"A Cochlear Nucleus Auditory prosthesis based on microstimulation"

Contract No. **No. NO1-DC-1-2105**
Progress Report #11

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SUMMARY AND ABSTRACT

1- Development of an array of silicon substrate microelectrodes

Our contract calls for the development of arrays of silicon substrate electrodes, which should allow placement of many more electrode sites into the human cochlear nucleus than is possible with discrete iridium microelectrodes. In a cat model, we are developing an array for implantation into the human cochlear nucleus that has 16 electrode sites distributed on 4 silicon shanks extending from an epoxy superstructure that is 2.4 mm in diameter. The silicon probes with stimulating sites at 0.8, 1.2, 1.5 and 1.8 mm below the probe spine, are fabricated at the University of Michigan under the direction of Design Engineer Jamille Hetke.

We report interim results from 3 arrays that have been implanted in the ventral cochlear nuclei of 3 cats, for 15 to 352 days. We have continued to experience failures related to fracturing of the delicate silicon substrate during fabrication and cleaning of the arrays, but we have extensively revised our fabrication and handling procedures and these problems are becoming less frequent. Once implanted, the arrays have been reliable. In the three cats, we have made serial recordings of the response growth functions (RGFs) of the compound action potentials evoked in the inferior colliculus by the microstimulating sites in the cochlear nucleus. These reveal significant movement of the array through the cochlear nucleus (on the scale of the spacing between the electrode sites; 300 to 400 µm) during the first weeks after implantation, but indicate good stability between 75 and 352 days. In this respect, it is notable that our policy with the human patients has been to activate the processor at 90 days after implantation of the prosthesis.

While the threshold of the RGFs evoked from these electrodes are generally similar to those that we have recorded previously with the chronically implanted discrete iridium electrodes, there has been a tendency for the thresholds of the RGFs from the shallowest sites to be slightly higher, and the slopes of the RGFs to be lower, that those evoked from the deeper sites. While this difference may be due to the particular location of the shallow sites in the ventral cochlea nucleus, it also suggest that the broad, thin silicon shanks may induce somewhat more injury in the surrounding tissue than the cylindrical discrete iridium electrodes, particularly around the shallow electrode sites close to the array superstructure, where the (tapered) shanks are widest. We have requested a reduction in the width of the shanks in our next batch of probes from the CNCT.

2: Results from patients with penetrating cochlear nucleus arrays

Four patients have received the penetrating auditory brainstem implant array (PABI) as of April 2004. No adverse effects have been observed either during or after surgery or during laboratory testing. The implant in PABI patient #4 has not yet been activated, and we report here results from the first three patients. Interim results from patients 1 and 2 were described in the previous 2 reports. PABI#1 received auditory percepts on only one of the penetrating microelectrode. The procedure for targeting the cochlear nucleus during the implant surgery was subsequently changed and PABI#2 received auditory percepts on 7/8 penetrating electrodes and their responses have been quite stable over the 3-month inter between initial hook-up (at 90 days post-implantation) and the first follow-up (90 day later). PABI#3 received auditory percepts on 4/8 penetrating electrodes. However, unlike PABI#2, the penetrating electrodes did not improve his ability to recognize speech-related material. Also, in this patient, the penetrating electrodes did not elicit the full range of pitch percepts seen in PABI #2, and in particular, they did not elicit pitch percepts in the range that is critical for speech perceptions.

Furthermore, all of the functional penetrating electrodes were located on the anterior part of the penetrating array. This patient illustrates the need for a more reliable means of targeting the penetrating array into the center of the ventral cochlear nucleus, during the implant surgery. Dr. McCreery has been working with Dr. Waring to develop a hand-held stimulating probe that will allow the surgeon to more precisely locate the center of the ventral cochlear nucleus prior to implanting the penetrating array.

1- Development of an array of silicon substrate microelectrodes

METHODS

The objective of this project is to develop central auditory prostheses based on an array of microelectrodes implanted into the ventral cochlear nucleus, in order to restore hearing to patients in whom the auditory nerve has been destroyed bilaterally. Our contract calls for the development of arrays of silicon substrate electrodes, which should allow placement of many more electrode sites into the human cochlear nucleus than is possible with discrete iridium microelectrodes. We are developing an array for implantation into the human cochlear nucleus that has 16 electrode sites distributed on 4 silicon shanks extending from an epoxy superstructure that is 2.4 mm in diameter. This is the same footprint as our first- generation human arrays employing discrete iridium microelectrodes and is designed to be implanted using the same inserter tool. The silicon probes (Figure 1-1A) with stimulating sites at 0.8, 1.2, 1.5 and 1.8 mm below the probe spine, are fabricated at the University of Michigan under the direction of Design Engineer Jamille Hetke. Figure 1-1B shows an array with 2 of the probes (4 shanks and 16 electrode sites) extending from an epoxy superstructure that floats of the surface of the cochlear nucleus. The cable is angled vertically, to accommodate the transcerebellar approach to the feline cochlear nucleus.

To date, 6 of the silicon arrays have been implanted into 6 young adult female cats with normal hearing. Two of the implants (CN146 and CN147) were made during the past quarter of this contract period, and one has been implanted for nearly a year (cn144). All three cats remain alive and healthy.

The arrays are implanted using aseptic surgical technique. The scalp is opened in a midline incision, and the muscles reflected. A small craniectomy is made over the right occipital cortex and the bipolar recording electrode is introduced into the rostral pole of the right inferior colliculus. The reference electrode is slightly dorsal to the colliculus. These electrodes are solid 100 µm ss wire, with ~ 1 mm of the Teflon insulation removed for the tips. The recording electrode was inserted at the extreme rostral-medial margin of the IC, so as not to interfere with the mapping studies that are conducted just before the animal is sacrificed.

To access the cochlear nucleus, a craniectomy is made over the left cerebellum, extending up to the tentorium. In cat cn144, the array was inserted into the cochlear nucleus with the shanks in a near dorsal-ventral orientation, so that the electrodes would cross the isofrequency lamina at a steep angle. However, the dorsorsolateral surface of the feline cochlear nucleus is inclined at a rather steep angle (about 40^{O}) and thus when the array is implanted along an axis close to the vertical, the underside of the array button (superstructure) does not lie flat on the surface of the nucleus. Also, recent experience with the human patients has demonstrated the desirability of implanting the array into the lateral surface of the cochlear nucleus. Thus in the recent cats, we elected to insert the array at angle of approximately 40 degrees from the vertical. To accommodate the low insertion angle, the craniectomy was extended laterally as far as the large bone sinus.

The rostrolateral portion of the left cerebellum was then aspirated using glass pipettes. The electrode array was held by a partial vacuum onto the end of a metal inserter tube, and advanced into the cochlear nucleus.

Before releasing the vacuum, the array cable was fixed to the bone at the margin of the craniectomy, using medical grade SuperGlue and the cavity was filled with gelfoam.

RESULTS

CN144

Cat CN144 has been followed for 352 days after implanting the electrode array. Figure -1-2 shows the arrangement of electrode sites on the silicon shanks. During the final stages of fabrication, the rostral- lateral shank (with electrode sites 4,8,12,16) fractured from the array. Periodically, the responses evoked from each of the microelectrodes in the left PVCN were recorded via the electrode in the rostral pole of the right inferior colliculus. The stimulus was cathodic-first, charge-balanced pulse pairs, each phase 150 µs in duration. 512 to 2048 successive responses were averaged to obtain each averaged evoked response (AER, Figure 1-3). The response growth functions, which represent the recruitment of the neural elements surrounding the microelectrode, were generated for each stimulating electrode site in the PVCN, by plotting the amplitude of the first component of each of the AERs evoked from that site, against the amplitude of the "probe" stimulus that evoked the AER.

