Recent Advances in Cochlear Implants - A Review

REGISTER NO. M2K20

***in* Independent project submitted in part fulfillment of the first year M.Sc. (Speech and Hearing), University of Mysore, Mysore.**

ALL INDIA INSTITUTE OF SPEECH AND HEARING, MANASAGANGOTHRI, MYSORE - 570 006.

MAY, 2001

Dedicated to
my dearest
Amma & Acha

CERTIFICATE

This is to certify that this independent project entitled **"Recent advances in cochlear implants** - A **review"** is the bonafide work in part fulfillment for the degree of Master of Science (Speech & Hearing) of the student with (Register No. M2K20).

Mysore,

May, 2001

Dr.M.**Jayaram**
Director

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CERTIFICATE

This is to certify that this independent project entitled **"Recent advances in cochlear implants - A review"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any University for the award of any other Diploma or Degree.

Mysore,

May, 2001

Guide

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DECLARATION

This independent project entitled **"Recent advances in cochlear implants - A review"** is the result of my own study under the guidance of **Dr. Asha Yathiraj,** Reader and HOD, Department of Audiology, All India Institute of Speech & Hearing, Mysore, and has not been submitted earlier in any University for the award of any other Diploma or Degree.

Mysore, Register No. M2K20

May, 2001.

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INTRODUCTION

Cochlear implants are biomedical electronic devices that convert sound into electrical current. This current stimulates the remaining auditory nerve elements directly, thereby producing hearing sensations. Research in the area of electrical stimulation of the auditory system has an extensive history, however, it has only been in the past 25 years that implantable devices have been developed for the purpose of long term electrical stimulation in humans. During this relatively short period, cochlear implants have evolved from single channel system to more complex multichannel devices (Luxford and Brackmann, 1985; Shallop and MecKlenburg, 1987; Mecklenburg and Shallop, 1988; House and Berliner, 1991; Tyler and Tye-Murray, 1991). Today, multichannel cochlear implantation is considered a safe and effective medical treatment for severe to profound bilateral sensori-neural hearing loss in appropriately selected adults and for profound bilateral hearing loss in children.

Single channel implants were popular before the arrival of multichannel implants. Devices like 3M/House, 3M/Vienna etc. were available which had its own advantages and disadvantages. Due to the better performance in auditory perception with multichannel implants, they have became very popular and widely accepted by the implantees.

Currently, there are several different multichannel cochlear implant system available The systems that have received approval for commercial distribution by the United States Food and Drug Administration are the -

(i) Nucleus 22 and Nucleus 24 cochlear implant systems

(ii) Clarion multistrategy cochlear implant system.

(Beiter & Brimacombe, 2000)

Other multichannel implants available are Ineraid device, Combi 40 implants, Laura cochlear implants, etc.

Although the design features of specific devices exhibit some elemental differences, there are general principles that characterise cochlear prostheses. All systems are composed of an implantable internal component and an externally worn microphone and processor. Acoustic signals picked up by the microphone are electrically transduced and sent via cabling to the processor so that they maybe filtered, analysed or processed in some manner. Speech processing strategies, process and code the speech which is then sent to the internal device of the implant. This is carried out as two basic approaches . In the first, an attempt is made to present all of the information in the acoustic speech signal. The task of selecting the most important elements or features is left to the auditory system. The second approach involves extracting those features that are believed to be important for speech recognition from the acoustic signal and presenting them in a codified manner (Hnath-Chisolm, 1994; Seligman & McDermott, 1995; Hochmair-Desoyer & Hochmair, 1996).

The electrical outputs from the processor are delivered to the electrodes implanted in the cochlea. The applications of electrical current at the electrode site results indirect stimulation of remaining neural elements. The resultant electrical discharge of auditory nervous proceeds up through the central auditory system, reaches the brain and is interpreted as sound (Tyler & Tye-Murray, 1991).

The speech encoding strategies can be classified as (Pfingst, 1986)

(i) Based on signal selection strategies as

- neurophysiologically based approach
- feature extraction approach
- analog approach
- psychologically based approach

(ii) Based on nature of electrode stimulation

- simultaneous analog
- nonsimultaneous pulsatile

The development or the advances in the coding strategies leads from F_o F_2 strategy which was followed by the $F_oF_1F_2$ strategy. The third generation feature-extraction coding strategy was the multipeak (MPEAK) strategy. Parkinson, Tyler, Woodworm, Lowder & Gantz (1996) referred to mis as the F_o F_1 F_2 B_3 B_4 B_5 processing strategy. These strategies were all developed by the cochlear corporation for the Nucleus Cochlear implant systems. The latest speech processing strategy developed by cochlear corporation is the spectral peak (SPEAK) strategy. This strategy received FDA approval for use with the Nucleus-22 channel system in 1994 and is one of the strategies currently provided with the Nucleus 24 implant system (Kirk , 2000). The Clarion multichannel cochlear implant system originally offered two types of processing strategies — compressed analog (CA) and a new generation of compressed analog systems, the simultaneous analog strategy. The other processing strategy available with the Clarion is the continuous interleaved sampling (CIS) strategy (Wilson, Lawson, Finley, Wolford, 1991). CIS is also used by Med-EL, Ineraid, Laura etc. The latest strategy developed for the processing of speech signal is the ACE used by Nucleus which is Advnced Combination Encoder, or combinations of SPEAK and CIS (Kirk, 2000).

Developments have also taken place in Speech Processor. Research has lead to the miniaturization of the processors. The size and the weight of the more recent speech processors is almost half of those that were available in 1985 (Beiter & Brimacombe, 2000). Currently ear level speech processors are available (Cochlear ESPrit, Clarion BTE-1 and Med-EL Tempo processor).

AIM

The literature in the eight years will be reviewed to compare the performance across the different cochlear implant systems. Speech perception performance of adults and children for different aspects of speech like vowels, consonants, words, sentences as reported in the literature for different cochlear implant systems will be compared. The technical details or the device description of an implant system across different companies will also be done.

Need of the study

It is essential to establish the efficacy of different implant systems in reproducing the natural speech efficiently. It is needed to know if vowels, consonants, words and sentences are being perceived equally in different implants or whether some implants result in a better performance.

It will be useful for an audiologist while selecting a device or processing strategy for an implantee. This information could also be used to counsel the client regarding the choice made.

This review will provide information regarding the similarities and dissimilarities in performance of adults and paediatric users, implanted with various implant systems and its strategies.

This review will update the audiologist with the advances taken place in uie recent past in cochlear implant technology.

REVIEW OF LITERATURE

In the following section, information regarding speech perception through various cochlear implants, that have been published in the last eight years, is compiled. Single channel cochlear implants are dealt with first, followed by the multichannel devices. Prior to the section on the speech perception, a brief description of the external and internal components of the device is given. Studies regarding perception of vowels, consonants, words, sentences and continuous discourse is given for each device, wherever available.

Single Channel Implants

Implant systems using only a single channel of stimulation were used extensively in 1980's. Devices like 3M/House, 3M/Vienna, UCSF (University of California, San Francisco), PRELCO, All Hear etc. were popular due to their advantages and comparatively less cost. Even though there are many single channel devices the review is confined only to those devices which have literature published in the recent eight years.

AH Hear Cochlear Implant System

The All Hear Cochlear Implant *is* a modification of the 3M/House cochlear implant

Device Description of 3M/House Implant

In 1972 Dr.William F House implanted the first single channel cochlear implant. This system is sometimes referred to as the "Sigma" device. In 1981, the House Ear Institute and 3 M company began a collaborative effort to improve some of the functional characteristics. The new system has often been referred to as 'Alpha' device.

The descriptions of the device has been reported by Fretz and Fravel (1985). The major components of the 3M/House cochlear implant system are the signal processor, the external transmitter and the internal device.

External components

The signal processor contains the electronics, controls and batteries for the amplification and shaping of the audio signal that is received by the microphone. The microphone is a subminiature electrets type that is mounted on a small connector. There are two user adjustable controls - volume,which controls the output of processor and sensitivity, which determines the amount of amplification within the processor.

The external transmitter consists of a copper wire coil and a parallel capacitor. The transmitter is broadly tuned to 15 kHz. In the center of the transmitter coil is a permanent magnet which works with a similar magnet in the internal receiver to align and hold the transmitter over the receiver. An epoxy resin encapsulates the coil, capacitor, magnet and connector to secure the components and to provide a biocompatible skin contact surface.

Internal components

The internal receiver consists of two platinum electrodes, a copper wire coil, and a permanent magnet. The electrodes are commercially pure platinum wire, 0.2 mm in diameter with a 0.5 mm diameter ball formed on the end. The electrodes are used in a monopolar configuration with the active implanted in the scale tympani and the return (in different) placed in the temporalis region. The active electrode is 6 mm long and the return electrode is 53 mm long. The coil is 670 turns of 40 gauge copper wire insulated with a polyimide coating. The permanent magnet mounted in the centre of the coil is coated with a pin-hole free layer of gold to ensure that none of the magnet material can leech in to body tissue. The coil, magnet and connection between the coil and electrodes are all encapsulated in epoxy resin (Fretz and Fravel, 1985).

Device Description of All Hear Cochlear Implant System

It had its beginnings in 1986 when the 3M/house processor was decided to be miniaturized. The All Hear cochlear implant consists of two main parts - the implanted receiver (called the in-the-head or ITHX and the external processor, which is designed to be worn on the head (the OTH).

External component

The All Hear OTH processor is a self-contained unit that is worn entirely on the head just behind the user's ear. It is held in place by a magnet and incorporates a microphone, an external transmitter and a signal processor. The OTH magnet is adjustable so that its holding force can be varied. The OTH electronic package has a class 'D' amplifier which sends its signals to the coupling coil for electromagnetic transmission to the implant.

Internal component

The All Hear ITH receiver consists of a small titanium shell housing a 670 turn coil insulated copper wire. Both ends of the coil are connected to tantalum hermetic glass-sealed feed through. The electrodes are welded to the opposite end of the feed throughs. The ends of the electrodes are formed with a 0.5 mm sphere. One electrode is the active (implanted in the cochlea) and the second is the return (a ground, placed in the temporalis muscle).

The difference between the receiver of 3M/House and this is that the former receiver used the titanium case as the return electrode. Also the older 3M/House processor used linear amplifications (i.e. no compression) and was not designed with frequencies above 3 kHz in mind. The new All Hear OTH processor provides all of the frequencies significant to speech, upto 6 kHz and beyond.

The 3M/House processor had a class 'A' liner amplifier. The All Hear processor is a class 'D' analog compression amplifier. It is widely used because they have fewer components, are more easily miniaturized, have reduced battery current requirements, offer a more faithful reproduction of sound and demonstrate increased reliability due to their having fewer internal and external connections. The amplifier used in the All Hear OTH processor is a nonlinear compression one. It has a compression of 2.7 to 1. Compression is the process of applying a degree of amplification that depends on the loudness of the sound; the louder the sound, the less it is amplified. This 'compresses' the larger dynamic range of speech into the generally smaller range of voltage changes between threshold and uncomfortable loudness level (House, 1996).

Speech Perception Performance

Vowel Recognition

Vowel test containing nine /hVd/ utterances spoken by a male talker was used. On average Vienna patient scored 22% (8-30%) and the House patients scored 16% (8-20%) (Danley & Fretz, 1982).

Hochmair-Desoyer, Hochmair & Stiglbnmner (1985) report data on eight - set vowel test; performance ranged from about 15% to 78% for 12 patients using single-channel Vienna implant.

The results of an experiment with filtered speech suggests the added information comes from frequencies above 900 Hz. As the frequency of a low pass filter in the patient's signal processor was reduced successively from full bandwidth to 900 Hz and then to 300 Hz, percent correct vowel recognition fell from 78% correct, to 58% correct and men to 41% correct (Hochmair and Hochmair-Desoyer, 1985). The 20% reduction in percent correct with a reduction in bandwidth from

5000-900 Hz indicates that information from F_2 and F_3 contributes to vowel recognition.

Von Wallenberg, Hochmair-Desoyer and Hochmair *in* 1990 studied the formant frequencies of German vowels used in a recognition experiment. Identification of 8 vowels (I, y, u, e, Ø, o, ε., a) by a patient who used the Vienna single channel implant was done. The recognition data mirror the distinctiveness of the F_1 frequencies, i.e. /ε/ and /a/ are recognized essentially without error. /i/ is identified most often as /u/ indicating that F_2 of /i/ is not used as a cue.

Consonant Recognition

Consonant recognition scores of six patients using Vienna implants who evidenced some open-set word understanding were studied by Hochmair-Desoyer, Hochmair & Burian (1985). It is suggested that manner and voicing which have cues in the time/intensity waveform, might be relatively well identified i.e. the stop consonants /b, d, g/ are rarely confused with nasals and semivowels. Also the voiced stop consonants /b, d, g/ are rarely confused with voiceless stops /p, t, k/. The place of articulation is relatively well identified. Eg. /l/ and /r/ are not confused and /b, *p/,* /d, t/ and /g, k/ are not often confused.

Hochmair-Desoyeret al, (1985) observed scores that ranged from about 18% to 80% on a 16 set consonant test in 12 of their patients with single channel Vienna implant.

Word and Sentence Recognition

Studies by Hochmair-Desoyer et al, (1985) and Von Wallenberg et al, (1990) studied 22 individuals using Vienna implant. The subjects obtained a mean score of 30% for one syllable word identification (range — 0-90%) and a mean score of 45% for words in sentences (range — 0-98%).

Gantz et al, (1988) and Rosen and Ball (1986) report no open-set speech intelligibility in their subjects (four and three patients, respectively) using the Vienna extra cochlear single channel implant.

I Tyler, Moore and Kuk (1989) reported open-set word recognition scores. Results showed that for German words, the scores averaged 15% (0-34%) for Vienna patients.

