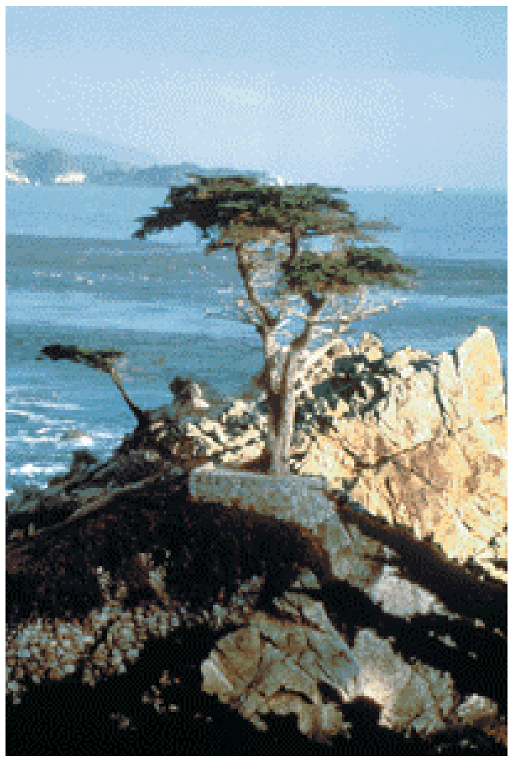
2005 CONFERENCE ON IMPLANTABLE AUDITORY PROSTHESES



JULY 30 - AUGUST 04, 2005

ASILOMAR CONFERENCE GROUNDS
PACIFIC GROVE, CALIFORNIA

2005 Conference on Implantable Auditory Prostheses

Saturday, July 30 - Thursday, August 4, 2005

Asilomar Conference Center
Pacific Grove, California

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ACKNOWLEDGEMENTS

The 2005 Conference on Implantable Auditory Prostheses (CIAP) is the 12th biennial meeting in a series, which started in 1983 under the auspices of the Gordon Research Conferences and has been regarded as the premier venue for presenting the best research in cochlear implants. Recently, the CIAP has expanded to other neural prostheses such as vestibular and retinal implants. We are honored to organize the 2005 CIAP and would like to acknowledge the support from the following individuals and organizations.

First, Rob Shepard and Mario Svirsky, chairs of the past CIAP, have greatly reduced our stress level by walking through the overall organization, documentation, and timeline of the conference. The Steering Committee has advised on the scientific topics and speakers to be included at the conference. Almost 200 attendees from the past CIAP have provided valuable feedback on both the conference venue and scientific topics. The advice and feedback, plus our own bias, has led to the selection of Asilomar as our conference venue and the current program selected from many competing topics and worthy investigators. We have listened to you by inviting more than 30 speakers who will speak for the first time at the CIAP. Many of these first-time speakers are young investigators, representing new blood to a fast-growing research field.

Second, the following organizations contributed financially to the 2005 CIAP:

- The National Institutes of Health (NIDCD, $30,000);
- Advanced Bionics Corporation ($20,000);
- MED-EL ($18,000);
- Cochlear Corporation ($10,000);
- The Whitaker Foundation ($6,000);
- Defeating Deafness (~$1,000)

The NIH fund helped cover facility rental and invited speaker expenses. The industrial support paid for the popular Aquarium dinner, refreshments at the conference, and the young investigator award program. The Whitaker Foundation supported 13 Biomedical Engineering students, while Defeating Deafness supported 1 student from UK, to attend the conference. Bob Shannon, administrative co-chair, served as the PI on the NIH conference grant. Mike Faltys, Erwin Hochmair, Jim Patrick and Chris van den Honert helped secure the industrial support. Leslie Collins spearheaded the Whitaker application and selected the student financial aid recipients. Monita Chatterjee chaired the young investigator award program. Beth Holstad and Margo Skinner applied for and obtained AAA CEUs for the 2005 CIAP.

Finally, we thank the superb administrative support from the following individuals:

- Bob Shannon, Administrative Co-Chair at the House Ear Institute
- Dana Rosario, Conference Coordinator at the House Ear Institute
- Abby Copeland, Jeff Carroll, Hongbin Chen, and Ginger Stickney at UC Irvine

We look forward to seeing you and having a successful meeting at Asilomar.

