Wide-field Calcium Imaging for Evaluating Cochlear Implant Stimulation Strategies in the Auditory Cortex

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Background

- **Listening performance with Cochlear Implants (CI) remains well below natural hearing. While better CI processing strategies may help, investigating the effects of changes in processing strategies remains difficult.**
- By far the most commonly used processing strategies are variants of **Continuous Interleaved Sampling (CIS)**, first proposed in 1991 [1,2].
- Animal models are useful for comparing processing strategies without the bias of lengthy experience with a clinical device. But electrophysiology is contaminated by artefacts.
- **Here we test whether optical recordings are a useful tool for evaluating CI strategies by decoding from rat AC optical responses to different CI stimulus patterns delivered at different pulse rates and with or without interleaved sampling.**

Methods

1. **Subjects**

- Six hearing experienced, young adult (~ P90) female Wistar rats.

2. **CI implantation & stimulation parameters**

- In young adulthood (~P90), CIs were inserted into the middle turn through a cochleostomy towards the apex.
- CI-Stimuli: 1 s long**, monaural, multichannel stimulation, 4 patterns** of **channel activation** (Fig. 1A) presented with **CIS** and **SS** strategies (Fig. 1C).
- Stimulation rate: **300** and **1800 pulses per second** (pps) (Fig 1B).

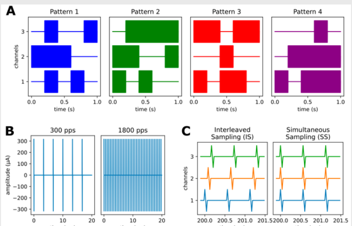


Figure 1: (A) Electrodograms of the four spectro-temporal patterns used in the experiment. (B) Biphasic pulse trains at the two pulse rates used in this experiment (300 pps and 1800 pps). (C) Electrodogram, zooming in on a portion of Pattern 1 where all three channels were active, showing the two sampling modes used in this experiment: in interleaved sampling, pulses in neighboring channels are offset in time so only one channel is active at any one time. In contrast, in simultaneous sampling, pulses on neighboring channels are triggered at the same time.

Imaging Procedure&Setup

3. **Imaging procedure**

- Fluorescent Calcium Indicator OGB was micro-injected into the Auditory Cortex (AC).
- After the injection, the animal was placed in a dark sound-proof booth and the AC was focused on the camera.
- The stimuli were then displayed. We stopped collecting data after 90/120 minutes because the Calcium Indicator will deteriorate due to photobleaching after prolonged exposure.
- We ran 30 trials per animal for each condition in this stimulus

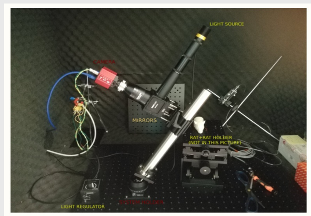


Figure 2: Calcium Imaging Setup. The camera captures 30 images per second. The mirrors are excitation filters, which selectively transmit light at the wavelength at which OGB fluorescence changes when intracellular Ca++ concentrations increase. This gives an optical readout of neural activity.

Imaging Example Data

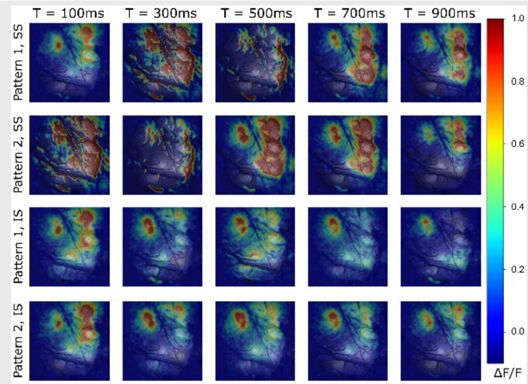
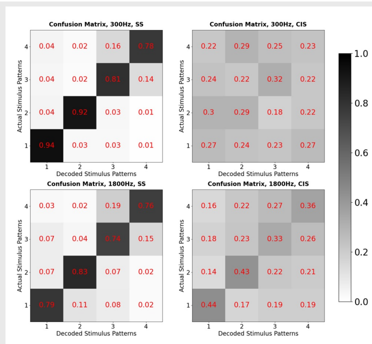


Figure 3: Color maps showing changes in fluorescence at different time points during presentations of stimulus patterns 1 and 2 in SS and CIS method at 300 pps. Averaged optical responses over 30 trials are shown superimposed on a BW image of the cortical surface. Red colors indicate large increases in neural activity as indicated by fluorescence changes.

Results: CIS vs SS at low and high pulse rates

Figure 4: Results of single trial image classification. Image time series as in Fig 3 in response to a single stimulus presentation are compared against mean responses for all 4 stimulus patterns, and individual responses are assigned to the stimulus that gave the mean response that they most closely resembled. The red numbers indicate the proportion of times that a response to the stimulus on the x-axis was assigned to ("decoded as") the stimulus on the y-axis. The main diagonal of each confusion matrix represents correct classifications. Note that the proportion of correct classifications was much higher for SS than CIS.



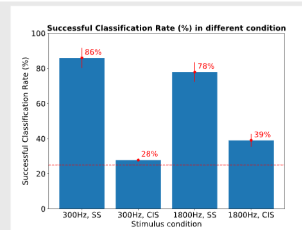


Figure 5: Successful Classification Rate (SCR) (mean proportion of correct classifications in Fig 3) in different stimulus conditions. The red error bars represent the standard error across six animals. Stimulus in simultaneous sampling (SS) have much higher SCR than the one in continuous interleaved sampling (CIS), regardless of the pulse rate.

References

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Results/Outcomes

- All CI rats showed a **significantly better information decoding with SS rather than with CIS**.
- This happens consistently in all the stimulation patterns presented.
- The effect of pulse rate is small.

Conclusions

- **Ca++ imaging of AC is a useful tool for studying neural responses to CI stimuli without contamination by electrical artefacts.**
- **Perhaps surprisingly, AC in CI rats** decodes information **much better** with a **simultaneous sampling strategy** rather than the **continuous interleaved sampling strategy**, which is **widely used in clinics.**
- Perhaps the prohibition of spike collisions in CIS style stimulation can be relaxed, making the use of temporal fine structure (TFS) coding in cochlear implants easier, which might improve binaural [3] and temporal pitch cue delivery**.**

Supported by:

Hong Kong Medical Research Fund (HMRF) grant Nr 07181406.
We thank MedEl for providing intracochlear electrodes.

URL:

auditoryneuroscience.org/CIAP2023_Bruno