First Quarterly Progress Report
NIH-NO1-DC-9-2107

The Neurophysiological Effects of Simulated Auditory Prosthesis Stimulation

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January 31, 2000

Contents

1 Introduction

The purpose of this contract is to explore issues involving the transfer of information from implantable auditory prostheses to the central nervous system. Our investigation is being pursued along multiple tracks and include the use of animal experiments and computer model simulations to:

1. Characterize the fundamental spatial and temporal properties of intracochlear stimulation of the auditory nerve.
2. Evaluate the use of novel stimuli and electrode arrays.
3. Evaluate proposed enhancements in animals with partially degenerated auditory nerves.

In this first quarterly progress report, we present single-fiber and gross-potential data from our animal studies of the refractory properties of the electrically stimulated auditory nerve. The data demonstrate physiological properties that illuminate a deficiency in an EAP acquisition scheme currently in use by a commercial, clinical cochlear implant system. We addressed this problem by conducting studies with our animal preparations. An improved, modified, version of the data collection scheme is presented here. We have also evaluated the utility of the modified method in human patients and present data from those subjects as well. This modification may be of interest to clinicians, implant manufacturers, and experimental physiologists.

2 Summary of activities in this quarter

In our first quarter (1 October - 31 December, 1999), the following activities related to this contract were completed:

1. We attended and presented at the 30th Neural Prosthesis Workshop in Bethesda, Maryland.
2. We completed histologic preparation of thick sections for all deafened and control animals. We have now completed cell counts for 18 of 23 animals in the chronically-deafened animal study.
3. We collected additional pulse-train EAP data from 7 acutely deafened guinea pigs. We also collected limited single-fiber forward-masking

data from two acute cat preparations. Data collection uses a two-pulse paradigm and is ongoing in order to collect sufficient group statistics.

4. We purchased and received Labview software from National Instruments for use in new data acquisition system to be developed for this contract. We also received our new isolated current source, as well as a new capnometer to replace our old, failing unit.

5. Submitted a manuscript for publication detailing the experiments and findings of this QPR.

6. Presented the findings of this QPR at the 6th NRT Workshop conducted in Kiel, Germany, by Cochlear AG, in November, 1999.

3 Focus topic: An improved method for obtaining EAP refractory data

3.1 Background

In our animal measurements, we record the electrically evoked whole-nerve action potential (EAP) using an electrode positioned directly on the surgically exposed auditory nerve. When stimulating at an intracochlear site, we are often able to record EAP waveforms that are relatively free of large, deleterious effects of the stimulus artifact; that is, the EAP waveform is usually readily identified and analyzed without waveform manipulations. In many cases, however, we employ a stimulus artifact correction based on a subthreshold template technique. This method, described in Miller et al. (1998), first obtains a record of the stimulus artifact (using a sub-threshold stimulus level), then scales it upward to match the artifact amplitude of a suprathreshold record, and finally subtracts that scaled template from the suprathreshold record. This process greatly reduces the stimulus artifact present in the suprathreshold record.

With the advent of the Neural Response Telemetry (NRT) system of Cochlear Corporation's Nucleus 24 implant, clinicians are now able to record the EAP from cochlear implant users. However, in the case of humans, the stimulus artifact problem is more severe, due, in part, because the recording site is an intracochlear electrode. This reality has led to the use of a forward-masking scheme developed by Brown et al. (1990). This method is an integral part of the NRT system and is described in Abbas et al. (1999),

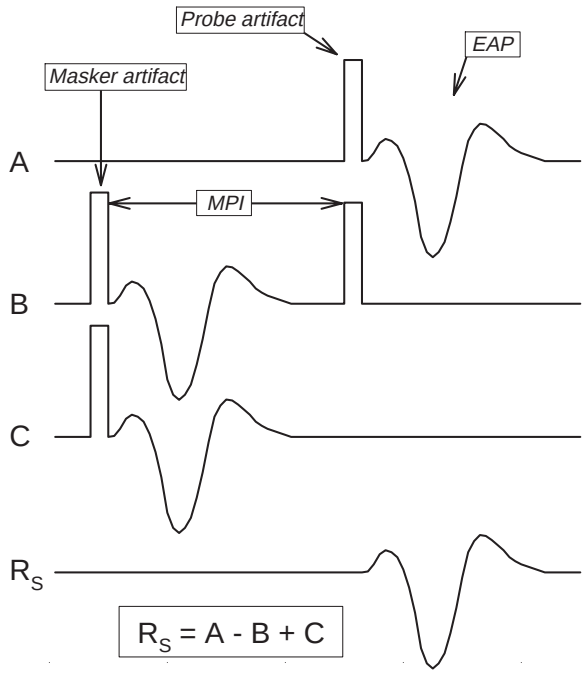

Figure 1: The "standard" forward-masking scheme of Brown et al. (1990) used to reduce stimulus artifact when recording the EAP. By setting the masker-probe interval (MPI) to a short value (0.3 - 0.5 ms), the nerve is nearly completely refractory and unresponsive to the second (probe) pulse of condition B. Waveform B thus provides a template of the probe stimulus artifact, which is subtracted from waveform A. Waveform C is then added to that subtraction to cancel the masker pulse and response.

Abbas and Brown (2000), Brown et al. (in press), and Hughes, et al. (in press). We note that our subthreshold technique used in our animal experiments would be relatively difficult to apply to the NRT system, since that system does not faithfully record stimulus artifacts (i.e., the NRT amplifier would saturate on the artifacts).

