Sixth Quarterly Progress Report

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Speech Processors for Auditory Prostheses

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submitted by

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1.0 Introduction

Work performed with the support of this contract is directed at the design, development, and evaluation of sound-processing strategies for auditory prostheses implanted in deaf humans. The investigators, engineers, audiologists and students conducting this work are from four collaborating institutions: the Massachusetts Institute of Technology (MIT), the Massachusetts Eye and Ear Infirmary (MEEI), Boston University (BU) and the University of North Carolina at Chapel Hill (UNC-CH). Major research efforts are proceeding in four areas: (1) developing and maintaining a laboratory-based, software-controlled, real-time stimulation facility for making psychophysical measurements, recording field and evoked potentials and implementing/testing a wide range of monolateral and bilateral sound-processing strategies, (2) refining the sound processing algorithms used in current commercial and laboratory processors, (3) exploring new sound-processing strategies for implanted subjects, and (4) understanding factors contributing to the wide range of performance seen in the population of implantees through psychophysical, evoked-response and fMRI measures.

This quarter's effort was directed at three areas: (1) continuing experiments in the use of triphasic stimulation waveforms to reduce nonsimultaneous electrode interactions, (2) psychophysical and speech-reception measures associated with bilateral intracochlear stimulation, and (3) analysis of evoked-response recordings designed to characterize the peripheral electrode interactions in subjects who have received the Clarion CII implant system. In this QPR, we concentrate on our work characterizing the ability of subjects with bilateral cochlear implants to localize sound sources.

2.0 Sound-Source Localization

As we reported in our Third Quarterly Progress Report (QPR) (Eddington, et al. 2002), three subjects who had already received monolateral Clarion CII/HiFocus (with positioner) implants underwent cochlear implantation of their unimplanted ear (also with the Clarion CII/HiFocus [with positioner] implant system) in the 1st and 2nd quarters of this contract. A summary of these subjects is provided in Table I.

Table I: Bilaterally-Implanted Subjects

Subject (ear)	Years Deaf	1st Surgery (date)	2nd Surgery (date)	CNC Score (% words)
C092(r)	5		3/2002	
C092(l)	3	1/2001		98%
C105(r)	10		5/2002	
C105(l)	1	6/2001		38%
C109(r)	3	8/2001		90%
C109(l)	3		3/2002	

Note that each subject wore their first implant for at least six months before receiving their second implant. This made it possible to insure that their monolateral performance using the first implant was (1) not substantially improved when used together with a hearing aid in the unimplanted ear and (2) significantly better than their performance using a hearing aid alone in the unimplanted ear.

In our last QPR (Eddington, et al. 2003), we described the methods used to design bilateral sound-processing strategies for these three subjects. Each of the subjects now wears asynchronous bilateral sound processors full time. The focus of this QPR is to report the measures we have made to characterize the subjects' ability to localize sound sources as a function of their experience with full-time bilateral sound processor use. The analyses reported below are, for the most part, qualitative and preliminary. We anticipate a more complete, quantitative analysis will follow in a future QPR.

2.1 Methods

The measures reported here were all made in a carpeted 12' by 13' single-wall IAC room. In order to simulate a realistic environment, the walls/ceiling were not treated to reduce reverberation. Seven speakers (~2" diameter) were placed at 30^{o} intervals on an 180^{o} arc 5 feet from the subject's head (see Figure 1). The subjects were instructed to maintain a fixed head position facing 0^{o} throughout each block of trials. While Informal monitoring of head position verified compliance, very small shifts in head position were possible because the subject's head was not restrained.

