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 (BCI) 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]

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

EXPERIMENTAL METHODS

HYPOTHESIS AND PREDICTION

- We hypothesized that ITD sensitivity will be greatest when the same ITD cues are used 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

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) [8] with 10 channels and 1000 pulse per second (pps) stimulation rate per channel and can only provide Envelope ITDs
2. Mixed-Rate strategy is 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.

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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).

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

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) Localization responses are transformed into sensitivity index (d') with the formula shown in [8]

PRELIMINARY RESULTS

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

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REFERENCES