The Brown forward masking (or subtraction) technique also obtains a template of the stimulus artifact, but does so by taking advantage of the refractory properties of the electrically excited nerve. This process is illustrated in Figure 1. The desired EAP response to a stimulus is associated with a large stimulus artifact (waveform A of Figure 1). However, a high-level masker pulse puts the nerve fibers in a refractory state just prior to

stimulation by a probe pulse (B). Proper selection of the masker-probe interval (MPI) is essential, since the nerve must be unresponsive to the probe stimulus. In our experience, an MPI value between 0.3 and 0.5 ms is optimal and may depend upon the species under investigation and the status of the nerve. With the nerve in a refractory state, the response to the probe pulse consists only of probe-stimulus artifact. This template is subtracted from the original response (i.e., A-B) to eliminate the probe artifact. However, this subtraction itself is contaminated by an inverted copy of the response to the masker pulse. A second manipulation is therefore necessary: the response to the masker presented alone (waveform C) is added back to the previous subtraction to cancel out the influence of the masker pulse.

An extension of this method is used by the NRT system to obtain forward-masking refractory recovery data. In this extension, the masker-probe interval (MPI) is systematically varied over a range typically spanning from about 0.3 to 6 ms. This range has been found to encompass the epoch over which the mammalian auditory nerve recovers from forward masking (Stypulkowski and van den Honert, 1984; Brown and Abbas, 1990; Finley, et al., 1997). It is important to note that, when this method is used to obtain refraction recovery data, the resultant EAP waveform represents the *difference* between the response to the unmasked probe stimulus and the masked probe stimulus. As a result, as MPI is increased, the resultant EAP waveform decreases in amplitude.

An implicit assumption of this method for obtaining recovery data is that the EAP waveform to the masked probe stimulus is simply an amplitude-scaled version of the unmasked EAP. That is, it is assumed that the morphology of the masked EAP is identical to that of the unmasked EAP. This, however, is unlikely. During the relative refractory period, inactivation of voltage-gated sodium channels results in lowered conductivity and reduced depolarization to subsequent stimuli. This can result in reduced action potential amplitude and delayed action potentials. Finley et al. (1997) obtained EAP refractory recovery data from one implant patient and demonstrated that EAP latency was prolonged for short MPI values (around 1 to 1.5 ms). Thus, the use of the forward-masking technique for deriving refractory recovery data may produce biased results, since it is probable that the non-refractory and partially refractory EAP waveforms are not simply amplitude-scaled versions of each other. In that case, the resulting subtraction of those two waveforms would result in a measure reflecting not

simply the state of refraction, but some combination of refractory and non-refractory states.

3.2 Animal data & model simulations demonstrate the conceptual problem

In a pilot investigation of the refractory properties of single feline auditory nerve fibers, we have noted refractory effects on both the latency and amplitude of action potentials. This effect of a prior, forward-masking pulse was demonstrated in Figure 18 of the final report of contract NO1-DC-6-2111 and is shown in Figure 2 of this report. Figure 2-A depicts the raw waveforms obtained in response to 100 repeated stimulus presentations.

The two, large, negative-going peaks represent the electrical artifacts generated by the masker and probe stimulus pulses. In 99 of 100 cases, the masker elicits a spike. Of those cases, the probe either produces a spike (labeled "masked spikes" in the figure) or fails to elicit a spike (in 4 cases). In the one remaining case, the probe elicited a spike after the masker failed to elicit one ("unmasked" spike). The fiber was thus in a non-refractory state at the time of probe presentation in that case. The action potentials to the probe are more clearly seen in Figure 2-B, where the waveforms were subjected to an artifact reduction scheme described in Miller et al. (1999). The probe stimulus artifact is largely eliminated in the traces of the lower panel. There, it is clear that the "unmasked" spike has both shorter latency and greater amplitude than do the spikes occurring with the fiber in a relative refractory state. Similar results have been obtained in biophysical model simulations and are demonstrated in Figure 3.

Based on such single-fiber observations and model simulations, we suspected that the EAP produced under conditions of refractoriness is also characterized by prolonged latencies at short MPI values. This and other issues were investigated in the collection of EAP data from a cat preparation. The feline EAP waveforms shown in Figure 4 were obtained both with and without the presence of a preceding, forward-masking pulse (thick and thin lines, respectively).

All traces are displayed so that the onset of the evoking (probe) stimulus occurs at 0 ms. For the forward-masked responses, the response to the masker pulse was subtracted to eliminate any contamination to the probe response. Unlike human EAP waveforms obtained with the NRT system,