Fan-Gang Zeng and Russell Snyder

2005 CONFERENCE ON **I**MPLANTABLE **A**UDITORY **P**ROSTHESES

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SUNDAY JULY 31

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9:45	A. Quentin Summerfield – Bilateral Cochlear Implantation: Self–Reported Benefit, Quality of Life, And Health Economics
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11:10	Questions
11:15	Christopher Long – Binaural Unmasking with Bilateral Cochlear Implants
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11:35	Jill Firszt – Recognition of Speech at Varied Stimulus Levels and in Noise by Adult Recipients of Bilateral Cochlear Implants
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12:00	Lunch
2:00 – 4:00	Informal Discussion Group – Multichannel recording of neural responses in the cat inferior colliculus – Roger Miller will lead this discussion.

Session 2:	**Combined Acoustic and Electric Hearing – Paul Abbas Chair**
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7:45	Michael Dorman – Pre–implant Psychophysical Assessment of Low–Frequency Hearing in EAS Patients
8:10	Questions

8:15	Hugh McDermott – Comparing and Combining Acoustic Electric Stimulation: Pitch and Sound Quality
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8:45	Maike Vollmer – Neuronal Interactions of Combined Electric/ Acoustic Stimulation of the Cochlea in Cat Inferior Colliculus
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9:15	Ben Bonham – Physiological Measures of CI Channel Interaction
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11:20	Colette Boex – Frequency-Position Function Resulting from Electric Stimulation
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11:40	Belinda Henry – The Role of Spectral Resolution in Cochlear Implant Speech Recognition in Competing Backgrounds
11:55	Questions
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2:00 – 4:00	Informal Discussion Group – Bilateral cochlear implants: when and how to evaluate their efficacy in children – Ruth Litovsky will lead this discussion.

Session 4:	**Signal Processing and Speech in Noise – Blake Wilson Chair**
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7:45	Jan Wouters – Signal Processing Strategies for improved Speech Understanding in Noisy Listening Conditions
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9:30	Questions
9:35	Michael Qin – Simulating Aspects of Cochlear Implant Processing
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10:30	Hongbin Chen – Explicit Pitch Encoding to Improve Cochlear–Implants Music Perception
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11:10	Tim Green – Enhancement of Temporal Cues to Voice Pitch in Continuous Interleaved Sampling Cochlear Implants
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Company Reports

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11:15	Questions
11:20	Mike Faltys – Future of Electrode Development for Cochlear Implants
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11:35	General Discussion of Morning Session
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12:00	Lunch

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3:45	Michael Devous – Functional Brain Imaging and Auditory Cortex Plasticity in Cochlear Implant Users
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4:45	Todd Risley – Language Experience of Typical Babies in Everyday Life
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5:35	Edward Overstreet – Objective Measures and Program Levels: Important Lessons from Simple Measures
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8:30	Hugh Lim – Location of Stimulation within the Inferior Colliculus Affects Cortical Responses – Implications for an Auditory Midbrain Implant
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8:50	Minoo Lenarz – Electrophysiological Validation of the Auditory Midbrain Implant
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END OF CONFERENCE

SESSION 1: SPEAKER 1

CHANGES IN FUSION AND LOCALIZATION PERFORMANCE WHEN TRANSITIONING FROM MONOLATERAL TO BILATERAL LISTENING

Donald K. Eddington[1,2,3], Becky Poon[1] and Victor Noel[2]

[1]Massachusetts Institute of Technology, Cambridge, MA USA
[2]Massachusetts Eye and Ear Infirmary, Boston, MA, USA
[3]Harvard Medical School, Boston, MA, USA

Because normal hearing is binaural, it is not surprising to see the current trend toward bilateral cochlear implantation. The potential benefits implantees might derive from implantation of the second ear include better sound-source localization and improved speech reception in adverse listening conditions.