We also recorded the multi-unit responses through the electrodes sites in the cat's cochlear nucleus. Curiously, while responses to environmental sounds (speech, white noise, pure acoustic tones) were recorded from most of the electrode sites, compound action potentials could be evoked in the contralateral inferior colliculus only from Sites 1,5,9 and 13 (on the caudal-medial shank), and the threshold of the evoked response from the shallowest sites (site #1) was high. This may be due in part to the placement of the recording electrode at the extreme rostral-medial pole of the contralateral inferior colliculus, but it also may reflect some injury to the tissue in the immediate vicinity of the electrode sites. During the surgery, this array was inserted twice. After the first insertion the array was judged to be too medial on the surface of the CN. It was removed and reinserted, and this may have inflicted some tissue injury.

As shown in Figure 1-4, the response growth functions for the three deepest sites on the caudal-medial shank was quite stable between the 75th and 352nd day after implantation. During the first 75 days, the slopes and thresholds of the RGFs were quite variable (Quarterly Report #9). This may reflect a small amount of movement of the probe (and the stimulating sites) through the tissue. The RGFs from sites that are separated by only 0.3 to 0.4 mm induce markedly different RGFs (Figure 4D).

It is noteworthy that the thresholds and slopes of the RGFs from each site was quite stable over the interval between 75 and 352 days after implantation. On day 114, the sites 5 and 9 were pulsed for 7 hours using a stimulation regimen in which the pulse amplitude reached 48 µA (QPR #9). After this regimen, the electrical excitability of the sites was depressed, but eventually recovered completely, suggesting that there was no stimulation-induced neural injury.

In the next quarter, we will sacrifice this animal for histologic evaluation of the tissue surrounding the shanks of this long-term implant.

CN146.

The microstimulating array was implanted into cat CN146 on March 9, 2004. As in cat CN144, one of the shanks (the rostral- medial shank in Figure 1-5A) was fractured during the assembly and cleaning process. Figure 1-5B,1-5D show the response growth function recorded 43 days after array implantation. For all of the arrays, the slope of the RGFs from the shallow electrode sites (Sites 1,2,4) is low. However, in this case the threshold of the evoked responses from these shallow sites also is elevated, and this may be due to injury to the tissue around the shallow sites, and close to the dorsolateral surface of the nucleus. In this animal, some damage may have been inflicted by what in retrospect was an ill-advised modification of our implant procedure that was intended to seat the array superstructure firmly onto the surface of the CN. The threshold of the RGFs from the shallow sites increased markedly and their slopes decreased markedly during the first hour after array implantation, a course of events that we have not observed previously. However, the thresholds of the RGFs from all of the other sites were in the range of 6 to 11 µA, indicating little or no damage in the surrounding tissue.

In the next quarter, just before the cat is sacrificed for histologic evaluation of the electrode sites, the response from each of the electrode sites in the cochlear nucleus will be mapped as a function of depth in the contralateral inferior colliculus.

CN147

The array was implanted into the cochlear nucleus on April 9, 2004, using the experience gained from the previous animals. The changes in the response growth functions suggest how the sites migrate through the cochlear nucleus during the first two weeks after implantation. Figure 1-6B,1-6E show the response growth functions from 15 of the electrode sites (the connection to site #2 is open-circuited), taken 1 day after the implant surgery. With the exception of site 13 (the deepest site on the caudal medial shank), the thresholds of the RGFs from all of the sites is 6 to 11 µA, and this suggest that the neurons very close to the sites are intact and functional. Site 13 is electrically intact and we conjecture that the tip of the caudal-medial shank, and site 13, had passed completely through the posteroventral cochlear nucleus.

Figure 1-7A,1-7D show the RGFs take 14 days after implantation of the array, and plotted on the same ordinate scales as the corresponding graphs in Figure 1-6. The slope of the RGF from the shallowest sites has increased, and in most cases the threshold of the response from these sites has decreased. At the same time, the slope of the deepest sites on the caudal-lateral and caudal medial sites has decreased and the threshold increased, suggesting that they are being pushed completely through the posteroventral nucleus.

Late in the final quarter of this contract, after the RGFs have stabilized, the cat will undergo a regimen of prolonged stimulation in order to evaluate the histologic and physiologic consequences of pulsing many of the closely-adjacent electrode sites on the silicon shanks. All 12 sites on three of the shanks will be pulsed. The regimen will use stimulus parameters that we presume will not cause tissue damage, based on our experience with the discrete iridium microelectrodes. Then, just before the cat is sacrificed for histologic evaluation of the electrode sites, the response from each of the electrode sites in the cochlear nucleus will be mapped as a function of depth in the contralateral inferior colliculus.

DISCUSSION

Our experience with cats CN144 and CN146 exemplifies two persisting problems with the silicon probes. The probes are very fragile and are prone to be damaged during the many steps of the fabrication process by which they are incorporated into the arrays. We have made extensive revisions in our fabrication and cleaning procedures, in an effort to reduce the loss of the valuable probes late in the fabrication process .

While the threshold of the RGFs evoked from these electrodes are generally similar to those that we have recorded previously with the chronically implanted discrete iridium electrodes, there has been a tendency for the thresholds of the RGFs from the shallowest sites to be slightly higher, and the slopes of the RGFs to be lower, that those evoked from the deeper sites. While this difference may be due to the particular location of the shallow sites in the ventral cochlea nucleus, it also suggest that the broad, thin silicon shanks may induce somewhat more injury in the surrounding tissue than the cylindrical discrete iridium electrodes, particularly around the shallow electrode sites close to the array superstructure, where the (tapered) shanks are widest. We have requested a reduction in the width of the shanks in our next batch of probes from the CNCT. Also, we have proposed to modify the array so that most of the stabilization of the array in the tissue is provided by 3 iridium pins, each 75 µm in diameter that will form a cage around the fragile silicon shanks. This should allow the use of narrower silicon shanks, while also reducing stain on the shanks during insertion of the array and in the surrounding tissue during the array's residence in the brain.

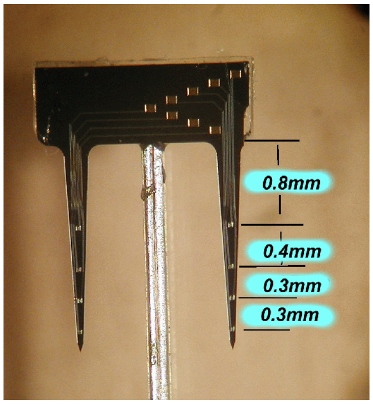
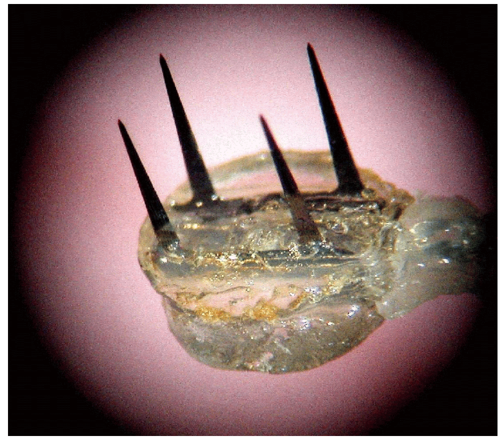


