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SYNTHETIC SPEECH TESTS AND USABLE HEARING

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INTRODUCTION

In 1982 the RNID became involved in a screening procedure for the UCH/RNID Cochlear Implant Programme [1]. Primary criteria for consideration as a suitable candidate included:

(1) Total or profound hearing loss.
(2) Unable to benefit from conventional hearing aids.

Our participation in this project has raised the following questions:

(1) What is total deafness?.
(2) What is usable hearing?
(3) What is the best treatment for a profoundly deaf person with usable hearing?
(4) What benefit can the person expect from an implant as compared to a conventional aid?

During the last four years more than 50 patients have been assessed for cochlear implants, and 29 have had a full audiological assessment. During this period many other profoundly deaf persons have also passed through the RNID and had similar tests. Thus we have had recent involvement with about 100 profoundly deaf adults, all seeking some sort of better remediation for their condition.

Typically these clients do not use a hearing aid (though some do), and report that a hearing aid is of no use to them, based on past experience. Also typically we get 'response' when testing these persons at the high sound levels (up to 130 dB HL) necessary to establish whether they can, in fact, 'use' sound.

Why do persons who respond to sound get no benefit from hearing aids? In brief, our answer now is that about 1/3 of such persons will benefit from conventional aids (about the same proportion as would potentially benefit from an implant), but that it takes sensitive and sophisticated techniques (like audiometry with synthetic speech) to determine the benefit. Further, careful fitting and considerable patient follow-up may be required in order for the benefit to be fully obtained. Thus the benefit is not necessarily dramatic; it is, however, commensurate with that obtained by a totally deaf person from a single-channel electrocochlear implant. The remainder of this paper will present the evidence for these conclusions.

SCREENING PROCEDURE

Audiological Assessment [2]
Pure tone audiometry was carried out up to 130 dB HL. There are two reasons to test up to these high levels: one is that one must be able to improve the reliability of determination of true auditory detection at slightly lower levels, such as 120 dB. The second is to look for Uncomfortable Loudness Levels (ULLs).

Thresholds of detection were measured following the British Society of Audiology recommended method. Patients were questioned about their own perception of the nature of the sensation, as a first step in separation of auditory from vibrotactile responses.

Patients were then tested for the ULL at each detected frequency. The presence of a clear ULL is an indication that the response is auditory in origin. Presence of ULLs also has implications for hearing aid fitting. The range between detection level and ULL is the dynamic range for the patient at that frequency. Therefore though they may require a high level of amplification they will also require a 'ceiling', or suitable signal compression, if they are to be comfortable with an aid.

Patients with measurable pure-tone thresholds were then tested for their ability to discriminate between the frequencies which they could detect. Frequency discrimination is another indicator of auditory rather than vibrotactile response, and (for the patients we have observed) correlates with the ability to benefit from a hearing aid. Frequency discrimination needs to be performed with tones of equal loudness, and for this task we used a purpose-built two-channel device.

Abnormal adaptation (tone decay) was measured at the nearest frequency to 1 KHz for which a threshold existed. The tone was presented 5dB above threshold, and held for a maximum of 30 seconds. The time to complete subjective decay (if experienced) was noted, as well as any partial decay. This test could not be used with accuracy on some patients with tinnitus. Abnormal adaptation relates to nerve damage. It is thus another indicator that the sensation is auditory, but a negative indicator for benefit from a hearing aid if the adaptation is rapid (less than five seconds).

The results of the audiological tests for 29 cochlear implant candidates are given in Table 1. Results are given for those who might benefit from a hearing aid, and those who would not. The decision was made on the basis of:

(1) presence of auditory thresholds for more than one audiometric frequency between 250 Hz and 4KHz; and
(2) some frequency discrimination ability.

Table 1. Outcome of audiological assessment

Test	N=14 Aidable	N=15 Not Aidable
Some auditory thresholds	14	3
Some vibrotactile thresholds	3	9
Some ULL's	14	1
Abnormal adaptation	7	2
Frequency Discrimination	10	0

Speech Tests

The goal of the assessment procedure is to determine presence or absence of useful hearing. The single most important use of hearing is speech communication. Therefore an attempt was made to specifically assess 'hearing for speech'.

In conventional speech audiometry the test items are single words, words embedded in a 'carrier phrase', or sentences. Lists of such items are presented and the patient is required to identify the word or sentence heard.
For many profoundly deaf listeners, even at an intensity level which yields the best result, the score is likely to be near zero. This does not mean that amplification is of no use in the perception of speech. Any ability which they have to discriminate between simple sound-patterns may provide a helpful supplement to the information they obtain from lipreading, so that their lipreading ability with appropriately amplified acoustic input is greater than with visual information alone. Their auditory discrimination may also enable them better to monitor their own speech, particularly in its prosodic aspects such as timing, rhythm, pitch and intonation.

