Sensitivity of Inferior Colliculus to Interaural Time and Level Differences in Neonatally Deafened Rats

Muhammad Zeeshan[1], Fei Peng[1], Bruno Castellaro[1], Shiyi Fang[1], Nicole Rosskothen-Kuhl[2], Jan W Schnupp[1]

[1] Department of Neuroscience, City University of Hong Kong, Hong Kong (SAR China); Email: mzeeshan6-c@cityu.edu.hk

[2] Department of Oto-Rhino-Laryngology, Section of Clinical and Experimental Otology, Neurobiological Research Laboratory, Medical Center – University of Freiburg, Germany

香港城市大學
City University of Hong Kong

Normal spatial hearing relies on Interaural Time Differences (ITDs) as well as Interaural Level Differences (ILDs).

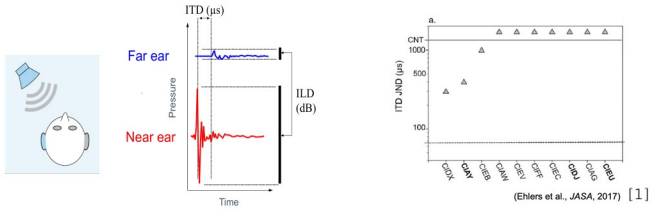

Figure A: Background

Cochlear Implant (CI) patients are reasonably good at using ILD, but their ability to use ITD cues falls far below that of their normal hearing peers [1].
However, CI rats can lateralize ITDs very well even if neonatally deafened [2].
We need to understand how ITD and ILD sensitivity co-evolve in the auditory pathway. In this study we explore the "innate joint sensitivity" to ITD and ILD in the auditory midbrain of ND rats.

We used 8 Wistar rats as animal model. The rats were deafened with kanamycin injection (P9-P20) before the onset of hearing and allowed to mature (>P60). They were then implanted with bilateral CIs in the middle turn of the cochlea, and multiunit activity was recorded from their inferior colliculus under terminal urethane anesthesia.

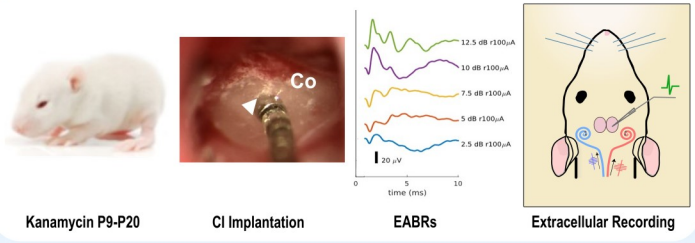

Figure B: Methodology [3]

Stimulation Parameters:

- Biphasic Pulse Trains
- 200 ms stimulus duration
- Wide range of ITDs / ILDs combinations
- ITDs (+/- 0, 0.04,0.08, 0.12) ms
- ILDs (+/- 0, 1, 4) dB
- 3 different pulse rates: 1,100 and 900 pps

Normally ITD and ILD covary, the ear that receives the earlier stimulus will also receive the louder one (A or D).
Experimentally we can also trade ILDs and ITDs off against each other (B or C).
We recorded responses to all ITD/ILD combinations of the values shown above.

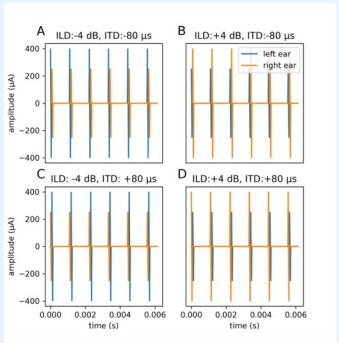

Figure C: Stimulus waveforms

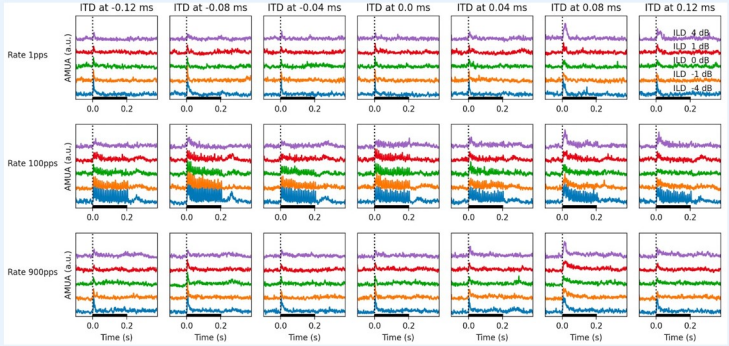

Figure D: Multiunit acitivity (MUA) from a representative example multiunit.
Each panel represents the aMUA over different ILDs, and the dashed line represents the stimulus onset. Each row represent the neural responses at different pulse rates of 1, 100, and 900 pps, respectively. Each column represents the neural responses across different ITDs.