We are interested in the degree to which a subject's capability to integrate bilateral stimuli are influenced by their listening experience. We hypothesize that the listening strategy used by an individual who has been listening monolaterally for many months will be different than that of a subject with several months of bilateral listening experience. This is important for two reasons. First, if experience plays a substantial role in functional ability, the current practice of comparing the performance of monolateral and bilateral listening conditions in long-term users of bilateral stimulation probably puts the monolateral listening condition at a disadvantage. Second, if fundamental characteristics of sensations elicited by bilateral stimulation depend on bilateral listening experience, it is possible that monolateral implantation of a very young child constrains his/her brain's ability to develop the machinery to take advantage of bilateral stimulation when introduced later in life.

We will report results from five postlingually-impaired subjects who enjoyed normal (binaural) hearing at least through age 16. They were monolaterally implanted as adults and after using their monolateral implant successfully for at least six months, their second ear was implanted. We then conducted a battery of psychophysical, localization and speech-reception tests before they began wearing the 2nd sound processor. This made it possible to test monolateral and bilateral performance while subjects are still using a monolaterally-developed listening strategy. Once they began using two implants, we tracked their performance as they developed a strategy based on bilateral listening.

Measures of fusion (when stimulating single interaural electrode pairs) and of localization (using asynchronous sound processors) will be presented. These results show changes with bilateral experience that suggest: (1) basic changes in the brain leading to fundamental changes in the perception of bilateral stimuli and (2) monolateral localization performance measured in a subject using a listening strategy developed during monolateral listening can be substantially better than monolateral performance measured in the same subject using a bilaterally-developed listening strategy.

Supported by the NIH-NIDCD, the Keck Foundation and Advanced Bionics a Boston Scientific Corp.

SESSION 1: SPEAKER 2

BINAURAL ABILITIES WITH BILATERAL COCHLEAR IMPLANT USERS

Richard van Hoesel[1], Ruth Litovsky[2], Thomas Lenarz[3]

[1]Cooperative Research Centre for Cochlear Implant & Hearing Aid Innovation, Melbourne, Australia
[2]University of Wisconsin, USA
[3]Medizinische Hochshule Hannover, Germany

Results have shown that a majority of adults using bilateral cochlear implants (CI) experience significant benefits when listening through both devices as compared to either ear alone. However, it is not clear whether binaural hearing mechanisms per se play an important role. This may be partly due to the fact that clinical sound processing strategies do not adequately preserve binaural fine-timing cues, but may also reflect reduced binaural sensitivity to timing information using electrical stimulation as compared to normal hearing.

A broad range of psychophysical studies was completed with three bilateral CI users in Melbourne. Sensitivity to interaural time-delays (ITDs) was examined with simple pulse trains as a function of stimulation rate, and with high-rate modulated signals as a function of modulation rate. The effects of stimulation level and signal duration were also considered. Comparative monaural rate-discrimination abilities as a function of reference rate were measured in the same subjects. Monaural results were further compared to dichotic rate sensitivity by stimulating the contralateral ear at the fixed reference rate, resulting in dynamic ITDs (or "binaural beats"). The precedence effect, which allows normal hearing listeners to largely ignore confounding timing cues from later arriving echoes in reverberant conditions, was assessed for electrical two-pulse sequences by assessing the ability to correctly lateralize sequences with ITDs applied to either the leading or lagging pulse whilst preserving 0-ITD on the other. Binaural unmasking was assessed by measuring detection thresholds for low-rate simple pulse trains in the presence of temporally jittered noise on the same electrode.

Interaural level and time-delay sensitivity at low stimulation rates were studied in a larger group of subjects in a collaborative study with the University of Wisconsin. The effects of broad place matching and onset of hearing loss for this group of subjects are discussed.

The speech intelligibility advantage offered by using both ears with diotic signal and noise presentation, as is approximately the case when signal and noise are both in front of the listener, was assessed as a function of level reductions in the bilateral condition to compensate for binaural loudness summation in a collaborative study with MHH in Hannover.

Preliminary data are presented from studies that examine the potential of a research sound-processing strategy to improve binaural hearing by preserving fine timing cues in the electrical stimulus coding.

