

# Longitudinal Changes in Word Recognition by Patients Who Use the Ineraid Cochlear Implant



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## ABSTRACT

The time course for reacquisition of spondee word recognition was examined for 27 patients who use the Ineraid cochlear implant. At 1 month postfitting, test scores ranged from 0 to 84% correct. The median score was 10% correct. At 22 to 28 months postfitting, the scores ranged from 0 to 100% correct. The median score was 56% correct. The rate of improvement in spondee recognition varied greatly within the sample. Most patients continued to extract new information from the electrically evoked representation of the speech signal over a period of a year or more.

IN THIS ARTICLE we describe the time course for reacquisition of spondee word recognition by 27 patients who use the Ineraid cochlear prosthesis. Data of this nature are of interest on two broad accounts.

On one account, information about the time course of reacquisition is essential for proper counseling of patients about likely levels of performance at different times following implantation. This information is necessary also to plan and evaluate rehabilitation strategies.

On another account, information about the time course of reacquisition can provide a window on the fidelity of electrically evoked, auditory representations of speech and on the plasticity of central neural mechanisms responsible for word recognition. The most likely outcome, given that patients undoubtedly differ in the magnitude of damage to their peripheral auditory system, and may differ in rate of accommodation to a distorted representation of speech, is that the rate of reacquisition of word recognition will be relatively slow and will vary among patients. However, two other outcomes would be of particular interest. If all patients require a long period, perhaps a year or more, to achieve

a high level of word recognition, then we might suppose that the auditory representation of speech is always greatly degraded and that a great deal of accommodation by central mechanisms is necessary for word recognition. Consider now the possibility that patients can identify words soon after fitting with the prosthesis; for example, within a month. This outcome would suggest that it is possible to provide a nontrivial auditory representation of speech and that a great deal of central accommodation is not necessary for word recognition.

Previous reports, for example, Waltzman, Cohen, and Shapiro (1986) and Youngblood and Robinson (1988), have described changes in word recognition scores over a 9 to 12 month period for a small number of patients who use multichannel implants. Waltzman et al (1986) report a 2 to 20% increase in spondee recognition scores and no change in either CID sentence scores or monosyllabic word recognition scores over a 12 month period for five patients fitted with the 22-channel Nucleus prosthesis. In contrast, Youngblood and Robinson (1988), who followed five patients fitted with the Ineraid prosthesis over a 9 month period, report a very rapid gain in intelligibility for spondee words and the CID sentences in the first 3 months (26–29%) followed by either a smaller gain (12%) in the following 6 months (for spondees) or no gain (for CID sentences). Monosyllabic word recognition scores increased gradually over the 9 month period from 7 to 18% correct.

The different prostheses, small samples, and brief follow-up period of the studies reviewed above limit the conclusions that can be drawn about longitudinal change in word recognition. In the present study, we report on a relatively large sample of patients (27) who were tested over a period of 2 years. The sample size and follow-up period should be sufficient to observe at least major variations in patient performance.

If changes in word recognition scores are to be observed over time, test materials must be neither so difficult that changes cannot be measured, nor so easy that all patients achieve 100% correct recognition soon after receiving the prosthesis. For our patients, spondee words, administered in an open set format, fit this bill. Moreover, because the spondee words were adminis-

tered via tape recordings, test data could be gathered and combined from several implant centers.

## METHOD

### Subjects

Twenty-seven patients were selected from the data pool of patients who participated in the clinical study for premarket approval of the Ineraid implant. The patients had been tested at one of nine implant centers. Patients were included in this report on the basis of having spondee recognition scores at 1 month, 6 to 9 months, 12 to 15 months, and 22 to 25 months postfitting. Patients were excluded from this report if they had not been tested at these intervals\*.

All of the patients in this report were found to have an "open" (nonossified) cochlea into which at least five of the six electrodes were inserted. For all patients, electrode impedances and thresholds were within normal limits.

In Table 1, we list preimplant auditory thresholds at 250, 500, 1000, and 2000 Hz for each patient's implanted ear. No patient evidenced detection of a 4000 Hz signal. The audiometrically poorer ear of each patient was implanted. In Table 2, we list the etiology of deafness, years deaf and age of each patient.

### Aural Habilitation

A formal program of aural habilitation is not a part of the Ineraid protocol. Nonetheless, approximately half of the patients received some assistance during the first year of implant use. In most cases, the assistance was in the form of audio tapes which could be used for home study. No information is available on the amount of time each patient used the audio tapes. In other cases, the assistance was in the form of training a patient's spouse to engage in speech tracking. Again, no information is available on the amount of time each patient engaged in this activity.

### Speech Material

The patients were tested with the 25 words of the Spondee Recognition Test of the MAC battery (Owens, Kessler, Ragio, & Schubert, 1985). The word list was administered via tape recorder and loudspeaker at 70 dB SPL (peak energy). No feedback was provided to patients about correct or incorrect responses.

