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Eighth Quarterly Progress Report

February 1 through April 30, 1991

NIH Contract N01-DC-9-2401

Speech Processors for Auditory Prostheses

Prepared by

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CONTENTS

I. Introduction

The purpose of this project is to design and evaluate speech processors for implantable auditory prostheses. Ideally, the processors will extract (or preserve) from speech those parameters that are essential for intelligibility and then appropriately encode these parameters for electrical stimulation of the auditory nerve or central auditory structures. Work in the present quarter included the following:

1. Continued work on, and refinement of, the prototype for a portable processor, based on the Motorola DSP 56001 (see *QPR 7* for details on the initial design of this system).
2. Implementation of a new option for our consonant identification test, that will allow use of all 24 consonants on the Iowa laser videodisc (compared to our historic use of 16 consonants).
3. Continued development of speech processor software for the DSP 56001 system.
4. Continued development of automated testing procedures for functional evaluations of *continuous interleaved sampling* (CIS) processor implementations.
5. Continued development of isolated interfaces between a controlling PC computer and the DSP 56001 unit, for safe use of the combined system in the laboratory.
6. Continued development of a shell program that will allow high-level specification of parameters for CIS processors, and subsequent incorporation of those parameters, in a compiled program for execution on the DSP 56001 platform.
7. Continued studies with patient UP3, primarily to evaluate the CIS strategy with a patient who has the UCSF/Storz electrode array and a percutaneous connector.
8. Evaluation of results from past within-subjects comparisons of the *compressed analog* (CA) and *interleaved pulses* (IP) processors, and of the CA and CIS processors, to assess the importance of patient and processor variables in determining outcomes with cochlear implants.
9. Preparation for the *1991 Conference on Implantable Auditory Prostheses*, including preparation of two invited lectures (Wilson and Finley).
10. Presentation of project results in two papers at the *1991 Midwinter Meeting of the Association for Research in Otolaryngology*, held in St. Petersburg, FL, February 3-7 (Finley and Wilson).
11. Continued preparation of manuscripts for publication.
12. Revision of manuscripts under review.

In this report we present our evaluation of results from past comparisons of the CA and IP processors and the CA and CIS processors (point 8 above). As described in detail below, the purpose of this evaluation was to assess independently the importance of patient variables and processor variables in determining outcomes with multichannel cochlear implants. The principal findings show that (a) subject performances with one processing strategy are significantly correlated with those of alternative strategies while (b) different strategies may produce quite different outcomes across subjects.

Work related to points 1-7 above will be presented in future reports.

II. Importance of Patient and Processor Variables in Determining Outcomes with Cochlear Implants

Great variability in outcomes across patients is a common finding in studies of cochlear prosthesis systems. While any of several prosthesis systems can support relatively high levels of speech recognition for some patients, other patients have poor outcomes with the same systems. Factors contributing to this variability may include differences among patients in the survival of neural elements in the implanted cochlea, integrity of the central auditory pathways, or cognitive and language skills.

Such variability obviously complicates the task of comparing different prosthesis systems. For group comparisons, where different populations of subjects are used to evaluate each prosthesis system, large variability means that large numbers of subjects may be required to detect differences among systems. Most testing with cochlear implants has involved such group comparisons, and results from those tests do not clearly differentiate effects of patient variables from effects of system variables.

In this report we review studies we have conducted using within-subjects comparisons. This approach allows separation of patient and system variables, by letting each subject serve as his or her own control in comparisons of prosthesis systems.

Method

Processing Strategies

The studies involved comparisons of different speech processing strategies for multichannel cochlear implants. In one group of eight subjects we compared the *compressed analog* (CA) and *interleaved pulses* (IP) strategies, and in another group of eight subjects we compared the CA and *continuous interleaved sampling* (CIS) strategies.

The strategies and procedures to evaluate them have been described in other reports (Wilson et al., 1989, 1990a, 1990b, 1991a, 1991b). Briefly, the CA processor first compresses the wide dynamic range of input speech signals into the narrow dynamic range of electrically evoked hearing. The compressed signal then is filtered into frequency bands for presentation to each of three or four intracochlear electrodes or electrode pairs. The analog waveforms at the outputs of the bandpass filters are applied simultaneously to their respective electrodes.

