Poster #1406

A mixed-rate strategy for real-time delivery of interaural time differences to cochlear implant users

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INTRODUCTION

- **Interaural time differences (ITDs),** or delays in sound arrival between the ears, are one of the binaural cues for sound localization and understanding speech in noise [1]
- **Bilateral cochlear implant (BiCI)** listeners are sensitive to ITDs in envelopes of high rate pulses (>300 Hz) and in the timing of individual pulses when those pulses are delivered at much lower rates (<300 Hz) than the rates of clinical sound processors, see Fig. 1 [2,3]
  - **a) Pulse ITDs:** directly in the timing of low-rate pulse trains (<300Hz), only available with research processors
  - **b) Envelope ITDs:** amplitude modulations on high-rate pulse trains (~1kHz), possible with clinical or research processors

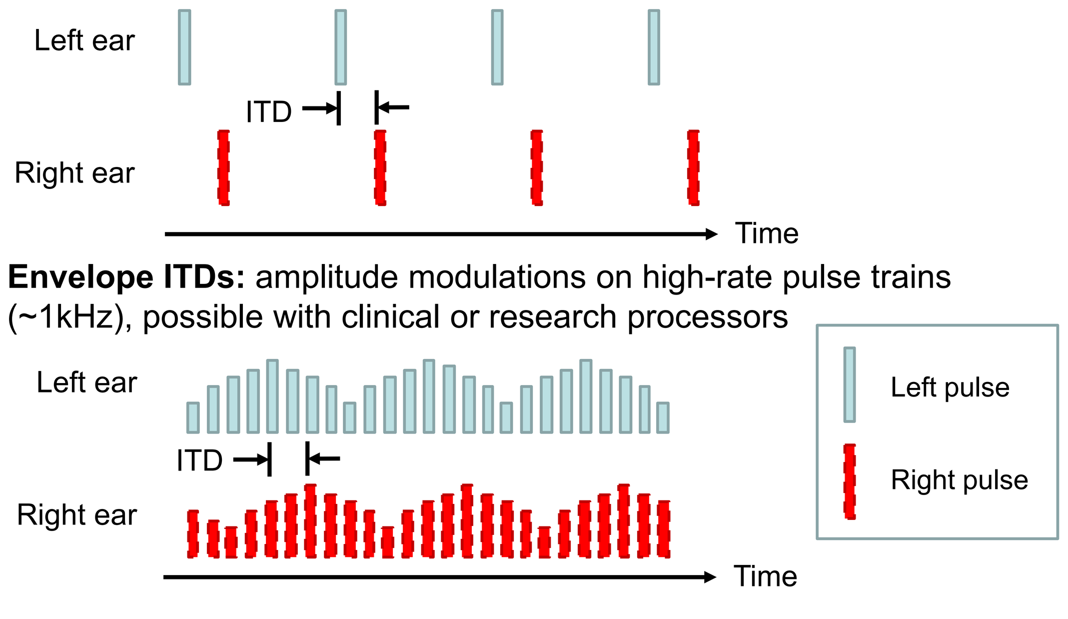


Fig. 1: Illustrations of a) pulse ITDs and b) envelope ITDs. Rectangles represent individual electrical pulses in the left or right ears. Black arrows represent ITDs between left and right ears.

- Providing ITDs in the envelope of high-rate electrical stimulation is potentially possible with clinical processing strategies, but ITD sensitivity is not guaranteed, especially in free-field [3,4]
- Previous work has investigated **Mixed-Rate stimulation**, or providing pulse ITDs on some low rate channels while maintaining high rates on other channels, to understand if low rate pulse ITDs provide ITD sensitivity in the presence of high rates [5]
- However, the benefits of combining **Envelope ITDs** and **Pulse ITDs** in a mixed-rate strategy have yet to be examined
- This study investigates a Mixed-Rate strategy that potentially encodes both Envelope and Pulse ITDs simultaneously by measuring the perceived spatial locations of sounds and calculating the sensitivity (d') to left-right ITD cues

PROCESSING STRATEGIES

Two processing strategies were compared in this study, see Fig. 2:

1. **All-High strategy** is continuous interleaved sampling (CIS) [6] with 10 channels and 1000 pulse per second (pps) stimulation rate per channel and can only provide Envelope ITDs
2. **Mixed-Rate strategy** is a downsampling of CIS which stimulates five high-rate (1000 pps) and five low-rate (125 pps) channels interleaved along the electrode array, potentially providing Envelope ITDs on high-rate channels and directly encoding Pulse ITDs on low-rate channels