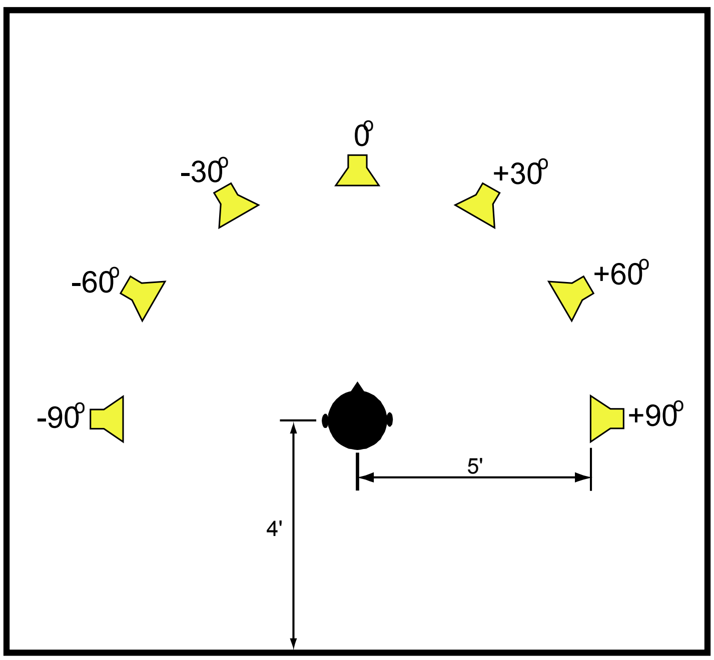

Figure 1. Schematic drawing of the set-up for the sound-source localization experiments.

Each stimulus trial consisted of 3 sequentially-presented, wide-band acoustic noise bursts (duration: 500 ms; inter-burst interval: 300 ms) played from a single speaker. A total of at least 35 trials (e.g., 5 trials/speaker in randomized order for constant-level stimuli) were presented in each block of trials. The listening (monolateral right, monolateral left and bilateral) and level (constant or randomly roved by up to 20dB) conditions were constant within each block. In the roved condition, three levels (50 dB SPL, 60 dB SPL and 70 dB SPL) were presented three times at each source position (order randomized) resulting in a total of 63 trials/block (3 trials, 3 levels, 7 source positions). In the constant-level listening condition, the presentation level was approximately 64 dB SPL.

The subject's task was to identify the source position for each trial by pressing a key corresponding to source speaker (1-interval, 7-alternative forced choice). Subjects did not receive feedback.

All subjects used the same sound-processing system/strategy for our testing that they use outside the laboratory. In the case of subjects C092 and C109, behind-the-ear (BTE) sound processors with the microphone in the BTE case ("T-microphones" have not been worn by these subjects) are used. C105 wears body-worn sound processors with the microphone located in the headpiece above each pinna.

