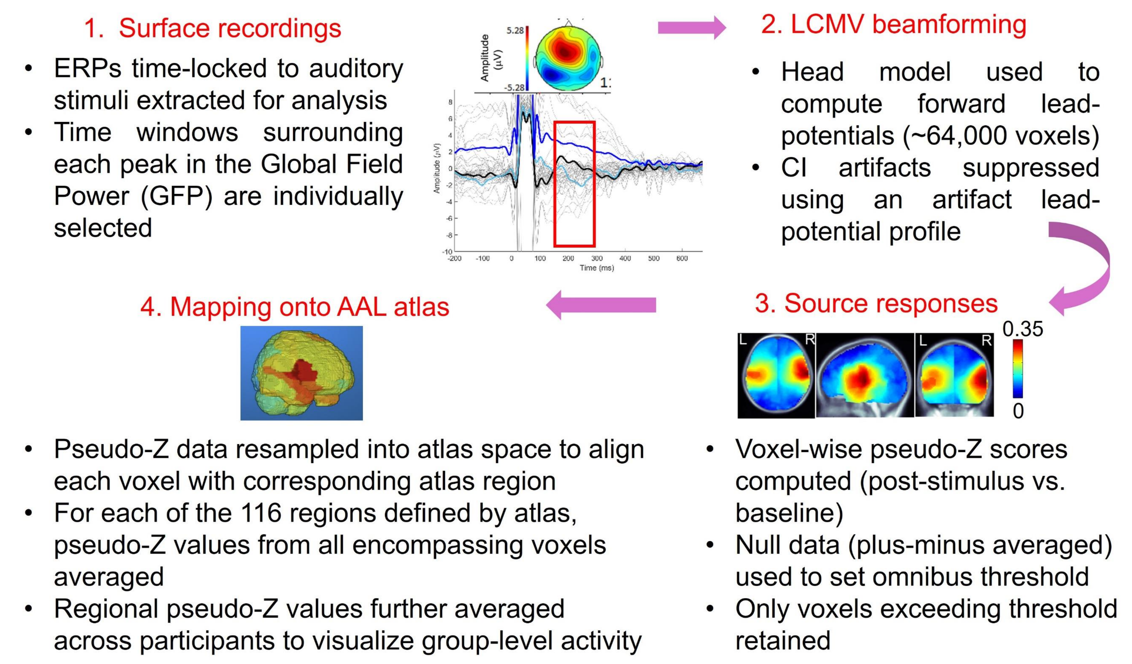
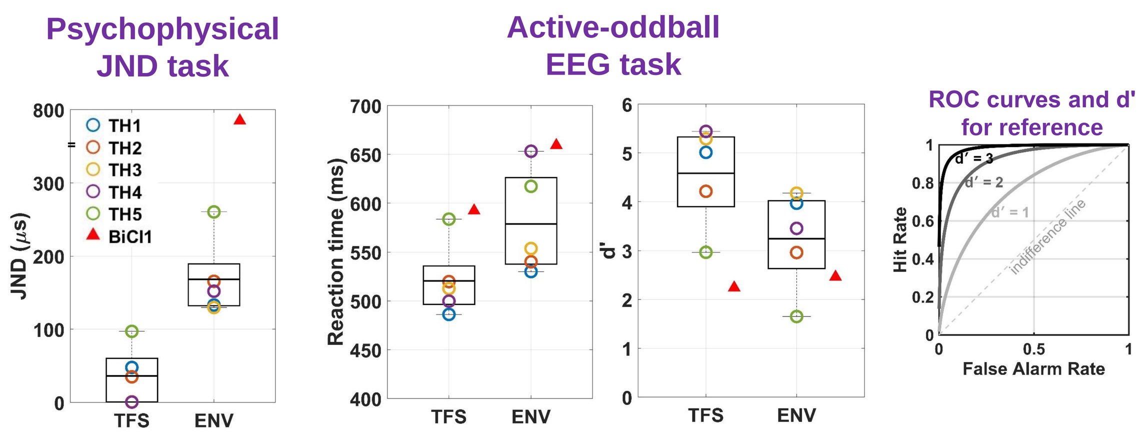