The IP processor uses nonsimultaneous interleaved pulses as stimuli. The energy in each frequency band of the input signal is represented by the amplitude of the pulses delivered to the associated electrode or electrode pair. Distinctions between voiced and unvoiced segments of speech are represented by the timing of sequences of stimulation across the electrode array. During voiced segments stimulation sequences are presented at a rate equal to the estimated fundamental frequency of the speech sound, while during unvoiced segments stimulation sequences are presented either at a jittered or fixed higher rate.

The CIS processor also uses nonsimultaneous interleaved pulses as stimuli, but presents the pulses at rates higher than those used in the IP processor. In addition, the CIS processor makes no distinctions between voiced and unvoiced intervals.

As discussed in detail elsewhere (Wilson et al., 1991a, 1991b), the CA, IP and CIS strategies provide fundamentally different representations of speech signals at the electrode array. The CA strategy presents the greatest amount of temporal information through its use of analog stimuli. However, most implant patients cannot perceive changes in the temporal variations of a stimulus above a "pitch saturation limit" of about 400 Hz (e.g., Shannon, 1983). Also, the simultaneous presentation of stimuli in the CA strategy may produce significant interactions among channels through vector summation of the electric fields from each electrode (e.g., White et al., 1984). The IP and CIS strategies eliminate such interactions through the use of nonsimultaneous stimuli. In addition, the CIS strategy uses relatively high rates of pulsatile stimulation so that rapid variations in speech can be tracked by pulse amplitude variations.

Subjects

The CA and IP strategies were compared in tests with six subjects implanted with the UCSF/Storz electrode array and two subjects implanted with the Ineraid electrode array (Wilson et al., 1991b). Stimuli were delivered through a transcutaneous transmission system (TTS) for the USCF/Storz subjects and through a percutaneous connector for the Ineraid subjects. The percutaneous connector allowed direct electrical access to all six intracochlear electrodes for the Ineraid subjects. In contrast, the TTS of the UCSF/Storz system imposed various limitations on the fitting of IP processors, including a maximum of four channels and inadequate voltage compliance for stimulation with short duration pulses.

Studies to compare the CA and CIS strategies were conducted with eight subjects implanted with the Ineraid electrode array. Seven of these subjects had excellent performance with their clinical CA processors, and were selected to be representative of the best patients using this or any other implant system (Wilson et al., 1991a). The remaining Ineraid subject had relatively poor performance with his clinical processor. This and one other Ineraid subject also participated in the studies to compare the CA and IP strategies. The remaining UCSF/Storz subjects participating in those studies had a wide range of performances with their clinical CA processors.

In each set of comparisons the clinical processor was used for evaluation of the CA strategy while a laboratory based processor was used for evaluation of the IP or CIS strategy. Each subject was studied for a one-week period in which (a) basic psychophysical measures were obtained on thresholds and dynamic ranges for pulsatile stimuli, (b) a variety of IP or CIS processors (with different choices of processor parameters) were evaluated with preliminary tests of vowel and consonant identification, and (c) performance with the best of these IP or CIS processors and the clinical CA processor was documented with a broad spectrum of speech tests. Experience with the clinical processor exceeded one year of daily use in every case. In contrast, experience with the IP and CIS processors was limited to no more than a few hours before formal testing.

Tests

The full set of tests included closed-set identification of consonants and vowels; the segmental and open-set tests of the Minimal Auditory Capabilities (MAC) battery (Owens et al., 1985); and connected discourse tracking (De Filippo & Scott, 1978; Owens & Raggio, 1987). In this report we review results from the open-set tests of the MAC battery. These are among the most difficult tests normally administered for implant patients, and they approximate closely the demands placed on implant users in their lives away from the laboratory. Results from the remaining tests may be found in the other reports from our group.

The open-set tests included recognition of words and sentences from the following lists: 50 one-syllable words from Northwestern University Auditory Test 6 (NU-6); 25 two-syllable words (spondees); 100 key words in the Central Institute for the Deaf (CID) sentences of everyday speech; and the final word in each of 50 sentences from the Speech Perception in Noise (SPIN) test (noise was not presented in our studies). All of these tests were conducted with hearing alone and used single presentations of recorded material with no feedback as to correct or incorrect responses.