To estimate test-retest reliability, we examined the scores of four patients who had been tested twice within a 3 month period. The range of difference scores was 0 to 8%.

### Implant Design

The Ineraid prosthesis consists of (1) six monopolar electrodes implanted in the scala tympani with remote reference,

\* The range of scores at 22 to 28 months for the patients who were not included in this report was 0 to 96% correct. The median score was 44% correct. The range of scores is similar to that found for the patients used in this report, that is, 0 to 100%. The median score (44% correct) is slightly below that of the patients included in this report (56% correct). The skewing of the distribution toward lower scores for the patients excluded from the sample is the result of having more patients with very poor scores in the excluded sample. Our sample included only three patients who scored 20% correct or less at 22 to 28 months. In contrast, 10 of the patients not included in the sample fell into this category. We suspect the reason for this is that clinicians did not wish to test (and stress) patients with materials the clinicians thought the patients could not understand.

**Table 1.** Preimplant detection thresholds for signals at 0.25, 0.5, 1 and 2 kHz.

Patient	Frequency (kHz)			
	0.25	0.5	1.0	2.0
1	90	NR*	NR	NR
2	85	90	105	105
3	NR	NR	NR	NR
4	75	100	120	NR
5	105	115	125	NR
6	90	NR	NR	NR
7	85	100	105	NR
8	90	NR	NR	NR
9	90	105	110	NR
10	70	105	105	NR
11	NR	100	100	105
12	45	95	105	NR
13	90	85	100	100
14	NR	NR	NR	NR
15	NR	NR	NR	NR
16	NR	NR	NR	NR
17	NR	NR	NR	NR
18	NR	100	NR	NR
19	80	110	110	NR
20	90	NR	NR	NR
21	95	110	110	110
22	75	100	NR	NR
23	70	80	100	NR
24	90	100	110	100
25	NR	NR	NR	NR
26	NR	105	110	NR
27	NR	NR	NR	NR

\* No response at 130 dB.

(2) a percutaneous pedestal to which the electrode wires are attached, and (3) a portable speech processing and electrode stimulation system (Eddington, 1980). The most apical electrode is located about 22 mm from the round window. The electrodes are spaced at 4 mm intervals. The four, most apical, electrodes are activated in most patients.

Each of the four activated electrodes is driven by an analogue signal derived from the input signal after the operation of an AGC circuit and bandpass filtering. The AGC circuit has a very rapid attack time and a relatively slow release time. The center frequencies of the filters for channels 1-4 (most apical to most basal electrodes) are .5, 1, 2 and 3.4 kHz. The filters roll off at 6 dB/octave.

## RESULTS AND DISCUSSION

The spondee recognition scores for all patients are shown in Tables 2 and 3. The data are ordered in the tables as a function of initial level of performance.

### Performance at 1 Month

As shown in Table 2, at 1 month word recognition scores varied over the range 0 to 84% correct. The median score was 10% correct.

The median score of 10% correct was not unexpected given the novel and inherently degraded auditory representation of speech provided by the prosthesis. However, the presence of two scores at or above 80% correct

was unexpected and suggests that a long learning period is not a necessary condition for the reacquisition of word recognition. This outcome, in turn, suggests that it is possible to produce an auditory representation of speech of nontrivial fidelity by electrical stimulation.

To probe further the issue of rapid reacquisition of word recognition, we searched the data base for scores from patients for whom 1 month scores were not reported, but for whom 3 month scores were reported, to determine whether patients other than Nos. 24 and 25 achieved very high scores soon after device activation. The results for two such patients are shown in Table 3. Both patients posted word recognition scores near 80% correct at 3 months. These data provide additional evidence that very rapid reacquisition of word understanding is possible with the Ineraid prosthesis.

## Asymptotic Performance as a Function of Initial Level

To facilitate discussion, we have grouped the patients, more or less arbitrarily, into three categories based on performance at 1 month: Patients scoring between 0 and 12% correct, patients scoring between 16 and 44% correct, and patients scoring between 80 and 84% correct.

For the 14 patients who scored between 0 and 12% correct at 1 month, the range of performance at 22 to 28 months was 0 to 88% correct. The median score was 38% correct. The range of improvement was 0 to 78%. The median amount of improvement was 32%.