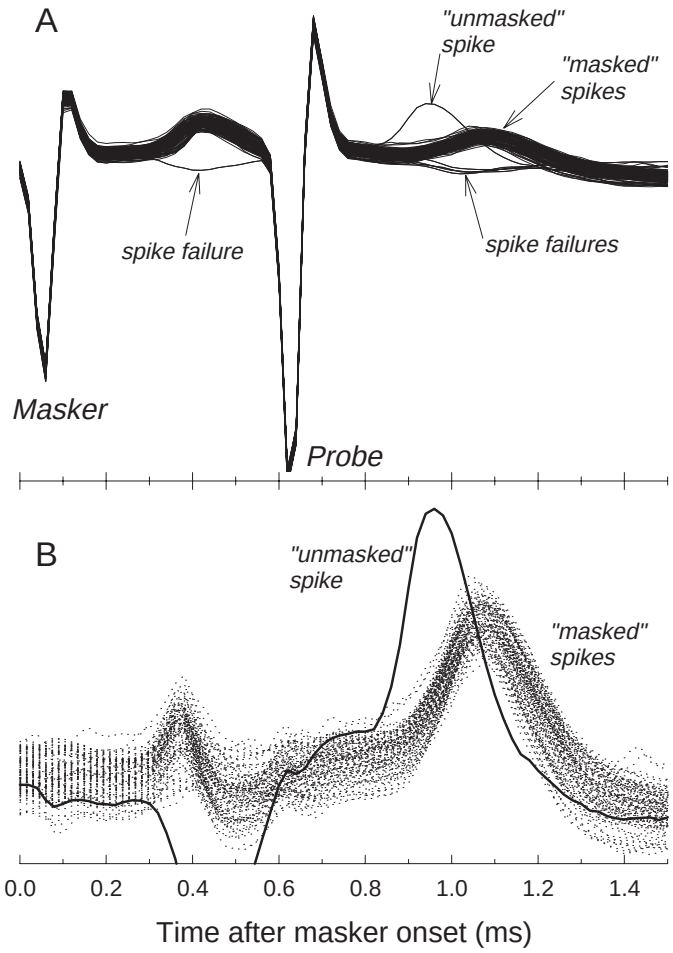

Figure 2: An example of single-fiber responses to a two-pulse, forward-masking stimulus paradigm. Shown are 100 superimposed waveforms collected sequentially in response to cathodic masker and probe pulses. In one case (labeled "unmasked spike"), the fiber responds only to the probe pulse, facilitating a comparison of spikes produced with and without prior excitation by the masker. Panel A shows "raw" waveforms that include large stimulus artifacts; Panel B waveforms were produced using a template subtraction scheme, more clearly showing the action potentials to the probe pulse.

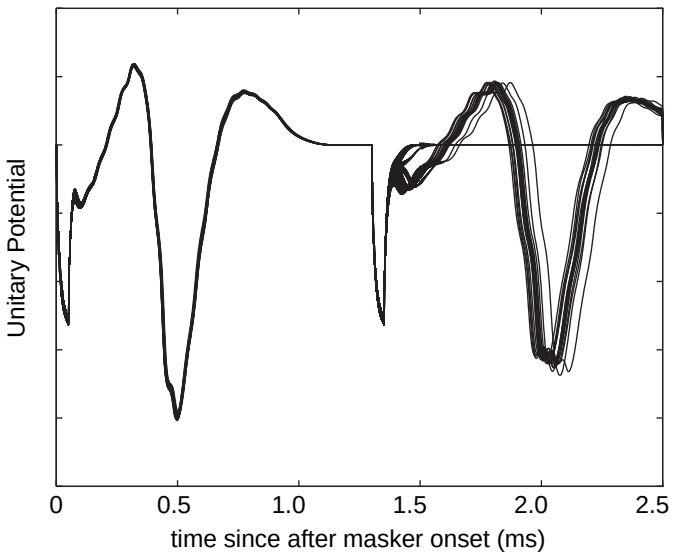

Figure 3: Unitary potentials simulated by our stochastic biophysical axon model in response to two-pulse stimuli. The responses to the second pulse have a longer latency, smaller amplitude and slightly wider waveforms.

the cat waveforms are relatively free from probe stimulus artifacts, due to the advantageous placement of the recording electrode directly on the nerve. Our animal preparation therefore allow us to evaluate the effects of forward masking without needing to resort to the forward-masking ("subtraction") technique used in the Nucleus NRT system.

The effect of increasing the masker-probe interval from 0.3 to 4.0 ms is demonstrated by the thick-line traces of Figure 4. At a MPI of 0.3 ms, the forward-masked cat nerve is apparently in a state of absolute refractoriness; a significant degree of recovery is observed at an MPI of 0.5 ms. Note that for intervals over which the nerve is in a state of partial recovery, EAP latencies are prolonged and amplitudes are diminished. This is particularly evident at MPI values of 0.5 and 0.75 ms. As in the case of the single fiber data, the gross (EAP) potential, under conditions of forward masking, demonstrates altered waveform morphology. This reinforces our concern about using the standard "subtraction" method for obtaining refractory recovery data. Model simulations shown in Figure 5 demonstrate that recovery functions obtained with the "subtraction" method can show non-physiologic non-monotonicities as well as prolonged recovery times.

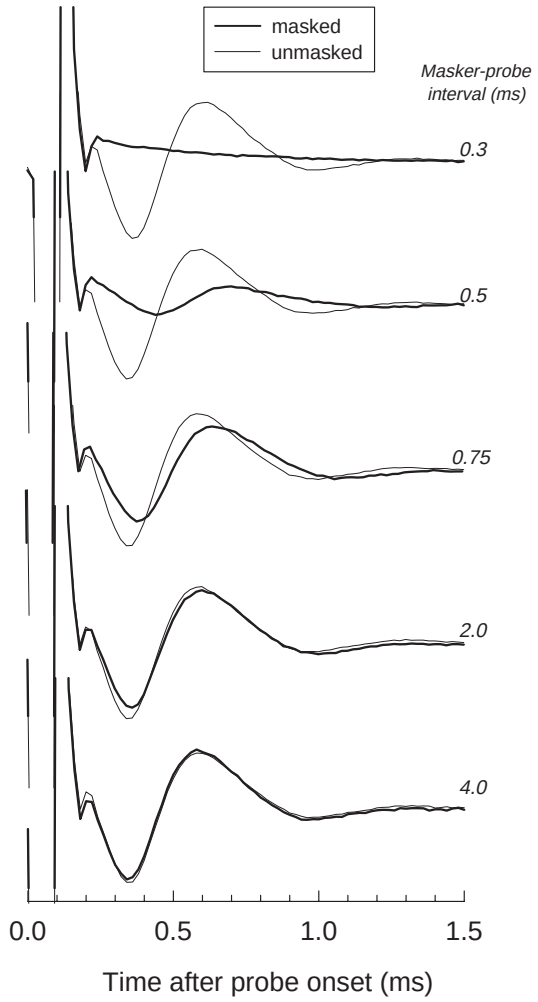

Figure 4: EAP's elicited from a cat under different forward-masking conditions. The "masked" waveforms (thick lines) were obtained with the nerve was excited by a prior, masker, pulse (not shown). The large stimulus artifact occurring between 0.0 and 0.2 ms is that of the second (probe) pulse. Masker artifact and EAP were subtracted from each of the masked responses. The "unmasked" EAP's were obtained in response to a single (probe) pulse without prior masker excitation.