A study done by Berliner et al. (1989) on 51 subjects using 3M/House Single channel cochlear implant. The test was administered live-voice at normal conversational levels to measure word recognition and/or sentence comprehension. The word recognition task uses 12 words including monosyllables, spondees, trochees, stressed words and polysyllabic words. For the word identification task, 26 of 50 children tested (52%) demonstrated some open-set performance. The overall mean score was 2.1 (17.5%) with a median of 1, as SD of 2.7 and a range fromO to 9 (75%). For those 52% of children, who did demonstrate open-set performance, the mean score was 4.0 (33.3%) correct.

Sentence comprehension stimuli included 10 open-set questions like What is your name?, What colour are your shoes? For this, 17 of 41 children tested (41.5%) obtained open-set discrimination. The overall mean score was 1.6 (16%) with a median of 0, SD of 2.8 and range from 0 to 10 (100%). Again, for those 41.5% of the children who did score other than zero, the mean score was 3.9 (39.0%) correct.

House (1996) compared the word and sentence recognition scores using 3M/House and All Hear for children and adults. For four choice spondee test adults scored 69% and 74% for 3M/House and All *Hear* respectively. Whereas mean score of children were 78% and 85%. Results of CID sentence test shows that scores of lip reading for 3 M/House was 66% and 68% for adults and children respectively and 68% and 65% for All Hear. Tests showed a better score for All Hear when compared to 3M/House.

The phoneme scores were better than word and sentence recognition scores as reported. Place of articulation was easily identified using Vienna implant for consonants. Results of word recognition showed a varied range of scores. All Hear implants had a better scores when compared to 3M /House.

Multichannel Implants

There are several multichannel devices available and several modifications has been taken place in both internal and external components which has lead to varied speech perception performance. The review regarding multichannel implants is confined to the devices which are used recently, also,some studies regarding the speech perception has been reviewed for those devices.

Clarion Implant System

Device Description

External Components

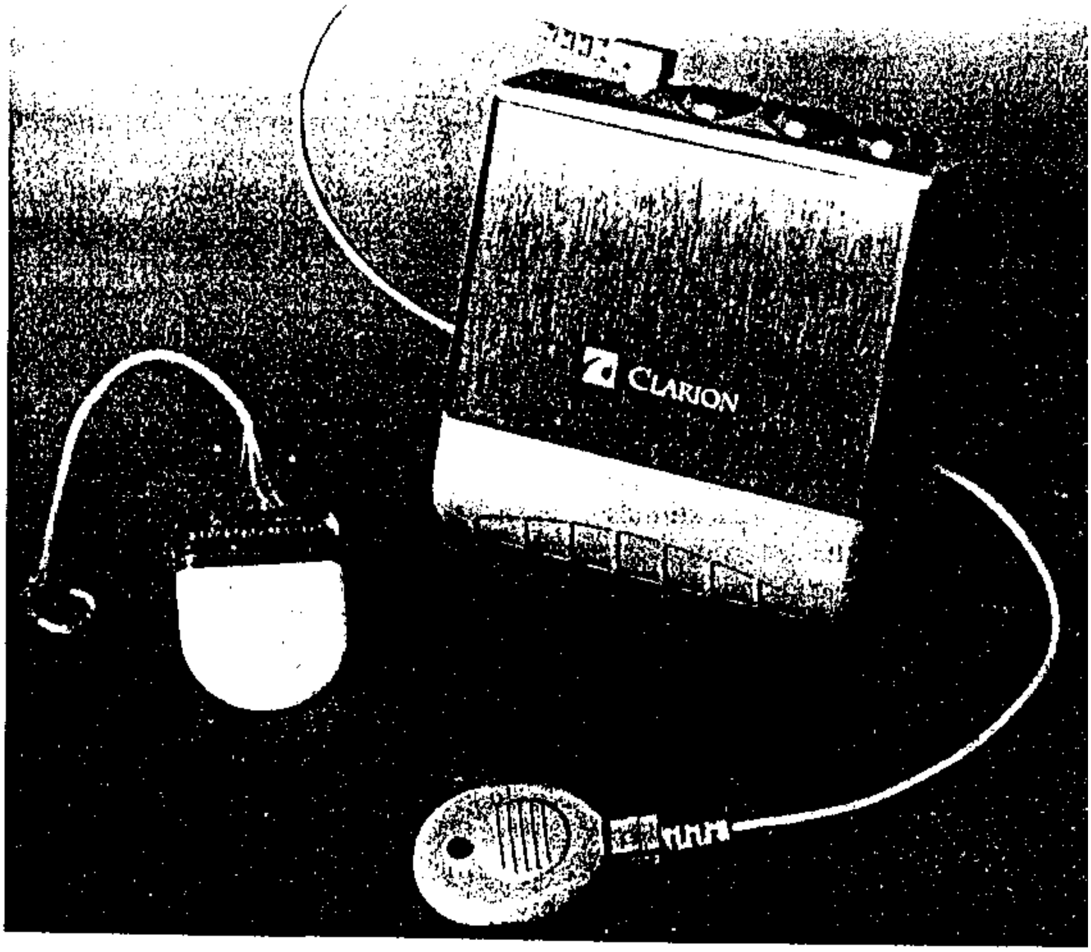
The external components of all versions of the clarion system include a body worn speech processor, one piece headset, cable and battery pack to power the processor and implant. The headpiece incorporates an omni-directional microphone, transmitting antenna in one unit and the companion magnet. The headpiece is connected to the speech processor by a single cable. The microphone picks up sound and the electrical signal goes through the cable to the speech processor. The processor has an overall bandwidth from 250 to 5500 Hz. It processes the signal through a maximum of eight programmable bandpass filters, digitizes the information and then sends the information to the transmitting coil where the digital code is sent across the head by RF transmission (Beiter and Brimacombe, 2000). Three versions of the speech processor have been made available: version 1.0, version 1.2 and the current S-series. The original Clarion was referred to as version 1.0. In 1995, it was miniaturized to accommodate placement in young children. This modification is referred to as vesionl .2. The latest, S-series processor was made available in 1997 (Kessler, 1999). The S-series processors has been miniaturized and stored up to 3 independent user selectable programs on the electrical erasable programmable read-only memory (EEPROM) chip in the processor. The processors also feature user adjustable microphone sensitivity and volume controls.

Internal Components

The internal portion of the system referred to as the implantable cochlear stimulator (ICS) includes a precurved intra-cochlear electrode array, receiving coil and the electronics package. The ICS has an extra-cochlear ground electrode, which is a platinum band that goes around the implant package. There is a cochlear implant specifically for the right and left ears, because the electrode array's silicone rubber carrier is precurved to fit the shape of the cochlea. The electrode array consists of 16 platinum-iridium ball electrode contacts; each contact is 0.3 mm is diameter. The contacts are arranged in eight near-radial pairs with the two contacts of each pair separated by 0.5 mm. The electrode contacts are arranged in this manner to focus the electrical stimulation closer to remaining auditory neural elements. The eight pairs are spaced 2.0 mm apart according to Schindler and Kessler, (1992); Kessler and Schindler, (1994).

The Clarion is an eight channel device and the implant can produce stimulation on the eight channels sequentially or simultaneously using either monopolar or bipolar stimulation. In monopolar stimulation, the active or stimulating electrode is intra-cochlear and the ground or reference electrode is outside the cochlea. Bipolar stimulation refers to passing current between two electrodes where the active and ground electrodes are both inside the cochlea.

A more recent version of the ICS, the Clarion S-series, incorporates a charge to the electrical connection of the electrodes to widen the spacing between the radial bipolar pairs effectively. An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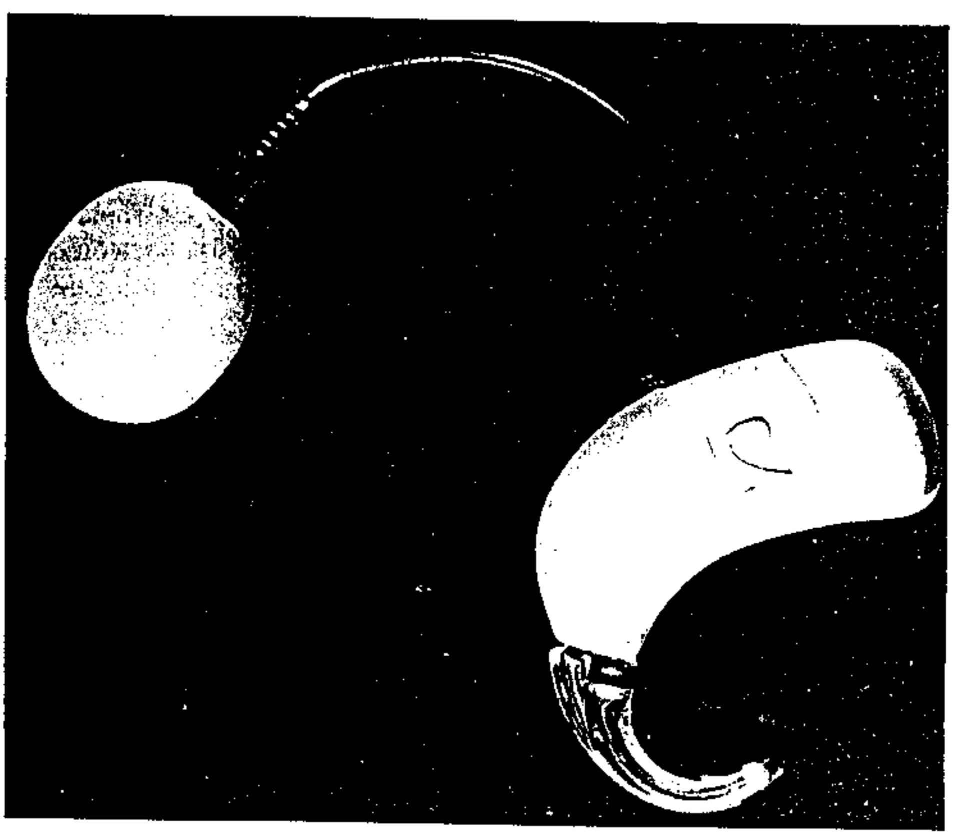


electrode from one pair is connected electrically to a contact of an adjacent pair to form what has been called enhanced bipolar coupling (Better and Brimacombe, 2000).

Speech Coding Strategies

The Clarion multichannel cochlear implant system originally offered two types of processing strategies, both of which were designed to convey information about the speech waveform (Wilson, 1993). The compressed analog (CA) strategy first compresses the analog signal into the restricted range for electrical hearing and then filters the signal into a maximum of eight channels for simultaneous presentation to the corresponding electrodes. Speech information is conveyed by me relative amplitudes of information in each channel and the temporal details of the waveform in each channel (Wilson, et a11 991). A new generation of the compressed analog system, the simultaneous analog strategy (SAS) has been introduced. The other processing strategy available is the continuous interleaved sampling (CIS) strategy.

In SAS, the input signal is divided into seven frequency bands, processed, and then the output of each band is presented simultaneously as a continuous reconstructed analog waveform to the seven electrode pairs. One filter is assigned to each pair of electrodes along the array, following the normal tonotopie organization of the cochlea. The lowest frequency bandwidth is assigned to the most apically placed electrode pair and progressively more basally placed electrodes are assigned higher frequency bandwith as reported by Schindler and Kessler, (1993); Kessler and Schindler, (1994).

The CA or SAS strategy used was successful for only a small proportion of implant recipients did not receive sufficient loudness when stimulated in a bipolar node according to Tyler, Gantz, Woodworm, Parkinson, Lowder and Schum (1996). With the introduction of enhanced bipolar coupling in the S-series implant, a larger proportion of recipients may be find with the SAS (Osberger, 1998).

Monopolar stimulation is used in the implantation of the CIS strategy in the clarion system. Again, the input signal is processed through the eight filters and the output from each determine the pulse amplitude of the short-duration electrical pulses that are sent sequentially to the eight active electrodes along the array. The maximum stimulation rate per channel is 833 Hz, for a total stimulation rate of 6664 Hz (Kessler, 1999).

Speech Perception Performance -Adults

Vowel Recognition

Preliminary speech perception findings from 19 patients with the clarion was reported by Tyler et aL, (1996). The speech tests administered consisted of the Iowa Medial Consonant Test and the Iowa Medial Vowel Test, the Iowa Sentence test and the NU-6 Word Recognition Test. The Iowa Medial Vowel Test is a 54 items, forced-choice test with the vowel stimulus presented in an /b/ - v - /d/ context. The average scores for these were approximately 60% correct for vowels.

Consonant Recognition

Consonant recognition of Clarion cochlear implant users who used compressed analog or CIS processing strategy were examined by Doyle, Mills, Larky, Kessler, Luxford, Schindler (1995). It was analyzed using a closed-set consonant list. Results indicated that on an average, both groups correctly identified about 50% of the consonants presented in a closed-set format.

Tyler et al, (1996) studied the consonant recognition in addition to vowel and word recognition using Iowa Medial Consonant Test on 19 patients. It was a 78-items (13 consonant repeated six times), forced choice test with the consonant stimulus presented in an /i/ C /i/ context. Scores obtained were 60% correct for consonant recognition.

Word Recognition

In 1995, Schindler, Kessler and Barker examined open-set word performance is 40 adults with Clarion implant. They reported mean word recognition scores of 30% correct for monosyllabic words.

Tyler et al, (1996) reported the speech perception findings from 19 patients. Word recognition was assessed, using NU-6 word recognition test, in addition to vowel, consonant and sentence recognition assessment. Results showed scores of 37% correct for open-set monosyllabic word recognition.

Reports of the postoperative outcomes of 31 subjects with 6 months of device experience was given by Lalwani, Larky and Wareing (1998). Open-set mean scores were 32% on monosyllabic words.

Osberger in 1998 compared the word recognition performance of adults who preferred the SAS strategy (n=l 1) with that of adults who preferred the CIS strategy (n=16). She reported a trend toward improved performance for patients with the SAS strategy. Mean word recognition scores were 48% and 31% correct for users of SAS and CIS strategy respectively.

