Pulse timing interval sensitivity in the inferior colliculus of cochlear implanted rats exceeds thresholds observed in human cochlear implant users

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Background

Temporal coding is a key limitation in cochlear implant (CI) hearing, affecting pitch, melody, and tonal language perception despite good speech scores in quiet. Paired-click auditory brainstem responses in normal hearing show a physiological temporal resolution limit of about 3–4 ms[1], and CI psychophysics using paired electrical pulses suggests a similar ~3 ms limit for discriminating interpulse intervals (IPIs)[2].

Previous studies from our lab[3,4] have shown that neonatally deafened rats have much better ITD discrimination than human CI users. If these rats are better at binaural timing task, are they also better in monaural task? It could be that the constant-rate stimulation may desensitize human CI users to precise pulse timing information.

Research question:

Do IC neurons exhibit finer sensitivity to interpulse interval changes in CI pulse pairs than the ~3 ms behavioral and ABR limit?

Methods

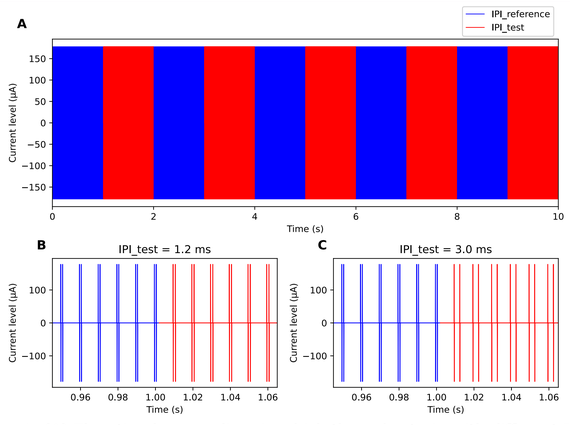

Figure 1. (A) The stimulus paradigm in which the pulse train with different IPIs alternates every 1 s. Blue blocks represent the IPI_reference (1 ms), and red blocks represent the IPI_test. (B) and (C) Stimulus waveforms with IPI_test of 1.2 ms and 3 ms, respectively. Pulse pairs were delivered at 100 Hz.

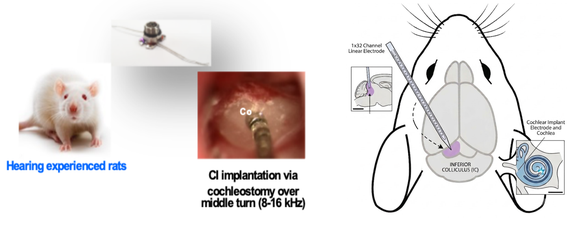

Figure 2. Rats were implanted via cochleostomy over middle turn. Neural responses were collected with a 32-channel Atlas probe in the contralateral inferior colliculus (IC) of anesthetized rats.

IC neural response patterns varied with interpulse interval (IPI)