2.2 Results

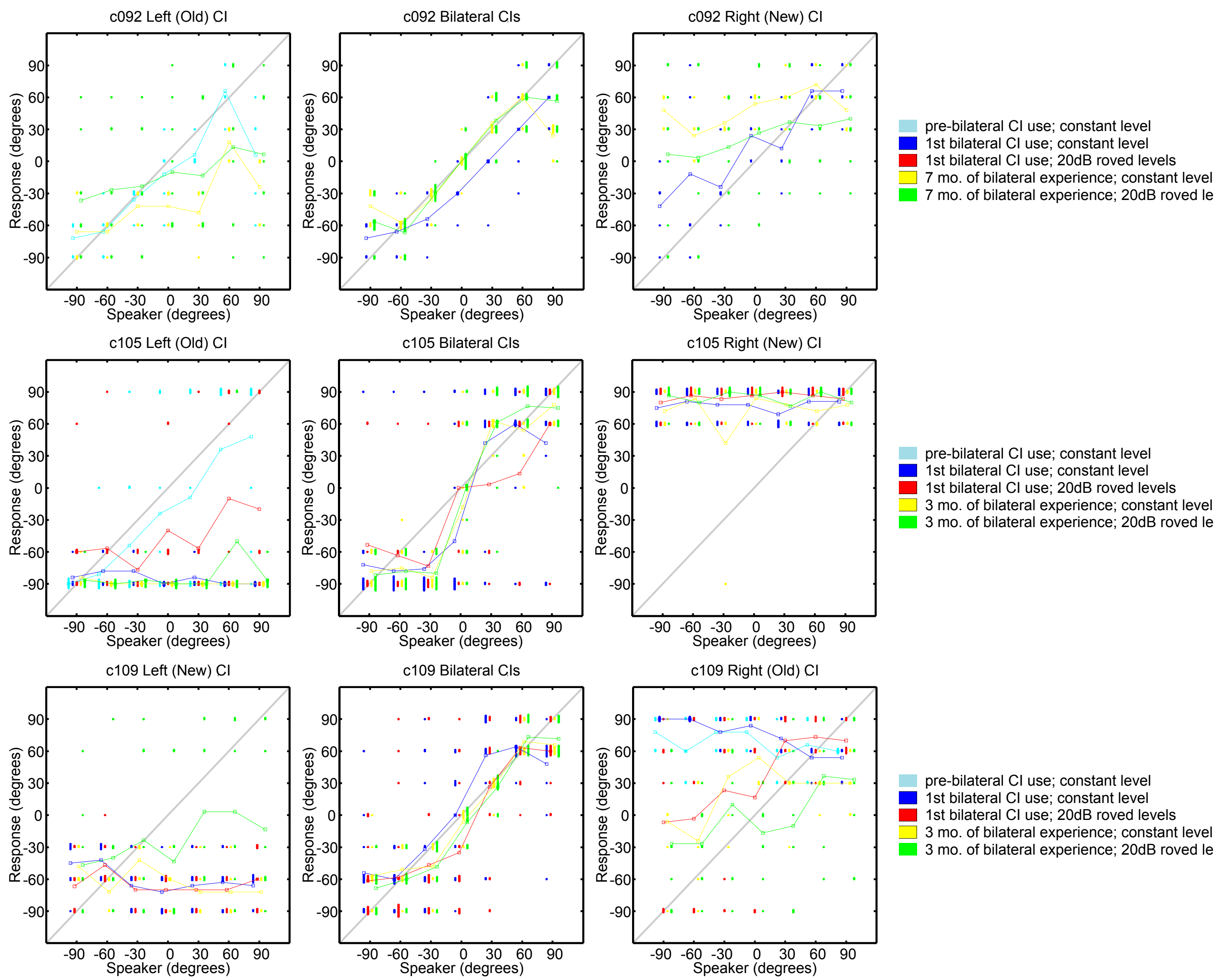

Figure 2. Scatter plots of the localization responses of subjects C092, C105 and C109 . Three panels in each row represent responses from a single subject in three listening conditions: left cochlear implant only, both implants and right cochlear implant. The labels "(Old)" and "(New)" are used in the monolateral panels' titles to identify the 1^{st} and 2^{nd}-implanted ear respectively. In each panel, a single colored circle represents a single response. Note that for each speaker position, the different colored circles aligned vertically above that position represent responses to a stimulus from that source at different times and level conditions. The open squares connected by lines identify the mean of the responses associated with each testing time/level condition.

Scatter plots of each subject's responses are shown in Figure 2. The legends are similar across subjects. Light blue denotes scores from tests conducted at least several weeks before the subject had any experience listening to bilateral sound processors. The red and dark-blue colors mark scores measured the same day the subject was fit with asynchronous bilateral sound processors. At the time these tests were conducted, the only experience the subject had with bilateral processors was about 15 to 20 minutes of live-voice interaction as the parameters of the bilateral sound-processing strategy were refined. The colors yellow and green are used to identify scores measured after months of continuous bilateral sound-processor use. Light blue, dark blue and yellow represent scores measured with constant level stimuli while red and green represent measurements made with 20-dB level roving.

The raw data of Figure 2 are summarized in Figures 3-5. The four major panels in each figure represent results for different sets of sound sources. The three subpanels within each major panel represent three different listening conditions: left implant only, both implants and right implant only.

Bars in the top-left panel represent the RMS error computed across the responses to all sound sources while the top-right, bottom-left and bottom-right show RMS error for the single source directly in front, the three left hemifield sources and the three right hemifield sources respectively. The error bars represent standard deviations estimated by the bootstrap (resampling) technique (e.g., Efron and Tibshirani 1993). The horizontal dashed lines mark chance performance for 7 response alternatives. If the number of response alternatives were limited to the number of sources in each hemifield (3), chance performance would be approximately 34.6°.