Results

Processor Comparisons

Results from the CA/IP comparisons are presented in Table 1 and Figure 1, and results from the CA/CIS comparisons are presented in Table 2 and Figure 2. The tables show average scores and the figures individual scores.

Comparisons of the CA and IP processors demonstrate an equivalence of speech recognition performance, under the conditions of our tests, across subjects. As indicated in Table 1, none of the differences in scores for the open-set tests is significant.

In contrast, scores for the comparisons of CA and CIS processors demonstrate a marked superiority of the CIS processor. Both the high scores obtained with the CIS strategy and the substantial improvements made by each subject are impressive. Indeed, the sensitivity of several tests is limited for these subjects by ceiling (saturation) effects: five subjects scored 96% or higher for the spondee test when using the CIS processor; seven subjects scored 95% or higher for the CID test; and five subjects scored 92% or higher for the SPIN test. Despite these approaches to the upper scale limits, though, differences in average scores for each processor are significant for all tests. For the one test that does not exhibit ceiling effects (NU-6), the difference in processor scores is highly significant ($p < 0.0005$).

An additional aspect of the results from each set of processor comparisons is the apparent relation between a subject's performance with one processor and his or her performance with a distinctly different, alternative processor. In Figure 1 low CA scores generally are paired with low IP scores, and high CA scores are paired with high IP scores. Similarly, in Figure 2 scores obtained with

TABLE 1. Means and standard deviations of percent-correct scores for the CA and IP strategies.

	CA		IP		
	Mean	SD	Mean	SD	Paired t
Spondee	50.3	33.2	53.3	30.4	NS
CID	54.0	31.9	50.1	30.4	NS
SPIN	25.0	27.0	26.3	30.3	NS
NU-6	24.8	17.2	22.0	16.8	NS

Note. Paired t = level of significance from paired t comparisons of scores across subjects; NS = not significant at $p = 0.05$.

TABLE 2. Means and standard deviations of percent-correct scores for the CA and CIS strategies.

	CA		CIS		
	Mean	SD	Mean	SD	Paired t
Spondee	71.5	19.6	90.0	14.5	.01
CID	79.1	25.3	95.3	10.3	.05
SPIN	44.3	32.0	81.8	23.7	.005
NU-6	38.3	18.8	59.5	18.0	.0005

Note. Paired t = level of significance from paired t comparisons of scores across subjects.

the CA processor appear to be correlated with those of the CIS processor.

Correlations of Subject Performances

These apparent correlations were evaluated by calculating the Pearson product-moment correlation coefficient for each of the tests and processor comparisons. The results are presented in Figure 3, which shows scatter plots of the scores along with indications of significant correlations. Note that such correlations are found for all conditions except for the CA/CIS comparisons with the spondee test ($r = 0.670$; $p < 0.10$). For this test, three subjects achieved a score of 100% correct with the CIS processor. Such identical scores imposed by a scale limit would be expected to bias calculated correlation coefficients toward lower values. A counter example may be found in the CA/IP comparisons for the same test. In that case the distribution of scores is not distorted by scale limits, and the correlation of scores is found to be highly significant ($p < 0.002$).