A study was conducted by Battmer, Zilberman, Haake and Lenarz (1999) on twenty two postlingually deafened German speaking adults. The subjects objective performance over time with both SAS and CIS was evaluated. Word recognition was assessed using monosyllable words. A comparison of the performance demonstrates the improvement for the group that had a choice of strategies compared to the subjects who could use only CIS. Patients who used CIS only (n=30) obtained scores of 28.7% while those who had the option between CIS/SAS (n=17) this scores were 39.4%.

Sentence Recognition

Open set word recognition performance in 40 adults was examined by Schindler et al. (1995). They reported a mean score of 60% words correct in sentence.

Study done as 19 postlingually deafened adults by Tyler et al. (1996) using IOWA Sentence Test in addition to other tests reported mean scores of 61.5% as sentence recognition.

Lalwani et al. reviewed the post operative outcomes in 1998 for 31 subjects with 6 months of device experience. Open-set mean scores of 72% on sentence were obtained.

Speech Perception Performance-Children

Word Recognition

Zimmerman-Philips, Osberger, Geier, Barker (1997) evaluated children having a mean age of 5 years. Data were reported for children tested at 3 months after implantations (n=60) and 6 months after - implantations (n=23). Word recognition was analyzed using PB-K list and word recognition in a sentence context. By 6 months after implantation, mean word recognition scores were 23% for the PBN-K and 38% for the test of word recognition in a sentence context

In 1998, Osberger and Fisher examined the performance of children implanted with the Clarion device after the age of 5 years (n=30). The children were divided into two groups (oral and total communication) based on communication method. PB-K word list was used to assess word recognition. After six months of deice use, children in the oral group correctly identified an average of 27% of the words as PB-K. The average PB-K word score for children in total communication group was 8% correct.

Phoneme recognition scores using Clarionweare higher than word and sentence recognition scores. Performance with CIS strategy is contradictory, in one study word recognition was better with CIS where as in the other SAS was better. Adult obtain better scores than children.

Combi 40

Device Descriptions

External Components

The Combi 40 implants external components include a body-worn speech processor, the external coil and the microphone. It runs on four AA sized rechargeable batteries.

It is a transcutaneous, eight channel device that has all its electronic components in a hermetically sealed ceramic housing measuring 34x23x6 mm. It is provided with two electrode arrays, a stimulating electrode and a reference electrode, to stimulate monopolarly at the overall rate of 12,120 pulses per second. The stimulating electrode consists of 8 pairs of contacts in a twin surface configuration distributed evenly on a silastic silicone rubber carrier.

Three types of Combi 40 electrodes, with different electrode contact distributions lengths, are available. The lengths are:

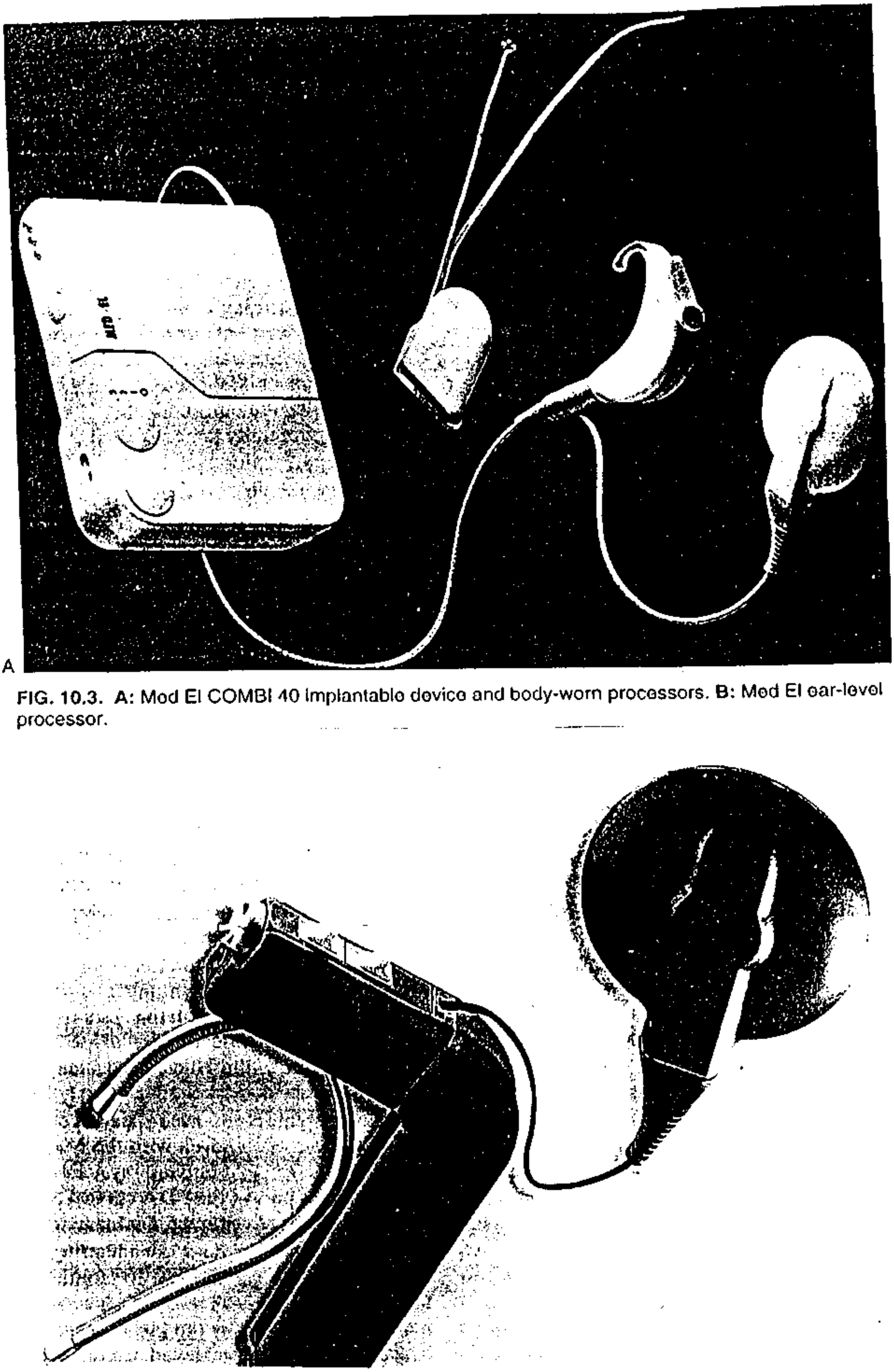
- 21 mm standard electrode
- 11 mm for ossified cochlea
- 27 mm for deep insertions.

The Combi 40 electrode is a non-performed flexible, free fitting electrode with a diameter of 0.4 mm at its tip. An annular thickening marks the 30 mm distance from the electrode tip. A coupling capacitor located at the source output of each of 8 channels prevents the occurrence of direct currents. Telemetry enables the implant function to be tested (Gstoettner, Hamzavi and Baumgartner, 1998).

Two versions of Combi 40 are made available. They are Combi 40+ and Combi 40-H. Combi 40+ implant electrode array has been designed to enable deep placement. The 24 stimulating electrodes are arranged as connected pairs for 12 channel high rate stimulation.

Speech Coding Strategy

This device incorporates the CIS coding strategy. In (his, the interleaved non-simultaneous pulses are delivered to the electrode contacts with temporal offset in order to avoid channel interactions. A key feature of this strategy is the high stimulation rate on each channel.



A

FIG. 10.3. **A:** Med El COMBI 40 implantable device and body-worn processors. **B:** Med El ear-level processor.

Speech Perception Performance

Vowel and Consonant Recognition

Helms, Muller and Schon (1997) studied sixty adults who met the criteria of 18 years and older, for whom the duration of deafness was less than half of the participants life time. Participants were evaluated before implantation and then at three, six and twelve months after implantation. Their speech recognition performance was assessed using closed set vowel and consonant tests. In addition to this open-set tests of words and sentence recognition were also used.

Results demonstrated that vowel and consonant recognition improved the most during the first three months of implant use. The scores reached 30% correct by 12 months of usage for both consonants and vowels.

Twenty-one post-lingually deaf adult patients (11 female, 10 male, age range 31 to 76 years, average age 48.6 years) who used Combi 40 implants were studied by Gstoettner et al, (1998). The assessment included a combination of live voice, recorded speech and direct electrical input. Besides evaluating patients on an eight vowel test and sixteen consonant test, they were also evaluated on other tests like two digit number test, monosyllable test sentence test and sotscheck test. Vowel test included a closed set test in which eight different vowel sounds (a, e, i, u, ä, ü, ö) each in /bvb/ context. Sixteen consonant test is a closed set test of 16 different consonants (1, r, m, n, j, w, h, b, d, g, p, t, s, , f) each in /aCa/ context.

The results obtained from the vowel test showed the scores ranging from 16 to 66% at 1 month of implantation improving to 28 to 97% at a 12 month follow-up. A commentable improvement was noticed within 1 year of usage. Consonant recognition improved from 15 to 81% at 1 month assessment to 40 to 97% at 12 month assessment.

Word Recognition

Helms et.al's study (1997) showed that the scores for monosyllabic word recognition ranged from 5% to 85% correct, with a mean of 54% and the percent of words correctly identified in a sentence context ranged from 30 to 100% with a mean of 89%.

Word recognition abilities of twenty-one post lingually deaf were studied by Gstoettner et al, (1998). The tests used were two digit number test which included 10 groups of 10 two-digit numbers, and sotscheck test which is a closed-set test of 10 rhyming word groups differing in one vowel or consonant. Patients obtained the best results with the two digit number test. The scores ranged from 30 to 100% at the 1 month assessment, improved to 60 to 100% after six months, the performance men plateauing at 12 months (range 70-100%). Sotscheck test showed that the lowest scores obtained at 1 month assessment was 20% (range 20-91%) and 37% (range 37-39%) at 12 month assessment.

Sentence Recognition

Study which was reported earlier (Gstoettner et al, 1998) also evaluated the sentence recognition. For this a sentence test consisting of three tests of lOeveryday 3-8 word sentences from Innsbrucker sentence test was used. Results shows recognition scores as 58% initially with a range of 23-98% which increased to 78.5% (range = 42-100%) by twelve months. A significant improvement in sentence recognition was noticed within one year of implant use.

The research carried out on the Combi 40 shows significantly better scores in all the parameters of speech perception like phonemes, words and sentences.

Digisonic Implant System

Device Description

External components

The processor used is a standard digisonic processor, that has complete flexibility of programming, to allow the frequency channels to be adjusted to the electrodes tonotopic order. The digisonic processor allows complete control of frequency bandwidth sand allocation to appropriate electrodes. The normal mode of electrode stimulation of the digisonic implant is sequential, with high frequency information being delivered first to the proximal electrodes of the array, which lie in the most basal part of the cochlea, then the second and then the third array is stimulated followed by the next electrode of each array and so on. This will give spacing in time and frequency and so minimize the problem of cross talk between adjacent electrodes.

Internal Components

The new MXM Digisonic multi array cochlear implant has three arrays, with the aim that one could be inserted into the basal turn of the cochlea another into the second turn, and the third could reach the apical part of the cochlea. The implant is mechanically robust, and tolerant of handling during surgery. Each intra cochlear array is articulated, and is uniform 0.5 mm in diameter and 5 mm long. The spacing between adjacent electrodes is 0.7 mm. The geometrical surface area of the electrodes is 0.8 mm or more, being increased by a micro relief effect to counteract the increased impedance expected in the ossified cochlea. Each array carries four recessed iridium platinum electrodes, 0.5 mm in diameter.

The Digisonic multiple array implant was made and implanted as a customs made device. The first version had ten separate electrodes which were inserted one by one into ten recesses drilled it the surface of the cochlear (Richardson, Beliaeff, Clarke, Hawthorne, 1999).

Information regarding the speech perception performance with this device is not available in the literature.

Ineraid Device

Device Description

External Components

The signal processor was a 6 channel design with sixth order band pass filters, 400 Hz first smoother, and full wave rectification. The channels were of equal width on a logarithmic scale. Signals were pre-emphasized above 1200 Hz. Pulse durations and pulse rate were chosen for each patient based on the results of tests of consonant understanding conducted with, most generally, pulse rates of 823, 1120 and 2020 pps and pulse durations ranging from 40 μs/period and 100 μs/period (Dorman and Loizou, 1996).

Internal components

The Ineraid prosthesis consists of (i) six monopolar electrodes implanted in the scale tympani with remote reference (ii) a percutaneous pedestal to which the electrode wires are attached and (iii) a portable speech processing and electrode stimulation system (Eddington, 1980). The most apical electrodes is located about 22 mm from the sound window. The electrodes are spaced at 4 mm intervals. The four most apical electrodes are activated in most patients. Each of the four electrodes is driven by an analogue signal derived from the input signal after the operation of an AGC circuit and filtering by fourth-order band-pass filters (Eddington, 1980; Wilson et al, 1991). The filter center frequencies are 0.5, 1, 2, and 3.4 kHz.

Speech Coding Strategies

The speech coding strategies used by the Ineraid device include a Compressed Analogue (CA) processor and CIS processor.

Ineraid Processor

The four channel CA processor of the Ineraid system was developed by Eddington in 1980. Briefly, sounds picked up by an ear-hook microphone are first processed by an automatic gain control (AGC) and then divided into four channels by four analog band-pass filters.

CIS Processor

In 1991, Wilson et al. described a new signal processing strategy, continuous interleaved sampling (CIS), for cochlear implants. The literature was reviewed on similar grounds by Wilson, Lawson and Finley (1993). The CIS strategy was first tested on Ineraid patients because it could be coupled directly to intra-cochlear electrode via the Ineraid's percutaneous pedestal. CIS processor provides continuous, high-rate, pulsatile stimulations in a non-overlapping sequence to six electrodes (Dorman and Loizou, 1996). The signal processor was a six channel design with a sixth-order band-pass filters, 400 Hz first order smoother and full wave rectification. Channel center frequencies were 393 Hz, 639 Hz, 1037 Hz, 1680 Hz, 2730 Hz and 4440 Hz. The channels were of equal width on a logarithmic scale. Signals were pre-emphasized above 1200 Hz. All available electrodes (four to six) are activated successively from apex to base in monopolar mode and at maximum speed as studied by Pelizzone, Cosendai and Tinembart (1999).