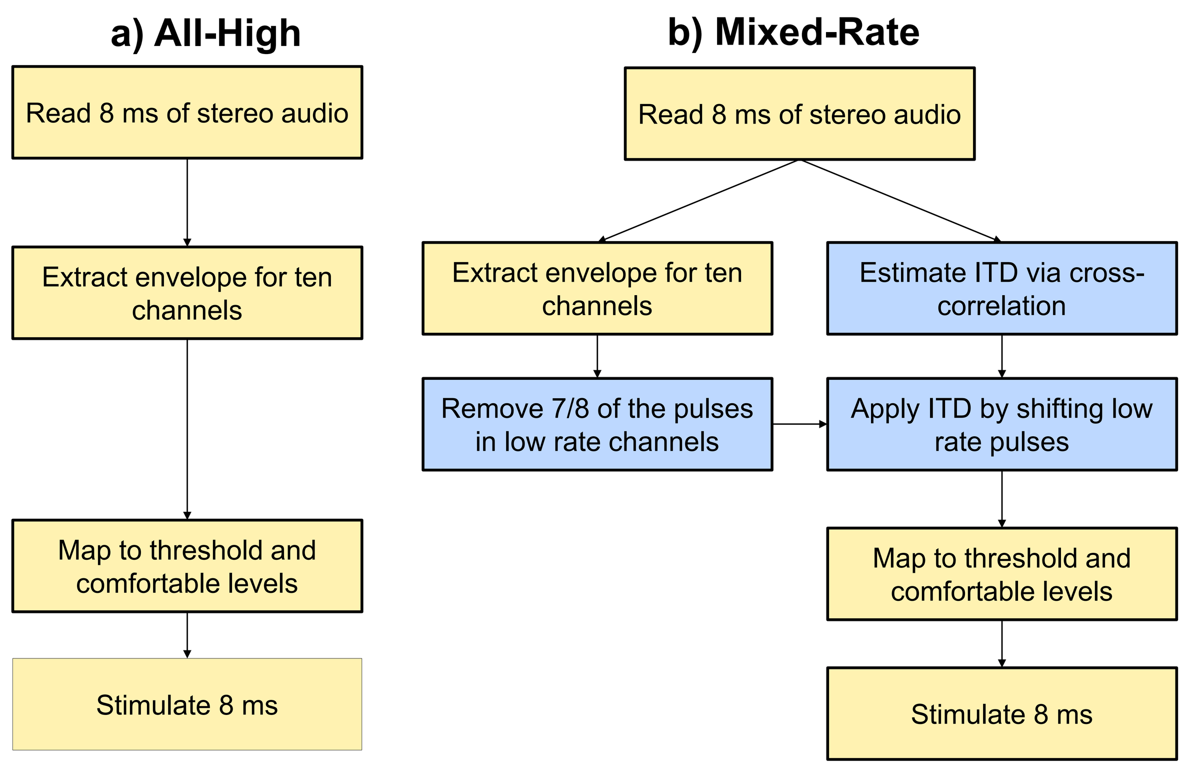


Fig. 2: Block diagram for a) All-High and b) Mixed-Rate strategies used in this experiment. Shared steps are in yellow, while mixed-rate only steps are in blue.

HYPOTHESIS AND PREDICTION

- We hypothesized that ITD sensitivity will be greatest when the same ITD cues are provided in both the signal envelope and low-rate pulse timing, via the Mixed-Rate strategy
- Therefore, we predicted that the perceived distance between a sound with left and right ITDs will be greatest when Envelope and Pulse ITDs are provided by the Mixed-Rate strategy

EXPERIMENTAL METHODS

Stimuli

- Three conditions, as described in Table 1, were presented to the listeners (see Table 2) with the CCi-MOBILE research platform, developed at the University of Texas at Dallas [7]
- Audio input for each condition was a complex of acoustic sinusoids, with the frequency of each sinusoid at the center of the analysis bands shown in Table 3