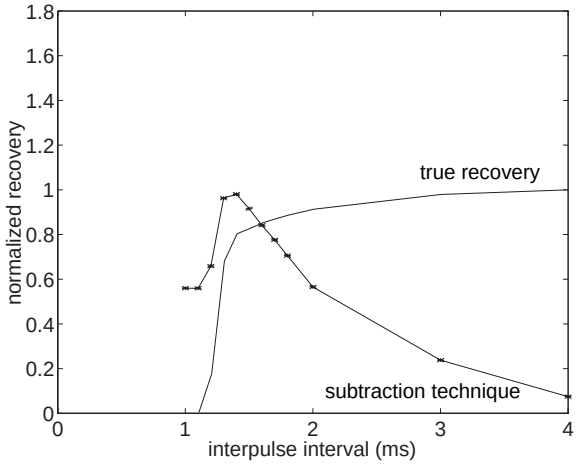

Figure 5: Simulated EAP recovery functions obtained using the biophysical model. Two-pulse stimulus paradigm as in Figure 3. The subtraction technique produces an artifactual non-monotonic recovery function that is artifactually prolonged relative to true model EAP recovery. The model EAP recovery can be directly assessed without problems of stimulus artifact.

3.3 Modification of the "standard" forward-masking technique

Our concern about the possible weakness of the forward-masking technique for collecting refractory recovery data led us to propose a modified technique. This new version relies on a different means of eliminating the probe stimulus artifact. In the standard version, the EAP to the masked probe is subtracted from the EAP to the unmasked probe for a series of different MPI values. In our modification, we chose to discard the use of the EAP in the unmasked state. Instead, it relies upon a direct measurement of the EAP to the masked probe at various MPI's. The probe artifact is subtracted by obtaining a template waveform under the condition of absolute refractoriness; that is, by recording a template with the masker and probe pulses separated by a short MPI to ensure total refractoriness.

Figure 6 provides a diagrammatic comparison of the standard and modified methods. The stimulus conditions used to derive the refractory state with the standard method are shown in the left column. This method collects an unmasked EAP response (A), the forward-masked response at the desired MPI (B), and the response to the masker pulse (C). The resultant

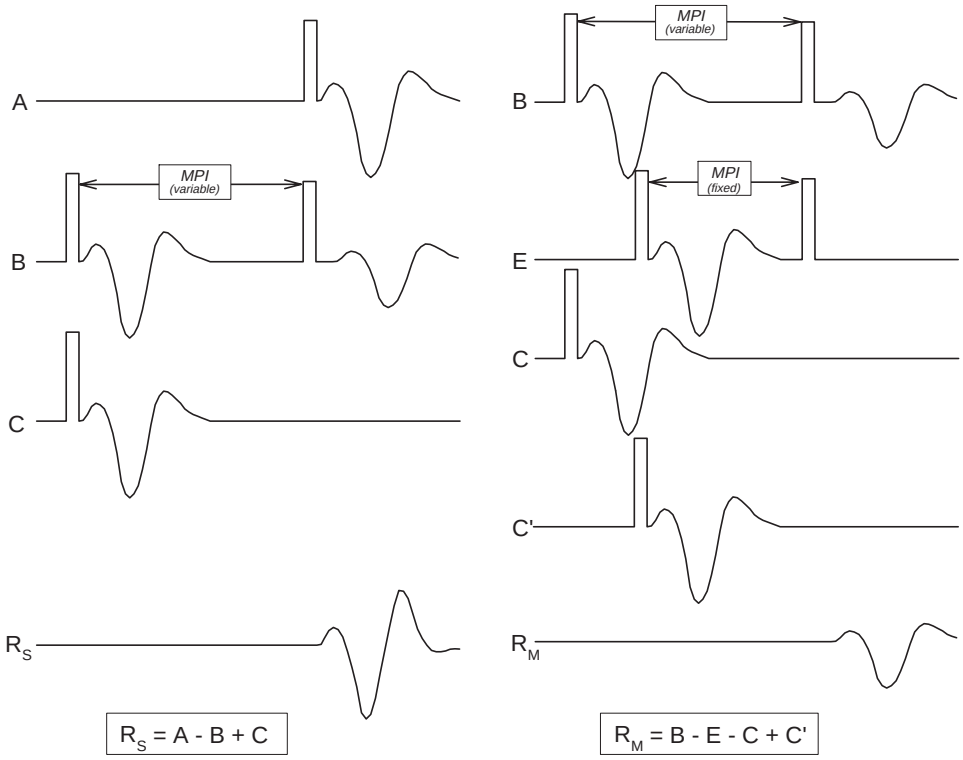

Figure 6: A comparison of the "standard" (left column) and "modified" (right column) forward-masking techniques used to collect refractory recovery data. In the standard method, as MPI is varied, the onset of the probe in both A and B are varied by equal amounts. This leads to the partial masking shown in B, which, in turn, compromises the method. In the modified method, MPI is systematically varied only in condition B (right column). Condition E - used to obtain a template of the probe artifact - always uses a short MPI to assure nearly total refractoriness. Conditions C and C' are used to cancel out contributions of the masker pulses of conditions B and E.