Speech Perception Performance

Vowel Recognition

Dorman and Loizou (1998) studied ten normal hearing students at Arizona State University, who ranged in age from 21 to 62 years and seven cochlear implant patients using Ineraid device, who ranged in age from 37 to 73 years.

The scores obtained were compared with normal hearing subjects listening to speech processed through six channels. Stimuli for the normal-hearing subjects were preprocessed through simulations of implant processors with two to nine channels. The speech stimuli used were synthetic vowels is /bVt/ context, naturally produced vowels in /bVd/ context. Results show that when the test material was synthetic vowels, normal hearing subjects listening to six channels of stimulations achieved a mean score of 81 % with as SD of 13. When the test material was multitalker vowels, normal hearing subjects achieved a mean score of 80% correct with an SD of six. The scores of the four implant patients fell with ± 1 SD of the mean for normal hearing subjects.

Twelve post-lingually and totally deafened adults participated in the study by Pelizzone et *aX,* (1999). Speech perception was evaluated with consonant and vowel identification tests. Vowel identification tests consisted of eight different utterances of seven French vowels /a, a, e, i, , u, ü/ presented alone. The vowel group mean score at fitting with CIS processor was 63.8% (SD of 15.7%) versus 67.1% (SD of 14.3%) for Ineraid processors. The vowel group mean score at 1 year with CIS processor was 78.3% (SD of 17.2%). Scores obtained were better with CIS processor compared to Ineraid processors.

Consonant Recognition

Dorman, Soli, Dankowski, Smith, McCandless, Parkin (1990) studied consonant recognition for seven patients. Manner and voicing were well recognized. Manner errors for nasals were other voiced signals. The identification of place varied with manner. Neither stops nor nasal place of articulation were well identified. The intense fricative / / was well identified as was the affricate /t /. Recognition of stop consonant place of articulations improved as did discrimination between the intense fricative / / and /s/. Recognition of nasal place and semivowel place remained relatively poor. The increased identification accuracy for stop consonants and for /s/ suggests that the patients received more information from middle and high frequencies than the patients who showed poorer performance. Similar observations have been made by Tyler (1990).

In 1996, seven subjects who used the Ineraid processor for no less than 4 year, ranged in age from 31 to 72 years were studied by Dorman and Loizou. The stimuli were single exemplairs of /b, d, g, p, t, k, s,f, θ. t , z, m, n, w, 1,j / spoken in a 'aCa' format by a male talker. Results showed mat each patient achieved or higher score with the CIS processor than with the Ineraid processor. The range of improvement was 15 to49%. The mean percent correct scores of 51% (SD=9%) for the Ineraid and 81 % (SD=14%) for the CIS processor was obtained.

Dorman and Loizou (1998) used en normal hearing students and seven cochlear implant adults, for their study. Performance was compared with normal-hearing subjects listening to speech processed through six channels.

The speech stimuli to study consonant recognition was naturally produced consonants in /aCa/ context. The stimuli for the IOWA consonant test were 16 consonants in /aCa/ context spoken by a single male speaker (Tyler, Preece and Tye-Murray, 1986). An information transmission analysis for consonants was conducted using the features of Miller and Nicely (1955). Only the data for place of articulation were reported.

The mean score for the normal hearing listeners in the six channel condition was 85% correct with as SD of 17. The scores of five implant patients fell within ± 1 SD of the mean for normal hearing subjects.

Speech perception was evaluated in twelve post-lingually deafened adults who used Ineraid multichannel implant by Pelzzone et al, (1999). Consonant and vowel identification tests were conducted in the sound only condition. Consonant identification tests consisted of four different utterances of 14 French consonants /p, t, k, b, d, b, f, s, v, z, m, n, 1, v/ presented in /aCa/ format. The consonant group mean score at fitting of CIS processor was 55.3% (SD=20%) versus 45% (SD=18.7%) for Ineraid processors. After one year of use individual consonant scores with the CIS processor improved further for 10 out of 12 patients. The mean score with CIS processor at one year was 65.6% (SD=24.1%).

Word and Sentence Recognition

Dorman et al. (1998) studies the distribution of scores for 50 patients on lists of spondee recognition, monosyllabic word recognition and the recognition of words in sentences. For monosyllabic words, the median score was 14% correct with a range of (0-100% correct). For the CD sentences, the median score was 45% correct with a range of 0-100% correct.

From the research on the device using the Ineraid and CIS processor, speech perception was better using the latter. With use, scores improved with the CIS processor. Phoneme recognition scores obtained were better than word and sentence recognition as per the literature.

Laura Cochlear Implant

Device Description

External components

It uses the Laura Flex speech processor which has a Linlong filter design. It has a linear spacing from 100 Hz to a transition frequency of approximately 800 Hz, and with a logarithmic spacing from the transition frequency to 5000 Hz. If fewer than eight channels are activated, the filter bands are rearranged over the 100 to 500 Hz interval.

Internal components

The internal device consists of an array of 16 electrodes of which each adjacent pair of electrodes is defined as a bipolar channel. The overall stimulation rate for the standard biphasic current pulses of 40 usec per phase is fixed at 10,000 pulses per second. The rate per the channel depends on the number of active channels. For this standard setting, a biphasic current pulse is sent to one of the active channels each 100 µsec. Hence, the stimulation rate of eight active channels is 1250 pulses per second per channel. Besides the standard pulse width of 40 µsec/phase biphasic pulses of 100 usec/phase and 200 usec/phase can also be used, but then only at lower stimulation rates. In the Laura Flex the acoustical input received by the microphone is filtered by as many as eight fourth-order band pass filters from 100 Hz to 5000 Hz, one for each active channel. After envelope detection and compression, which is done in a manner comparable with the CIS algorithm (Wilson et al, 1991), the electrical variations are transmitted to the internal device through a transcutaneous link. Amplitude is coded by changing title amplitude of the electrical pulse, not the direction (Wieringen and Wouters, 1999).

Speech Perception Performance

Study was conducted by Wieringen and Wouters (1999) with the aim to examine phoneme recognition of three pre and twenty two post-lingualry deafened adults the subjects used the Laura cochlear implant fitted with the Laura Flex speech processor. Subjects included only those who used CIS strategy.

Vowel and consonant recognition were examined. Vowel recognition was tested using ten /hVt/ utterances where V was /u, y, i, o, e, a, 1,0,a/. The results for vowels showed mat chance performance is 10% correct. A score of 14.5% correct was considered significantly above chance. Subject performance varied widely, ranging from 14% to 79% (mean = 42%, SD =19%).

Consonant recognition was examined using sixteen /aCa/ nonsense syllables, with C being / p, t, k, b, d, r, L m, n, s, f, x, z, v, *j/*. In mis test the chance performance is 6.25% and scores should be at least 9.1%

to be considered significantly above chance. Consonant recognition ranges from 7% to 62% correct. The mean percent correct score for the Laura implantees were 33% (SD 13%).

Mean percentage scores for vowel recognition is higher than consonant scores using CIS strategy with Laura Flex processor. Further information regarding speech perception using Laura device is not available.

Nucleus Cochlear Implant Systems

a) Nucleus 22

Device description

External components

The external components of the system include an ear level directional microphone, transmitting coil, cables and a body worn speech processor, the spectra 22. Spectra 22 incorporates the speech processing strategy called SPEAK. The features of the spectra include microphone sensitivity control, auto sensitivity control for use in the background noise, indicator lights for microphone and transmitting coil and is powered by single AA battery. The speech processor receives the electrical signals sent from the microphone, performs an analogue-to-digital (A-D) conversion, then digitally extracts and encodes specific information about the acoustic input signal. The resulting digital code is routed to the transmitting coil and then to the implanted receiver/stimulator via radio frequency (RF) transmission (Beiter and Brimacombe, 2000)

Internal components

It consists of an implantable receiver and a banded electrode array. It provides both bipolar and common ground stimulating modes. It consists of 22 electrodes spaced 0.7 mm apart (Patrick and Clark, 199l).It can stimulate up to 22 specific areas of the cochlea. It takes maximum advantage of the natural pitch arrangement of the cochlea by offering a high number of stimulation sites.

b) Nucleus 24

Device description

External components

As mentioned in the catalogue the Nucleus 24 cochlear implant system consists of the CI24M implant and a choice of either SPrint body worn speech processor or the ESPri t processor.

The SPrint is a fully digital processor that holds up to four independent programs or MAPs. It offers the whole range of system benefits, including the widest range of programmening parameters and coding strategies maximize the hearing potential in different listening environments. The advanced circuitry and flexibility of this processor makes it possible to programme the SPrint using the advanced speech coding strategies. The SPrint also feature a visual display which indicated the status of the processor's primary function. Symbols are used to indicate low battery power, lock symbol (prevention from children), microphone sensitivity and programme control. It also has an audible alarm to indicate low battery power.

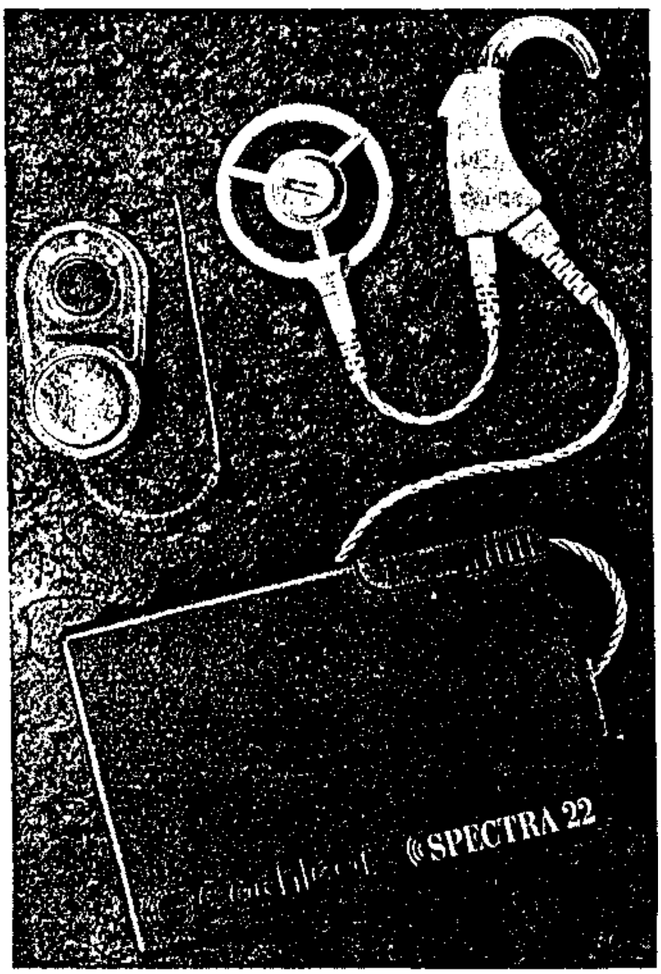
The ESPrit is the first multichannel ear level processor. It combines a speech processor and a built in microphone in a case as combact as a BTE hearing aid. The ESPrit is connected to the transmitting coil by a thin cable. It has a choice of two individual programmes (MAPs). There is a rotary control which can be enabled as volume or microphone sensitivity. It is powered by two 675 high power Zinc air batteries providing up to 80 hours of operation. The ESPrit implements the SPEAK strategy.

Nucleus 24 provides a choice of CIS, SPEAK, or ACE coding strategies.

Internal components

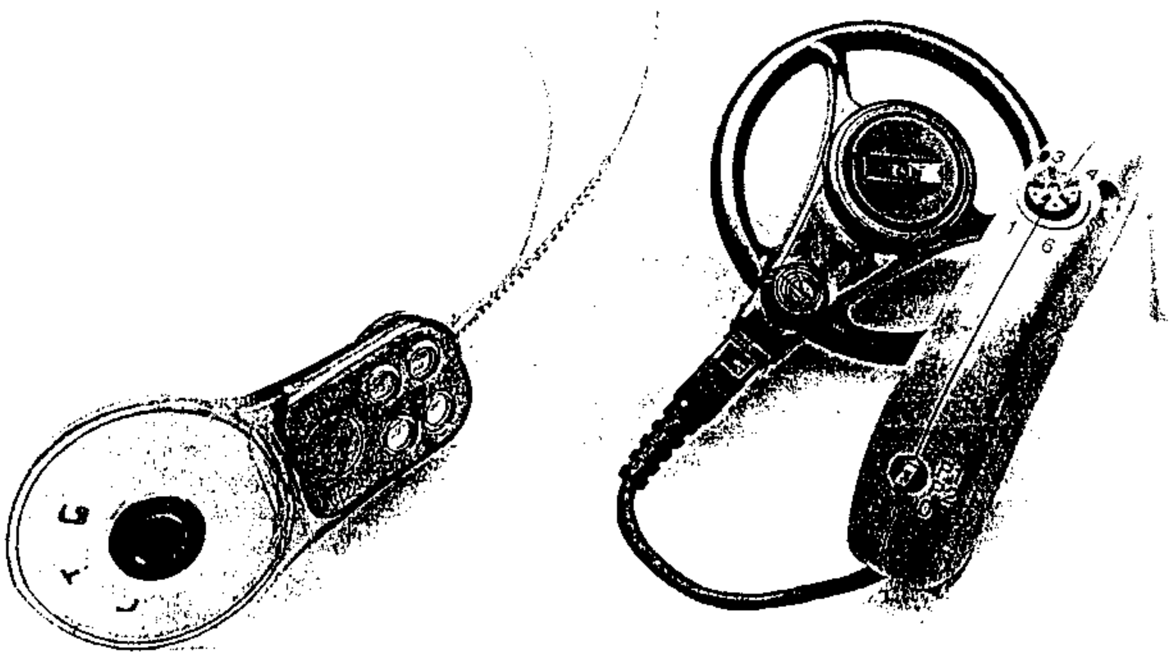
Consists of implantable receiver and a banded electrode array. The Nucleus 24 implant includes a new custom integrated circuit that allows stimulation of the auditory nerve at rates up to 14,400 Hz. It includes two independent extra-cochlear ground electrodes to provide the capability of monopolar stimulation. It provides bipolar and common ground stimulation modes.