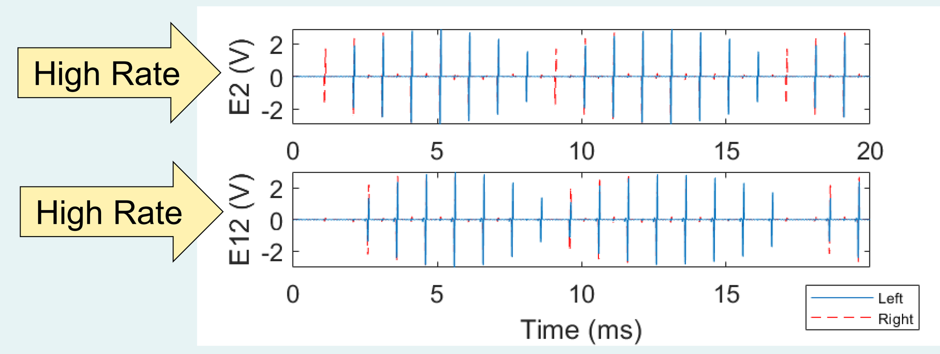
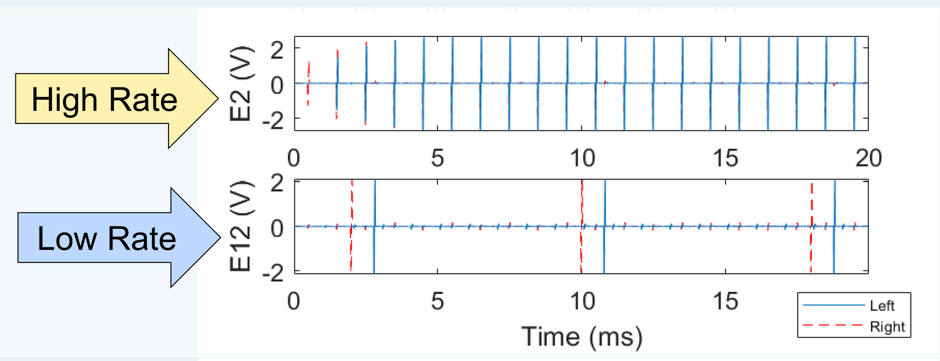
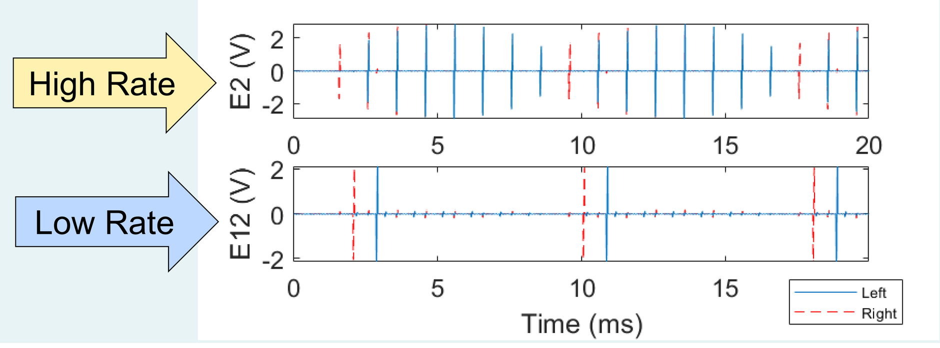
Condition	Audio Input	Strategy Used	Examples of Bilateral Stimulation for +800 µs ITD	Prediction
Envelope ITD only	• 10 sinusoids • 125 Hz AM • +/-800 µs ITD • 300 ms duration	All-High		Worst d'
Pulse ITD only	• 10 sinusoids • No AM • +/-800 µs ITD • 300 ms duration	Mixed-Rate		Moderate d'
Envelope + Pulse ITD	• 10 sinusoids • 125 Hz AM • +/-800 µs ITD • 300 ms duration	Mixed-Rate		Best d'

Table 1: Descriptions of experimental conditions. AM = amplitude modulation. Y-axis labels in "Example Stimulation" column refer to electrode (e.g. E2 represents electrode number 2).

Participant Information:

Participant Code	Age	Site Tested	Previously tested for prior ITD Sensitivity?
IAJ	75	UW-Madison	Yes
IBO	57	UW-Madison	Yes
IDL	67	UW-Madison	Not Known
IDN	20	UW-Madison	Yes

Table 2: Participant information. Participants are recruited from two sites, University of Wisconsin-Madison (UW-Madison) and New York University (NYU). ITD sensitivity was previously measured for some participants but was not required for participation in the study, and having been tested for ITD sensitivity does not mean they exhibited ITD sensitivity.