Figure 1-1A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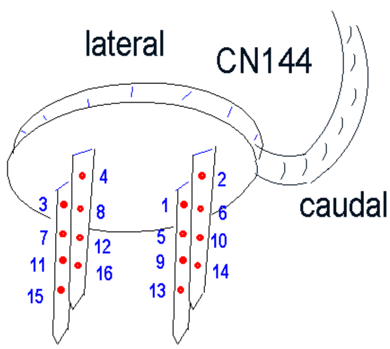
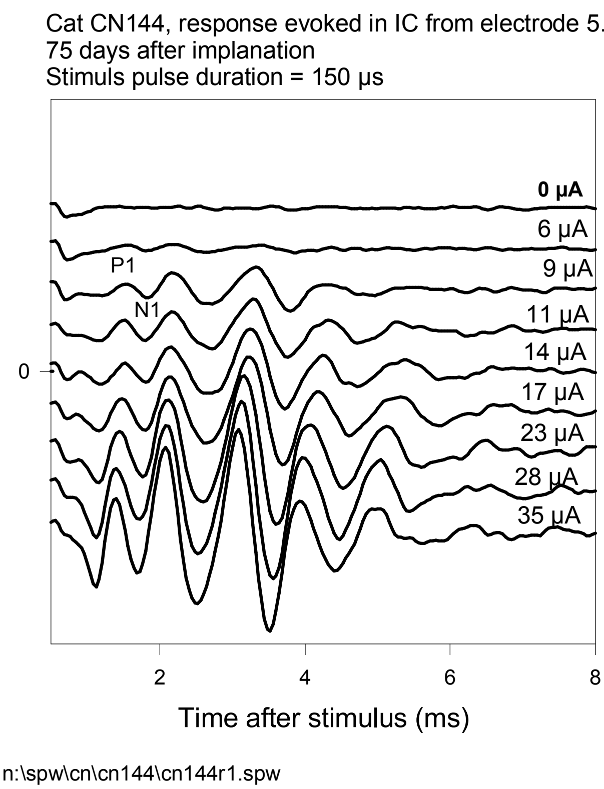


Figure 1-2



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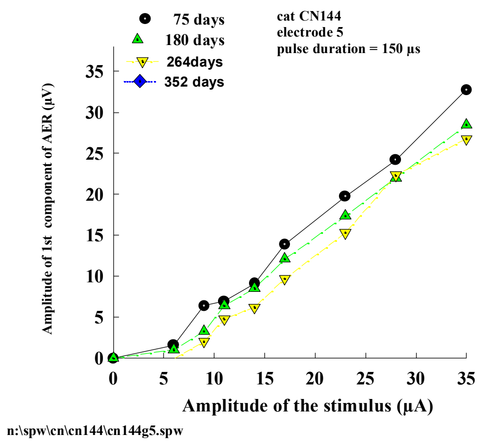

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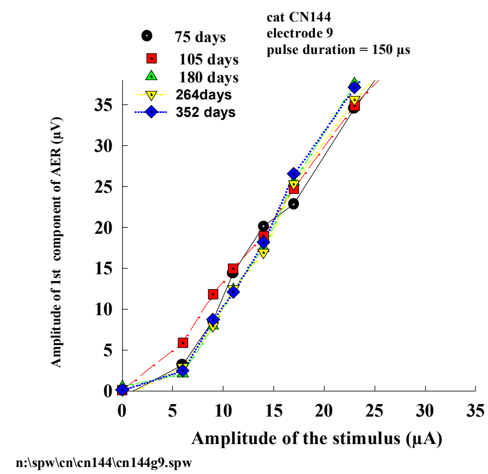

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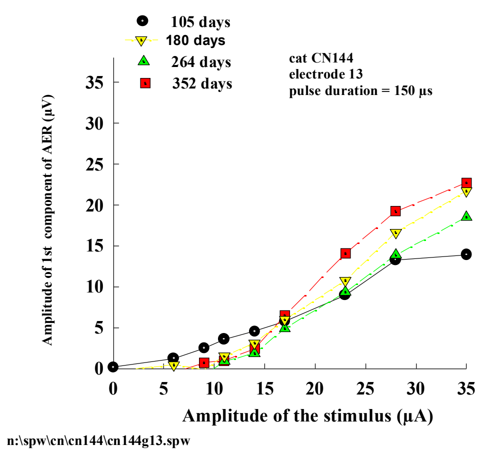