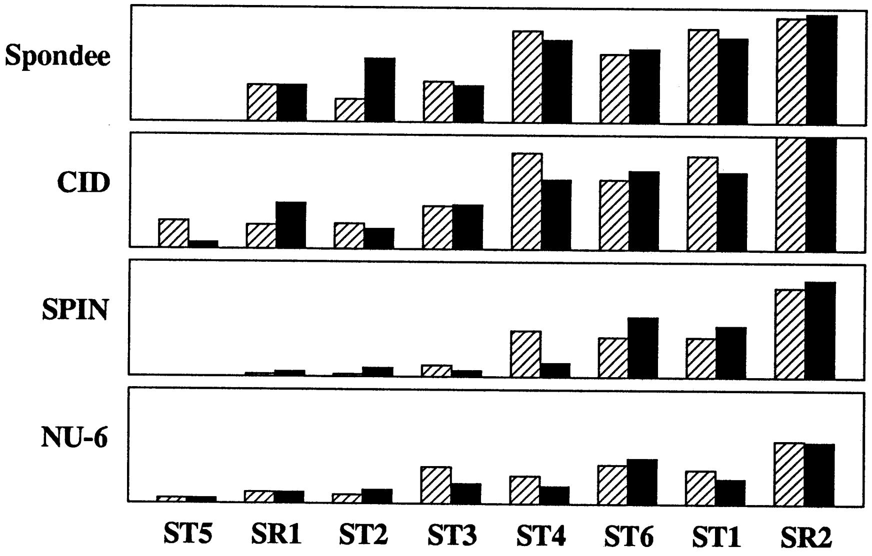

FIGURE 1. Speech recognition scores for the CA and IP processors. Scores for the CA processor are shown in the striped bars, and those for the IP processor in the solid bars. Subjects ST1-6 used the UCSF/Storz device and subjects SR1-2 used the Ineraid device. The vertical scale in each panel is from 0% correct to 100% correct.

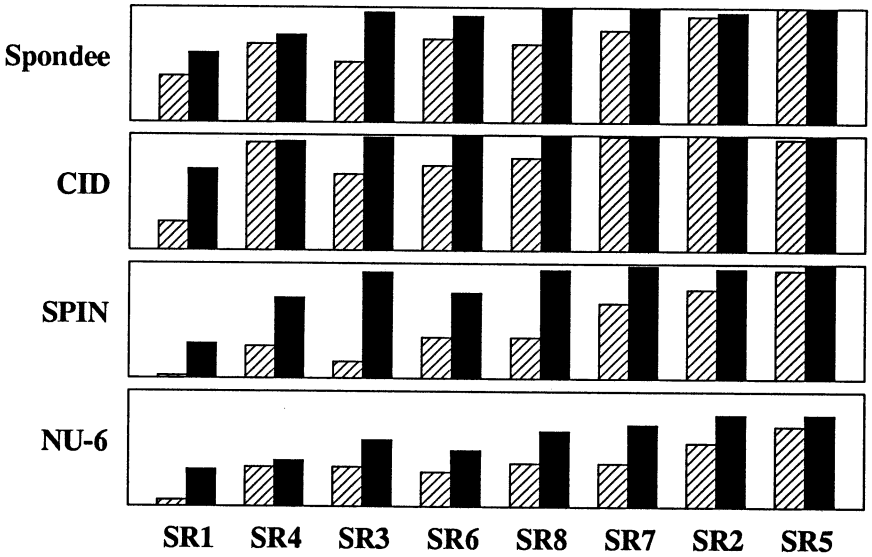

FIGURE 2. Speech recognition scores for the CA and CIS processors. Scores for the CA processor are shown in the striped bars, and those for the CIS processor in the solid bars. All subjects (SR1-8) used the Ineraid device. The vertical scale in each panel is from 0% correct to 100% correct.