Supported by CRC HEAR, Australia and NIH-NIDCD, USA

BILATERAL COCHLEAR IMPLANTATION: SELF-REPORTED BENEFIT, QUALITY OF LIFE, AND HEALTH ECONOMICS

A. Quentin Summerfield

Department of Psychology, University of York, York, UK.

Health economic analyses have helped consolidate the position of unilateral cochlear implantation with commissioners of health care (3rd-party payers) by demonstrating that the benefits to quality-of-life justify the costs in relation to the other ways in which the health-care resources could be spent. These analyses have shown that unilateral implantation is associated with substantial gains in health-related quality of life of the order of +0.20 on scales where 1.00 corresponds to the state of full health and 0.00 to the state of death. The position of bilateral implantation is weaker. Previously, we asked clinicians and researchers with knowledge of implantation to estimate the likely additional gain from a second implant. Their mean estimate, +0.03, is too small to justify the additional cost of a second implant in many health-care systems. We have now conducted a trial of bilateral implantation in which existing adult users of one implant were randomised either to receive a second implant immediately or to wait 12 months during which time they acted as controls for late-emerging benefits of the first implant. Results show significant self-reported advantages in spatial hearing, and smaller but still significant advantages in quality of hearing and hearing for speech. However, there were no significant advantages in the measures of health-related quality of life that have previously shown substantial advantages for unilateral implantation. The trial has the limitation that some patients reported material increases in annoyance due to tinnitus following bilateral implantation. Those increases attenuated their gain in quality of life. Regression modelling shows that quality of life would have increased by +0.03 in the absence of any change in annoyance due to tinnitus and would have increased by +0.08 if bilateral implantation had eliminated annoyance due to tinnitus. These results can be fed back into a consideration of the prices that would have to be charged for a 'bilateral' implant system to be acceptably cost-effective. We estimate that a package consisting of a bilateral processor costing 1.1 times the current cost of a unilateral processor and a pair of electrode arrays which together cost 1.7 times the current cost of two arrays would be judged to be acceptably cost-effective in relation to criteria adopted in UK. Achieving these goals would be challenging, but perhaps not impossible, for manufacturers of implants.

Supported by the UK Medical Research Council.

ASPECTS OF BILATERAL COCHLEAR IMPLANTATION

Peter Nopp[1], Peter Schleich[1], Alexander Möltner[1], Heike Kühn-Inacker[1]
Bernhard Laback[2], Piotr Majdak[2]
Wafaa Shehata-Dieler[3], Joachim Müller[3]

[1]Medical Electronics, Innsbruck, Austria
[2]Acoustics Research Institute, Austrian Academy of Sciences, Vienna, Austria
[3]ENT Clinic of the University of Würzburg, Würzburg, Germany

To assess the principal benefits of bilateral cochlear implantation, we have in the last years conducted extensive studies which demonstrated large improvements in both speech perception and sound localization, with bilateral cochlear implants (CI) in both adults and children. However, these studies also revealed some of the limitations bilateral CI users experience in comparison to normal hearing subjects. This presentation discusses some of these limitations in terms of magnitude and possible reasons:

- Sound localization – Experimental results showed that bilateral CI users show larger localization errors in the frontal horizontal plane than normal hearing subjects. Further studies revealed that these errors can be at least partly contributed to the automatic gain control (AGC), the maplaw, and differences in electrode insertion depths. In relation to this, it is also well known that bilateral CI users show less sensitivity to interaural time delays than normal hearing subjects. Here, another study assesses the potential of providing ITD information better through fine structure coding. In children, a particularly important aspect is the development of spatial hearing as is demonstrated by longitudinal data.

- Speech perception – Experimental results showed that bilateral CI users show a smaller head shadow effect and a smaller squelch effect than normal hearing subjects. Further studies revealed that at least the smaller HS effect can be partly attributed to bilateral CI users lacking the pinna as in a CI system today the microphone is normally located above the pinna. Tests in children showed similar bilateral benefits as in adults.