Figure 1-4C

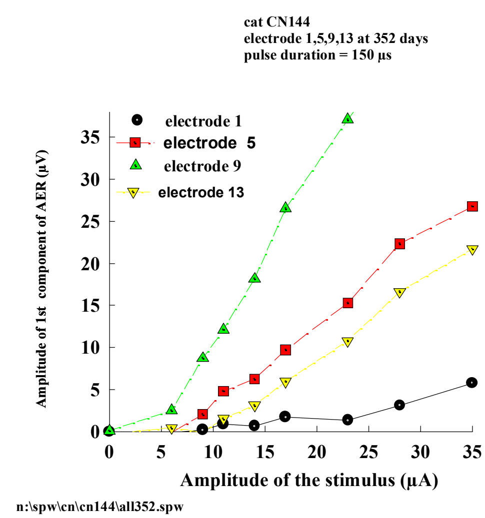


Figure 1-4D

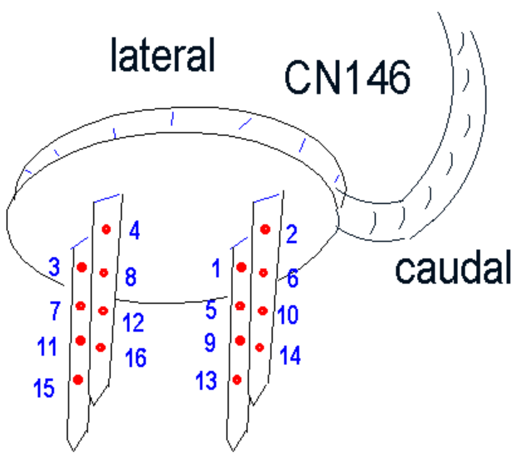


Figure 1-5A

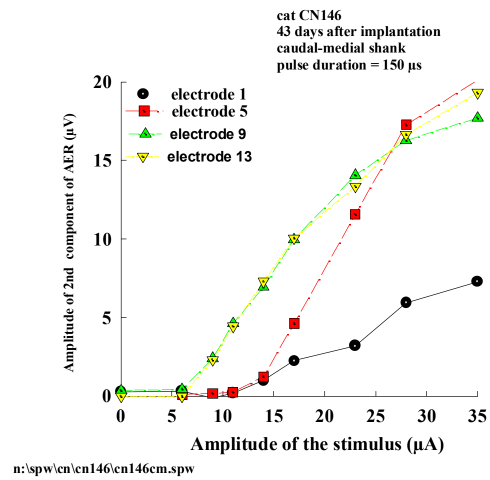


Figure 1-5B

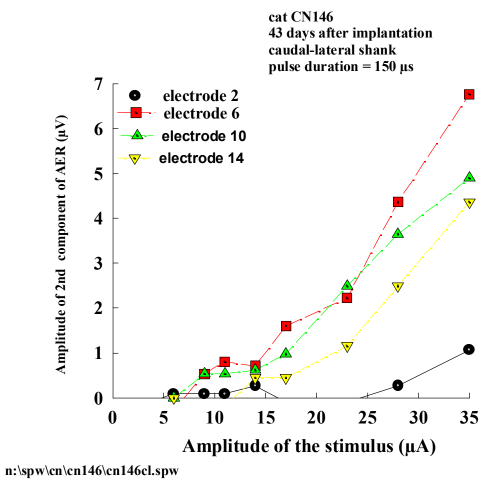


Figure 1-5C

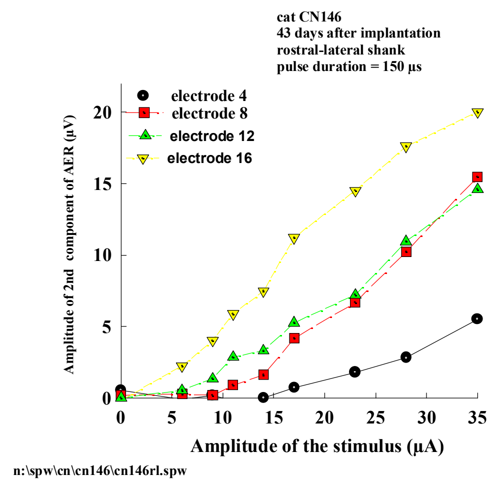


Figure 1-5D

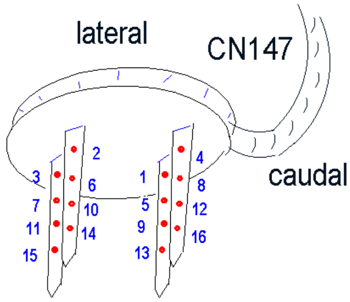


Figure 1-6A

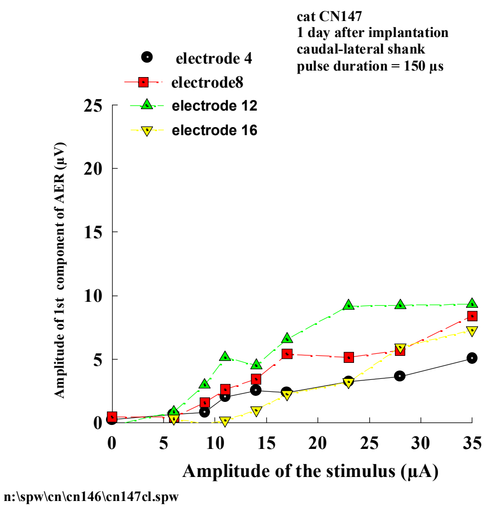
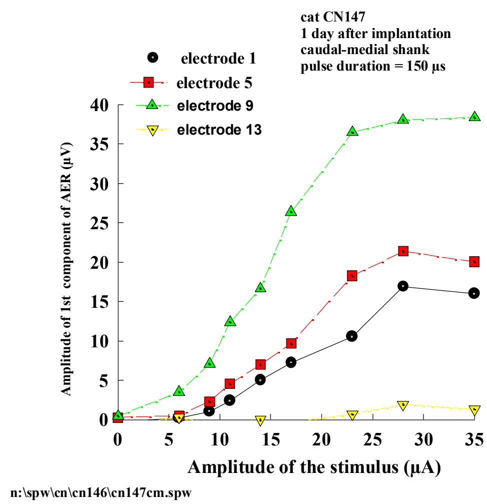


Figure 1-6B



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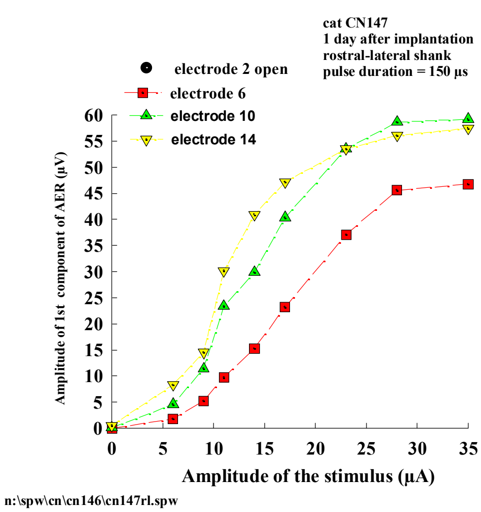
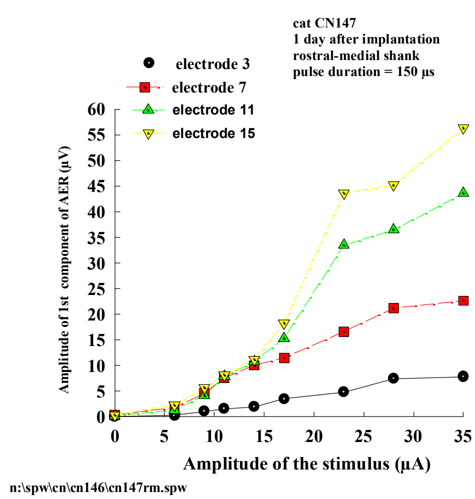


Figure 1-6D



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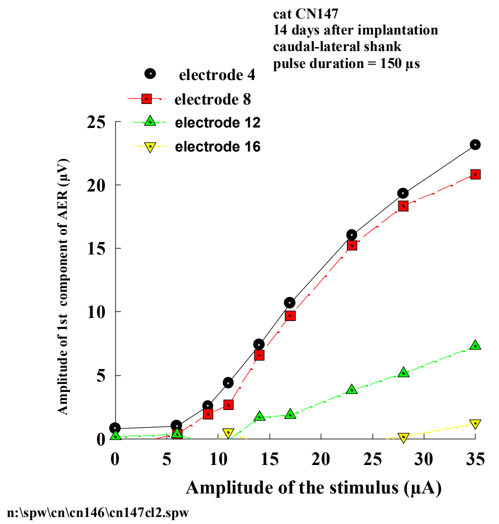


Figure 1-7A

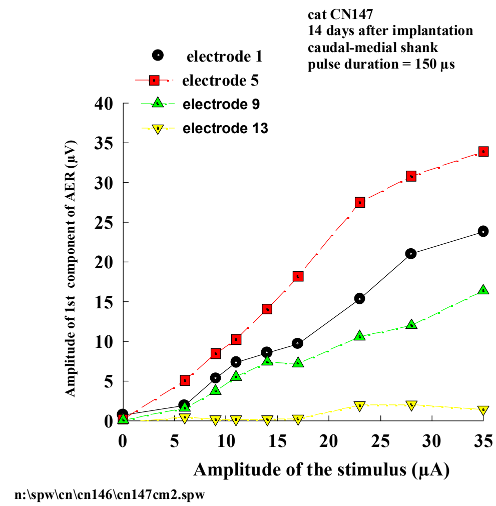
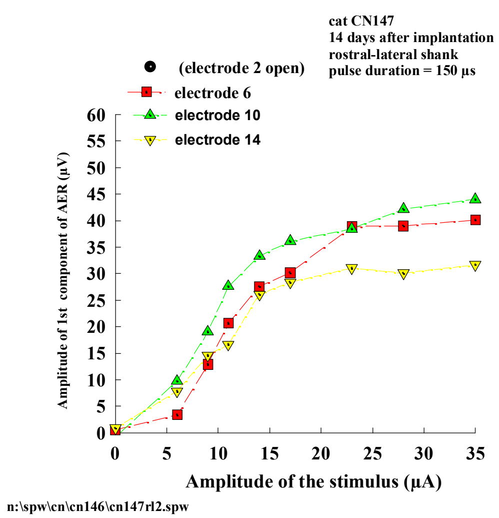