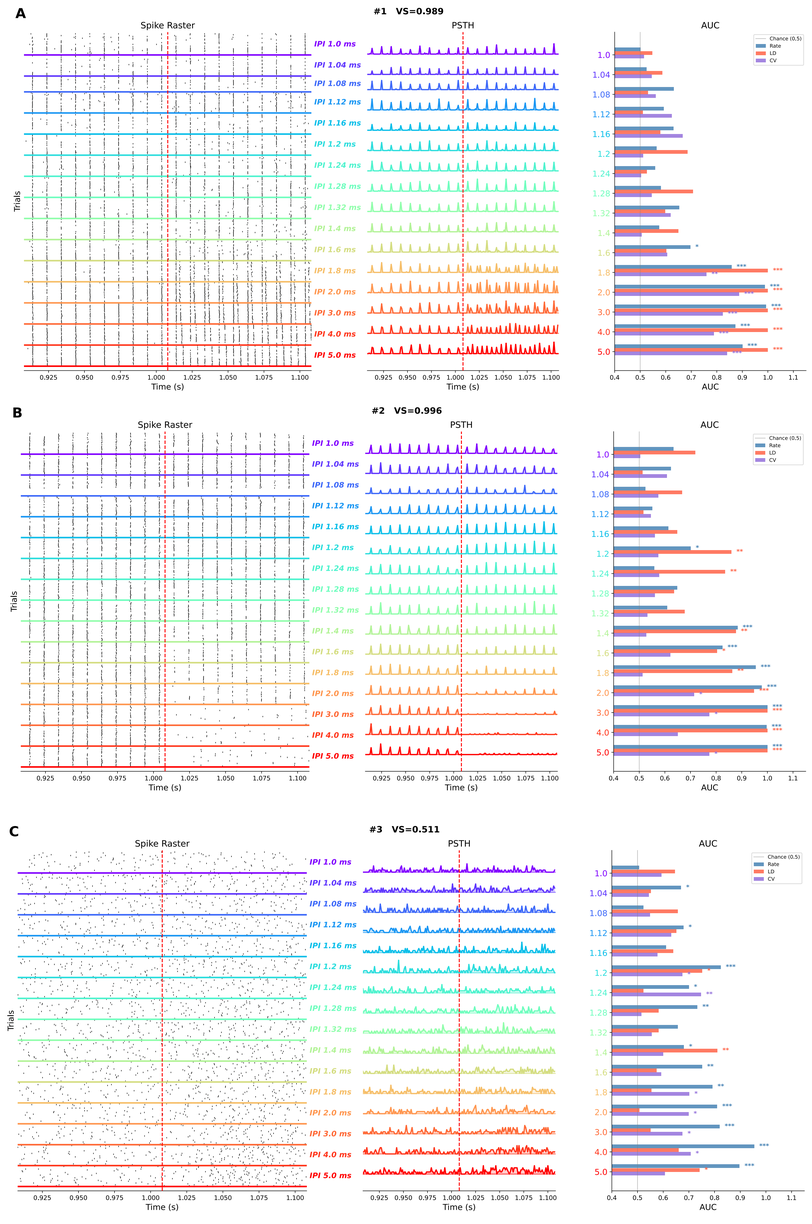

Figure 3. Representative IC units demonstrating distinct response patterns in IPI discrimination. Raster plots, PSTHs, and ROC-AUC metrics are shown for three example units. (A) A phase-locked unit in which neural responses were progressively enhanced for IPIs ≥ 1.6 ms. (B) A phase-locked unit in which responses to pulse pairs were progressively suppressed at IPI ≥ 1.4 ms. (C) A non-phase-locked unit encoding IPI changes through firing rate and spike regularity. Together, these examples illustrate that IPI discrimination can manifest in spike rate as well as in spike timing pattern metrics.

30% of IC neural discrimination threshold is lower than 3 ms

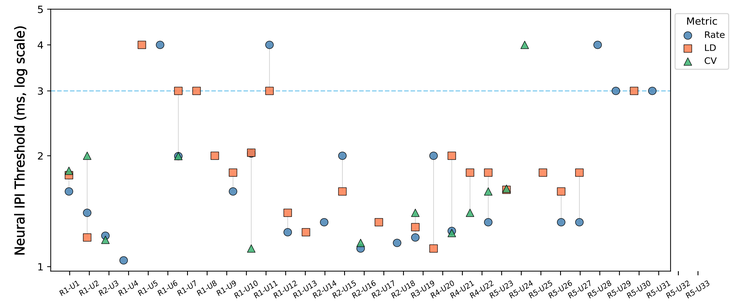

Figure 4. Per-unit IPI discrimination thresholds for firing rate (circles), LD (squares), and CV (triangles) across 33 units (analysis window: 500 ms). Threshold was defined as the lowest IPI yielding significant AUC above chance (permutation test, $p < 0.05$) for two consecutive stimulus conditions. Vertical grey lines span the threshold range across metrics within each unit. Dashed blue line indicates 3 ms, corresponding to the human psychoacoustic IPI discrimination threshold (Fielden et al., 2014).

IPI-induced firing rate modulation occurs across both phase-locked and non-phase-locked populations, but is substantially more common among phase-locked units.

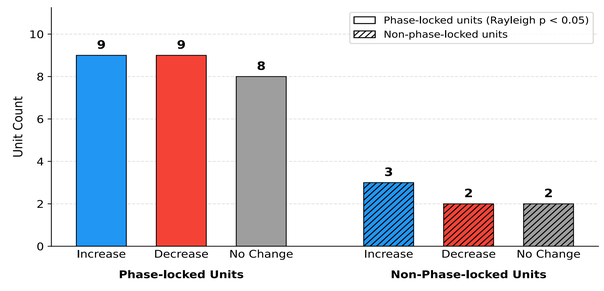

Figure 5. Counts of IC units classified as showing firing rate increase, decrease, or no change for stimulus conditions with IPI values at or above the unit-specific discrimination threshold, plotted separately for phase-locked and non-phase-locked units (Rayleigh test, $p < 0.05$).

References

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[4] Buck, A. N., Rosskothen-Kuhl, N., & Schnupp, J. W. (2021). Sensitivity to interaural time differences in the inferior colliculus of cochlear implanted rats with or without hearing experience. Hearing research, 408, 108305.