waveform (R_S) is computed as the difference between the unmasked response and masked response plus the response to the masker alone (i.e. R_S= A - B + C). In the modified method, we again collect the forward-masked response at the desired MPI (B). To eliminate the probe artifact, the response to the fully masked probe (E) is subtracted from trace B. The responses to the masker alone (C) is then subtracted from that (B-E) to eliminate the artifact and response to the masker pulse. Finally, to eliminate the influence of the masker pulse present in trace E, a time-delay version of the masker-alone condition (C') is added back. The resultant waveform (R_M) is therefore equal to B - E - C + C'. Note that the modified method records only one neural response to the probe stimulus (the partially-masked response of B), whereas the standard version subtracts the response to the partially-masked probe (B) from the unmasked probe (A).

EAP waveforms derived by the standard and modified methods are shown in Figure 7. The waveforms were derived from the same records shown in Figure 4. Since the cat's nerve was apparently absolutely refractory with a MPI of 0.3 ms, that condition was used in the modified method to eliminate probe artifact (i.e. analogous to waveform E of Figure 6). As a result, the waveform produced by the modified method for MPI= 0.3 ms is a flat line. As a function of MPI, the standard and modified methods demonstrate opposing trends, with the former producing decreasing amplitudes with MPI and latter, increasing amplitudes. The latencies and amplitudes of the EAP waveforms of Figure 7 are plotted in Figure 8 (panels A and B). The peak labeled "N1" is the prominent negative peak of the EAP, while "P2" is the subsequent positive peak. EAP amplitude is defined as the voltage difference between those two points. Note that the latency-level functions produced by the modified method are consistent with the aforementioned single-fiber data and contrast with the more complex trends produced by the standard method. To facilitate comparison of the amplitude recovery curves, the data of panel B are transformed and plotted in panel C. To transform the standard-method amplitude plot, each amplitude was divided by that obtained at an MPI of 0.3 ms (arrow in Figure 8-B) and then subtracted from 1.0. The assumption in this transformation is that the amplitude recorded at 0.3 ms MPI equals that which would be obtained with no forward masking. The modified-method amplitudes were normalized by dividing each value by the same amplitude used to normalize the standard-method data.

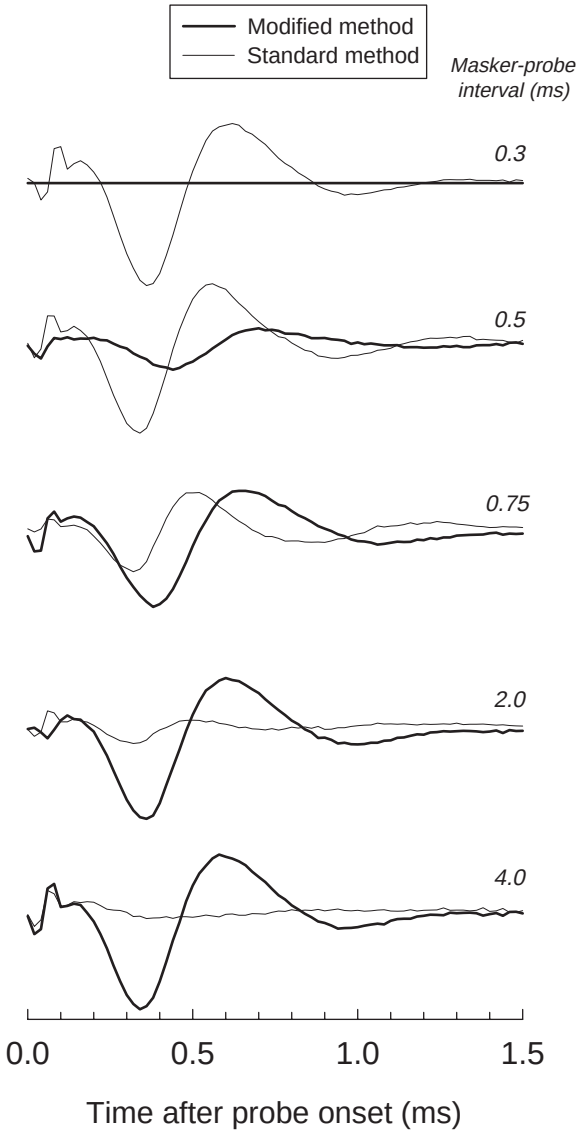

Figure 7: EAP's obtained using the standard (thin lines) and modified (thick lines) forward-masking schemes. Masker-probe intervals are noted at the right margin. Since the standard method relies on subtracting the non-refractory EAP from the relative refractory EAP, it produces a potential that decreases with MPI. In contrast, the modified method produces a potential directly reflecting the condition of the forward-masked nerve.