The Nucleus CI24M implant has comprehensive telemetry capabilities- impedance telemetry, compliance telemetry, and Neural Response Telemetry. The unique use of common ground mode for impedance and compliance telemetry establishes the degree of integrity of the implant and the electrode array. Neural Response Telemetry is a window to the underlying physiology of the cochlear nerve, which may provide insight into optimal rate and electrode selection as well as psychophysical assessment to aid programming.



A

FIG. 10.1. A: Cochlear Corporation's Nucleus 22 internal device and body-worn processor. B: Cochlear Corporation's Nucleus 24 internal device ear-level (Esprit) processor. C: Cochlear Corporation's Nucleus 24 body-worn (SPRINT) process.



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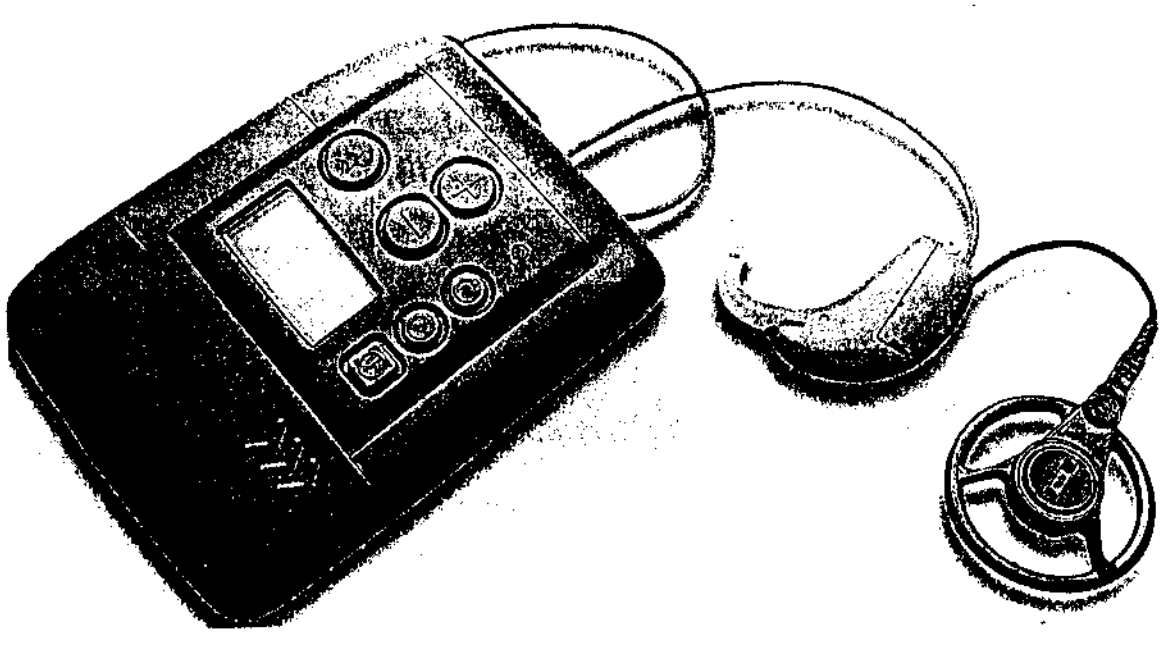

C

Speech encoding strategies

The Nucleus 22 and 24 systems use digital signal processing and incorporated several different speech coding strategies. These strategies represent a set rules that define how the incoming acoustic speech signal will be analyzed and coded by the speech processor.Currently, the Nucleus 22 and 24 implements various other strategies including continuous interleaved sampling (CIS) and advanced combination encoder (ACE) strategies.

The SPEAK strategy is a spectrally based one that intakes advantage of the place pitch sensitivity of the cochlea. It continuously analyses the incoming acoustic signal (150 to 7.8 KHz) and divides it into 20 acoustic bandwidths. During each scan, the energy in each hand is measure to determine which bands contain the highest amplitudes or maxima at that point in time . Each electrode along the array (up to 20 to 22 available) is assigned to a band in accordance with the tonotopic order of the cochlea. As the spectral characteristics of the input signal vary, different electrodes along the array, will be stimulated to represent the ongoing changes in the acoustic input. The SPEAK stimulated the cochlea at a modest rate that varies depending on the number of maxima delivered during each scan cycle. The average rate is 250 Hz. (McKay, 1991)

In contrast to SPEAK, CIS strategies (Wilson et al, 1991) attempt to reproduce the ongoing fine temporal changes in the acoustic waveform, as opposed to changes in the frequency domain. The Nucleus 24 implements a 4, 6, 8, or 12 channel CIS strategy. In CIS strategy, the overall signal bandwidth is divided by the number of electrode to be used (in the case 4, 6, 8, or 12) to determine the bandwidth for each filter or channel.During each scan cycle, the output amplitudes from each filter are determined and represented as changes in the amount of electrical current sent to the selected electrodes.

In contrast to SPEAK, in which the place of stimulation varies along the array, in CIS strategies the same subset of electrodes or channels is always stimulated sequentially during each scan of the filters regardless of the amount of energy detected in the filter. To represent the temporal variations, CIS strategies stimulate the auditory nerve at rated of more that 800 Hz per channel. The maximum stimulation rate available with the Nucleus 24 implant is 14,400 Hz across all channels.

The Nucleus 24 system implements strategies referred to as advanced combination encoder (ACE). It combines some of the best features of spectrally and temporally based strategies, such as selection of the number of maxima and stimulation sites along the array with overall higher stimulation rates.

Speech Perception Performance :Adults

Vowel Recognition

Whitford et al. (1995) did an evaluation of the SPEAK strategy implemented in the Nucleus Spectra 22 speech processor on 24 post linguistically deafened adults. Prior to the investigations, all subjects had used the MPEAK strategy for a minimum of eight months. The test battery included one closed-set vowel identification list which had 11 pure vowels of Australian English in an /h/ vowel /d/ context. In addition to this performance on one closed-set consonant identification, one list of open-set CNC words, two lists of open-set sentences in quiet, two lists of open-set sentences at +10 dB S/N ratio and two lists of open-set sentences at +5 dB or +15 dB S/N ratio, were evaluated.

Results showed that mean scores obtained using the SPEAK coding strategy were significantly higher at the 5% level than scores obtained using MPEAK for 33.3% of subjects in vowels. The group mean score for the vowel identification test was only 3% higher for the SPEAK coding strategy than that obtained for MPEAK.

Skinner, Fourakis, Holden, Demorest and Holden (1999) studied the differences in performance associated with the two, MPEAK and SPEAK, strategies. Acoustic and electrical analyses of vowels identified by cochlear implant recipients were compared. Subjects taken were nine post-linguistically deaf adults. Fourteen vowels were presented an /hVd/ context. Nine pure vowels (ε , i, I, u. ae a , o, U, Λ,) and five r-colored vowels (iɚ, εɚ, aɚ, oɚ, ɝ). Results showed that there was no difference in mean vowel score across subjects between strategies, MPEAK and SPEAK (72.3% and 73.4%) respectively. For four of the five r-colored vowels, mean scores were higher (9 to 22%) with the SPEAK strategy man with MPEAK. In contrast, mean scores for three pure vowels were higher with the MPEAK strategy than with SPEAK (10 to 14%).

In 1998, Fujiki et al. studied the effects of speech coding strategy, MPEAK and SPEAK, on speech perception performance. Nineteen post-lingually deaf adult CI users were included in the study. Six of the nineteen used MPEAK and twelve used SPEAK. To evaluate speech perception performance, vowel perception, consonant perception and speech tracking performance in Japanese language were used. In vowel recognition test, five Japanese vowels (u. o, a, e, I) were presented, In the MPEAK group, vowel recognition performance ranged from 48 to 100% (mean 79.1) and in SPEAK group ranged from 40 to 100% (mean 88.4).

The effect of electrode location and spacing of electrodes on phoneme identification was studied by Fu and Shannon (1999). Three post-lingually deafened adults with Nucleus 22 participated in the study. All were using SPEAK strategy. Phoneme recognition was assessed using two types of test material - vowel and consonant recognition. Vowel recognition was measured in a 12-alternative identification paradigm. The stimuli consisted of 10 monophthongs and 2 diphthongs (i, I,ε, , u, V, a,Λ, *o,3,* o, e) presented in a /h/ -vowel /d/ context. Vowel recognition scores showed that performance at the most apical location of the four electrodes (50.3%) was significantly poorer than performance with full 20-electrode processor (61.5%). The average performance decreased from 50.2% in the most apical location of four electrodes to 24.0% when shifted 3 mm basalry. Recognition of vowels was poorest

(24.5%) when the electrodes were most closely spaced. When the electrode spacing was increased to 3 - 3.75 mm vowel recognition increased to 50.2% correct.

Vowel recognition scores increased significantly to 49.5% in condition where the electrodes were located at equal mm spacing along the cochlea. When compared to score of 12.1% in condition where electrodes are separated by equal frequency differences.

Zeng and Galvin (1999), conducted a study on four Nucleus-22 cochlear implant users using the SPEAK strategy. The study examines to what extent the amplitude mapping parameters mat are available affect speech recognition in quiet and in noise. Stimuli were medial vowels and consonants. The 12 vowels included : (U, ae ,Λ,O, ε , e, I, i, o, U,) in b/v/d format. Results showed that there is no systematic effect of amplitude compression in vowel recognition. Analysis confirmed that there was no significant differences between the compression conditions. The electrode number effect shows that for vowel recognition, the percent correct score decreased from 78% with 20 electrodes to 73% with 10 electrodes to 49% with four electrodes. The data also show that, atleast under quiet conditions, vowel and consonant recognition was not greatly affected by reducing the electric dynamic range. Analysis indicated that vowel recognition was marginally affected by dynamic range reduction.

Fu and Shannon in 2000 studied six post-Iingually deafened adults using the Nucleus-22 cochlear implant The experiment measured vowel and consonant recognitions a function of stimulation rate in CI listeners fitted with CIS strategy. Vowel and consonant recognition was also measured as a function of cut off frequency of the envelope filters. Here they took five normal hearing listeners in addition to the six CI users. Vowel recognition was measured in a 12 alternative identification paradigm, including 10 monophthongs **(I, i, ɛ , æ, U, u, a,ʌ ,ɔ, ɜ)** and 2 diphthongs (o, e) presented in a /*bl* vowel /d/ context. When the stimulation rate was 50 pps/channel, 32% of vowels were correctly recognized. When rate was increased from 50 pps to 100 pps/channel, mean vowel recognition increased significantly to 48% correct. No significant improvement was observed when the stimulation rate was further increased.

Results of the second experiment shows that the vowel scores increased from 48% to 65% for normal hearing listeners and from 34% to

49% for implant listeners when the cutoff frequency was increased from 2 Hz to 10 Hz. No significant improvement was noticed above 10 Hz.

Consonant Recognition

Twenty-four post-lingually deafened adults were evaluated for the SPEAK strategy implemented in the Nucleus Spectra 22 speech processor (Whitford et al.1995). Consonant recognition was tested using one closed-set consonant identification list which includes 12 consonants (p, b, m, v, f, s, z, t, n, d, k, g) in an /a/- consonant /a/ context. Results indicated that the mean scores of individual subjects obtained using SPEAK strategy were significantly higher at the 5% level than scores obtained using MPEAK for 58.3% of subjects. The group mean score for consonant identification test was 12% higher for SPEAK than that obtained for MPEAK and that difference was highly significant.

In 1995, Manrique, Ramos, Morera, Sainz, Algaba and Cernera-paz reviewed the benefits of the implantation with a Nucleus-22 device in nine post-lingual deaf adults. Study also compared performance with hearing aid preoperatively and with CI postoperatively or CI with contralateral hearing aid. Analysis of the open-set consonant test showed mean improvement for the implant alone and binaural listening conditions post implant. Mean scores improved from 20.1 % preoperatively to 49.2% (implant alone) and 45.9% (binaural) by 6 months post-implantation. Scores for the contralateral (non-implant) ear remained essentially unchanged at the six month test interval.

Fujiki et al, (1998) evaluated the effects on speech perception performance of coding strategies MPEAK and SPEAK. Nineteen postlingually deaf adult CI users participated in the study of which six used MPEAK and twelve used SPEAK. The evaluation of speech performance included consonant perception in addition to vowel recognition and speech tracking performance. In consonant recognition test. 13 Japanese consonants as C-V syllables were used (pa, ta, ka, ba, da, ga, ha, sa, za, ma, na, ra, ja). The CV syllable recognition for MPEAK group ranged from 9 to 54% (mean 32.7) and 9 to 71% (mean 43.5) for SPEAK group. One patient who had upgraded his CI from MPEAK to SPEAK showed an improvement in CV syllable recognition from 20 to 57%.

The objective of the study done by Fu and Shannon in 1999 was to determine how phoneme identification was affected by the cochlear location and spacing of electrodes m Nucleus-22 implantees. Three postlingually deaf adults were included. Vowel and consonant recognition scores were analysed. Consonant recognition was measured in a 16 alternative identification paradigm for the consonants (b, d, g, p, t, k, L, m, n, f, s,J,v, z, e, *dz)* presented in as /a/ consonant /a/ context. Consonant recognition scores with electrodes in the most apical location, there was no significant difference between four and 20 electrodes. Consonant recognition decreased from 63.6% in condition where placement was most apical to 52.6% when electrodes were shifted 3 mm basally Recognition of consonant was poorest (45.9%) when electrodes were most closely spaced. When electrode spacing was increased to 3-4.5 mm consonant recognition increased to 67.6% correct. Consonant recognition for four electrodes with spacing between 3 to 4.5 mm was not significantly different from 20 electrode performance.