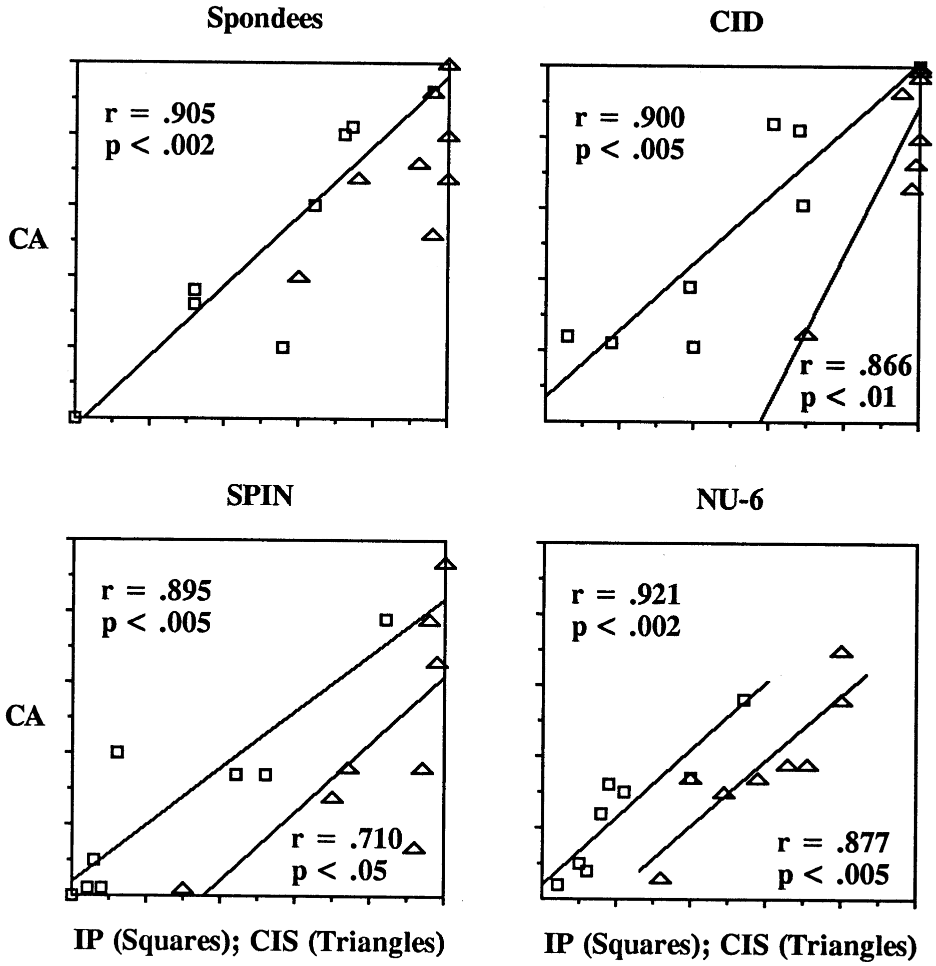

FIGURE 3. Scatter plots of percent-correct scores from each of the open-set tests. The scales in each panel are from 0% correct to 100% correct. Scores for the CA/IP comparisons are indicated with squares, and scores for the CA/CIS comparisons with triangles. In instances of significant correlations, the Pearson correlation coefficient, level of significance, and regression line are shown. Such correlations are depicted in the upper left corner of each panel for the CA/IP comparisons and in the lower right corner for the CA/CIS comparisons.

The number of near-perfect scores with the CIS processor also may have limited the significance of correlations obtained for the CA/CIS comparisons with the CID and SPIN tests.

In contrast, the NU-6 test is sufficiently difficult to retain its sensitivity even for the best subjects. None of the subjects achieved a score of 100% correct on this test, and a broad distribution of scores was obtained for both sets of processor comparisons. The correlations of NU-6 scores are highly significant for both the CA/IP comparisons ($p < 0.002$) and the CA/CIS comparisons ($p < 0.005$).

Discussion

The results of these studies indicate that patient variables can be quite important in determining outcomes with cochlear implants. For tests that do not exhibit ceiling effects, correlations of subject scores for different processing strategies range from 0.88 to 0.92. Such correlations are highly significant ($p < 0.005$ for three conditions and $p < 0.002$ for two conditions) and demonstrate strong relationships between subject performances with alternative processors. Indeed, the coefficient of determination, r^2, indicates that, once the overall patterns are known, measures of performance with the CA processor contain approximately 80% of the information needed to predict fully the scores of individual subjects using the IP or CIS processors.

In addition to the strong relationships between patient scores for the various tests, the results demonstrate that different processing strategies can produce distinctly different outcomes. While the CA and IP processors produced similar scores on all open-set tests, highly significant differences in scores were obtained in the comparisons of the CA and CIS processors. Thus, a change in the processing strategy may or may not produce a significant change in prosthesis performance.

Given the high degree of intersubject variability with cochlear implants, it is indeed fortunate that high correlations may be found between subject scores with manipulations in system variables (such as a change in the processing strategy, electrode coupling configuration, etc.). Such correlations increase greatly the statistical power of within-subjects comparisons. That is, use of within-subjects designs allows finer distinctions to be made with a given number of subjects, if the correlations across subjects are high. Also, their use allows the same distinctions to be made with a number of subjects much smaller than that required for group comparisons.