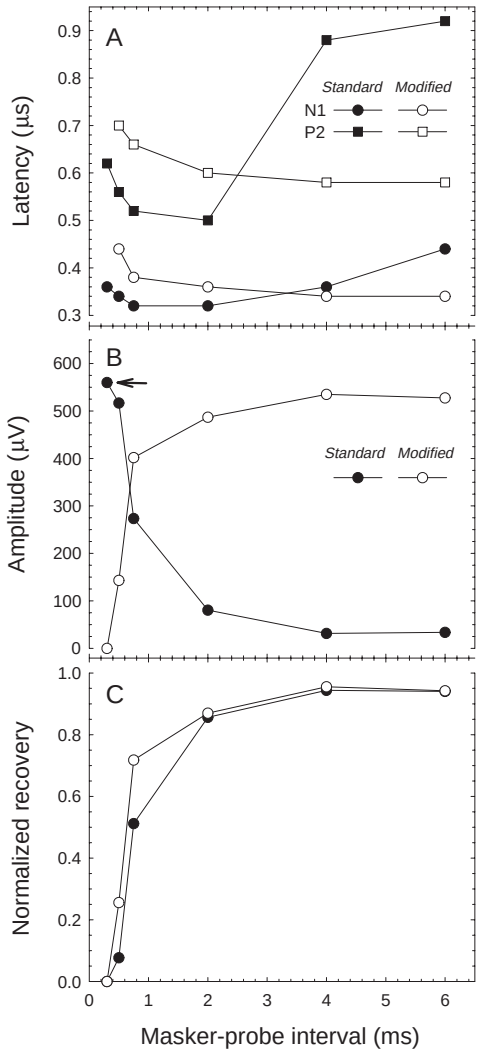

Figure 8: Latency and amplitude data for the EAP waveforms of Figure 7, plotted versus masker-probe interval. Results of the standard forward-masking scheme are plotted with solid symbols and results of the modified scheme are plotted with open symbols. The latencies of the prominent negative peak (N1) and the subsequent positive peak (P2) are plotted in panel A. EAP amplitudes are plotted in panel B. To facilitate comparison between the two methods, the amplitude data of panel B are normalized by the maximum EAP amplitude (arrow) as described in the text and plotted in panel C.

3.4 Application of modified method to human data

We proceded to investigate the usefulness of the modified technique by applying it to data obtained from human cochlear implant users. Human EAP responses were recorded from patients implanted with the Nucleus 24 device. Stimuli were presented in a monopolar mode, i.e., one intracochlear electrode was used to present current pulses while a second, extracochlear electrode in the temporalis muscle served as the return electrode (i.e., the "MP1" mode). EAP responses were also recorded in a monopolar mode. The active recording electrode was an intracochlear electrode 1.5 mm distant from the intracochlear stimulating electrode. The return (or reference) recording electrode was located on the casing of the implanted receiver unit (i.e., the "MP2" mode). In most cases, the stimulating site was electrode 10, chosen to be near the midpoint of the inserted array.

The Nucleus NRT system relies upon the "standard" forward-masking scheme to obtain EAP recordings. For our study, the masker level was always set at a fixed level determined by the patient's maximum comfort level. The level of the probe was always set 5-10 clinical units less than that. Both the masker and probe stimuli were biphasic pulses with durations of 25 microseconds/phase. As in the case with the cat experiments, the masker-probe interval (MPI) - the time interval between the offset of the masker pulse and onset of the probe pulse – was systematically varied to obtain probe EAP responses at different refractory recovery times. MPI values ranged from 0.3 ms to 4.0 ms.

Subjects were adult patients implanted at the University of Iowa with normal and full electrode insertions. All subjects were awake and asked to sit comfortably during data collection. The stimulus paradigms used to obtain EAP refractory recovery data with the Nucleus NRT system were essentially the same as those used in acquiring the feline EAP data (cf. Figure 6, left column). Indeed, conditions A, B, and C of Figure 6 correspond to the same conditions as labeled in the Nucleus NRT manuals (Cochlear Corporation, 1999; Lai, 1999). There is one difference between the feline and NRT methods for the collection of the standard-method data. Since the amplifier of the NRT system generates a switching transient, a fourth condition - condition D in the NRT manuals (Cochlear Corporation, 1999) is also recorded. Although no stimulus is presented in condition D, it is needed to obtain a recording of a switching transient generated by the NRT amplifier (Cochlear Corporation, 1999; Lai, 1999).

In the experience of the Iowa cochlear implant program, the standard forward-masking technique provides EAP waveforms demonstrating a robust negative peak and a subsequent positive peak. However, in some of our sets of patient data, the modified version of this technique provided a noticeable improvement in the quality of the EAP waveforms. This is illustrated in Figure 9, where EAP waveforms from two patients are shown. The top panels of the figure show waveforms obtained at various MPI values using the standard method, while results from the modified version are shown in the lower panels. In the each panel, the waveforms are each offset by 0.5 ms from each other to facilitate display of the data. Note that, for both subjects, the negative portion of the EAP waveforms is fully defined by the modified method, whereas it is usually not defined by the standard method. Furthermore, unusual morphologies (such as the double peaks seen in the top right panel) are not evident when the modified method is employed.

As in the case of the feline data, these two artifact reduction schemes can result in different EAP amplitude-vs-MPI plots. Figure 10 depicts EAP recovery curves for 9 implanted ears of 8 patients (one patient was implanted bilaterally). In each case, amplitude-vs-MPI plots are shown for both the standard and modified methods. The intracochlear electrode used to record the potentials is indicated in each panel; in most cases, electrode 10 was used. Also indicated in each panel is the maximum EAP amplitude that was obtained over all the MPI values using the standard method. Maximum amplitudes were obtained at an MPI value of either 0.3 or 0.5 ms. To facilitate comparisons across methods and subjects, each subject's EAP amplitudes have been normalized. EAP amplitude data obtained by the modified method were normalized by dividing each amplitude by the maximum EAP amplitude. Normalizing the standard method data entailed division by the maximum EAP amplitude and then subtracting that amplitude from 1.0.