Differences in consonant recognition with MPEAK and SPEAK strategies of Nucleus-22 cochlear implants were studied by Skinner, Fourakis, Holden, Demorest and Holden (1995). Nine post-linguistically deaf adults participated is the study. Fourteen consonants were presented in an /aCa/ context (p, b, t, d, k, g, s, z, , dz, f, v, m, n) for evaluating the scores Mean consonant score across subjects was significantly higher with the SPEAK strategy (76.2%) than with the MPEAK (67.5%)

Zeng and Galvin (1999) studied the effect of amplitude mapping parameters on speech recognition. Four Nucleus-22 patients using SPEAK participated in the study. Stimuli for consonant recognition was 16 consonants which included /b, d, g, p, t, k, f,θ, s, , v, *x*, z,z, m, n/ in /aCa/ format. Results indicated no significant effect of amplitude compression on consonant recognition. Effect of electrode number shows that for consonant recognition, the percent correct score decreased from 66% with 20 electrodes to 59% with 10 electrodes to 53% with four electrodes. Effect of dynamic range reduction shows that consonant recognition was not significantly affected.

Six post-lingually deafened adults using the Nucleus-22 cochlear implant were studied by Fu and Shannon (2000). Experiments measured vowel and consonant recognition as a function of stimulation rate and cut off frequency of the envelope filters. Consonant recognition was measured in a 16-alternative identification paradigm, for the consonants, (b,d,g,P,t,k,l,m,n,f, s, , z, v, dz) presented in an /a/ consonant /a/ context. Mean individual consonant, recognition score was 37% for stimulation rate as 50 pps/channel. Mean scores increased significantly to 61% correct when rate was increased. For second experiment, consonant scores increased when the cutoff frequency was increased from 2 to 20 Hz dramatically to 56% correct.

Agelfors in 2000 evaluated two groups of hearing impaired adults. One group consisted of four cochlear implantees who used MPEAK strategy for some time and was upgraded to the SPEAK strategy. The other group consisted of hearing aid users. The aim was to evaluate the change in performance when SPEAK replaced MPEAK strategy. The test battery consisted of speech perception tests and self-rating performance inventory. The speech test include segmental test, test of prosodic contrasts and connected discourse tracking.

Test for consonant recognition consisted of sixteen consonants in /aCa/ context preceded by a carrier phrase. Swedish consonants like (p, b, m, t, d, n, k, g, f, v, s, , v, 1, j). These were distinct in voicing, place of articulation and manner of articulation. Results showed that subjects obtained audiovisually a significant improvement $p < 0.05$ with SPEAK compared to MPEAK on VCV-test.

Word Recognition

Whitford et al. (1995) studied twenty-four postlingually deaf adults using Nucleus spectra 22 speech processor and SPEAK strategy. One list of open-set CNC words were used to analyze the word recognition.

For 33.3% of subjects mean scores obtained using SPEAK were significantly higher at the 5% level than scores obtained using MPEAK. There was a small (5%) increase in the group mean score for SPEAK compared to MPEAK coding strategy.

The benefits of Nucleus-22 device used by nine post lingual deaf adults was studied by Manrique et al, (1995). A comparison was made between hearing and preoperatively and CI post operatively or CI with contralateral hearing aid.

Bisyllable words were used to assess the word recognition. Improved performance was observed on this test for both the implant alone and implant with contralateral hearing aid conditions compared to the best preoperative hearing aid score. By six months after implantations, mean scores improved from 20.4% preoperatively to 57.4% (implant alone) and 44% (binaural devices) postoperatively.

Sentence Recognition

In addition to studying consonant and word recognition Manrique et al, (1995), also evaluate the perception of sentences on nine post lingual deaf adults. They compared the performance of the subjects with hearing aid preoperatively and with Nucleus 22 post operatively or the CI with contralateral hearing aid. CID translated sentence lists were used to analyze sentence recognition

Mean results improved from 22.3% (preoperatively) to 72.6% (implant alone) and 71.2% (binaural) after implantation.

Whitford et al. (1995) in the evaluation of SPEAK strategy on 24 adults, used two lists of open-set sentences in quiet, two lists of open set sentences at +10 dB S/N ratio and two lists of open-set sentences at +5 dB and +15 dB S/N ratio to study sentence recognition in addition to other tests. Also a CUNY (City University of New York) sentence list was used for nine subjects and an alternative Speech Intelligibility Test for Deaf

Children (SIT) sentence test was used for 12 subjects in addition to the other tests for sentence recognitions.

Results showed that the mean score in quiet for the group of subjects evaluated with SIT sentences was 59.0% for the SPEAK and 49.6% for the MPEAK. The mean score for the group evaluated with CUNY sentences was 87.6% for SPEAK compared to 75.7% for MPEAK Mean test scores for open-set sentences at +10 dB S/N ratio for SPEAK were twice that compared to that obtained for MPEAK. Mean scores obtained for sentences at +15 dB S/N ratio for SPEAK were significantly higher than those for MPEAK.

Battmer, Reid and Lenarz (1997) examined the effects of different listening conditions on the performance of subjects. Two groups of adult cochlear implanters were taken. One group filted with Nucleus Mini 22 with SPEAK strategy and the other group used clarion with CIS strategy. Test battery included the Innsbrucker Sentence Test which had 20 lists withlO sentences and 53 words per list and Gottinger Sentence Test consisting of 20 lists each containing 10 sentences and a total of 50 words. Subjects were assessed in +15 dB S/N and +10 dB S/N test condition.

Results showed that at +15 dB S/N a mean of 76.5% and at + 10 dB S/N a mean of 68.5% was obtained for Innsbrucker Sentence Test for the Nucleus subjects. For the Gottinger Sentence Test a mean of 68.9% at +15 dB S/N and 55.3% at +10 dB S/N was obtained for the Nucleus subjects.

Ebinger, Staller and Hines (1999) evaluated SPEAK, CIS, and ACE strategies incorporated in Nucleus 24 device. Subjects were post-lingual deaf adults. They had access to all three strategies simultaneously and were evaluated in both quiet and noise conditions. Mean Hearing In Noise Test (HINT) sentence scores in quiet were 69.2% for SPEAK, 66% for CIS and 72.3% for ACE. The ACE mean was significantly higher than the CIS mean. The mean CUNY sentence recognition in noise was significantly better for ACE (71%) compared to both CIS (65.3%) and SPEAK (63.1%). Mean sentence recognition in noise improved from 63.1% when subjects had access to only one strategy SPEAK, to 76.2% when each subject had access to any strategy, supporting the hypotheses that access to multiple coding strategies and flexible parameter choices results in improved patient outcome.

Connected Discourse Tracking (CDT) Performance

Study done by Fujiki et al. (1998) evaluated the effects of speech coding strategy on speech perception performance. Nineteen deaf adult CI users were studied. Speech tracking performance in Japanese language was assessed in addition to vowel and consonant recognition. In speech tracking test, as easy modern Japanese literature was orally given to the patients and task was to repeat after each phrase. The correct phrases per minute was calculated. The results of the speech-tracking test for the MPEAK ranged from 1 to 25 (mean 12.4) phrases/min in Japanese sentences. Whereas for SPEAK group it ranged from 14 to 34 (mean 3.2) phrases/min. Result of speech-tracking test in the SPEAK group was significantly better than that in MPEAK group.

Agelfors (2000) evaluated the tracking performance in four adult cochlear implantees (Nucleus-22) in addition to segmental test and test, of prosodic contrast. Aim was to evaluate the change in performance when MPEAK was replaced by SPEAK strategy. The speech material chosen had a relatively consistent level of reading difficulty. Results of CDT in audio mode for MPEAK group was 15 words/min and 22.5 words/min for the SPEAK group. Whereas scores for audiovisual mode was 52 words/min and 62.5 words/min for MPEAK and SPEAK group respectively.

Suprasegtnentals

A group of four adult cochlear implanters who used MPEAK and then upgraded to SPEAK strategy were studied by Agelfors (2000). The test battery consisted of speech perception tests which included segmental test, test of prosodic contrast and connected discourse trading. In the test of prosodic contrast specific prosodic features like vowel length (long and short vowels) juncture, tone and word emphasis in 2-word sentences were assessed. Two test lists were created and was done in situations as audiovisual and audition alone.

The mean score for the prosodic contrast showed no differences between the two coding strategies. Percentages correct scores in audition alone situation are 82.3% and 83.9% for MPEAK and SPEAK respectively. Whereas the scores were 86.1% for MPEAK and 88.9% with SPEAK in audiovisual mode of presentation.

Speech Perception Performance-Children

*Vowel **and Consonant Recognition***

Investigations done by Sehgal, Kirk, Svirsky and Miyamoto (1998) examined the speech perception skills of pediatric cochlear implant users who changed from their original speech processors and strategies to the spectral peak strategy. Eleven profoundly hearing-impaired children below nine years participated in the study. Speech perception skills were evaluated on closed-set and open-set word recognition tests. Children's responses were scored by the percentage of consonant features (voicing, manner and place) or vowel features (vowel height and place) that were recognized correctly in addition to getting word scores. In PBK test, the results showed a trend for mean phoneme scores to increase in SPEAK condition (40% and 50% for the original and SPEAK strategies). Two subjects obtained a significantly higher phoneme score with SPEAK than MPEAK. Increases in phoneme scores ranged from 24% to 39%.

Word Recognition

Besides evaluating the phoneme scores Sehgal et al. (1998) examined the word recognition scores in eleven profoundly hearing impaired children. These children had changed their strategy to SPEAK. The word scores where obtained for one closed set test and three open set tests. The closed set test was the Minimal Pairs Test which assesses discrimination of 80 pairs of words that differ by a single vowel or consonant feature. The PBK 50, a four 50 item word list assess recognition of monosyllabic words. Open set word identification was also assessed using the Lexical Neighbourhood test (LNT) and Multisyllabic Lexical Neighbourhood Test (MLNT). These two test contains words frequently produced by young children.

Results of minimal pair test, the mean pre-SPEAK (MPEAK/FO, FI, F2) score was 80% (SD=10) and the mean post-SPEAK score was 84% (SD=10). Change was not significant. For PBK test average word recognition scores were somewhat lower at the pre-SPEAK (14%) man at the post-SPEAK (27%).

The average LNT word recognition scores were 28% for the original strategy and 51% for the SPEAK. The percentage of words correctly identified by the 11 subjects ranged from 0% to 80% in the SPEAK condition. Average MLNT word recognition scores increased from 38% for the original strategy to 71 % for the SPEAK strategy.

Environmental sound detection

Staller, Dowell, Beiter and Brimacombe (1991) administered sound effect recognition test (SERT) on children wearing Nucleus implant and reported that fifty-seven out of fifty-eight children detected the presence of environmental sounds presented at 70 dB SPL. Thirty of fifty-eight (52%) children scored above chance on the test.

SERT was done on twenty-four children, with Nucleus implant, prelingual and postlingual, by Osberger, Robbins, Miyamoto and Berry (1991). They averaged 52% correct scored on this test. About 50% of the children scored above 40%. It was concluded that one half of the children with the Nucleus cochlear implant can recognize environmental sound without visual cues.

Majority of the studies indicate that speech was perceived better when SPEAK strategy was used. It was noted that perception of pure vowels was better with MPEAK. Perception of vowels varied depending on the number of electrodes stimulated and the placement of electrodes. It did not vary with use of amplitude compression. Results of speech tracking testing using SPEAK was a better compared to MPEAK. Studies on paediatric population also showed a similar trend. More recent literature show that scores on sentence recognition showed highest results with ACE when compared to CIS and SPEAK strategy.

SUMMARY

Literature on various recent advances in cochlear implant technology and improvement in speech perception performance have been reviewed for the past eight years. Different multichannel implant systems like Clarion, Ineraid, Nucleus, Combi 40, Laura, Digisonic are discussed on about their device descriptions and performance. Table 1 gives a summary of the design characteristics of cochlear implant system.

Speech recognition performance studies are reviewed for adults and children. Variations in performance across speech encoding strategies MPEAK, SPEAK, CIS. Studies in various parameters of speech perceptions in terms of vowels, consonants, words, sentences and continuous discourse are summarised. Information regarding perceptional suprasegments and environment sounds have also been reported wherever available. A few studies in single channel implants have been highlighted, but main concentration is on the multichannel implants and its advances in recent past. The number of studies carried out on the peadiatric population is lesser when compared to adults.

Table 1 : Design characteristics of cochlear implant system.

