16th Quarterly Progress Report

July 1, 2006 to September 30, 2006

Neural Prosthesis Program Contract N01-DC-02-1006

The Neurophysiological Effects of Simulated Auditory Prosthesis Stimulation

Submitted by:

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This report describes our progress during the 16th quarter of contract NIH-NIDCD-DC-02-1006 (July 1, 2006 - September 30, 2006). During this quarter, we continued work on several manuscripts describing results of experiments conducted under this contract. We also conducted five additional physiology experiments that continued and extended our investigations of interactions between cochlear implant channels in the central auditory system. These experiments, as well as other work completed during the quarter, are described briefly in the next section. Following sections identify abstracts and a manuscript submitted for publication, contract travel, and one public presentation. The final section of this report briefly describes the work we plan for the next quarter.

Summary description of work over the last quarter

During the previous quarter we continued work on three of several manuscripts currently in preparation for publication in archival journals. In addition, we completed five neurophysiology experiments that continue our investigation of responses to stimulation of single and multiple auditory information channels. These experiments used acoustic stimulation of the cochlea by pure-tone bursts delivered by a calibrated speaker, as well as electrical stimulation of the cochlea by modulated and unmodulated biphasic and pseudomonophasic current pulse trains delivered by a cochlear implant. The extent of cochlear activation during stimulus presentation was determined by using a multichannel silicon recording probe (NeuroNexus Technologies) to observe neuronal activity along the tonotopic axis of the inferior colliculus (IC). No new experimental series were initiated during this quarter. Instead, experiments during the this quarter continued our ongoing studies of central auditory response to stimulation by:

- Unmodulated single- and two-tone stimuli
- Sinusoidally amplitude modulated (SAM) single- and two-tone stimuli
- Single (isolated) biphasic and pseudomonophasic electrical pulses delivered via a cochlear implant
- Multiple isolated pulses delivered via the same and different channels of a cochlear implant
- Unmodulated single- and two-channel pulse trains
- Single- and two-channel SAM pulse trains using a range of modulation depths and stimulus levels

The immediate goals of these experiments were to identify the physiological basis for creation of virtual cochlear implant channels by current steering and to evaluate the effects of modulation on interaction between pulse trains presented on two cochlear implant channels.

We have also fabricated one additional guinea pig cochlear implant electrode and continued analyses of experimental data acquired during this and previous quarters. Further, we have continued to modify experiment and analysis software to facilitate these analyses.

Abstracts submitted

Bonham, B.H., Snyder, R.L., and Stakhovskaya, O. (2007). Inferior Colliculus Response to Monopolar and Bipolar Dual-channel Cochlear Implant Stimulation. 30th ARO Midwinter Meeting, Denver, Colorado.

Bonham, B.H. and Snyder, R.L. (2007). Inferior Colliculus Neuronal Responses to SAM Tones and Electrical Pulse Trains. 30th ARO Midwinter Meeting, Denver, Colorado.

Text of these abstracts is included below.

Manuscripts submitted

An, S.K., Park, S.I., Jun, S.B., Lee, C.J., Byun, K.M., Sung, J.H., Oh, S.H., Wilson, B.S., **Rebscher, S.J.**, and Kim, S.J. Design for a Low-cost but Still Highly-effective Cochlear Implant System. Submitted to IEEE.

Invited Presentations

Bonham, R.L. Snyder, S.J. Rebscher, P.A. Leake, and A. Hetherington (2006). Minimizing Channel Interaction during Cochlear Prosthesis Stimulation, Neural Interfaces Workshop , Bethesda, MD.

Travel

B. Bonham and R. Snyder traveled to Bethesda Maryland to attend the Neural Interfaces Workshop.

J. Middlebrooks traveled to UCSF to continue collaboration on our manuscript describing results of forward masking experiments using electrical stimulation of the cochlea by a cochlear implant.

Work planned for next quarter

During the next quarter we plan to complete and submit several manuscripts that are currently in various stages of preparation. Topics of these manuscripts, and primary authors, include: Responses to interleaved pulse trains (S. Bierer), Acoustic forward masking (B. Bonham), Effects of changing the remote current fraction (B. Bonham), Effects of electrode design and placement within cochlea (R. Snyder), Development and fabrication of the UCSF-type cochlear implant for the guinea pig (S. Rebscher), and Electrical forward masking (J. Middlebrooks).