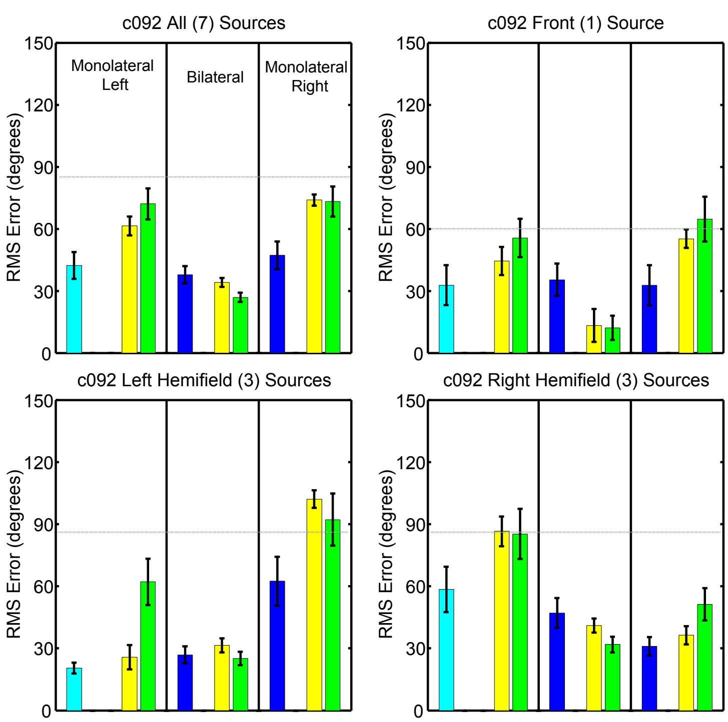

Figure 3. Summary of localization data for subject C092.

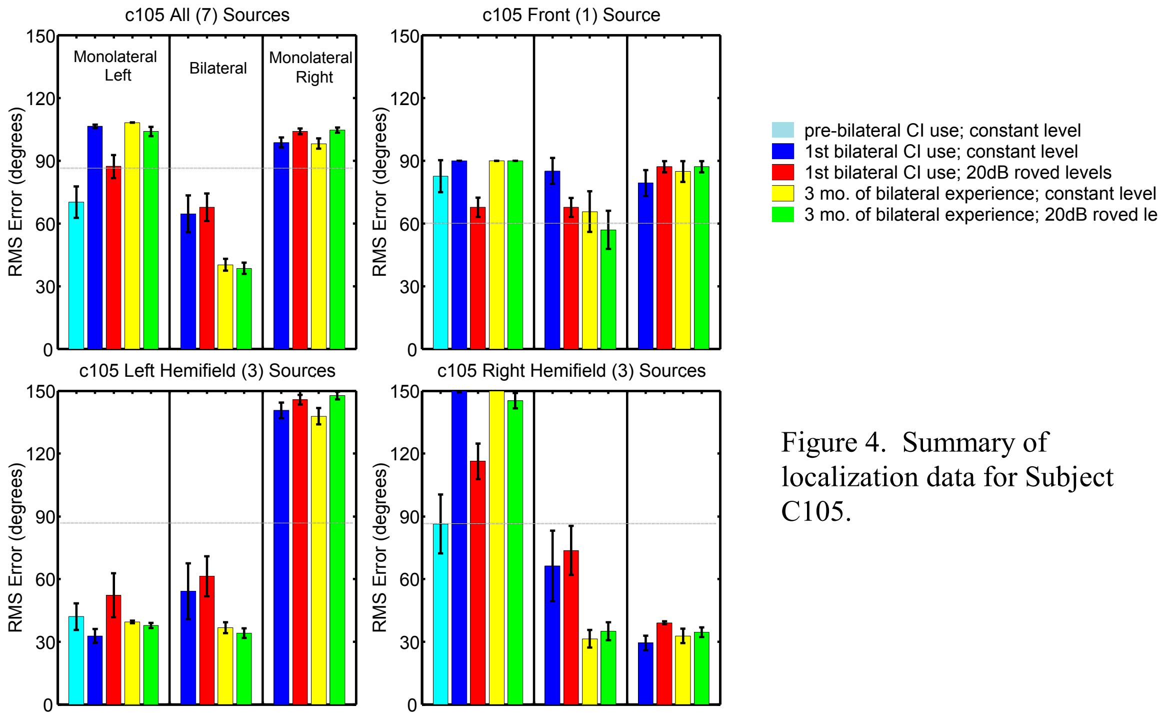

Figure 4. Summary of localization data for Subject C105.