For most subjects, the EAP is largely recovered at an MPI of 4 ms. For some subjects, the two methods provide essential the same result (e.g., subjects I24-6 and I24-52-L). In other subjects, recovery rates are quite different for the two methods (e.g., subjects I24-11 and I24-54-L). One trend observed across subjects is that the modified version tends to demonstrate faster EAP recovery from forward masking. This is consistent with our notion that the standard method introduces error by subtracting the partially refractory EAP response from the non-refractory response. In the case of

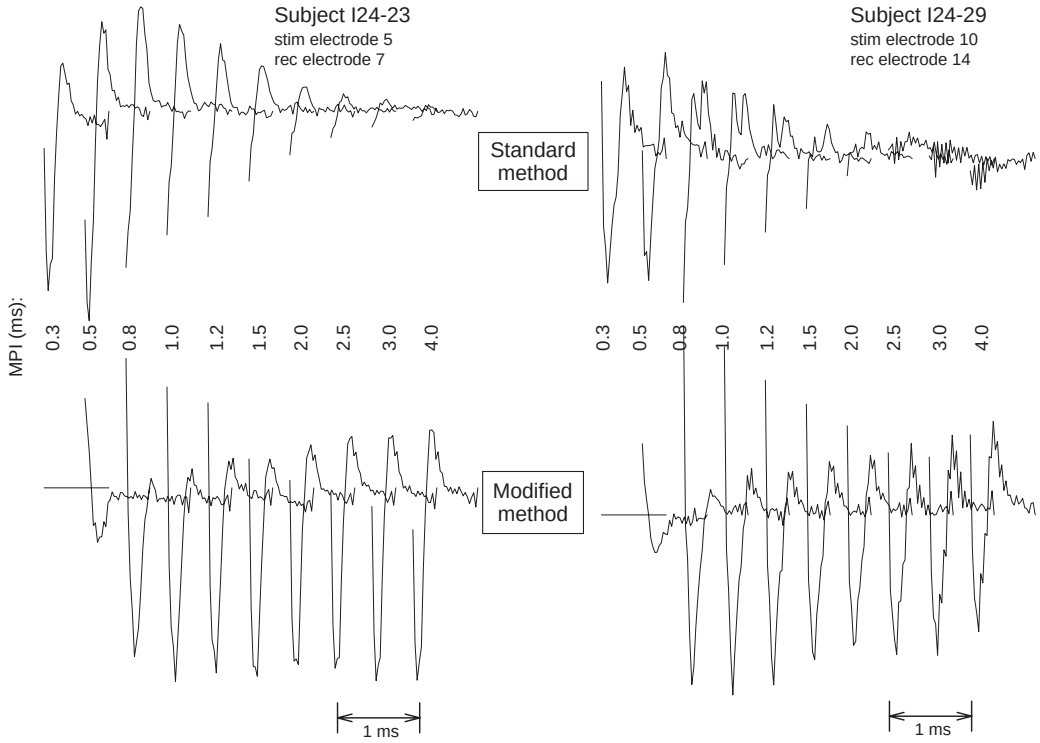

Figure 9: EAP waveforms from two human cochlear implant users, demonstrating the results of using the standard (top panels) and modified (bottom panels) forward-masking template schemes. All waveforms were collected using the Nucleus 24 NRT system. MPI was systematically varied (from 0.3 ms to 4.0 ms) in order to obtain a series of waveforms demonstrating recovery from a refractory state. For efficiency, each EAP waveform is displaced horizontally from the next by 0.5 ms. The MPI used to obtain each EAP waveform is indicated by the numbers between the top and bottom panels.

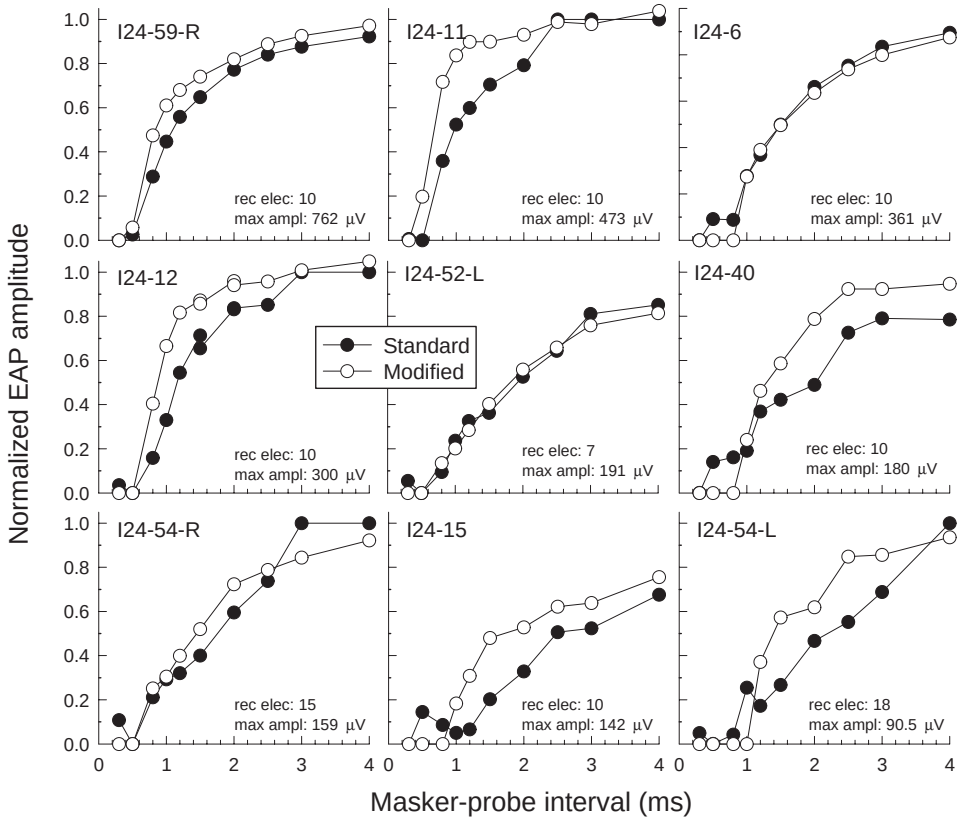

Figure 10: Refractory recovery curves obtained from 9 implanted ears of 8 patients. Data gleaned with the standard technique are shown by the filled symbols; data from the modified technique are shown by the open symbols. Shown in each panel are the subject code, the intracochlear electrode used for recording, and the maximum (i.e., unmasked) EAP amplitude obtained from that patient. All EAP amplitudes are normalized to the patient's maximum EAP amplitude for that electrode.