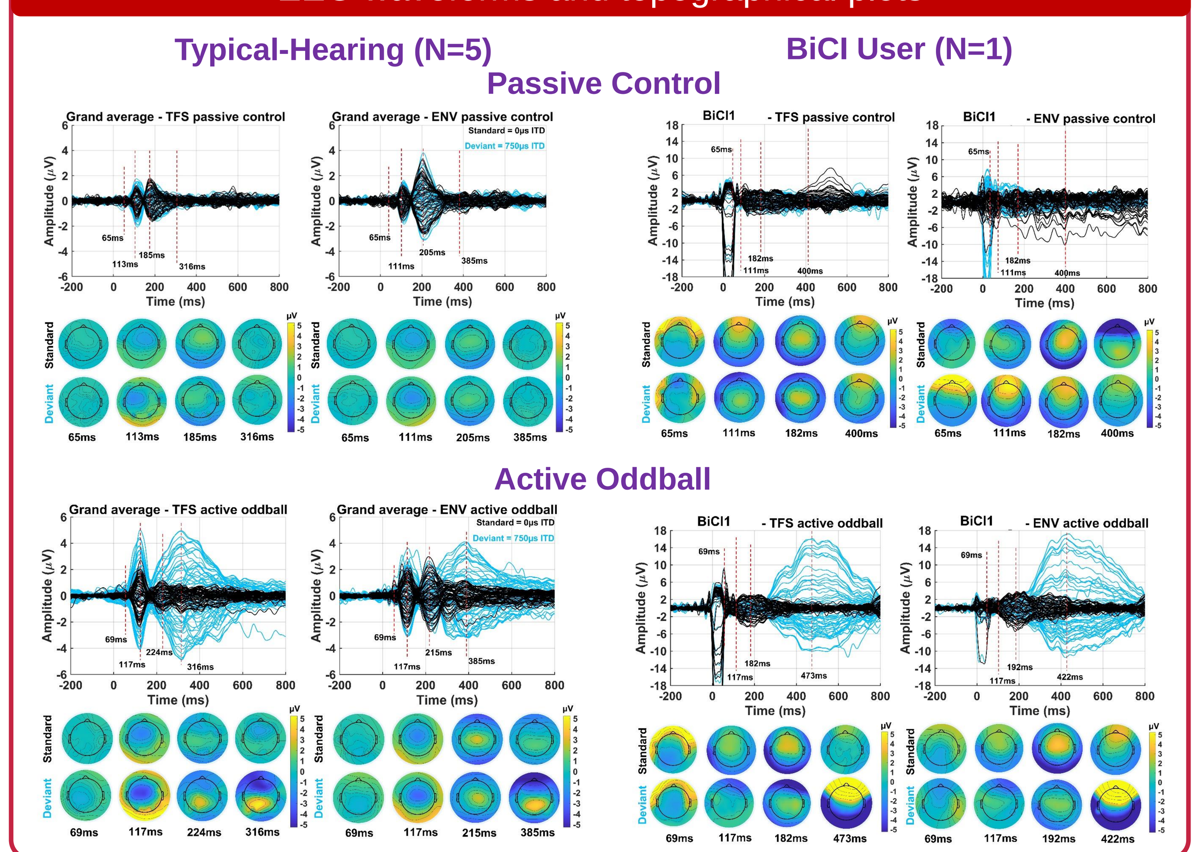
Figure 7: *Example dataset processed through the source analysis pipeline.*