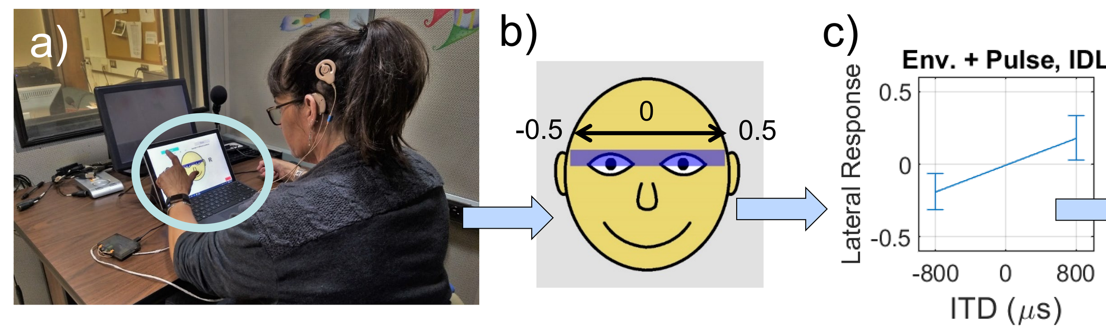
Analysis Channels:

Analysis Channel #	Electrode Array #	Analysis Band Low Freq. (Hz)	Analysis Band High Freq. (Hz)	All-High Rates (pps)	Mixed-Rate Rates (pps)
10	22	188	438	1000	1000
9	20	438	688	1000	125
8	16	688	1063	1000	1000
7	14	1063	1438	1000	125
6	12	1438	1938	1000	1000
5	10	1938	2563	1000	125
4	8	2563	3438	1000	1000
3	6	3438	4563	1000	125
2	4	4563	6063	1000	1000
1	2	6063	7938	1000	125

Table 3: Guide to processor analysis channels and selection of electrode array numbers for this study. If listeners had deactivated electrodes, the next closest pair was used. pps = pulses per second.

Protocol

1. *Mapping:* Patient's own clinical MAPs were adjusted for only ten active channels, see Table 3 for which channels were selected
2. *Loudness matching:* Listeners adjusted volume for the three stimuli until they were of similar loudness
3. *Training:* Listeners reported the perceived intracranial position of stimuli with either left or right interaural level differences (ILDs) to familiarize with task
4. *Testing:* Listeners responded to stimuli with +/-800 µs ITDs, see Fig. 4
   a) Twenty repetitions were collected for each condition (three conditions x two ITDs)
   b) Stimuli presented in four completely randomized blocks



$$d' = \frac{|\mu_{right} - \mu_{left}|}{\sqrt{\sigma_{left}^2 + \sigma_{right}^2}}$$

Fig. 4: (a) A participant uses the CCi-Mobile. (b) Listener indicates on the interface where they perceive the location of the auditory event. Responses are recorded as values from -0.5 to +0.5. (c) Lateralization responses are transformed into sensitivity index (d') with the formula shown [8].