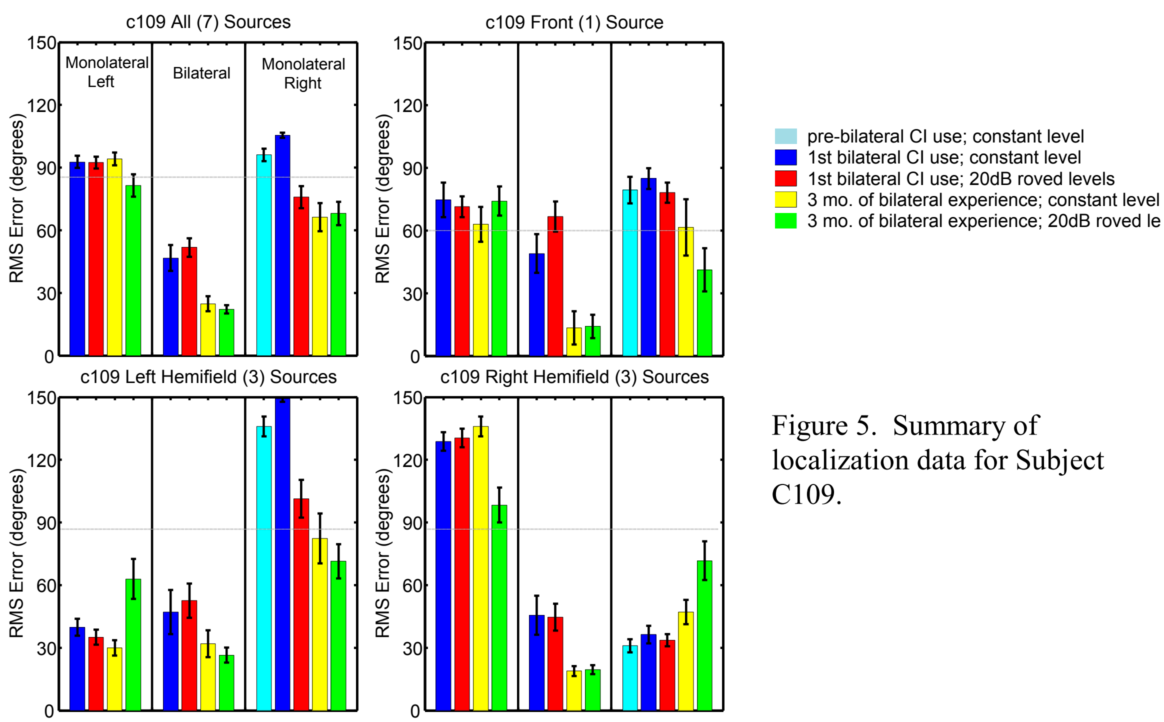

Figure 5. Summary of localization data for Subject C109.

2.3 Monolateral vs. Bilateral Listening

Consider first Figure 3 (C092). The light-blue bars show the RMS error associated with listening to monolateral input from C092's original left implant (constant-level stimuli). Up to this point in time, C092: (1) had not listened through bilateral sound processors, (2) used this original monolateral implant for more than 12 months and (3) developed a strategy to extract sound-source information using the left implant monolaterally. C092's monolateral performance is well below chance for all sources combined and also when analyzed separately for the front, left hemifield and right hemifield sources. However, C092's monolateral localization strategy does not work as well for sound sources contralateral to the implant (right hemifield sources) where her performance is significantly worse than for left hemifield sources. The top-left panel of Figure 2 shows that C092 makes no hemifield confusions when sources are in the left hemifield, but right hemifield sources are sometimes confused with sources outside that hemifield.

The yellow and green bars represent localization scores measured seven months after C092 received wearable (asynchronous) bilateral sound processors. At this point in time, we assume the subject has developed a new strategy for sound-source localization; one that attempts to optimally use the bilateral cues presented by the two implants. When in this state and listening to constant-level stimuli (yellow bars), C092's bilateral performance is better than monolateral performance with either the left or the right implant for the front sound source. But for the right or left hemifield sources, bilateral performance can be explained by attending to the ear with better monolateral performance. However, when amplitude is roved to eliminate all but interaural level cues, bilateral performance is better than performance measured for either implant alone for all of the source groupings. Note that when the sound source is positioned on the same side as the original implant (left hemifield), C092 scored as well using her optimized monolateral strategy as she scored in "bilateral mode."