RESULTS

Better behavioral sensitivity to TFS- than ENV-ITD

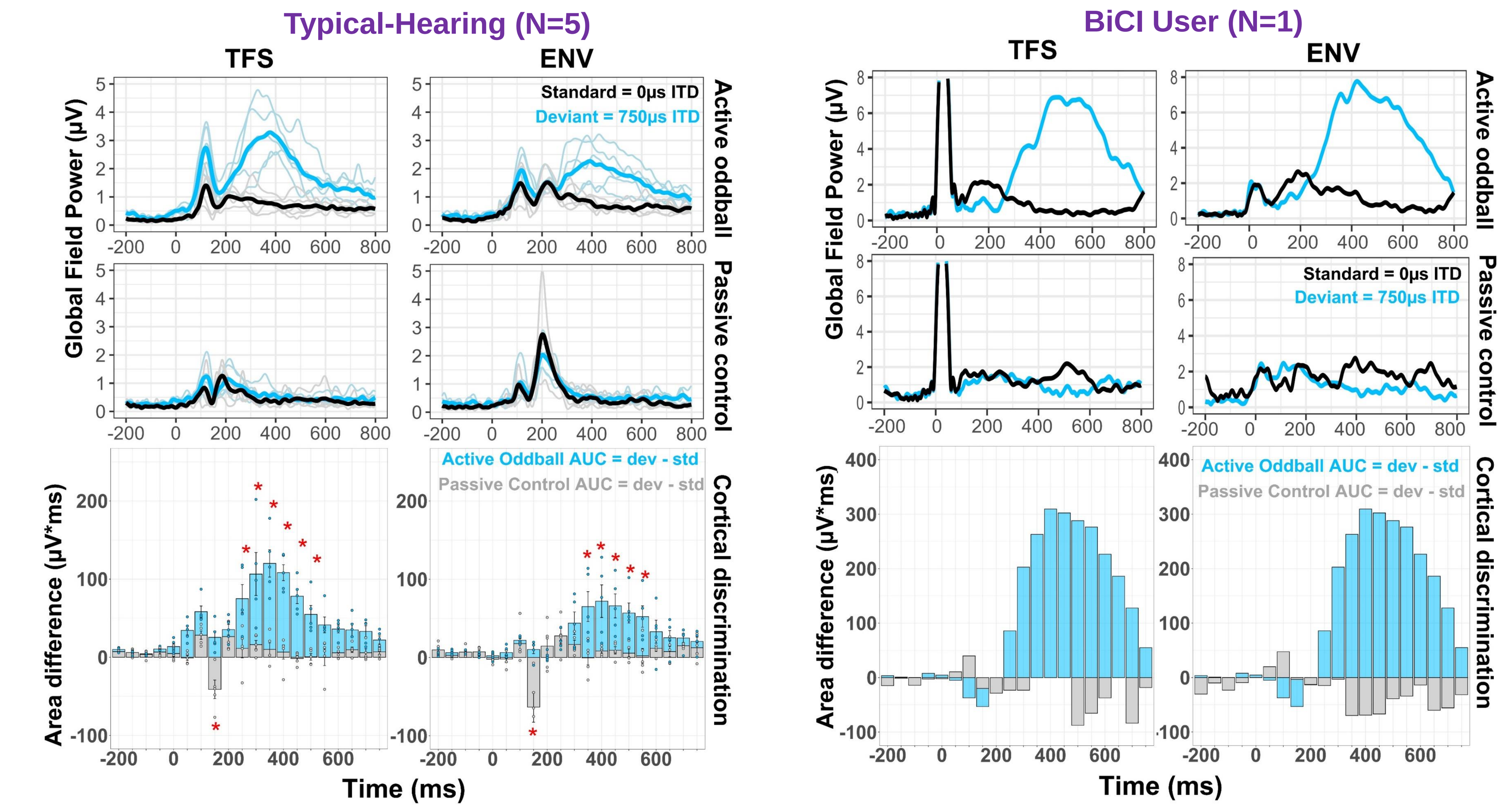


EEG waveforms and topographical plots



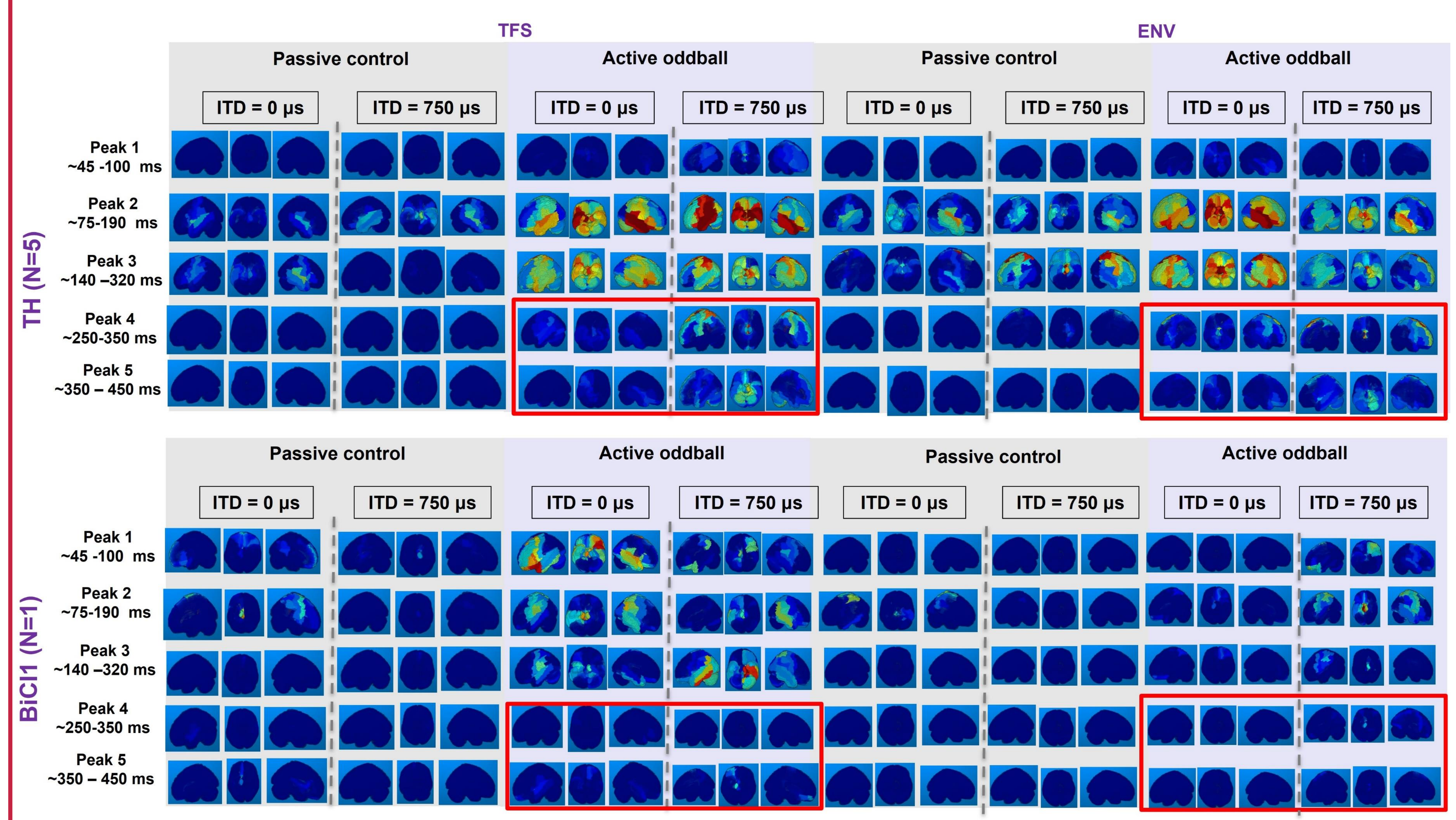
RESULTS

Active attention enhances cortical discrimination of binaural cues



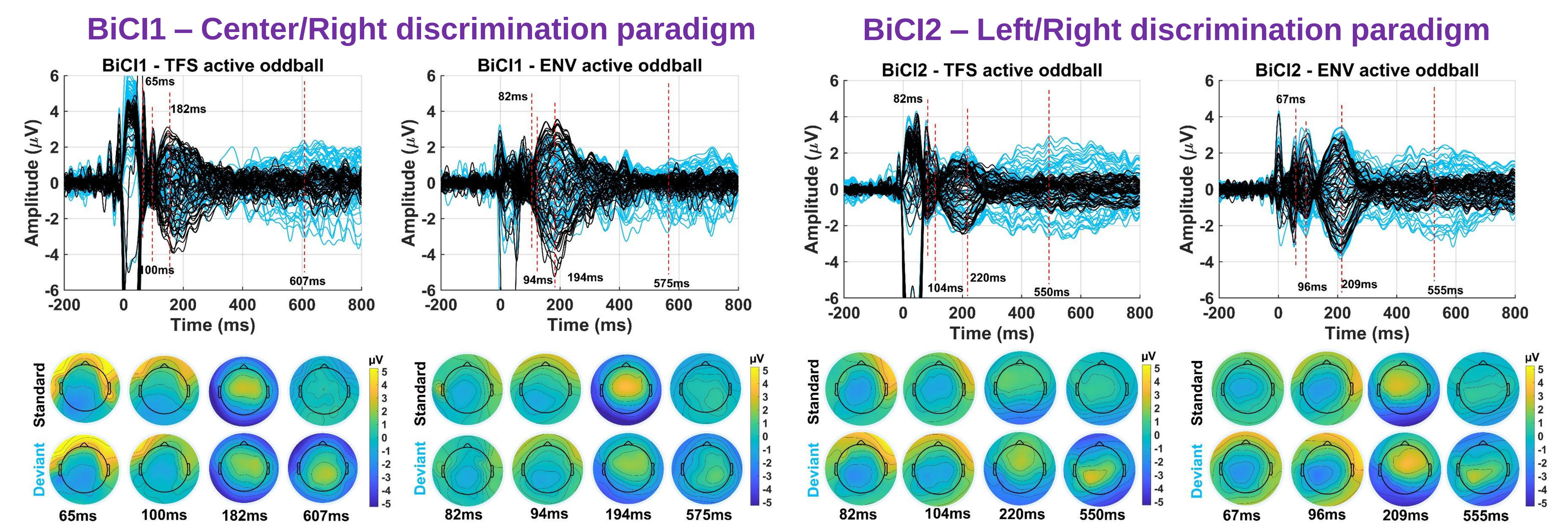
- TH listeners show strong P300 to the deviant stimulus for both TFS- and ENV-ITD during active listening.
- In TH listeners, the P300 amplitude was greater for TFS- than for ENV-ITD.
- P300-like responses seen in the BiCI listener for both TFS- and ENV-ITD in the active listening conditions.
- TFS- and ENV-ITD cues show distinct neural responses even in passive conditions.