These data indicate that very poor word recognition scores at 1 month are not incompatible with average or above average scores 1 or 2 years postfitting (the

**Table 2.** Percent correct spondee recognition as a function of the time since device activation.

Patient	Months Postfitting				Etiology	Years Deaf	Age	Years Aided
	1	6-9	12-15	22-28				
1	0	4	4	0	Meningitis	49	51	0
2	0	16	16	32	Unknown	4	43	10
3	0	28	24	52	H. Prog. <sup>a</sup>	18	49	27
4	2	16	16	18	Meningitis	4	40	12
5	2	10	32	28	Unknown	5	40	28
6	4	16	32	16	Unknown	9	38	0
7	4	44	50	56	Unknown	33	38	0
8	6	22	20	64	Unknown	10	65	15
9	8	24	24	56	Unknown	8	50	8
10	8	40	52	76	Unknown	8	77	0
11	10	22	12	28	Unknown	4	18	0
12	10	36	30	64	Trauma	2	42	8
13	10	72	58	88	Unknown	1	21	14
14	12	42	58	38	Ototoxic	25	63	20
15	16	8	48	48	Unknown	3	78	10
16	24	48	44	32	Ototoxic	7	59	7
17	24 <sup>b</sup>	56	68	82	Menieres D.	5	57	15
18	28	52	64	84	Unknown	4	39	0
19	30	52	60	52	H. Prog.	30	38	35
20	32	72	72	64	Unknown	9	37	?
21	32	52	70	86	Unknown	28	50	28
22	36	84	84	96	Ototoxic	1	28	0
23	44	76	76	78	H. Prog.	1	58	2
24	80	100	100	100	Unknown	8	32	20
25	84	72	100	92	Unknown	4	30	5

<sup>a</sup> Hereditary Progressive Hearing Loss.

<sup>b</sup> Score obtained at time of device activation. One month score not available.

**Table 3.** Percent correct spondee recognition as a function of time since device activation for two patients without a score at 1 month.

Patient	Months Postfitting				Etiology	Years Deaf	Age	Years Aided
	3	6-9	12-15	22-28				
26	76	72	76	96	Trauma	4	45	30
27	80	92	92	— <sup>a</sup>	Unknown	4	39	20

<sup>a</sup> Score not available.

median score at 22–28 months for the entire sample was 56% correct). On the other hand, for some patients poor scores at 1 month presaged poor scores at 2 years.

For the nine patients who scored between 16 and 44% correct at 1 month, performance at 22 to 28 months ranged from 32 to 96% correct. The median score was 78% correct. For these patients, as for patients with poor scores at 1 month, the magnitude of improvement in word recognition varied greatly. The range of improvement was 8 to 60%. The median amount of improvement was 33%.

For the two patients who scored 80 and 84% correct, respectively, at 1 month, performance at 22 to 28 months was 92 and 100% correct. The range of improvement was 8 to 20%. For one of these patients the range of improvement was constrained by a ceiling effect.

### Changes in Performance Over Time

A central question about the reacquisition of word recognition is the time period over which improvements in recognition occur. The data in Table 2 reveal several patterns of improvement. For some patients, for example, Nos. 24 and 25, the largest gain in word recognition occurred in the period between device fitting and 1 month postfitting. For other patients, for example, Nos. 21 and 17, scores increased at each observation interval. For yet others (e.g., Nos. 3 and 8), scores increased between 1 month and 6 to 9 months, remained at that level for 6 months to a year, and then increased once again.

The relatively large gains in word recognition score posted by patients after 1 year of device use are of particular interest because they indicate that central mechanisms of signal decoding can continue to improve over a period of years. The practical significance of this outcome is that patients can be advised that a plateau, or a very small gain over a period of 6 months to a year, need not herald asymptotic performance in word recognition.

The data in Tables 2 and 3 also speak to the issue of whether repeated testing with the same set of words necessarily elevates scores collected after the first administration of the test. If this were so, we would expect scores to steadily increase from first to last test session. This is not the case for all of our patients.

### How to Become a “Star”

Nine of the 27 patients achieved a score of 80% correct or better at 22 to 28 months. We have classified these patients as “star” patients. Our interest in these patients was whether all performed extremely well very soon after being fitted with the signal processor.

The data do not support the hypothesis of rapid acquisition of word recognition by all star patients. While three patients (Nos. 24, 25, and 27) achieved star status within 3 months following fitting with the sound processor, and one (No. 26) came near that status, three others (Nos. 17, 18, and 21) gradually increased their

scores over a 2 year period to finally achieve greater than 80% correct. One patient (No. 13) charted an erratic course toward 80% correct.

It would be of great interest to discover whether the “fast” and “slow” star patients use the same information in the speech signal to recognize words. It is possible that “slow” patients simply need longer to extract the information that other star patients extract with little experience. However, it is also possible that the “slow” patients come to rely on different cues than the “fast” patients rely on.