As an example, consider the comparison of two processors (or other system variables) with the NU-6 test. If the standard deviations in Table 2 (and the correlation coefficient in Figure 3) are used as typical measures for this test, then a 7.7% difference could be detected in paired t comparisons with eight subjects (at $p = 0.05$). In contrast, only a 19.8% difference could be detected in group comparisons involving 16 subjects, with eight in each group. A total of 92 subjects would be required to detect a 7.7% difference using group comparisons. The efficiency of paired t comparisons (or other types of within-subjects comparisons) is related to the correlation of subject scores for the different treatments. The higher the correlation, the more efficient the test.

While some evaluations of prosthesis systems require group comparisons, such as evaluations of various commercial devices among different groups of implanted patients or comparisons of different types of implanted hardware, the high correlations of subject performances found in the present study suggest that within-subjects designs should be used whenever possible. Indeed, the high correlations indicate that within-subjects designs can be especially powerful for studies with implant patients.

The present results also indicate that the choice of test(s) is important. Certain tests may either be too easy or too difficult to produce an unbiased distribution of scores for the system variables under study. Such was the case in our comparisons of the CA and CIS processors. For those comparisons, perfect or nearly-perfect scores were obtained by many of the subjects for the spondee, CID, and SPIN

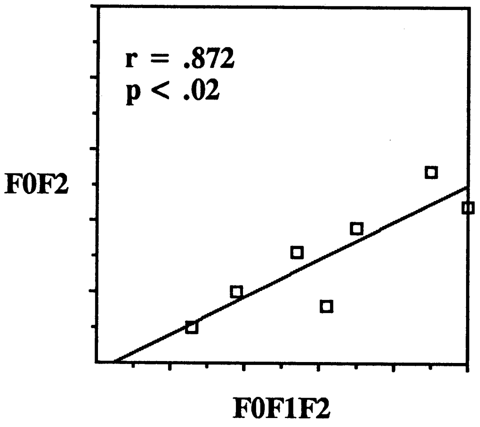

FIGURE 4. Scatter plot of percent-correct scores from the CID sentence test, as administered in the study of Dowell et al. (1987).

tests when using the CIS processor. These compressions of scores at or near the upper scale limits can reduce the apparent correlations across subjects and, consequently, the power of within-subjects comparisons.

While within-subjects designs have important potential advantages for studies with implant patients, we note that use of such designs may involve an imbalance in experience with the different treatments. In the present studies, for instance, experience with the CA processors exceeded one year of daily use for each of the subjects whereas experience with the alternative IP or CIS processors was no more than several hours before formal testing. In other studies involving within-subjects comparisons, such differences in experience have strongly favored the processor with the greatest duration of use (Dowell et al., 1987; Tyler et al., 1986). Thus, higher levels of performance may have been obtained with the IP or CIS processors if our subjects were allowed to use them for some substantial period before testing, e.g., several weeks or months. In addition, because rates of learning may be different among patients, even a fixed period of experience with the second processor (or treatment) might not avoid bias in the calculated correlations of scores across patients.

We are aware of one other study in which experience with a second processor was fixed and in which the number of subjects was at least marginal for meaningful correlation analyses. In that study the "F0F2" and "F0F1F2" processing strategies were compared for seven users of the Nucleus implant system (Dowell et al., 1987). Initial experience with the F0F2 strategy ranged from 3 to 18 months, and subsequent experience with the F0F1F2 strategy was fixed at 2 weeks. The performance of each subject was evaluated with the CID test (with materials presented live voice) at the end of each period, first for the F0F2 processor and then for the F0F1F2 processor. The results are presented in Figure 4, and again show a strong correlation of scores. Indeed, the correlation of 0.87 is comparable to those observed in our tests, where experience with the second processor was essentially zero. This similarity of findings suggests that high correlations may be found across subjects if (a) experience with the first treatment is relatively long, e.g., one year, (b) experience with the second treatment is fixed, e.g., at zero or two weeks, and (c) the difficulty of the test(s) is appropriate for the particular subjects and treatments under study.

While the correlations observed in the present studies, and in the study of Dowell et al., are quite high, it is important to remember that the numbers of subjects included in each of the studies are relatively small. Use of seven or eight subjects is marginal for correlation analyses, and results from additional subjects could reduce the magnitudes of the correlations reported here.