Characteristics	Nucleus CI-22M	Nucleus CI-24M	Clarion	MED-EL/Combi 40	Symbion/Ineraid	Laura
Manufacturers	Cochlear Limited, Australia	Cochlear Limited, Australia	Advanced Bionics Corporation, USA	MED-EL, Austria	Symbion	Philips, Belgium
Actual channels per stimulation cycle	3-10 Avg. 6, bipolar common ground	12 bipolar monopolar, common ground	8 mono/bipolar	12 monopolar	4 monopolar	8 mono/bipolar
Electrode contacts	22	24 + ground	16 +ground	24 + ground		16 + ground
Electrode spacing	0.75		2.0 mm	2.6 mm	4 mm	2.05 mm
Stored programs	1	4	3	3	-	1
Transcutaneous or percutaneous link	Transcutaneous	Transcutaneous	Transcutaneous	Transcutaneous	Transcutaneous	Transcutaneous
(Max. Stimulation rate	Max 2,000	Max 14,000	Max 6,677	Max 1,800	Continuous wave form	Max 12,500
Rate per channel	300	2,400	833	15,000		1,500
Intra/extra cochlear implant	22 intra	22 intra-bipolar 2 extra-monopolar	16 intra	22 intra 2 intra,	6 intra	16 intra
Strategies used	Fo/FI, Fo/FI,F2, MPEAK, SPEAK, CIS	SPEAK, CIS, ACE	Analog, CIS	CIS	Analog, CIS	

Table 2 : Comparison of speech perception performance across strategies for various implant system

A. Vowel recognition

MPEAK	SPEAK	Analog	CIS
Scores were lower than SPEAK for closed-set vowels using Nucleus (Whitford et al., 1995)	3% higher scores than MPEAK with Nucleus for closed set vowels (Whitford et. al., 1995)		
Scores of 72.3% for 14 vowels (9 pure & 5 'r' coloured) using Nucleus implant Scores were 10-14% higher with MPEAK for pure vowels (Skinner et al., 1999)	73.4% scores for 14 vowels (9 pure & 5 'r' coloured) using Nucleus For V coloured vowels scores were 9-22% higher with SPEAK than MPEAK (Skinner et al., 1999)		
40% scores on PB-K list with MPEAK in Nucleus On LNT, scores obtained were 46% using MPEAK (Sehgal 1998)	50% phoneme score on PB-K test using Nucleus with SPEAK strategy Phoneme score of 63% on LNT with SPEAK (Sehpiet al., 1998)		
		67.1% with SD of 14.3 for seven French vowels using Ineraid speech processor. Pelizzone et al., 1999)	63.8% (SD = 15.7) for seven French vowels with Ineraid device using CIS strategy. (Pelizzone et al., 1999)

B. Consonant recognition

MPEAK	SPEAK	Analog	CIS
Scores were lower on closed-set consonants with Nucleus using MPEAK (Whitford et al., 1995)	12% higher scores than MPEAK on closed-set consonants with SPEAK in Nucleus (Whitford et al., 1995)		
		Lower scores were obtained compared to CIS strategy on 14 French consonants using Ineraid device (Pelizzone et al., 1995)	Scores were 11% higher than Ineraid analogue strategy on 14 French consonants with Ineraid device (Pelizzone et al., 1995)
	-	50% correct scores in a closed-set format of consonants using CA strategy with Clarion (Doyle etal., 1995)	Scores were 50% for consonants in closed-set format using CIS strategy with Clarion. (Doyle et al., 1995)
		51% scores (SD = 9%) obtianed for 16 consonant test using Ineraid processor strategy (Dorman & Loizou, 1996)	81% scores for the 16 consonants with CIS in Ineraid implants (Dorman & Loizou, 1996)
9-54% (Mean = 32.7) for 13 Japanese consonants using Nucleus with MPEAK (Fujiki et al., 1998)	9-71% (Mean = 43.5) for the 13 Japanese consonants using SPEAK in Nucleus (Fujiki et al., 1998)		-

		Scores were 45.4% (SD = 18.7%) on 14 French Consonants using Ineraid processor (Pelizzone et al. 1999)	55.3% scores (SD = 20%) on 14 French consonants using CIS with Ineraid device. Fricatives were better identified with CIS (Pelizzone et al., 1999)
Scores were 67.5% on the 14 consonant test using MPEAK with Nucleus device (Skinner et al., 1999)	76.2% scores on 14 consonant test using SPEAK with Nucleus stops and fricatives were well identified compared to MPEAK (Skinner et al., 1999)		
57.4% mean score on 16 Swedish consonant test with SPEAK using Nucleus device (Agelfors, 2000)	Mean score of 62.6% on 16 Swedish consonants with SPEAK using Nucleus device Fricatives & stops were better perceived with SPEAK in Nucleus (Agelfors, 2000)		

C. Word recognition

MPEAK	SPEAK	Analog	CIS
			96% or higher scores on 25 two syllable words compared to C.A. 95% or higher as 100 key words is CK) sentence 92% or higher on final word in each of 50 sentences of SPIN test using Ineraid device (Wilson et al., 1993)
Scores lower as open-set monosyllabic words, compared to SPEAK, using Nucleus device (Whitford et al., 1995z)	5% higher scores than MPEAK while using SPEAK with Nucleus on open-set monosyllabic words (Whitford et al., 1995)		
Range of 20-74% for MPEAK as monosyllabic word test using Nucleus (Diller, Battmer, Doling & Muller-Derle, 1995)	Scores ranged 22.5 - 85% on monosyllabic word test for SPEAK with Nucleus (Dilleretal., 1995)		
Scores of 19.2% obtained on NU-6 word test for Nucleus using MPEAK (Tyler, Lowder, Parkinson, Woodworth & Gantz, 1995)			

[Lower scores with MPEAK in Nucleus device on Monosyllabic word test (Holden et al., 1997)	13% higher scores for SPEAK, compared to MPEAK, using Nucleus as monosyllable word test (Holden et al., 1997)		
14% scores for MPEAK with Nucleus on PB-K test. Scores of 28% obtained on LNT with MPEAK (Sehgal etal., 1998)	27% scores obtained on PB-K test for SPEAK with Nucleus. 51% recognition scores for LNT with SPEAK (Sehgal et al., 1998)		
		48% word recognition scores with SAS using Clarion device (Osberger, 1998)	31% correct scores for CIS strategy for word recognition with Clarion (Osberger, 1998)
		39.4 % scores as monosyllable words when had a choice of CIS/SAS with Clarion device. (Battmer et al., 1999)	28.7% scores obtained on monosyllable words when used CIS only with Clarion system (Battmer et al., 1999)

MPEAK	SPEAK	Analog	CIS
4-96% of scores for MPEAK was Nucleus on Innsbruck sentence test (Diller et al., 1995)	Range of 46-100% for SPEAK with Nucleus on Innsbruck sentence test (Diller et al., 1995)	-	
42.6% is the Iowa sentence test for Nucleus using MPEAK strategy (Tyler et al., 1995)			
49.6% scores on SIT sentences in quiet for MPEAK users of Nucleus Scores on CUNY sentences in quiet for MPEAK was 75.7% 23.4% in the presence of + 15 dB noise for SIT and 50.9% for CUNY sentences using MPEAK with Nucleus (Whitford) et al., 1995)	59.0% scores for SIT sentences in quiet using SPEAK with Nucleus 87.6% on CUNY sentences in quiet for SPEAK 42.1 and 75.5 % scores for SIT and CUNY sentences in the presence of + 15 dB noise with SPEAK (Whitford et al., 1995)		

	Scores were 79% for quiet, 66% for 15 dB noise and 56% for 10 dB noise conditions for Innsbruck sentence (Keifer, Muller & Pfennigdorff 1996)		In quiet scores were 88% for 15 dB noise and 72% correct for 10 dB noise for Innsbruck sentences using CIS (Keifer et al., 1996)

SPEAK	ACE	CIS
69.2% for SPEAK in HINT sentence scores in quiet suing scores in quiet using Nucleus device 63.1% for SPEAK on CUNY sentences in noise using Nucleus (Ebinger etal., 1999)	72.3 % on HINT sentence n quiet using Nulceus for ACE Score of 71% when used ACE with Nucleus in noise on CUNY sentences (Ebinger et al., 1999)	66 % in quiet for CIS using Nucleus on HINT sentences. 65.3% scores as CUNY sentences in noise conditions for CIS with Nucleus. (Ebinger et al., 1999)

The results of the investigation carried out to evaluate speech perception abilities of the cochlear implantees with different implant systems and speech coding strategies are summarised in Table 2.

The results based on the studies done on a single channel and multi channel users revealed that overall speech perception abilities were better with multi channel implants (Cohen, Waltzman & Fisher, 1991). Review of multi channel implants show that Nucleus, Cochlear limited, has the maximum number of studies. Literature gives very less information regarding latest deviced systems like Laura and Digisonic implant system.

For the speech encoding strategies, the maximum number of studies available on the comparison of SPEAK and MPEAK. Researches have also been done for CIS and other analog strategies. ACE is the latest advancement in coding strategy. Currently, the research available using this strategy is rather limited. Considerably more research is available regarding SPEAK and CIS. A definite conclusion regarding the usefulness of strategies cannot be drawn as a direct comparison is not possible due to the variabilities in the studies. These variables include age of subjects, age of implantation, language used, number of years of use with the implants. However an attempt has been made to compare different studies using various strategies.

Comparing the studies, it can be noted that the SPEAK strategy has resulted in the maximum score for recognition of a combination of pure and V coloured vowels. However, for pure vowels, MPEAK resulted in the best perception. (Skinner etal., 1999). CIS strategy used with the Ineraid device shows better recognition scores for consonants (Dorman and Loizou, 1996) as well as for words (Wilson et al., 1993).

For sentence recognition, the highest scores were obtained with ACE in Nucleus, in both quiet and noisy conditions. This was followed by SPEAK in quiet and CIS in noisy conditions (Ebinger et al., 1999).

/ In conclusion, based on the evidences of the research, devices incorporating strategies like SPEAK, CIS and ACE have shown to have better speech recognition. However, there is considerable variability among individuals for each of the strategies. The choice of the most appropriate strategy would have to be decided on an individual's personal preference.

BIBLIOGRAPHY

Agelfors (2000). Comparison between the multipeak (MPEAK) speech coding strategies on objective and subjective speech tests by some cochlear implants. TMH - QPSR 2-3/2000, 69-83.

Battmer, R.D., Zilberman, Y., Haake, P., & Lenarz, T., (1999). Simultaneous analog stimulation (SAS) - continuous interleaved samples (CIS): Pilot comparison study in Europe. Annals of Otology, Rhinology, Laryngology, 108, 69-73.

Battmer, R.D., Reid, J.M., & Lenarz, T. (1997). Performance in quiet and in noise with the Nucleus spectra-22 and the clarion CIS/CA cochlear implant devices. Scandinavian Audiology 26, 240-246.

Beiter, A.L., Brimacombe, J.A. (2000). Cochlear implants. In J. J. Alpiner, PA. McCarthy (Eds.) Rehabilitative Audiology : children & adults, pp. 473-500, Philadelphia : Lippincott Williams & Wilkins

Berliner K.I., Tonokawa, L.L., Dye, L.M., & House, W.F. (1989). Open-set speech recognition in children with a single channel cochlear implant. Ear & Hearing, 10(4), 257-242.

Cohen, N.L., Waltzman, S.B., & Fisher, S.G. (1991). Prospective randomised clinical trial of advanced cochlear implants : Preliminary results of a Department of veterans Affairs cooperative study. Annals of Otology, Rhinology, Laryngology, 100, 823-829.

Danley, M.J., & Fretz, R.J. (1982). Design and functioning of the single-electrode cochlear implant. Annals of Otology, Rhinology, Laryngology. 91 (Suppl. 91), 21-26.

Diller, N., Battmer, R.D., Doring, W.H. & Muller - Weile, J. (1995). Multicentric field evaluation of a new speech coding strategy for cochlear implants. Audiology, 34 : 145-159.

Dorman, M., Soli. S., Dankowski, K., Smith, L., Mc Candless, G. & Parkin, J. (1990). Acoustic cues for consonant identification by patients who use the Ineraid cochlear implant. Journal of the Acoustical society of America, 88, 2074 - 2079.

Dorman, M.F. & Loizou, P.L. (1996). Improving consonant intelligibility for Ineraid patients fit with continuous interleaved sampling (CIS) processors by enhancing contrast among channel outputs. Ear and Hearing, 17(4) 308 - 313.

Dorman, M.F., Loizou, P.C. (1998). The identification of consonants and vowels by cochlear implant patients using a 6 channel continuous interleaved sampling processor and by normal subjects using simulations of processors with two to nine channels. Ear and Hearing, 19(2), 162-166.

Doyle, K.J., Mills, D., Larky, J., Kessler, D., Luxford, W.M. & Schindler, R.A. (1995). Cited in Kirk, K.I.(2000). Challenges in clinical investigation of Cochlear implant outcomes. In J.K. Niparko, K.I. Kirk, N.K. Mellon, A.M. Robbins, D.L. Tucci, B.S. Wilson (Eds.) Cochlear implants - principles and practices pp. 240 Philadelphia: Lippincott Williams and Wilkins.

Eddington, D.K. (1980). Speech discrimination in deaf subject with cochlear implants. Journal of Acoustical society of America, 68, 885-891.

Fertz, R.J., & FraveL R.P. (1985). Design and function : A physical and electrical design description of the 3M/House Cochlear Implant. Ear and Hearing, 6 (Suppl.3), 148-193.

Fu, Q.J., & Shannon, V.V. (1999). Effects of electrode location and spacing on phoneme recognition with the Nucleus - 22 cochlear implant. Ear and Hearing, 20(4), 321-351.

Fu, Q.J., & Shannon, V.V. (2000). Effect of stimulation rate on phoneme recognition by Nucleus - 22 cochlear implant listeners. Journal of Acoustical Society of America, 107(1), 589-597.

Fujiki, N., Naito, Y., Hirano, S., Kojima, H., Kamoto, Y., Nishizama, S., Konishi, J., Honjo, I. (1998). Influence of speech-coding strategy on cortical activity in cochlear implant users : a position emission tomographic study. Acta Otolaryngologica (Stockh), 118.787-802.

Gantz, B., Tyler, R., Knutson, J., Woodworm, G., Abbas, P., McCabe, B., Hinricks, J., Tye-Murray, N., Lansing, C, Kuk, F., & Brown, C. (1988). Evaluations of five different cochlear implant designs:

Audiologic assessment and predictors of performance. Laryngoscope, 98, 1100-1106.

Gstoettner, W.K., Hamzavi, J., & Baumgartner, W.D. (1998). Speech discrimination scores of post lingually deaf adults implanted with the Combi 40 cochlear implant. Acta Otolaryngologica, 118, 640-645.

Gstoettner, W.K., Baumgartner, W.D., Franz, P., & Hamzavi, J. (1997). Cochlear implant deep insertion surgery. Laryngoscope, 107, 544-546.

Helms, J., Muller, J., & Schon, F. (1997). Cited in Kirk, K.I. (2000). Challenges in clinical investigation of cochlear implant outcomes. In J.K. Niparko, K.I. Kirk, N.K. Mellon, A.M. Robbins, D.L. Tucci, B.S. Wilson (Eds.). Cochlear implants - principles and practices, pp.241. Philadelphia : Lippincott Williams and Wilkins.