For these reasons, it makes sense to look for a method of assessing speech perception in profoundly deaf people, even though conventional speech audiometry is not appropriate. Speech perception tests for the profoundly deaf must test the ability to discriminate between the kinds of simple acoustic patterns which give information that facilitates lipreading. A secondary aim is to determine which features of speech the person fails to perceive.

Sound Pattern Tests. Distinguishing one word from another involves the perception of contrasts between different speech sounds. Speech consists of a constantly changing spectral pattern in time, but it cannot be segmented strictly into individual phonemes. The investigation of acoustic cues to contrasts between consonants has involved looking at what happens to the spectral pattern during vowels which come before and after the consonants in question. In addition to phoneme contrasts, there are the other linguistically significant contrasts of syllable rhythm and intonation to consider, and the relatively simple acoustic cues to these have also been studied.

By the 1970's a substantial body of knowledge about acoustic cues had been built up, and investigators began to apply the same techniques to the study of difficulties in speech perception experienced by those with impaired hearing [5]. Vowel contrasts are cued by differences in spacing between formants (vocal tract resonances). It has been found that the more severe the hearing loss, the more difficulty is likely to be experienced in discriminating formant differences, particularly in the higher frequency region. Place of articulation of consonants is cued by relatively brief transitions in the frequency of the formants of adjacent vowel sounds. People with sensorineural hearing loss have been found to have poor discrimination of second formant transistions, particularly in the presence of the lower frequency first formant (as in natural speech). They also have shown poor discrimination of rate of transition, a cue to whether a consonant is made in an obstruent (plosive) or approximant manner.

Application of sound pattern tests to profoundly deaf listeners. The techniques of speech synthesis and acoustic cue studies can be applied in the case of those with profound losses. However, for these persons it makes sense to limit the sound patterns used to those which are the most basic in speech perception, since it is already established that their auditory perception of acoustic cues to consonant contrasts is very poor indeed and in many cases non-existent. We use (i) a simple battery of tests employing sound patterns related to the prosodic aspects of speech: syllable rhythm and intonation; (ii) a vowel contrast test, using vowels which differ in 1st formant position; (iii) a test of periodic vs aperiodic sounds (a cue to voicing).

Suitable sound patterns can be generated using commonly available microcomputers and speech synthesis chips. A degree of phonetic expertise is necessary to ensure that while the patterns are simplified to test perception of a particular acoustic feature, the parameters are kept appropriately speech-like.

The use of a microcomputer gives further advantages: automatic control of the randomised presentation of stimuli and automatic recording of responses and reaction-times. In addition, the procedure can be made adaptive so that progress to different levels of difficulty is based on a statistical criterion of success, and the hardest level of discrimination at which a particular listener can still succeed is pinpointed rapidly without the need for a tedious number of stimulus presentations or the discouraging effects of repeated failures.

Our battery of tests has been employed at the RNID over the past few years to assess the auditory discrimination ability of profoundly deaf patients using appropriate amplificaton [2]. The patient hears one of two possible sounds and is required to identify it by pressing a labelled button. Each test is preceeded by a practice session with immediate knowledge of success or failure on each item. The five tests are:

1. Gap detection: the sound is identified as "broken" or "smooth". Duration of the gap is varied.

2. Detection of amplitude dip: the sound is again identified as "broken" or "smooth". Duration of the dip is held constant but amplitude of the dip is varied.

3. Identification of aperiodic and periodic sound: the sound is identified as "crackle" or "hum".

4. Identification of vowel-like sounds: the sound is identified as /i/ ("EEEE") or /ɑ/ (AAAH). The difference is in the formant spacing.

5. Perception of pitch contour: the sound is identified as "falling" or "flat". The range of fundamental frequency over which the fall occurs is varied.

For all test items except "crackle" the synthesised sound has a vowel-like spectrum with periodic excitation of resonances (formants). Apart from test 4. the formant spacing is that of neutral vowel-quality. The duration of each stimulus is approximately one second.

Table 2 shows results on the Sound Pattern Tests given by 23 profoundly deaf listeners (14 'aidable' implant candidates and 9 others, all with auditory thresholds in excess of 90 dB HL in the frequency range 500 Hz to 4 KHz), using appropriate amplification. Most of those tested could make some discrimination between sound patterns which could give useful information to supplement lipreading, even though in most cases this appears to be limited to the temporal pattern of amplitude changes rather than contrasts which involve frequency analysis.

