

Second Quarterly Progress Report

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Feasibility of an Intraneural Auditory Prosthesis Stimulating Electrode Array

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1. Introduction

The objective of this research is to evaluate the feasibility of intra-neural stimulation as a means of auditory prosthesis. We are stimulating the auditory nerve with a penetrating multi-channel electrode array and monitoring the tonotopic spread of activation in the central nucleus of the inferior colliculus (ICC) of cats. In the course of the study, we eventually plan to test lateral (“trans-bulla”) and intra-cranial approaches to the auditory nerve and a variety of stimulating arrays. In the present quarter, we continued our work with the trans-bulla approach and 16-site single-shank silicon-substrate stimulating electrode arrays (i.e., “Michigan” electrodes). We extended our previous descriptions of tonotopic activation and began study of ICC phase locking to the fine structure of pulse trains and phase locking to the envelopes of modulated pulse trains.

2. Summary of activities for the quarter

Technical activities:

- Completion of a 16-channel optically isolated current source for use with relatively high-impedance intra-neural electrodes. This device uses a 120-V AC power supply, which is a great convenience compared to our previous battery-powered device. The AC power supply introduces a small amount of 60-Hz noise, which is entirely eliminated by grounding the animal. We prefer to work with the animal electrically isolated, so we will attempt to modify the power supply to reduce or eliminate the 60-Hz noise.
- Update of stimulus-presentation software to accommodate the 16-channel current source.
- Set-up of a computer server linked to the experimental server by local-area network for backup and local distribution of data. Each of our 32-channel recording experiments typically generates 5-10 Gbytes of raw digitized waveform data plus additional Gbytes of processed data.
- Construction of a calibrated ear bar with microphone probe tube for *in situ* calibration of sound-delivery system. The tip of the calibrated probe tube is positioned within 3-4 mm of the tympanic membrane. Calibration software measures and stores sound levels in 50 Hz increments of frequency from 200 Hz to 40 kHz. The acoustic stimulation programs compensate on line for the system response.
- Comparison of recording head stages. As noted in the first quarterly progress report (QPR1), our 32-site recording probes pick up a stimulus-driven field potential that we tentatively attribute to distance-conducted auditory brainstem responses, similar to a scalp recorded brainstem auditory evoked response (BAER). This BAER-like response interferes with on-line spike sorting. We have not previously recorded responses of such large magnitude with 16-site probes. We speculated that the problem could be due either to our custom 32-channel head stage or to the 32-site probes. We built an adaptor that would permit 32-channel recording through two of our familiar 16-channel head stages from Tucker-Davis Technologies. That did not solve the problem, so we now attribute the problem to some not-yet-understood property of the 32-site recording probes. We hope that the situation can be improved with use of an on-probe electrical reference, but regardless, the BAER component can be eliminated using off-line software. We discuss other characteristics of the BAER-like potential below.

- Rearrangement of the recording booth, including construction of a new steel-topped table. This seemingly trivial furniture rearrangement now gives the surgeon access to both sides of the table, eliminating the need to turn the cat between implantation of the recording probe in the right ICC and exposure of the left cochlea. This eliminates a significant source of experimental mishap.

Scientific activities:

We conducted acute physiological experiments in two cats, with 32-channel recording from the ICC. The first of these experiments yielded only partial data due to technical difficulties. The second experiment yielded results for three modes of stimulation: acoustical stimulation in normal-hearing conditions using tones and click trains; electrical stimulation with an 8-channel intra-scalar banded electrode array; and intra-neural electrical stimulation with a 16-channel single-shank silicon-substrate electrode array. The intra-neural results confirmed the discontinuous non-monotonic cochleotopic projection that we reported in QPR1. The most distal sites on the stimulating array activated ICC loci representing apical cochlear regions and more proximal stimulus sites activated the basal representation. We observed only limited activation of the middle-turn representation in that experiment.

In the second of these two experiments, we began study of ICC phase locking to the fine structure of electrical pulse trains and phase locking to the envelope of amplitude-modulated pulse trains. Those measurements were complicated by the presence of the BAER-like potential. We were successful in eliminating the contribution of the BAER in off-line analysis by computing an average across 20 repetitions of each stimulus condition, then subtracting the resulting template from individual records. This resulted in elimination of the constant time-locked BAER and preservation of spikes, which vary in latency from trial-to-trial. We computed period histograms for ICC responses with and without the BAER subtracted out. The BAER component persisted for electrical pulse rates beyond 250 pulses per second (pps), whereas spike activity on most recording sites dropped out at about 150 pps. We computed the group delay from the site of electrical stimulation in the nerve to the ICC, based on the slope of mean response phase as a function of pulse rate. That yielded group delays of around 4 ms for the BAER component and around 7 ms for ICC spikes. The BAER-like component was absent from unmodulated pulse trains presented at rates of 1000, 2000, and 4000 pps. For that reason, we readily recorded ICC spike activity phase locked to amplitude-modulated pulse trains with carrier rates 1000 pps or higher. Phase locking to the envelope was observed for modulators as high as around 200 Hz, although most recording sites cut off around 150 Hz.

3. Plans for next quarter:

- Continue studies of the cochleotopic projection from the auditory nerve to the ICC using a trans-bulla approach. We will attempt to optimize placement and orientation of the stimulating electrode array to provide access to fibers originating from all turns of the cochlea, including fibers from the middle turn. We will attempt to further optimize the trajectory of our ICC recording probe to allow access to the representation of a wider range of acoustical frequencies, including ICC neurons having characteristic frequencies down to ~500 Hz.
- Continue studies of phase locking to pulse-train fine structure and amplitude envelope.
- Quantify temporal integration, using pairs of electrical pulses at varying inter-pulse timing.

- Quantify interaction between electrical pulses presented simultaneously on two stimulating electrode sites.
- Begin development of the surgical approach for placement of chronic multi-site recording probes in the cat's inferior colliculus. We envision a system that employs a guide tube and that largely preserves overlying cerebral cortex. We will begin development with *post-mortem* studies in cats that have been used for acute experiments, then will move to *in vivo* but non-recovery condition prior to recovery experiments using strictly aseptic conditions.