Figure 1-7B



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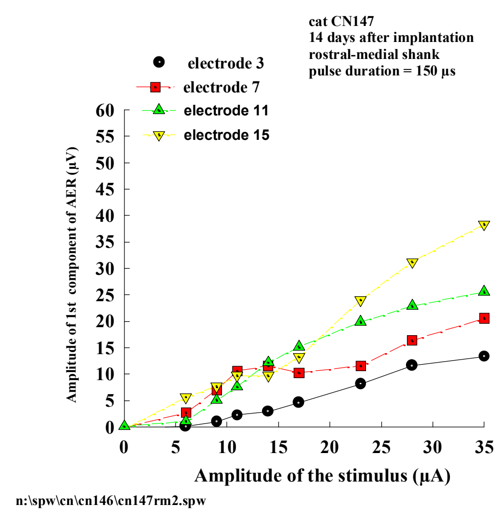

Figure 1-7D

2: Results from patients with penetrating cochlear nucleus arrays

Four patients have received the penetrating auditory brainstem implant array (PABI) as of April 2004. The implant in PABI patient #4 has not yet been activated and we present here the results from the first three patients. PABI#1 received auditory percepts on only one of the penetrating microelectrode. The procedure for targeting the cochlear nucleus during the implant surgery was subsequently changed and PABI#2 received auditory percepts on 7/8 penetrating electrodes and PABI#3 received auditory percepts on 4/8 penetrating electrodes. No adverse effects have been observed either during or after surgery or during laboratory testing.

PABI #1

PABI patient #1 is a 20 year old woman with Type 2 Neurofibromatosis (NF2) who received her implant following tumor removal on 24 July 2003. Her initial activation and mapping occurred on September 8-12, 2003 and those results were described in Progress report #9 (July-August-September 2003) from this contract. PABI#1 returned for testing December 2-5, 2003 and March 2-5, 2004. Figure 2-1 shows threshold and comfortable loudness levels for each electrode that produced no side effects for the three testing sessions. Of particular interest was whether threshold levels on the penetrating electrodes would change over time. Figure 2-1 shows threshold levels and comfort levels connected by a vertical line for each electrode. Three pairs of points are plotted for each electrode, with successive measures taken at three month intervals offset to the right of the original measures. It can be seen that some electrodes showed a slight increase in threshold and comfort levels, some electrodes showed a decrease, and some showed no change over time. The most striking difference in the repeated measures is the large reduction in the comfort level for electrodes 12 (surface) and 16 (penetrating) between the first and second test period. There was no apparent difference in the degree of increase over time between the penetrating and surface electrodes. A review of threshold stability on previous ABI patients with surface electrodes shows that increases in threshold of this magnitude over time are common, presumably due to increasing fibrous sheath thickness around the surface electrode array. The fact that the penetrating and surface electrodes show similar increases over time indicates that the increase is not representing damage specific to the penetrating electrodes.

Additional measures were made of forward masking, gap detection, intensity discrimination, and temporal modulation detection in PABI#1. The additional results were similar to the results presented in quarterly progress report #9, which show poor resolution in both amplitude and temporal domains compared to normal hearing, cochlear implants, and even previous surface electrode ABIs. Measures of electrode interaction were collected but the data are not yet analyzed. Electrode interaction measures will be presented in a future progress report.

PABI #2

PABI#2 is a 42-year-old woman who had her first vestibular schwannoma (VS) removed in 1988. At that time she received a cochlear implant (CI) in the contralateral ear, which provided useful hearing, presumably because the tumor in that ear had affected cochlear blood supply without damaging the VIII nerve. She continued to use the cochlear implant for more than 12 years, achieving performance levels that were on the poor end of performance for a cochlear implant. She was able to achieve limited telephone use by using a simple code and question-answer strategies with relatives and friends. CI use deteriorated from 2000 to 2003 due to tumor growth and she has her second-side VS removed and received a PABI on 11 November 2003. Her initial stimulation occurred on January 12, 2004 and a follow-up visit occurred April 13, 2004. Data are presented from these two test periods.

Figure 2-2 presents threshold (T) and maximum comfort levels (C) from the two test sessions. She received auditory sensations on all 14 surface electrodes and on 7/8 penetrating electrodes. Penetrating electrodes are indicated in Figure 2-2 by filled symbols. As in Figure 2-1, T and C levels from a given session are connected by a line, and the repeat measures from the second session are plotted with a slight offset to the right of the original measures. It can be seen that thresholds for penetrating electrodes were considerably lower in charge than surface electrodes, with thresholds near or below 1 nC/phase. In general, T and C levels appeared to be stable over the three months between the first and sessions test sessions.

Figure 2-3 presents initial speech processor test results for consonant, vowel, and sentence materials. Three speech processors were fit: one with seven surface electrodes (S7), one with five penetrating electrodes (P5) and one combination processor with seven surface and five penetrating electrodes (S7+P5). Not all available electrodes were used in the maps. Some electrodes that were similar in pitch to other electrodes were not used. In addition, some surface electrodes produced mild non-auditory sensations at high loudness levels and were not used. Two of the 7 penetrating electrodes only produced soft auditory sensations even at the maximum charge level (3 nC) and so were not included in the map. PABI#2 received minimal experience with each map prior to testing. Note that the combined surface and penetrating electrode map provided better speech recognition performance for all speech test materials. The levels of performance observed are comparable to those achieved by the better patients with surface electrode ABIs even after several years of experience. We have never observed 14% correct on open-set sentence recognition by any previous ABI patient at the initial test session. It is not clear at this point if this performance can be attributed to the penetrating electrodes per se, or to the many years of prior experience with a cochlear implant. Subjectively, she described the S7 processor as being muffled and indistinct, the P5 processor as being mechanical and that speech sounded like a circus calliope, and that the combined map had a nice quality and sounded similar to her previous cochlear implant.

Electrode discrimination was measured to assess the relative pitch sensations of the surface and penetrating electrodes used in the combined map. Each electrode was stimulated at a level to produce a comfortable loudness. Electrodes were played sequentially to ensure that they were all equally loud, and small adjustments were made to some electrode stimulation levels to equalize the loudness across electrodes. Once the electrodes were balanced for loudness the patient was presented with all possible combination of electrodes, presented two at a time (two alternative forced choice) and she was instructed to indicate which electrode had a higher pitch. Each electrode combination 12x12 = 144 combinations) was presented 15 times. Table 1 and Figure 2-4 show the results of these comparisons. A discriminability index was computed from this matrix and the cumulative d' across electrodes is plotted in Figure 2-4, compared with the frequency assignment to those electrodes. A straight line would indicate that the electrodes were equally discriminable and that the frequency assignments were also equally partitioned across electrodes. Horizontal segments indicate that electrodes are poorly discriminated although they are receiving successively higher frequency allocations.