The plots of Figure 4 show C105's performance with her first implant does not reach that of C092's. Whether this is due to the strategy emplyed by C105 to extract monolateral information and/or to the implant not providing the same level of information is unclear. In one respect C105's results are similar to C092's: after significant exposure to asynchronous bilateral sound processors, performance for the left and right hemifield sources can be accounted for by the subject listening to the implant with the better monolateral performance. Note also that C105's performance is not materially influenced by level roving.

C109's (Figure 5) monolateral performance before wearing bilateral processors is also poor compared to C092's. In the case of responses to both the front source and the right hemifield sources, bilateral performance with constant-level stimuli cannot be explained by the subject attending to the implant with the better monolateral performance. When stimulus level is roved, bilateral performance is better than the monolateral performance of either implant for all source groupings.

2.4 Changes with Bilateral Experience

In the bilateral listening condition, C092's responses (Figure 2, top-middle panel) tended to be grouped closer to the diagonal after seven months of experience (yellow and green circles) than when first tested bilaterally. Note that the lines representing the mean responses for monolateral listening (Figure 2, top-left and top-right panels) tended to become more horizontal after experience with the bilateral processor. This may be due to C092 not being able to switch from using a bilateral listening strategy to the rather successful monolateral strategy on demand.

Except for the front source in the bilateral listening condition, C105 showed a strong bias toward the +90°, +60°, -60° and -90° response categories (Figure 2, middle row). When first listening in the left monolateral condition, C105 varied the proportion of responses assigned to +90° in a way that resulted in the average-response line falling close to the diagonal. Subsequent tests (both before and after significant bilateral processor use) generated responses concentrated at -90°. Addition of roved levels tended to increase the number of 60° and 90° responses in this monolateral listening condition. When listening only through the right sound processor (new implant) responses were always 90° or 60°.

C109's responses to bilateral stimulation before wearing bilateral sound processors for a significant period (Figure 2, bottom-middle panel, red and blue circles) were widely distributed, but in a way resulting in average-response lines falling near the diagonal. After three months of experience with bilateral listening, the responses were more tightly clustered around the diagonal. Roved levels did not produce substantial changes in these patterns. In the case of monolateral listening, roved levels tended to produce a wider range of responses, but the impact of bilateral experience was smaller than for the bilateral listening condition.

2.5 Summary

While formal conclusions wait for completion of a more quantitative analysis, these preliminary results are consistent with the subjects' qualitative reports that they are better able to localize sound sources using their bilateral sound processors than when they were using their first implant system monolaterally.

3.0 Future Work

We plan to continue monitoring the relationships of pitch, fusion, ITD-JND and binaural interactions in electrically-evoked brain stem responses over the next Quarter. However, most of our effort in bilateral stimulation will focus on localization and speech reception in the presence of multiple noise sources using the asynchronous sound-processing systems described above. We will also begin preparing experiments to make similar measures using synchronized sound processors.

We plan to continue work directed at triphasic stimulation waveforms. We have finished collecting a set of interaction measures in subjects implanted with the Ineraid and the Clarion CII/HiFocus implant systems. We have implemented a wearable triphasic, CIS sound-processing strategy for one of these Clarion subjects and plan to provide wearable versions for additional subjects to wear for a period of several months. This will enable us to measure and compare asymptotic performance of high-rate triphasic and biphasic stimulation strategies.

Measurements of intracochlear evoked potentials (IEPs) are continuing using the custom software developed and tested during the first three Quarters in a group of monolaterally-implanted Clarion CII/HiFocus subjects. The primary objectives for collecting these initial data are to (1) better characterize system measurement noise and (2) characterize the magnitude and quality of IEP measures in a pool of subjects with a range of speech-reception performance. We are currently making IEP-based interaction measures in Clarion subjects and expect to continue that work in the next quarter.

4.0 References

Eddington, D. K., Poon, B. B., Colburn, H. S., Noel, V., Herrmann, B., Tierney, J., Whearty, M. and Finley, C. C. (2003). "Speech processors for auditory prostheses: fifth quarterly progress report," Neural Prosthesis Program, National Institutes of Health.

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