Group-level source activity maps of TH (N=5) and of 1 BiCI user mapped onto the AAL atlas



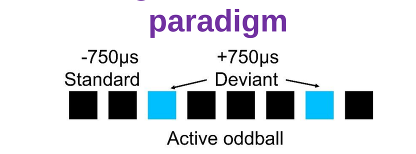
- Early peaks (~45-190ms) show bilateral temporal activation, later shifting to frontal regions during active listening.
- Suggests engagement of attentional networks up to ~450ms.
- Activation stronger and more bilateral for TFS- compared to ENV-ITD.
- LCMV beamformer highlights spatiotemporal dynamics of auditory cortical processing modulated by stimulus type and task demands.
- Future analyses will compare these patterns to those observed in BiCI users.

Future direction: Change of EEG paradigm to a Left-to-Right oddball discrimination task



*Note: Ocular artifact removed during the analysis of these surface responses

Left/Right discrimination paradigm



Comparing the two paradigms

Oddball paradigm	ID	ITD Stimulus	d'	JND (µs)	RT (ms)
Center-to-Right	BiCI1	TFS	2.38	CNT	590.85
		ENV	2.55	715	655.89
Left-to-Right	BiCI2	TFS	3.75	243	752.11
		ENV	3.16	188	598.00

- Anecdotally, the ITD = 0 µs standard in the oddball paradigm can be challenging for BiCI participants with an unstable center percept.
- A left-to-right discrimination paradigm, well-established in psychophysics experiments[4,9], facilitated slightly better performance in another BiCI user.

CONCLUSIONS

- Cortical responses to auditory cues are shaped by both acoustic salience and attention.
- TFS-ITD cues in TH lead to enhanced cortical responses (N1, P300) with attentional engagement, while ENV-ITD cues show weaker responses.
- The center-to-right discrimination task is suboptimal for BiCI users; a left-to-right task provides clearer perceptual distinctions and aligns with psychophysical methods.
- Findings highlight the importance of understanding distinct neural pathways for TFS-ITD and ENV-ITD in BiCI users, informing CI processing strategy optimization and future interventions.

REFERENCES

1. Blauert J. Spatial Hearing. Cambridge, MA: MIT; 1997. 494 p.
2. Bernstein, L. R. (2001). Auditory processing of interaural timing information: new insights. *Journal of Neuroscience Research*, *66*(6), 1035-1046.
3. Kan, A., & Litovsky, R. Y. (2015). Binaural hearing with electrical stimulation. *Hearing Research*, *322*, 127-137.
4. Ehlers, E., Goupell, M. J., Zheng, Y., Godar, S. P., & Litovsky, R. Y. (2017). Binaural sensitivity in children who use bilateral cochlear implants. *The Journal of the Acoustical Society of America*, *141*(6), 4264-4277.
5. Peng, Z. E., Kan, A., & Litovsky, R. Y. Binaural sensitivity and processing of envelope-based interaural difference cues by bilateral cochlear-implant users with perilingual and postlingual onset of deafness. *In prep.*
6. Wong, D. D., & Gordon, K. A. (2009). Beamformer suppression of cochlear implant artifacts in an electroencephalography dataset. *IEEE Transactions on Biomedical Engineering*, *56*(12), 2851-2857.
7. Van Hoesel, R. J. (2007). Sensitivity to binaural timing in bilateral cochlear implant users. *The Journal of the Acoustical Society of America*, *121*(4), 2192-2206.
8. Van Hoesel, R. J., Jones, G. L., & Litovsky, R. Y. (2009). Interaural time-delay sensitivity in bilateral cochlear implant users: Effects of pulse rate, modulation rate, and place of stimulation. *Journal of the Association for Research in Otolaryngology*, *10*, 557-567.
9. Ehlers, E., Kan, A., Winn, M. B., Stoelb, C., & Litovsky, R. Y. (2016). Binaural hearing in children using Gaussian enveloped and transposed tones. *The Journal of the Acoustical Society of America*, *139*(4), 1724-1733.
10. Fründ, I., Haenel, N. V., and Wichmann, F. A. (2011). Inference for psychometric functions in the presence of nonstationary behavior. *Journal of Visualized Experiments*, 11:16, 1–19. doi: 10.1167/11.6.16

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