Gap detection was measured as an indicator of temporal processing ability. Two markers were presented, each 200 ms in duration. In a standard interval the two markers were presented with no gap separating them, resulting in a continuous 400-ms stimulus. In the other interval of a 2AFC task the two marker bursts were separated by a short silent interval. The patient was instructed to select the interval that contained the gap. And the gap was then adjusted adaptively to converge on the gap duration that would result in 79% correct (3-down, 1-up). The patient was asked to rate the loudness of the stimuli on a scale from 0-10 arbitrary units. The results are presented in Figure 2-5 as a function of judged loudness. The top panel of Figure 2-5 shows gap detection results from previous ABI patients with surface electrodes, and comparison data from 38 cochlear implant subjects. The lower panel shows gap detection thresholds from PABI#2 for four electrodes: two penetrating electrodes and two surface electrodes. The electrodes were selected to be the highest and lowest pitch of each electrode type. Gap detection decreased with stimulus loudness, reaching thresholds of 2-15 ms for comfortably loud sounds. These values are comparable to gap thresholds for cochlear implant, ABI patients with the surface array, and listeners with normal hearing, implying that PABI#2 was similar in temporal processing ability compared to other listeners. PABI#1, whose gap detection thresholds were reported in Progress Report #9, was significantly poorer at gap detection than PABI#2.

Intensity Discrimination was measured for two penetrating electrodes in PABI#2 and the results are presented in Figure 2-6. Each curve shows Intensity difference limens (DLs) were greater than 20% of the standard at soft loudness levels and decreased to 10-15% at loud levels. Such DLs imply that PABI#2 would have 5-8 discriminable levels of sound intensity within her dynamic range. Previous work with cochlear implants (Loizou et al., 2000) have shown that 8 levels of amplitude are sufficient for good speech recognition.

PABI#3

PABI#3 is a 20-year-old male with NF2. He had two large tumors but normal hearing in both ears at the time of PABI surgery. Following surgical placement of the PABI he had prosthetic hearing in one ear and normal acoustic hearing in the other ear. The duration of his remaining acoustic hearing will depend on the rate of tumor growth, the decline of the remaining hearing due to tumor growth, and the potential risk to the facial nerve. Until the hearing deteriorates or the tumor requires surgery, we can compare electrical stimulation of the surface and penetrating PABI electrodes with acoustic stimulation in the other ear. This is a unique opportunity to directly compare acoustic and electrical hearing and this window of opportunity may be short duration due to the expected tumor growth.

Surgical placement of the surface and penetrating electrodes in PABI#3 proceeded uneventfully (January 21, 2004). Electrically-evoked responses were recorded from the surface array during surgery but no response could be obtained from the penetrating electrodes. No complications were observed upon electrode implantation and post-operative recovery was normal and uneventful. PABI#3 returned for initial testing on March 16-19, 2004.

Threshold and maximum comfortable levels are presented in Figure 2-7 for PABI#3. He received auditory sensations on 7 surface electrodes and on 5/8 penetrating electrodes. Penetrating electrodes are indicated in Figure 2-7 by filled symbols. As in Figure 2-1, threshold (T) and maximum comfort (C) levels from a given session are connected by a line. It can be seen that thresholds for penetrating electrodes were considerably lower in charge than surface electrodes, with thresholds near or below 1 nC/phase. Only 4 of the 5 penetrating electrodes could be used in a speech processor map because of insufficient loudness growth on one electrode.

Electrical stimulation was compared with acoustic stimulation in a 2alternative forced-choice discrimination task. Acoustic and electrical stimuli were balanced in loudness at a comfortable loudness level. A range of acoustic frequencies were selected that were close to the perceived pitch of each electrode, based on preliminary comparisons. For each electrode PABI#3 listened to 20 comparisons of the electrode and an acoustic frequency selected at random from the appropriate range. Figure 2-8 presents results of such comparisons for the 12 electrodes used in a speech processor. Sigmoidal functions were fit to the discrimination data with two parameters: the slope, and the frequency at which the function equaled 50%. This frequency is the matching frequency for that electrode, i.e. the acoustic frequency that was discriminable from the electrode pitch only at a chance level. Figure 2-9 plots the acoustic matching frequency for each electrode against the mid-point in the acoustic frequency band that was assigned to that electrode in the speech processor. Because 7 of the 12 electrodes had a similar pitch, between 271 and 321 Hz, the ordering of electrodes in the processor map for frequencies below 800 Hz was slightly nonmonotonic. Note that in this patient, the penetrating electrodes did not elicit the range of pitch percepts seen in PABI #2, and in particular, they did not elicit pitch percepts in the range that is critical for speech perceptions. Also, all of the functional penetrating electrodes were located on the anterior part of the array. This patient illustrates the need for a more reliable means of targeting the penetrating array into the center of the ventral cochlear nucleus, during the implant surgery. Dr. McCreery has been working with Dr. Waring to develop a hand-held stimulating probe that will allow the surgeon to more precisely locate the center of the ventral cochlear nucleus prior to implanting the penetrating array.

Speech recognition results are presented in Figure 2-10 for three speech processor maps: a surface electrode map with 7 electrodes (S7), a penetrating electrode map with 4 electrodes (P4), and a combined map (S7+P4). For consonants the combined map produced noticeably better performance than surface or penetrating maps, but this superior performance was not observed in vowel or sentence recognition. However, the level of performance was so low on all test materials that the pattern of performance differences were probably not significant. PABI#3 was instructed to try all three maps in different listening situations, but will not be dependent on them because he still has normal hearing in the contralateral ear.

PABI#4

PABI patient #4 is a woman in her 40's with NF2. She received the PABI on March 22, 2004. The surgery was uneventful: anatomical landmarks were clearly visible following tumor removal and both surface and penetrating electrode arrays were placed in the desired anatomical locations. No difficulties were encountered with the placement of the penetrating electrode array during surgery or in the post-operative recovery process. The patient recovered from surgery normally and was discharged from the hospital a few days post-op. PABI#4 is scheduled for initial stimulation and processor fitting on May 4-7, 2004.

Intra-operative electrically-evoked auditory brainstem responses (EABRs) were obtained during stimulation with the surface array but not from the penetrating array. Our experience in animal experiments leads us to believe that the penetrating electrodes activate too small a number (or volume) of neurons to produce a recordable EABR at the scalp. We will continue to explore intra-operative and post-operative techniques to record an EABR from penetrating electrodes. Also, we are investigating designs for hand-held stimulating probes that will allow the surgeon to more precisely locate the center of the cochlear nucleus before the penetrating array is implanted.

References

Loizou, P.C., Dorman, M., Poroy, O., and Spahr, T. (2000). Speech recognition by normal-hearing and cochlear implant listeners as a function of intensity resolution, J. Acoust. Soc. Am., 108(5), 2377-2387.