### Scores on Other Speech Tests

In order to verify that the patients had acquired word recognition skills which were broader than those required for recognition of spondee words, we show in Table 4 the Monosyllabic Word Recognition scores and Everyday CID Sentence Recognition scores assessed at two years following device activation. These two tests were subtests of the revised MAC battery (Owens, Kessler, Raggio, & Schubert, 1985). The monosyllabic word recognition test was administered via a tape recording; the CID sentences were administered live voice. The range of monosyllabic word recognition scores was 0 to 60% correct, with a mean score of 28% correct. The range of CID sentence recognition scores was 0 to 100% correct, with a mean score of 61% correct. We infer

**Table 4.** Word scores in percent correct, assessed at 2 years following device activation, for items from the CID Sentence Test and from the Monosyllabic Word Test.

Patient	CID Sentences	Monosyllabic Words
1	14	10
2	17	10
3	44	22
4	38	16
5	31	12
6	32	0
7	52	34
8	58	14
9	67	16
10	69	22
11	0	0
12	98	26
13	84	48
14	88	12
15	38	12
16	31	18
17	86	38
18	60	18
19	51	40
20	88	30
21	94	28
22	92	44
23	80	56
24	100	52
25	100	52
26	68	34
27	72	60

from these data that the patients had acquired word recognition skills of a broader nature than those required for spondee recognition.

### Correlations

In Table 5, we list the results of multiple regression analysis of the partial correlations between spondee recognition scores at 2 years following fitting and preimplant detection thresholds, years deaf, years aided, age, and spondee recognition scores at 1 month after fitting. The correlations with preimplant detection thresholds at 0.25, 0.5, and 1.0 kHz and years aided were not significant (a correlation with the 2 kHz threshold was not assessed due to the small number of patients with measureable thresholds). Thus, neither the magnitude of preimplant residual hearing nor years of using a hearing aid predicts postimplant speech recognition performance. The very small range of preimplant thresholds contributes significantly to this outcome.

Neither years deaf, nor patient age was correlated significantly with spondee recognition scores at 2 years postfitting. There were too few patients in each category of etiology (other than "unknown") to evaluate the relationship between etiology and speech recognition. This situation exists even with a sample size of 50 patients (Dorman et al, 1989).

Spondee recognition scores at 2 years postfitting were correlated significantly ( $r = 0.61$ ,  $p < 0.01$ ) with scores at 1 month postfitting. This correlation provides a quantitative description of our earlier discussion of changes in scores as a function of initial level of performance.

**Table 5.** Multiple regression analysis of correlations between spondee recognition score at 2 years postfitting and selected pre- and postimplant measures.  $r^2$  values are sequential and indicate the amount of variance accounted for by the independent variable.

	Score at 2 Years		
	Partial $r$	Simple $r$	Sequential $r^2$
Preimplant threshold at 0.25 kHz	0.039	-0.004	0.000
Preimplant threshold at 0.5 kHz	-0.160	-0.300	0.124
Preimplant threshold at 1.0 kHz	0.056	0.200	0.129
Years aided	0.080	0.136	0.157
Age	0.143	0.106	0.159
Years deaf	-0.116	-0.354	0.218
Score at 1 month	0.610	0.680	0.591

### Confounding Variables

Two variables, a patient's motivational state and the tuning of a patient's signal processor, potentially confound our conclusions about the time course of reacquisition of word understanding. It is possible that some interpatient differences in rate of reacquisition are a reflection of motivational state or, more concretely, the time the patient wears the prosthesis. It is also possible that some interpatient differences are due to some signal processors being tuned less optimally than other processors. Moreover, because signal processors may be tuned slightly differently over time or may "drift" over time, for some patients changes in word recognition may be due to changes in the fidelity of the auditory representation of speech and may not be due to more central processes of learning. This is almost certainly the case for patients who evidence markedly poorer performance in latter test sessions than in earlier ones.

### On Choosing a Measure of Performance

As we noted in our introductory remarks, we chose spondee recognition as our measure of word recognition because spondee words fit the requirement of being neither too difficult nor too easy for a large number of patients. We do not suppose that recognition of this set of words provides an exhaustive inventory of word recognition skills. Our data afford only an initial glimpse into the process of reacquisition of word recognition.

### REFERENCES

- Dorman MF, Hannley M, Dankowski K, Smith L, and McCandless G. Word recognition by 50 patients fitted with the Symbion multichannel cochlear implant. *Ear Hear* 1989;10:44-49.
- Eddington D. Speech discrimination in deaf subjects with cochlear implants. *J Acoust Soc Am* 1980;68:885-891.
- Owens E, Kessler D, Raggio M, and Schubert E. Analysis and revision of the minimal auditory capacities (MAC) battery. *Ear Hear* 1985;6:280-287.
- Waltzman SB, Cohen NL, and Shapiro MA. Long-term effects of multichannel cochlear implant usage. *Laryngoscope* 1986;96:1083-1087.
- Youngblood J and Robinson S. Ineraid (Utah) multichannel cochlear implants. *Laryngoscope* 1988;98:5-10.

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