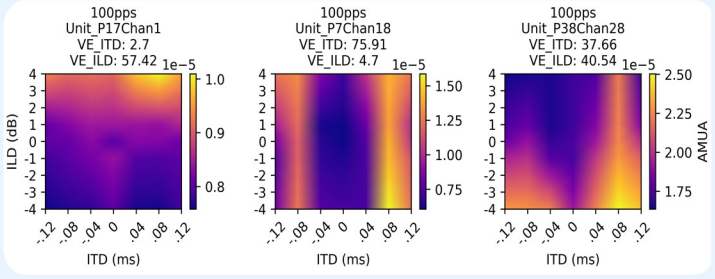

Figure E: Heat map showing joint ILD / ITD tuning for three different example multiunits. The MU on the left is strongly ILD but weakly ITD tuned. The MU in the middle is strongly ITD but weakly ILD tuned. The MU on the right is fairly strongly tuned to ILD and ITD. The strength of tuning was quantified as percentage variance explained (VE). Values are shown above each panel.

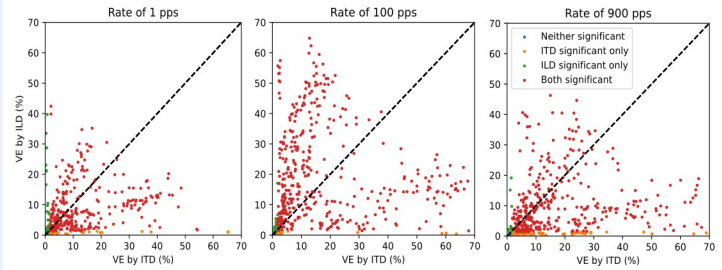

Figure F: Distribution of VE by ITD against VE by ILD.
Each dot is one multiunit, and each panel shows variance explained (VE) values for a different stimulus pulse rates. Interestingly, the multiunits seem to fall into predominantly ILD or predominantly ITD sensitive clusters.

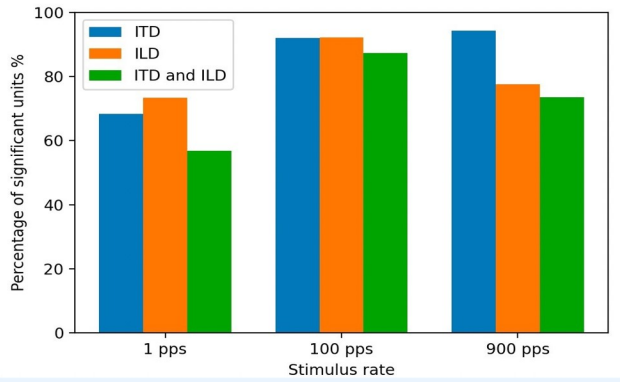

Figure G: The percentage of IC multiunits showing significant sensitivity to ITD and ILD across different stimulus rates. Blue color bars represent multiunits with significant sensitivity to ITD, orange bars to ILD, and green bars to both ITD and ILD. The large majority of multiunits is significantly sensitive to both ITD and ILD, even if sensitivity to one cue type usually dominates (see Fig F)

Results:
- Sensitivity to both ITD asnd ILD is widespread, but most multunits are more sensitive to one cue than the other.
- Changes in ITD as small as 40 µs can lead to substantial changes in the neural firing, and these are in line with behavioural thresholds that we have observed.
- Similarly, changes in ILD as small as a few dB can lead to substantial changes in the strength of neural responses.

Conclusions:
- Our results suggest that the large majority of inferior colliculus multiunits in ND CI were sensitive to ITD, ILD or both.
- The adult rat midbrain thus retains an innate joint sensitivity to both types of binaural cues even after deafness throughout infancy.
- We believe that this sensitivity is later shaped by experience in ways that can be beneficial or deleterious. Poor ITD sensitivity in human CI patients may be due to a loss of sensitivity after months of inappropriate electrical input.

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References

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