With this caveat in mind, we finally note that high correlations across subjects, especially if confirmed in studies with larger numbers of subjects, suggest the possibility that some common feature may establish ceilings of performance for individual patients. That is, a common feature may allow certain patients to enjoy high levels of performance across a variety of prosthesis systems, whereas a lack or diminution of this feature may produce lower levels of performance for other, less-fortunate patients. Identification of such a feature, or set of related features, could lead to the development of prognostic tests for prospective implant patients and to a better understanding of the basic mechanisms underlying implant performance.

Acknowledgements

We thank the subjects of the described studies for their enthusiastic participation. We also are pleased to acknowledge the important scientific contributions of D.K. Eddington, F.T. Hambrecht, D.K. Kessler, M.M. Merzenich, W.M. Rabinowitz, M.W. White, and R.D. Wolford.

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III. Plans for the Next Quarter

Our plans for the next quarter include the following:

1. Full evaluation of the prototype portable processor with subject SR2 (one of Ineraid patients with high levels of speech recognition performance), to confirm that performance using the prototype portable processor is comparable to that obtained in past studies using a laboratory system based on the TMS320C25 device (see, e.g., data reported for SR2 in *QPR 4* of this project).
2. Design of multilayer circuit boards for reducing the size, and increasing the reliability and reproducibility, of the prototype portable processor (the present prototype is implemented using wire wrap technology).
3. Continued development of software interfaces for the laboratory DSP 56001 system, to allow rapid specification of parameters for speech processing strategies.
4. Development of DSP 56001 software for new types of processors (e.g., hybrids of the CIS and "Peak Picker" strategies; new parametric variations of CIS processors).
5. Presentation of project results in an invited lecture at the *Meeting of the Acoustical Society of America*, to be held in Baltimore, MD, April 29 to May 3.
6. Participation in the *1991 Conference on Implantable Auditory Prostheses*, to be held at the Asilomar Conference Center in Pacific Grove, CA, June 2-7 (Wilson will serve as General Chair for the Conference, and Wilson and Finley each will present invited lectures).
7. Continued preparation of manuscripts for publication.

Appendix 1

Summary of Reporting Activity for the Period of February 1 through April 30, 1991

NIH Contract N01-DC-9-2401

Reporting activity for the last quarter included one publication and two presentations, listed below. The abstracts for the presentations are reproduced on the next two pages.

Wilson, B.S., D.T. Lawson, C.C. Finley and R.D. Wolford (1991). Coding strategies for multichannel cochlear prostheses. *Am. J. Otol.* **12**, Suppl. 1: 56-61.

Wilson, B.S., C.C. Finley, D.T. Lawson and R.D. Wolford (1991). New levels of speech recognition with cochlear implants. *1991 Midwinter Meeting of the Association for Research in Otolaryngology*, St. Petersburg, FL, February 3-7. [Abstract published in the book of *ARO Abstracts, 1991 Midwinter Meeting*, p. 35.]

Finley, C.C. (1991). Bipolar electrode placement in scala tympani: Effects on neural potential profiles, longitudinal recruitment and activating functions. *1991 Midwinter Meeting of the Association for Research in Otolaryngology*, St. Petersburg, FL, February 3-7. [Abstract published in the book of *ARO Abstracts, 1991 Midwinter Meeting*, p. 52.]

NEW LEVELS OF SPEECH RECOGNITION WITH COCHLEAR IMPLANTS.

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Two strategies for representing speech sounds with multiple channels of intracochlear electrical stimulation were evaluated in tests with seven subjects using the Ineraid cochlear implant. The standard Ineraid compressed analog (CA) strategy presented analog waveforms simultaneously to all channels, while the continuous interleaved sampler (CIS) strategy presented brief pulses to each channel in a non-overlapping sequence. Tests included open-set recognition of (a) spondee words, (b) key words in the CID sentences of everyday speech, (c) final words in the high-predictability SPIN sentences, and (d) monosyllabic words from the NU-6 list. All tests were conducted with hearing alone, using single presentations of recorded material. As shown in the Table below, the results demonstrated clear benefits from application of the pulsatile strategy. Indeed, some of the scores obtained with the CIS processor on this battery of tests approach those of listeners with normal hearing. Possible mechanisms underlying these high levels of performance include (a) reduction in channel interactions, through the use of nonsimultaneous stimuli, and (b) transmission of rapid variations in speech envelopes, through the use of high pulse rates on each channel.