Hnath-Chisolm, T. (1994). Cochlear implants and tactile aids. In J. Katz (Ed), Handbook of Clinical Audiology. pp. 747-748, Baltimore : Williams and Wilkins.

Hochmair & Hochmair - Desoyer (1985). Cited in Dorman, M.F. (1995). Speech perceptions by adults. In R.S. Tyler (Ed.) Cochlear implants - Audiological Foundations, pp. 145-190, Delhi: AITBS.

Hochmair - Desoyer, I, Hochmair, K., Burian, K. (1985). Cited in Dorman, M.F. (1995). Speech perceptions by adults. In R.S. Tyler (Ed.) Cochlear implants - Audiological Foundations, pp. 145-190, Demi: AITBS.

Hochmair - Desoyer 1, & Hochmair, E. (1996), Cited in Allum. D.J. (1996). Basics of cochlear implant systems. In D.J. Allum (Ed). Cochlear implant rehabilitation in children and adults, pp.12 - 14, London : Whurr Publishers.

Hochmair - Desoyer, I.J., Hochmair, E.S., & Stiglbrunner, H.K. (1985), Cited in Kirk, K.I. (2000). Challenges in clinical investigation of cochlear implant outcomes. In J.K. Niparko, K.I. Kirk, N.K. Mellon, A.M. Robbins, D.L. Tucci, B.S. Wilson (Eds). Cochlear implants - principles and practices, pp.234-235. Philadelphia : Lippincott Williams and Wilkins.

Holden, T.A., Holden, L.K., & Demorest, M.E. (1996). Identification of speech by cochlear implant recipients with the multipeak (MPEAK) and spectral peak (SPEAK) speech coding strategies I - vowels. Ear and Hearing, 17 (3), 182-197.

Holden, L.K., Skinner, M.W., & Holden, T.A. (1997). Cited in Kirk, K.I. (2000). Challenges in clinical investigation of cochlear implant outcomes. In J.K. Niparko, K.I. Kirk, N.K. Mellon, A.M. Robbins, D.L. Tucci, B.S. Wilson (Eds.) Cochlear implants - Principles and practices, pp. 236-237. Philadelphia : Lippincott Williams ad Wilkins.

House, W.F., & Berliner, K.K. (1991) Cited in Beiter, A.L., & Brimacombe, J.A., P.A. McCarthy (Eds.) Rehabilitative Audiology : children & adults, pp.473-474, Philadelphia : Lippincott Williams & Wilkins.

House, W.F. (1996). The All Hear Cochlear implant system : the All Hear Devices, their manufacture, preliminary Test results, & the Future Imitations CD-R 8X CA : All Hear Inc.

Keifer, J., Muller, J., & Pfenningdorff, T. (1996). Cited in Wilson B.S. (2000). Strategies for representing speech informations with cochlear implants. In J.K. Niparko, K.I. Kirk, N.K. Mellon, A.M. Robbins, D.L. Tucci, B.S. Wilson (Eds.). Cochlear implants-principles and practices, pp. 160. Philadalphia : Lippincott Williams and Wilkins.

Kirk, K.I. (2000) Challenges in the clinical investigations of cochlear implant outcomes. In J.K. Niparko, K.I. Kirk, N.K. Mellon, A.M. Robbins, D.L. Tucci, B.S. Wilson (Eds.). Cochlear implants-principles and practices, pp. 225-267. Philadalphia : Lippincott Williams and Wilkins.

Kessler, D.K. (1999). The clarion multi strategy cochlear implant. Annals of Otology, Rhinology, Laryngology, 108, 8-16.

Kessler, D.K., & Schindler, R.A. (1994). Cited in Beiter, A.L., & Brimacombe, J.A., P.A. McCarthy (Eds.) Rehabilitative Audiology : children & adults, pp.477-478, Philadelphia : Lippincott Williams & Wilkins.

Lalwani, A.K., Larky, J.B., & Warieng, M.J. (1998) Cited in Beiter, A.L., & Brimacombe, J.A., (2000) Cochlear implants. In J.G. Alpiner

& P.A. McCarthy (Eds.) Rehabilitative Audiology : Children & adults, pp. 479-480, Philadelphia : Lippincot Williams & Wilkins.

Luxford, W.M., & Brackmann, D.C. (1985). Cited in Beiter, A.L., & Brimacombe, J.A., (2000) Cochlear implants. In J.G. Alpiner & P.A. McCarthy (Eds.) Rehabilitative Audiology : Children & adults, pp.473-474, Philadelphia : Lippincot Williams & Wilkins.

Manique, M., Ramos, A., Morera, C, Saniz, M., Albaga, J., & Cervera-Paz, F.J. (1995). Spanish study group on cochlear amplification. Acta Otolaryngologica (Stockh), 118, 635-639.

Mecklenburg, D.J., & Shallop, J.K. (1988) Cited in Beiter, A.L., & Brimacombe, J.A., (2000) Cochlear implants. In J.G. Alpiner & P.A. McCarthy (Eds.) Rehabilitative Audiology : Children & adults, pp.477 - 479 Philadelphia : Lippincot Williams & Wilkins.

Mckay, C, (1991) Cited in Allum, D.J. (1996) Basics of Cochlear implant system. In D.J.Allum (Ed.) Cochlear implant rehabilitation in children and adults, pp. 12-14, London: Whurr Publishers.

Miller, G., & Nicely, P. (1995) Cited in Dorman, M.F., & Loizou, PC. (1998). The identifications of consonants and vowels by cochlear implant patients using a 6-channel continuous interleaved sampling processor and by normal hearing subjects using simulations of processors with two to nine channels. Ear and Hearing 19(2), 162-166.

Osberger, M.J., Robbins, A.M., Miyamoto, R.T., Berly, S.W., Mario W.A., Kessler, K.S., & Pope, ML. (1991) Cited in Tyler, R.S. (1995). Speech perceptions by chldren. In R.S Tyler(Eds), Cochlear implants - Audiological foundations, pp. 191-256, Delhi: A.I.T.B.S.

Osberger, M.J. (1998). Cited in Kirk, K.I (2000). Challenges in clinical investigation of cochlear implant outcomes. In J.K. Niparko, K.I. Kirk, N.K. Mellon, A.M. Robbins, D.L. Tucci, B.S. Wilson (Eds.). Cochlear implants-principles and practices, pp. 240. Philadelphia: Lippincott Williams and Wilkins.

Osberger, M.J., & Fisher, L.M. (1998). Cited in Kirk, K.I. (2000) Challenges in clinical investigation of cochlear implant outcomes. In J.K. Niparko, K.I. Kirk, N.K. Mellon, A.M. Robbins, D.L. Tucci, B.S.

Wilson (Eds.). Cochlear implants-principles and practices, pp.246. Philadelphia: Lippincott Williams and Wilkins.

Parkinson, A.J., Tyler, R.S., Woodworth, G.G., Lowder, & M.W., Gantz, B.J. (1996). A within - subject comparison of adult patients using the Nucleus F_0FiF_2 B3B4B5 speech processing strategies. Journal of Speech & Hearing Research, 39 : 261-277.

Patrick, J.F., & Clark, G.M. (1991). The Nucleus 22-channel cochlear implant system. Ear and Hearing, 12 (Suppl. 1) 35-93.

Pelizzone, M., Cosendai, G., & Tinembart, J. (1999). Within patient longitudinal speech reception measures with continuous interleaned sampling processors for Ineraid implanted subjects. Ear and Hearing. 20(3), 228-237.

Pelizzone, M, Spano, D.B., Sigrist, A., Francois, J., Tinembart, J., Degie, C, & Montendon, P. (1995). First field trials with a portable CIS processor for the ineraid multichannel cochlear implant. Acta Otolaryngologica (Stockh), 115, 622-628.

Pfingnt, B.E. (1986). Stimulation and encoding strategies for cochlear prostheses. Otolaryngologic clinics of North America 19(2).

Richardoon. H.C., Beliaeff, M.G., Clarke, K.E., & Hawthorne, M. (1999). A three - array cochlear implant : a new approach for the ossified cochlea. The Journal of Laryngology and Otology, 113, 811-814.

Rosen, S., & Ball, V. (1986). Speech perceptions with the Vienna extracochlear single - channel implant. A comparison of two approaches to speech coding. British Journal of Audiology, 20, 61-83.

Schindler, R.A., & Kessler, D.K. (1992). Priliminary results with the Clarion cochlear implant. Laryngoscope 102 : 1006-1013.

Schindler, R.A., Kessler, D.K., & Barker, M. (1995). Clarion patient performance : an update on the clinical trials. Annals of Otology, Rhinology Laryngology, 166 (Supl.), 269-272.

Sehgal, S.T., Krirk, K.I., Svirsky, M., & Miyamoto, R.T. (1998). The effects of processor strategy on the speech perception performance of pediatric Nucleus multichannel cochlear implant users. Ear and Hearing, 19(2), 149-169.

Seligman, P., & McDermott, H. (1995). Architecture of the Spectra 22 speech processor. Annals of otology, Rhinology, Laryngology 104 (Suppl. 166), 139-141.

Shallop, J.K., & Mecklenburg, D.J. (1987) Cited in Cited in Kirk, K.I. (2000) Challenges in clinical investigation of cochlear implant outcomes. In J.K. Niparko, K.I. Kirk, N.K. Mellon, A.M. Robbins, D.L. Tucci, B.S. Wilson (Eds.). Cochlear implants-principles and practices, pp.473-474. Philadelphia: Lippincott Williams and Wilkins.

Skinner, M.W., Fourakis, M.S., Holden, T.A., Holden, L.K., & Demorest, M.E. (1999). Identification of speech by cochlear implant recipients with the multipeak (MPEAK) and spectral peak (SPEAK speech. Coding strategies II. Consonants. Ear and Hearing 20,(6), 443 -460.

Staller, S.J., Dowell, R.C, Beiter, A.C., & Brimacombe, J.A. (1991) Perceptual abilities of children with the Nucleus 22 channel cochlear implants. Ear and Hearing, 12(4), 345-475.

Tyler, R., Preece, J., & Tye-Murry, N. (1986) Cited in Dorman, M.F., & Loizou, P.C. (1998). The identifications of consonants and vowels by cochlear implant patients using a 6-channel continuous interleaved sampling processor and by normal hearing subjects using simulations of processors with two to nine channels. Ear and Hearing 19(2), 162-166.

Tyler, R.S., Moore, B.C.J., & Kuk, F.J.K. (1989) Performance of some of the better cochlear implant patients Journal of speech and hearing research, 32, 887-911.

Tye-Murray, N., & Tyler, R.S. (1989) Audiology consonant and word recognition skills of cochlear implant users. Ear and Hearing, 10, 292-298.

Tyler, R. (1990) What should be implemented in Future in cochlear implants? Acta otolacyngologica (Suppl. 469) 268-278.

Tyler, R.S., & Tye-Murray, N. (1991) cochlear implant signal processing strategies and patient perception of speech and environmental sounds. In H Cooper cochlear implants A practical guide, pp. 58-83, London : Whurr Publishers.

Tyler, R.S., Lowder, M.W., Parkinson, A.J., Woodworth, G.G., & Gantz, B.J. (1995) Performance of adult Ineraid and Nucleus cochlear implant patients after 3 - 5 years use. Audiology, 34 : 135-144.

Tyler, R.S., Gantz, B.J., Woodworth, G.G., Parkinson, A.J., Lowder, M.W., & Schon, L.K. (1996) Initial independent results with the clarion cochlear implant. Ear & Hearing, 17 : 528-536.

Von Wallenberg, Hochmair - Desoyer, I, & Hochmair, E. (1985) Cited in Tyler, R.S. (1995). Speech perception by children. In R.S Tyler, Cochlear implants - Audiological foundations, Delhi: A.I.T.B.S.

Von Wallenberg, Hochmair - Desoyer, I, & Hochmair, E. (1990) Initial results with simultaneous analogue and pulsatile stimulation of the cochlea. Acta otoloryngologica (Suppl. 4699), 140-149.

Wieringen, A.V., & Wouters, J. (1999) Natural vowel and consonant recognitions by Laura cochlear implantees. Ear and Hearing, 20(2) 89-103.

Wilson, B.S., Lawson D.T., Finley, C.C., & Wordford. R.D. (1991) Coding strategies for multichannel cochlear prosthesis. Annals of Otology, Rhinology & Laryngology 12 (Suppl.): 56 - 61

Wilson, B.S. (1993) Cited in Kirk, K.I. (2000) Challenges in clinical invesatigations of cochlear implant outcomes. In J.K. Niparko, K.I. Kirk, N.K. Mellon, A.M., Robbins, D.L. Tucci, B.S. Wilson (Eds.). Cochlear implants - principles & practices pp. 238-239, Philadelphia: Lippincott Williams & Wilkins.

Wilson, B.S., Lawson, D.T., Finley, C.C., & Wordford, R.D. (1993) Importance of patient and processor variables in determining outcomes with cochlear implants. Journal of Speech and Hearing Research: 36, 373-379.

Whitford, L.A., Seligman, P.M., Everingham, C.E., Antogneli, T., Skok, M.C., Hollow, R.D., Plant, K.L., Gerin, E.S., Staller, S.J., McDermott, H.J., Gibson, W.R., & Clark, G.M. (1995). Evaluation of the Nucleus spectra 22 processor ad speech processing strategy (SPEAK) in post lingually deafened adults. Acta Otolaryngologica (Stockh). 115 : 629-637.

Zeng, F.G., & Galvin, J.J. (1999). Amplitude mapping and Phoneme recognition in aochlear implant listeners. Ear & Hearing 20(1), 60-74

Zimmerman . Philips, S., Osberger, M.J., Geier, L., Barker. M. (1997) Cited in Kirk, K.I. (2000) Challenges in clinical investigations of cochlear implant outcomes. In J.K. Niparko, K.I. Kirk, N.K. Mellon, A.M., Robbins, D.L. Tucci, B.S. Wilson (Ed). Cochlear implants - principles & practices pp. 245-246, Philadelphia: Lippincott Williams & Wilkins. v