PRELIMINARY RESULTS

Individual Responses

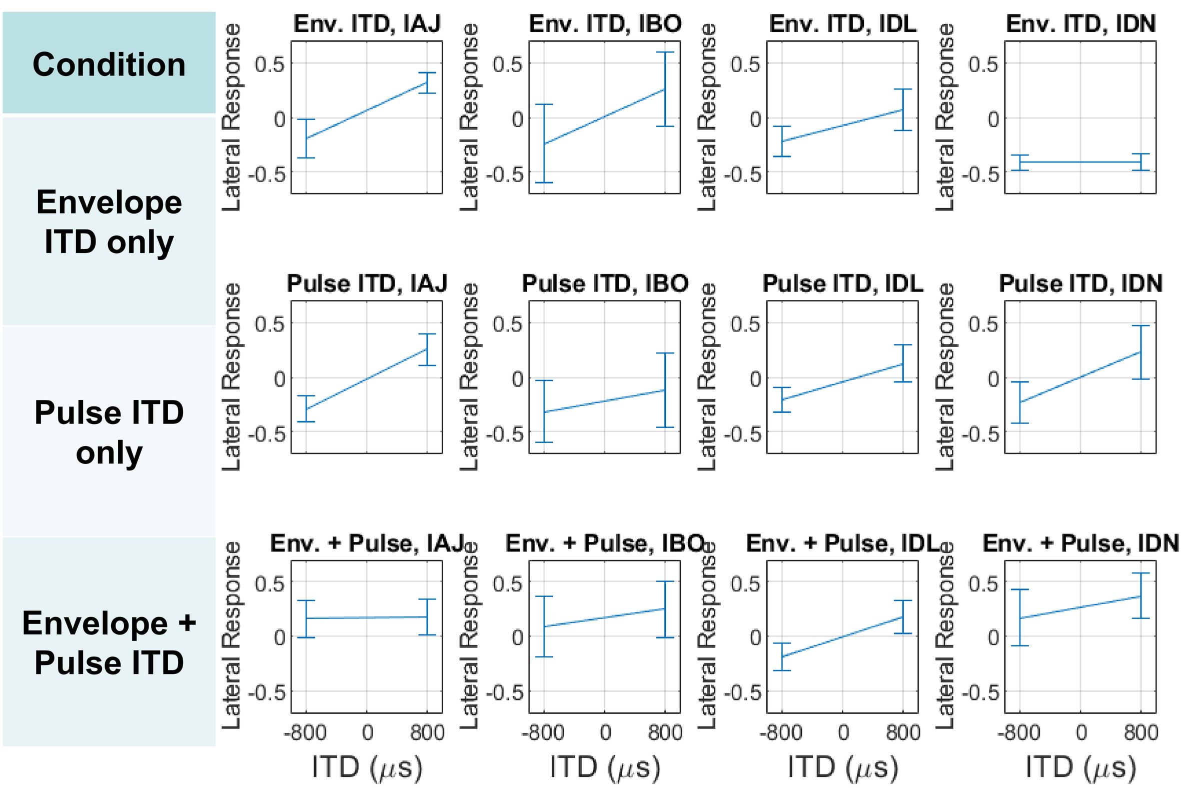


Fig. 5: Individual lateralization responses for participants. Error bars represent standard deviation. Three letter codes indicate participant codes.

ITD Sensitivity

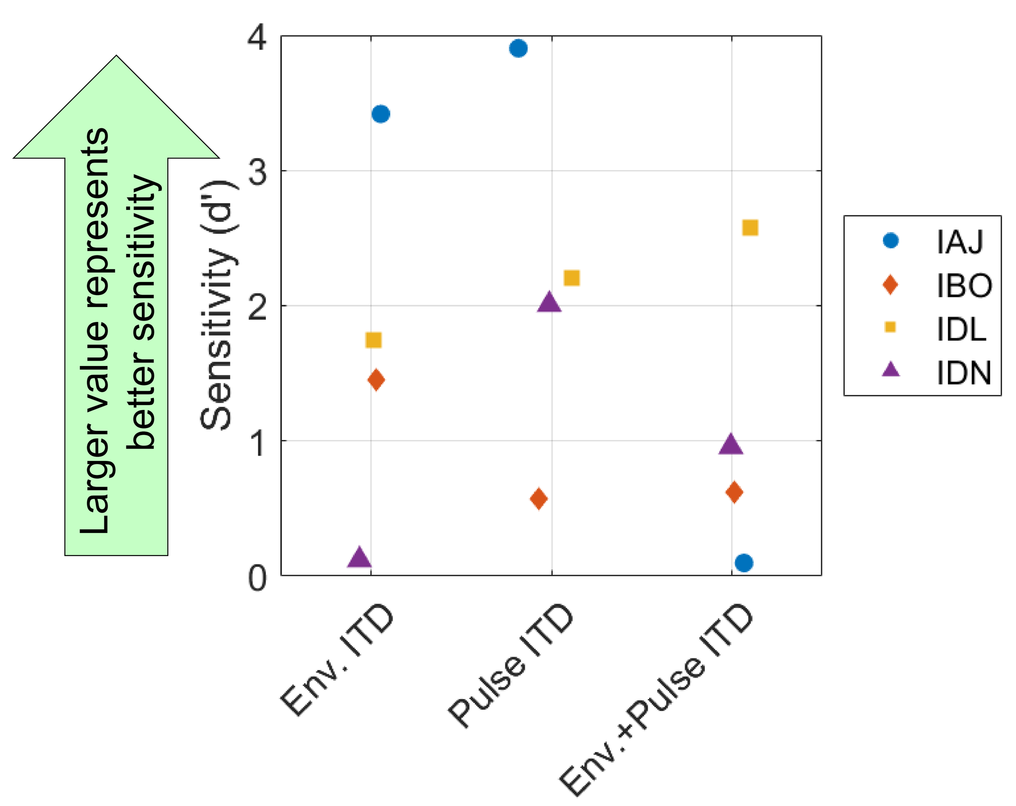


Fig. 6: ITD sensitivity index (d') for each participant and condition. Legend shows participant codes.

Listeners demonstrated ITD sensitivity with at least one condition

- **Envelope ITD:** Three of four listeners exhibited ITD sensitivity ($d' > 1$)
- **Pulse ITD:** Three of four listeners exhibited ITD sensitivity ($d' > 1$)
- **Envelope + Pulse ITD:** Only one listener exhibited ITD sensitivity
- Note: Listener IAJ completed an additional module to center the auditory image before testing

Preliminary data suggests that Mixed-Rate strategy is capable of providing pulse ITDs to listeners

More evidence is needed before making conclusions about the use of Envelope + Pulse ITDs

ACKNOWLEDGEMENTS

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