Table 2. Sound pattern tests, 'aidable' profoundly deaf listeners with amplification

Type of test	N=23	
	Pass	Fail
Gap Detection: 80 msec or less	16	7
95 to 125 msec	19	4
Amplitude Dip: 3 to 6 dB	14	9
9 to 12 dB	19	4
Aperiodic vs Periodic Sound	13	10
Vowel Identification /i/ vs /ɑ/	8	15
Falling vs Flat Pitch Contour	2	21

The data in Table 2 include nine subjects who were not implant candidates, but had similar audiograms and frequency discrimination. We have added results from these persons in order to bring the total number of subjects up to about the same level as for the non-speech tests (Table 1).

RESULTS OF TREATMENT

Cochlear Implants

Fifteen patients were assessed as suitable for the cochlear implant. Seven have had an implant operation, of which six were successful in terms of measurable benefit, and provide the results shown in Table 3. Five have been implanted for more than a year, and three have been extensively tested [6]. It should be remembered that this group was assessed as having 'no aidable hearing' on the basis of failure to exhibit auditory thresholds or frequency discrimination.

Using their implants, performance is dramatically improved: thresholds are easily obtained, there is some frequency discrimination, and they go on to some success with the synthetic speech tests (table 3). The results of electrical stimulation are at least as good as the results in Table 2, for an acoustic input to the 'aidable' group (and another nine similar subjects). The number of implant subjects is too small to say that the results of electrical stimulation are significantly better than for an acoustic input.

Table 3. Sound pattern tests on listeners with 'no aidable hearing' using a single channel electrocochlear implant

	time since implantation			
	<3 months, N=6		>1 year, N=5	
Type of test	Pass	Fail	Pass	Fail
Gap Detection: 80 msec or less	6	0	5	0
95 to 125 msec	6	0	5	0
Amplitude Dip: 3 to 6 dB	4	2	4	1
9 to 12 dB	5	1	5	0
Aperiodic vs Periodic Sound	5	1	4	1
Vowel Identification /i/ vs /ɑ/	3	3	3	2
Falling vs Flat Pitch Contour	4	2	4	1

Conventional Amplification

Table 1 showed 14 patients with 'aidable hearing', based on auditory thresholds and frequency discrimination (or speech tests). These 14 were immediately encouraged to have a trial of a conventional high-powered hearing aid. Four of the 14 rejected the aid. All four had tinnitus, and in one case this was much aggravated by the aid. Three of the four also exhibited abnormal adaptation, two with tone decay times of less than 5 seconds.

The remaining ten are considered 'successful' users of a conventional hearing aid. However about half of these patients experience abnormal adaptation and/or tinnitus; they have perservered with the aids but one or two report that they gain only marginal benefit.

CONCLUSIONS

There were 29 cochlear implant candidates who received the full RNID audiological assessment. Of these, 14 were judged to have usable hearing and thus were potential hearing aid users. All 14 have had a trial, and 10 continue to use an aid. Thus approximately 1/3 of the original candidates ultimately received benefit from a conventional aid.

The other 15 were classified as having 'no aidable hearing', and seven have had implant operations. A comparison of the electrically-aided results (Table 3) with those for the 'aidable' group (Table 2) shows that the single-channel electrocochlear implant used gives results commensurate with those obtained with conventional amplification by the 'aidable' group.

It should be emphased that a less stringent auditory assessment procedure (such as testing only up to 120 dB HL, or even only up to 110 dB HL; automatically assuming responses at high levels to be vibrotactile; not attempting to distinguish auditory from vibrotactile responses; not testing frequency discrimination; not seeking ULLs) would probably not have been able to distinguish the 'aidable' from the 'unaidable' candidates. In which case they might all have received cochlear implants (by virtue of having 'no hearing'), and achieved (at enormous effort and expense) results that might well have been obtained from conventional amplification.

Although half the patients were potentially 'aidable', and 1/3 were ultimately to become hearing aid users, the benefits of wearing the aid are not dramatic. This does not mean that it is not worth the bother for the patient. Rather, it means that it is not trivial to determine whether there is benefit, and certainly not trivial to convince the patient that a trial of a hearing aid is worthwhile. It is in precisely this difficult situation where sophisticated synthetic-speech tests are important. They provide the objective measures of small differences which enable both the patient and the professional to better know how to proceed with remediation. Further, small gains in auditory discrimination may be quite significant for audio-visual speech communication [6].

Synthetic speech materials also can be used in the follow-up therapy, for auditory training [4]. Finally, the use of microcomputer-based synthesis allows these procedures to come out of the laboratory and into the clinic.

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