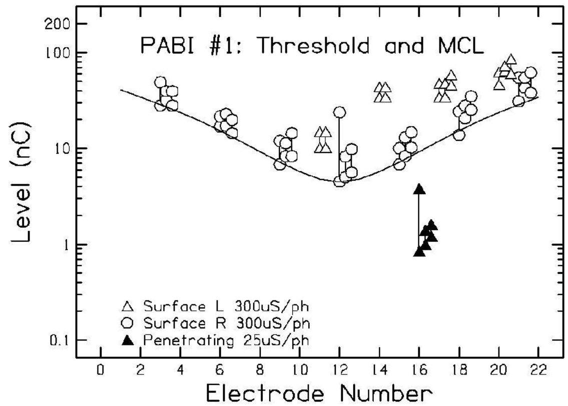

Figure 2-1

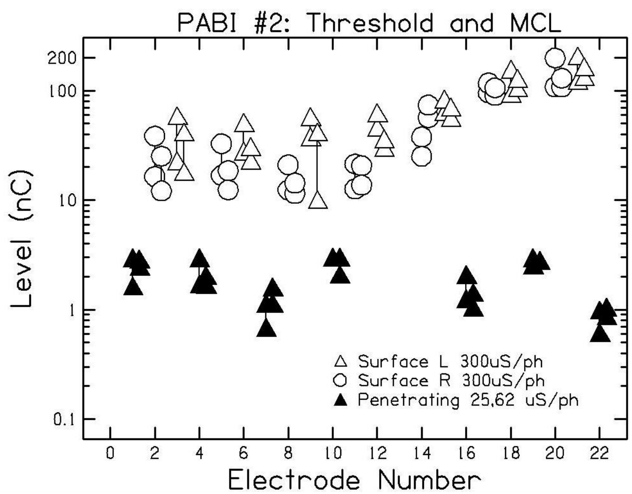

Figure 2-2

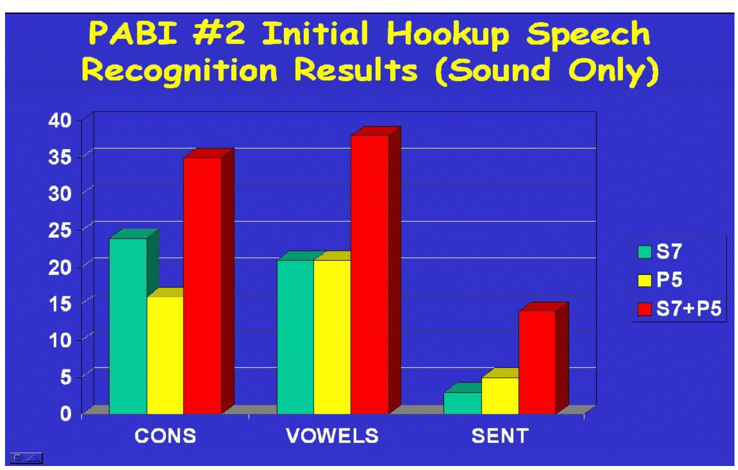

Figure 2-3

TABLE 1: Pitch comparison matrix for PABI#2. Entries in table are the percentage of times the electrode on left was judged to be higher in pitch than the electrode listed at the top of the column.
The two electrodes represented by each cell were presented 15 times.
Penetrating electrodes are indicated by bold entries.

				Compariso n										
Elec	us/ph	rate	uAmp	16	6	22	4	21	17	18	8	1	12	7
16	25	250	35.13	0.40	0.60	0.87	0.73	0.73	0.87	0.80	1.00	1.00	1.00	1.00
6	300	250	40.23	0.47	0.53	0.93	0.80	0.87	0.73	0.80	1.00	1.00	1.00	1.00
22	25	250	32.49	0.20	0.33	0.53	0.47	0.60	0.60	0.73	0.93	1.00	1.00	1.00
4	25	250	38.12	0.33	0.20	0.33	0.53	0.33	0.67	0.47	0.93	0.93	0.87	0.93
21	300	250	54.83	0.13	0.33	0.13	0.40	0.67	0.80	0.27	0.80	1.00	1.00	1.00
17	300	250	52.72	0.13	0.07	0.07	0.53	0.47	0.67	0.47	0.87	0.87	0.87	1.00
18	300	250	52.72	0.07	0.20	0.53	0.40	0.40	0.47	0.27	0.73	0.93	1.00	1.00
8	300	250	33.77	0.00	0.00	0.07	0.33	0.20	0.27	0.27	0.40	0.67	0.27	0.87
1	25	250	41.29	0.00	0.00	0.00	0.27	0.13	0.13	0.20	0.20	0.47	0.27	0.73
15	300	250	47.44	0.00	0.00	0.07	0.07	0.20	0.20	0.20	0.47	0.80	0.53	0.93
12	300	250	42.52	0.00	0.00	0.27	0.00	0.07	0.07	0.13	0.60	0.73	0.27	1.00
7	25	250	28.27	0.00	0.00	0.00	0.13	0.07	0.00	0.00	0.20	0.33	0.13	0.47

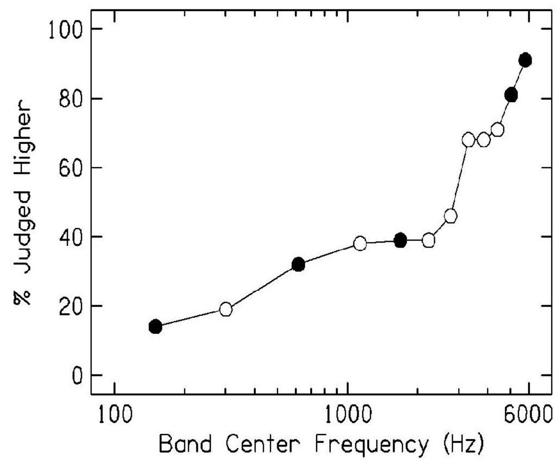

Figure 2-4

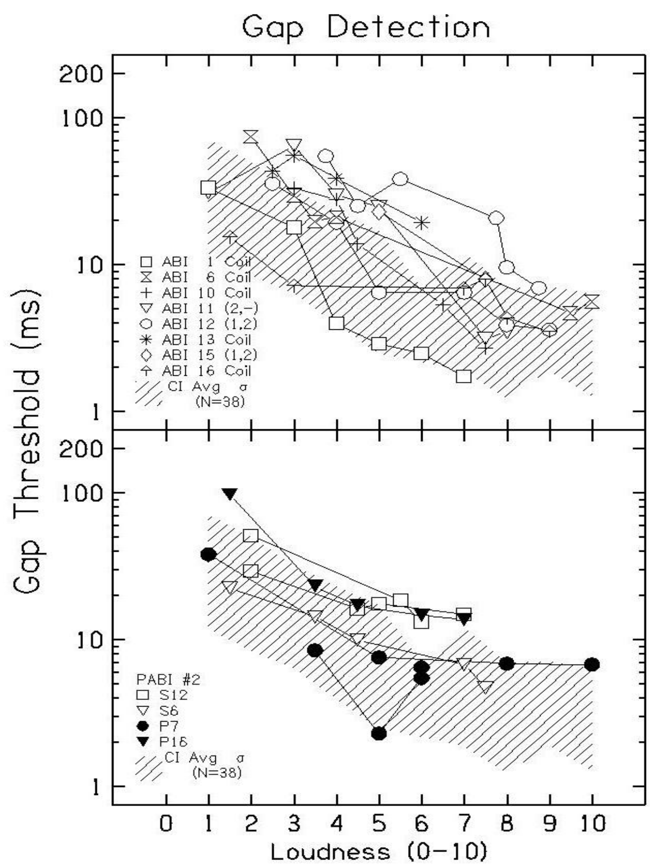

Figure 2-5

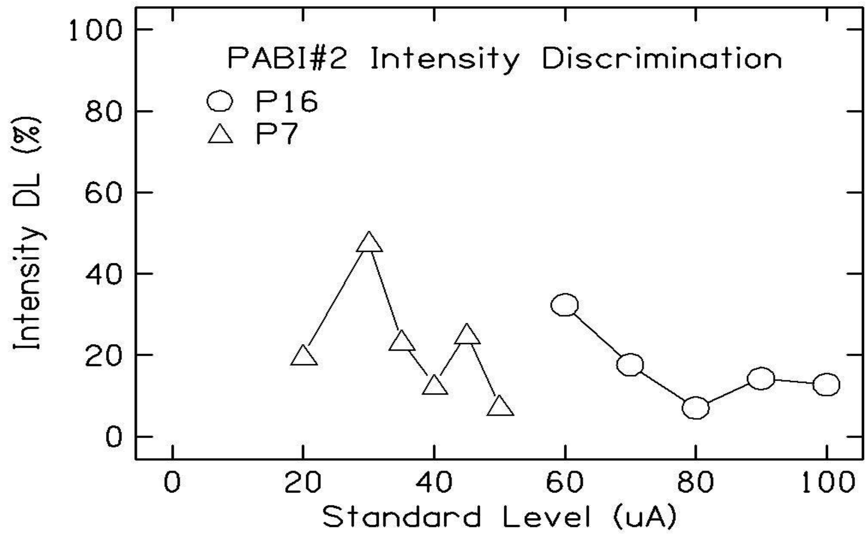
PABI#2 Intensity Discrimination
P16
P7
Intensity DL (%)
Standard Level (uA)
0
20
40
60
80
100
0
20
40
60
80
100

