Effects of Remaining Hair Cells on Cochlear Implant Function

16th Quarterly Progress Report

Neural Prosthesis Program
Contract N01-DC-2-1005
(Quarter spanning January-March, 2006)

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July 27, 2006

File: N01-DC-2-1005QPR16.PDF
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Summary of Activities in This Quarter

During the sixteenth quarter of this contract (April 1 – June 30, 2006), we accomplished the following:

1. Presentations:

Paul Abbas attended the 5th Dutch Endo-Neuro-Psycho Meeting (June 4-9, 2006, Doorwerth, Netherlands) and presented a paper: "Properties of the electrically stimulated auditory nerve: measures in experimental animals and patients with cochlear implants". Dr. Abbas also presented data related to this contract at the University of Utrecht and the University of Nijmegen.

Charles Miller attended the 9th International Conference on Cochlear Implants and Related Sciences in Vienna (14-17 June 2006. He presented a paper titled "Electric-acoustic stimulation: auditory nerve single fiber results."

2. Dissertation:

Kirill Nourski successfully completed and defended his dissertation titled "Acoustic-electric interactions in the auditory nerve: simultaneous and forward masking of the electrically evoked compound action potential". His work, in part, included data collected as during the execution of this contract that focused on the electrically evoked compound action potential (ECAP)

3. Results: Single fiber electric adaptation and recovery

We completed data collection and analysis on a series of experiments investigating the recovery of ANF responses from high-rate electrical stimulation. Preliminary descriptions of results from those studies were described in a previous progress report (Abbas et al., 2006).

The goal of this contract is to assess the effects of functioning hair cells on the response to electrical stimulation of the cochlea. We have used measures of both the compound action potential and ANF responses to investigate such effects. A primary finding of our previous work has been a clear effect of acoustic stimulation (typically wideband noise) on the responses to electrical pulses. Both ECAP and ANF measures have shown altered responses during the acoustic noise presentation as well as a relatively complex time course of recovery after noise offset (Miller et al., 2005; Nourski et al, 2005a,b). These results lead have led to a number of hypotheses relative to the source or sources of non-simultaneous masking. The extent to which responses produced by electrical adapters is consequently useful for determining whether or not the acoustic masking effects are specific to that modality of excitation or, rather, result from neural activity.

Details of the stimuli were previously presented (Abbas et al, 2006). The adapting stimulus was a 5000 pps electric pulse train with duration 200 ms. Recovery was assessed using a low-rate (250 pulse/s) electric train. Responses were analyzed across a time window of 300 ms after adapter offset. Analyses of

the complete data set are generally in agreement with the examples presented previously. This further analysis has included measurements of jitter and action potential amplitude in addition to discharge rate. The following summarizes those results:

- Time course of recovery, assessed by discharge rate, was typically on the order of 100 to 300 ms. This range is similar to that observed using acoustic noise stimuli in our previous work (Miller et al., 2005).

- Increasing the high-rate (masker) current level generally resulted in greater decrease in discharge rate and longer times of recovery.

- Increasing probe level, with a fixed adapter level, generally resulted in smaller decrease in discharge rate.

- ECAP measures have demonstrated that the relationship between masker and probe is a primary determinant of effectiveness of the electrical adapted on the response. Masker/probe ratios greater than one result in maximum masking; ratios of less than 0.8 result in little or no masking. ANF responses show more variability. For instance, in comparing responses across fibers, each stimulated with equal masker and probe level, we observe considerable variability in the rate decrement.

- The effect of the adapter on the ANF response to the probe is not simply determined by the response to the adapter. In many cases we have observed a decreased response to the probe with no response to the masker, suggesting interactions at the level of ANF membranes.

- Previous work from our laboratory has demonstrated changes in amplitude of the action potentials in the refractory state (Miller et al., 2001). We examined action potential amplitude during recovery from adaptation and, although not consistent across all fibers, amplitude decrements were commonly observed in ANF's in adapted states.

- We have found that ECAP measures are typically characterized by non-monotonic recovery functions when either acoustic or electric adaptors are used. We have hypothesized that such effects may be due in part to increased synchrony (decreased jitter) in the adapted state (Nourski et al., 2005b). Decreased jitter in response to electric pulses has been observed after acoustic stimulation. The present data do not consistently show such enhancements after electric stimulation. We propose below to investigate further by using longer duration adapting stimuli, motivated by observations that masker duration can increase the prominence of the non-monotonic ECAP recovery pattern.

4. Results: Relationship between cochlear place and electric threshold.

An issue raised at the "Future of Cochlear Implants" meeting (Ashland, MA, 17-19 March) was the possibility of a relationship between single-fiber electric threshold and best frequency. One possibility is that if a relationship between cochlear place and electric threshold existed, then acoustic-electric interactions would be expected to be similarly graded and may assist in the interpretation of results from humans with cochlear prostheses.

The relationship between electric threshold and best frequency was examined by linear regression for 21 fibers. It should be noted that the electric thresholds were based upon those for the α response, not the electrophonic response. A test of the significance of the linear correlation (Bevington, 1969) indicated that the two variables were negatively correlated ($r=0.566$, $p_{error}<0.01$, $n=21$).

The issue of a threshold gradient for monopolar electric stimulation has been studied and debated for many years. It has been sometimes assumed that monopolar stimulation has little place specificity, perhaps as a result of the study by van den Honert & Stypulkowski (1987). However, other studies have indicated that monopolar stimulation can be place specific (Liang et al., 1999; Rebscher et al., 2001) in a manner consistent with our findings. Discrepancies among these studies may be due to differing intracochlear positions of the stimulating electrode, electrode geometry, and sensitivity of the measures employed.

Plans for the Next Quarter

1. Begin a new series of ANF experiments to further investigate the effects of acoustic and electric stimulus duration on the recovery properties. Experiments that are part of this contract with guinea pig compound action potential (ECAP) measures have demonstrated complex recovery patterns that are dependent on the acoustic stimulus duration (Nourski et al., 2005). ANF measures obtained using the same stimuli will provide a better understanding of the underlying response patterns under such conditions.

2. Continue to evaluate and improve the computational model of acoustic/electric interactions.

3. Manuscript preparation

A manuscript will be prepared that describes ECAP responses both with and without the presence of an acoustic masker stimulus.

Preparations will begin on a manuscript describing ECAP responses with and without the presentation of an electric masker.

A manuscript on single-fiber responses to combined acoustic and electric stimuli will be submitted in the next quarter.

References

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