We plan to undertake a modest number of additional physiology experiments continuing our studies of channel interaction using complex multichannel stimulation, i.e., sinusoidally modulated pulse trains and implant-processed speech sounds. For the latter experiments, we will collaborate with D. Sinex of Utah State University.

Text of Abstracts Submitted

Abstracts submitted for the Midwinter Meeting of the Association for Research in Otolaryngology:

Inferior Colliculus Response to Monopolar and Bipolar Dual-channel Cochlear Implant Stimulation

Ben H. Bonham, Russell L. Snyder, and Olga Stakhovskaya

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Current steering, or division of a fixed total stimulating current between adjacent CI electrodes, has recently gained attention as a means to increase the number of perceptually independent stimulating channels available to implant users. Programming strategies based on current steering are attractive to both CI users and manufacturers because they provide a way to increase the frequency resolution of CIs without requiring physical modification or redesign of the implanted devices.

We examined the distribution of neuronal activity in the guinea pig inferior colliculus central nucleus (IC) evoked by stimulating current that was divided between two CI channels. Single current pulses or pulse trains were applied to adjacent or nearby monopolar CI electrodes, or to overlapping bipolar electrode pairs. Neuronal activity was measured using a 16-site recording probe inserted to an acoustically-calibrated depth along the IC tonotopic axis.

By choosing two CI channels that evoked unique distributions of activity, we were able to examine the change in distributed activity as current was gradually redirected from the first to the second channel. When current was divided between two channels, the minimum (threshold) current required to elicit a response was higher than when the current was applied to only one. When stimulating current was divided between two interdigitated bipolar channels the region of highest activity was usually narrow and shifted gradually along the tonotopic axis. When current was divided between two monopolar channels, the region of highest activity shifted gradually along the tonotopic axis in some cases, but in others exhibited a quantal change in location, and ectopic regions of activation were frequently observed.

On average, CI users are able to distinguish several "virtual" channels between adjacent monopolar channels (Litvak, ARO 2005). Our results may explain the poorer performance experienced by some users.

Inferior Colliculus Neuronal Responses to SAM Tones and Electrical Pulse Trains

Russell L. Snyder, University of California, San Francisco, and Utah State University
Ben H. Bonham, University of California, San Francisco

Contemporary cochlear implants (CIs) encode speech using several strategies. To examine the neural encoding of acoustic and electric signals relevant to speech, we compared responses of guinea pig

inferior colliculus (IC) neurons to sinusoidally modulated (SAM) tones and SAM electrical pulse trains. We inserted a 16-site recording probe along the IC tonotopic axis in normal hearing animals and recorded responses to acoustic tones to estimate threshold, CF, and Q of neurons at each site. We fixed the recording probe in place and recorded responses to one or two simultaneously presented SAM tones of various carrier frequencies, intensities, modulation frequencies (30-200Hz) and depths (0-100%).

We then deafened the cochlea, inserted a CI electrode custom-designed for guinea pigs, and recorded responses to single and two channel monopolar and bipolar pulse trains (20-1000pps). We systematically varied stimulus channel, intensity, and modulation frequency and depth.

At stimulus onset, unmodulated stimuli evoked activity across a relatively broad region of the IC tonotopic axis. Subsequent activity diminished rapidly but selectively. After 10-30ms, activity at locations remote from the best (strongest responding) location for a given tone or pulse train on a given channel decreased to near spontaneous levels, whereas neurons at the best location continued to respond. This remote decrease enhanced the selectivity of steady state responses and strongly influenced response to modulated signals. The remote decrease was greater for electric than for acoustic stimulation. SAM stimuli evoked progressively less remote decrease as modulation depth increased.

Our results suggest that 1) the response to speech sound transients is more broadly distributed across the tonotopic axis of the auditory CNS than would be predicted by acoustic spectra, and 2) the amplitude compression of CI-processed speech favors activation selectivity.