Figure 2-6

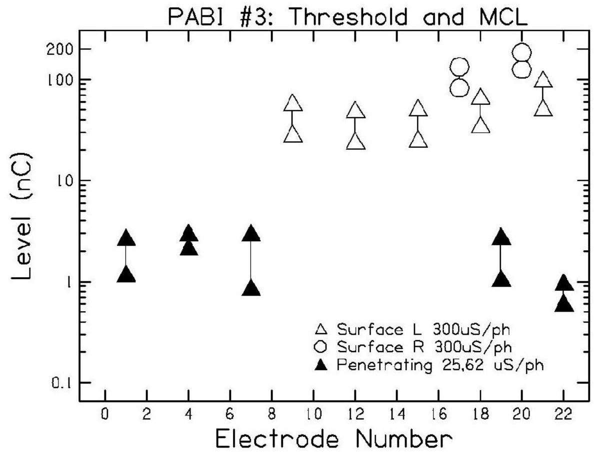

Figure 2-7

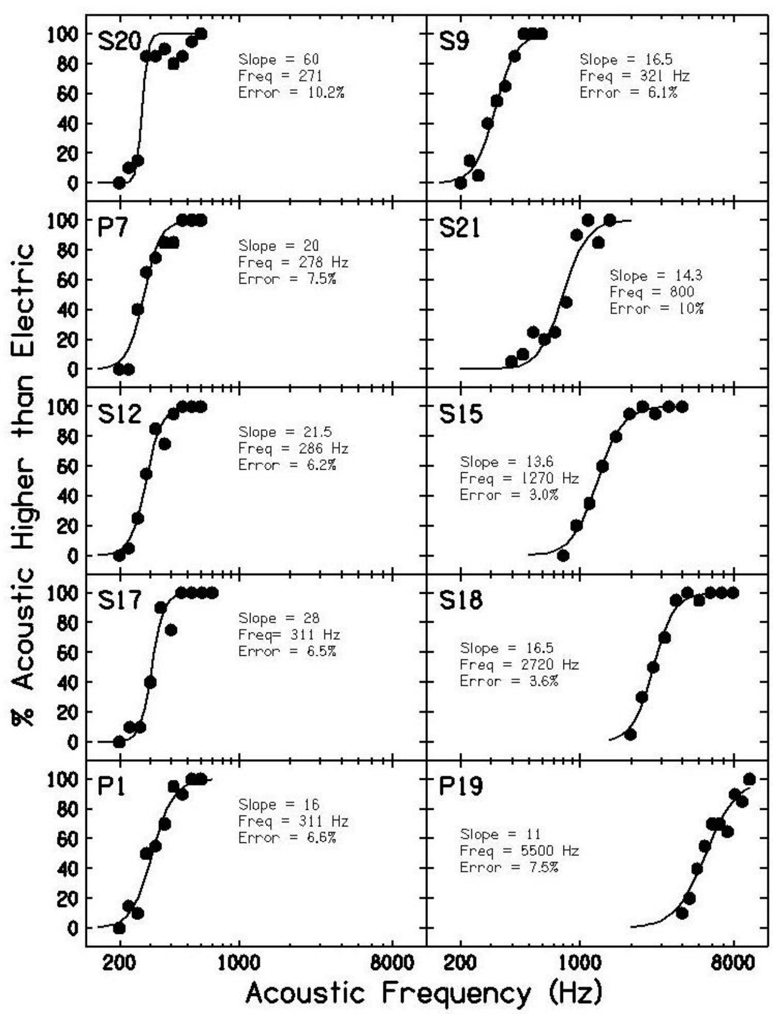

Figure 2-8

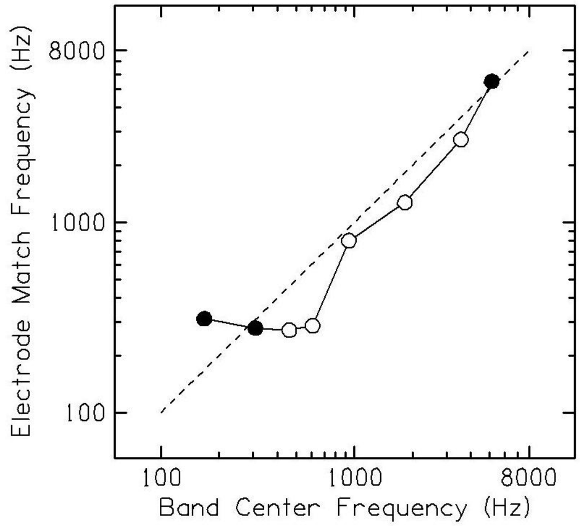

Figure 2-9

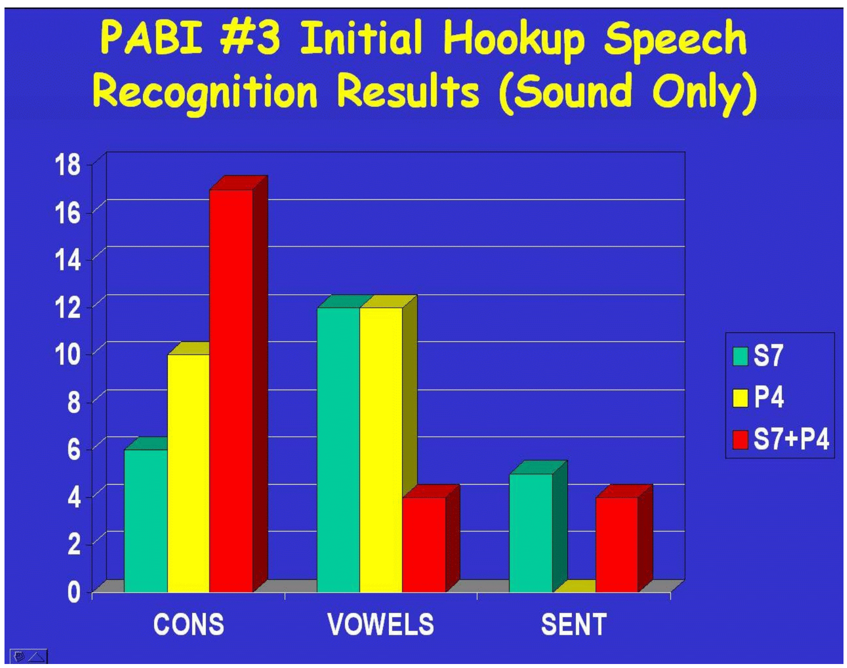

Figure2-10