the cat EAP data, the morphology differences apparent at MPI's of 0.5 and 0.75 ms (Figures 7) resulted in differing recovery rates for the two methods (Figure 8). In the feline data, the modified method produced a faster EAP recovery than did the standard method. While we do not have the ability to similarly examine the "raw" waveforms from our human subjects (due to larger stimulus artifacts), we assume that a similar phenomenon is at work in the human data. In the case of the human data, the largest deviations in the normalized amplitude typically occur at MPI values of 1.5 and 2.0 ms.

3.5 Remarks

Both single-fiber and gross-potential data obtained from our animal preparations demonstrated altered auditory nerve response characteristics under conditions of prior stimulation (i.e., refractoriness). These results motivated us to propose the modified method of obtaining refractory recovery data from human implant patients. We believe that the Nucleus NRT system – which enables acquisition of the EAP in humans - would be improved by implementation of this modification.

Our modification eliminates the conceptual weakness of the NRT's implementation of the forward-masking scheme by using condition E, the fully masked probe response of Figure 6, in place of condition B, a partially masked probe. The modified version thereby provides a direct measure of the relatively refractory neural response, instead of the indirect measure provided by the standard approach. In some patients, this direct method provided better-quality EAP response waveforms than did the standard method. The standard method may not only distort measures of EAP amplitude, but also significantly alter the morphology of the EAP response. This is demonstrated in the comparison of EAP waveforms obtained from subject I24-29 (Figure 9), in which double-peaked EAP waveforms are evident in the "standard" waveforms, but missing in the "modified" waveforms.

In some cases, the two methods provide essentially the same recovery curves. However, when the two methods produced differing recovery curves, the modified version consistently produced curves that recovered at a faster rate, reflecting the same difference observed in our cat data. In the case of the human EAP data, we are unable to provide the clear comparison of EAP waveforms that was obtainable in the cat (e.g., Figure 4). However, since similar discrepancies in the refractory recovery curves were obtained

in both species using the standard method, we conclude that that method is produces similar EAP distortions in our human subjects.

We should also note that both the modified and standard versions of the forward-masking technique provide the same resultant EAP waveform when a MPI value producing full masking is employed. At that MPI value, the two techniques are essentially the same. Thus, there is no advantage to using the modified version when using the forward-masking technique to obtain an EAP growth (i.e. amplitude-level) function, since that procedure uses a MPI value fixed at a short interval (typically 0.3 or 0.5 ms). The advantage of the modified technique is realized when collecting refractory recovery data, when the MPI is systematically varied over a range.

While implementation of the new method involves modification of the protocol currently used by the standard (i.e., NRT) method, it does not have to entail any greater amount of data collection or time. The comparison of stimuli shown in Figure 6 suggests more stimulus conditions for the modified method; however, proper implementation of the modified version can result in more efficient data collection. This is particularly true when obtaining a set of EAP responses for a refractory recovery curve. For each MPI value, this method requires the collection of unique waveforms A and C. In contrast, waveforms E and C' are constant across the different MPI values and only need be collected once and applied to the computation at all MPI values. In practice, it may be prudent to obtain repeated measures of conditions E and C', since good-quality versions of those two conditions are essential to this method. Finally, we note that the NRT implementation of the standard method requires the collection of an amplifier switch-on artifact that is subtracted from the result to eliminate a switching transient (Cochlear Corporation, 1999; Lai, 1999). However, since the modified version involves an even number of waveform additions and it is not necessary to subtract the amplifier transient waveform.

4 Plans for the second quarter

In the second quarter, we plan to do the following:

- Calculate relative volume measures of surviving spiral ganglion cell populations in the histological sections of the deafened guinea pigs. This will be done prior to making comparisons between histologi-

cal findings and electrophysiologic data obtained from the chronically deafened guinea pigs.

- Collect additional single-fiber data with a two-pulse forward-masking paradigm. We estimate that two additional cat experiments will be needed to complete the data set.

- Begin experiments with the University of Michigan thin-film electrodes. We will coordinate with Ms. J. Hetke to evaluate different designs that will most likely be successfully impailed into the exposed nerve. Once this mechanical evaluation is successfully completed, we will begin to make intra-nerve recordings from these electrodes.

- Design and build headstage amplifiers for the selected UM electrodes. Typically, these electrodes have high (1 megohm) impedance, requiring custom amplifiers. We are not aware of any supplier of headstages designed to mount (with short lead lengths) to these electrodes.

- Attend and make two contract-related presentations at the CI 2000: International Cochlear Implant Conference at Miami Beach, Florida, February 3-5, 2000.

- Attend and make two contract-related presentations at the Midwinter Meeting of the Association for Research in Otolaryngology, St. Petersburg Beach, Florida, February 20-24, 2000.

- Revise manuscript (regarding this QPR's findings) for submission and publication in Ear and Hearing.

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