Table 1. Percent correct scores from tests of open-set recognition.

	Spondee		CID		SPIN		NU-6	
Subject	CA	CIS	CA	CIS	CA	CIS	CA	CIS
SR2	92	96	100	100	78	96	56	80
SR3	52	96	66	98	14	92	34	58
SR4	68	76	93	95	28	70	34	40
SR5	100	100	97	100	94	100	70	80
SR6	72	92	73	99	36	74	30	49
SR7	80	100	99	100	66	98	38	71
SR8	68	100	80	100	36	94	38	66

(This work was supported by NIH project N01-DC-9-2401, through the Neural Prosthesis Program)

BIPOLAR ELECTRODE PLACEMENT IN SCALA TYMPANI: EFFECTS ON NEURAL POTENTIAL PROFILES, LONGITUDINAL RECRUITMENT AND ACTIVATING FUNCTIONS.

*C.C. Finley, Research Triangle Institute, Research Triangle Park, N.C. 27709 and Duke University Medical Center, Durham, N.C. 27710

The cross-sectional position of multichannel bipolar electrode carriers within scala tympani deserves attention. One carrier design (Melbourne) is thin and flexible and consequently tends to rest against the outer wall. Another design (UCSF) possesses a mechanical memory to hold the electrode close to the inner wall. In terms of mechanical placement of the electrodes, both designs work well in controlled cadaver studies. In clinical application, however, implantation success usually is measured simply by the number of electrodes passed through the round window and a confirming radiograph to show a basic spiral insertion. Actual placement within the scala tympani cross section might be affected significantly by factors such as size differences of the cochleas across patients, presence of scar tissue and/or bone, the entry angle through the round window, and/or rotational torque applied to the exiting cable.

Electrophysiological studies in the cat have shown that both threshold and dynamic range of neural responses are dependent upon placement of the bipolar electrode pair within scala tympani. Threshold differences of 12-16 dB have been reported for different placements. Such shifts are highly significant in terms of the 4-40 dB dynamic ranges of auditory percepts for implant patients.

To obtain a better understanding of the effects of variable electrode placement within the human cochlea, three-dimensional, finite-element field models of intracochlear electrical stimulation using (1) pure radial, (2) pure longitudinal, (3) offset radial (UCSF) and (4) banded longitudinal (Melbourne) bipolar electrode configurations have been developed. In these models, a cross section of a human cochlea is projected linearly along an axis perpendicular to the plane of the section, thus producing a short, straight segment of the cochlea. Each of the four electrode configurations is modeled at medial, lateral and baso-lateral positions within scala tympani. For each model, fiber potential profiles, longitudinal potential spread functions and nodal excitation patterns (based on activating functions of Rattay) to single monophasic pulses are evaluated with respect to differences in electrode configuration, electrode placement within scala tympani, and stimulus polarity.

The model results indicate that the electrical field patterns generated in the vicinity of the distal axonal processes are quite dependent upon placement of the bipolar electrodes within scala tympani. Changes in the placement of electrodes may (a) produce changes in the level of current passed into the neural elements and (b) shift the initial site of excitation along the neuron. In the lateral and baso-lateral positions, all bipolar electrodes produce uniform, nearly constant potential profiles along the length of the distal axonal processes. These profiles are independent of the basic electrode configuration, resulting in the loss of many of the unique characteristics of each bipolar electrode design. In addition, for laterally placed, pure radial and offset radial configurations, dramatic changes occur in the extent of recruitment of neurons longitudinally when stimulus polarity is reversed. These findings suggest that clinical psychophysical test differences between different electrode pairs, often interpreted as signs of variable neural survival, may also be due to variable placement of the electrode carrier within scala tympani.

(This work was supported by NIH contracts NO1-NS-3-2356, NO1-NS-5-2396 and NO1-DC-9-2401 from the Neural Prosthesis Program and a Professional Development Award from Research Triangle Institute.)