SESSION 1: SPEAKER 5

WHAT TO DO WITH THE "WHERE": A PHYSIOLOGICALLY INSPIRED STRATEGY FOR DELIVERING INTERAURAL TIMING CUES WITH BILATERAL COCHLEAR IMPLANTS

Zachary M. Smith and Bertrand Delgutte

Eaton-Peabody Laboratory, Massachusetts Eye and Ear Infirmary, Boston, MA

Speech and Hearing Bioscience and Technology Program, Harvard-MIT Division of Health Sciences and Technology, Cambridge, MA

The neural processing of interaural timing differences (ITD) in normal-hearing listeners is important for accurate sound localization and speech reception in noisy environments. Since current speech processing strategies for cochlear implants do little to preserve the fine time structure of acoustic signals, bilateral cochlear implants have yet to harness the specialized processing of ITD in the auditory brainstem and realize the full advantages of binaural hearing. We studied binaural interactions in auditory neurons with electric stimulation with the goal of proposing new processing strategies that would effectively deliver ITD information.

We recorded from single-units in the inferior colliculus (IC) of acutely deafened, anesthetized cats in response to electric stimulation delivered through bilaterally-implanted intracochlear electrodes. Here we focus on the neural coding of ITD with sinusoidally amplitude modulated (SAM) pulse trains, since most implant processors encode sound in each channel by amplitude modulations of a fixed rate carrier. ITD was introduced independently to the modulation and carrier in order to measure their relative efficacy in delivering ITD information.

Most cells in the central nucleus of the IC (>80%) were sensitive to ITD with low-rate (<100 pps) pulsatile stimuli with ITD selectivity similar to that in normal-hearing animals. Increasing pulse rates tended to degrade sustained responses and ITD sensitivity, but amplitude modulation restored responsiveness and some ITD sensitivity in many neurons at high pulse rates (e.g. 1000 pps). Modulation ITD tuning was generally broad at low modulation frequencies but improved with increasing modulation frequency. While fewer neurons showed sensitivity to ITD in the carrier than in the modulation (~50%), tuning to carrier ITD was significantly sharper than that to modulation ITD at any modulation frequency tested. This suggests that the carrier pulses hold the most potential for conveying useful ITD information.

Based on these results, we propose a processing strategy that uses the fine timing of the acoustic signal at each ear to determine the timing of delivered current pulses. Various implementations of such a strategy for bilateral cochlear implants will be discussed.

Supported by NIH grants DC05775 and DC05209.

SESSION 1: SPEAKER 6

BINAURAL UNMASKING WITH BILATERAL COCHLEAR IMPLANTS

Christopher J. Long[1], Robert P. Carlyon[1], Ruth Litovsky[2], Huw Cooper[3], Daniel Downs[1]

1 MRC Cognition and Brain Sciences Unit, Cambridge, UK
2 University of Wisconsin-Madison
3 Hearing Assessment and Rehabilitation Centre, Selly Oak Hospital

Bilateral cochlear implants can potentially aid speech understanding in noise by two types of effect. "Better-ear" effects arise primarily from the enhanced signal-to-noise ratio (SNR) at one ear, and have been reported in a number of studies. In contrast, advantages derived from a fusion of the information in the waveforms at the two ears, although well-established in acoustic hearing, have been more elusive with cochlear implants. Here, we show that this fusion can aid signal detection, and report a Binaural Masking Level Difference (BMLD) for electric hearing.

Seven cochlear implant users listened to stimuli containing signals in noise. The input noise was identical on the left and right sides while the signal was either identical across sides, or shifted by pi radians or 600 sec on one side. Signal-to-noise ratios (SNRs) from -25dB to 20dB were used. Stimuli were half-wave rectified, low-pass filtered, and used to modulate a 1000-pps pulse train; this is analogous to the “transposed” acoustic stimuli used by van de Par and Kohlraush (1997).

All seven subjects showed a substantial BMLD. In an NoSo versus NoSpi condition, at multiple SNRs, subjects showed approximately a 30% correct advantage in detection. Those three subjects performing a task allowing sufficiently complete psychometric functions, showed an NoS0 threshold of +15dB and an NoSpi threshold of –20dB (a 35dB BMLD). With their normal-hearing subjects, van de Par and Kohlraush showed thresholds of 0dB and –16dB, respectively (a 16dB BMLD) in the comparable condition. The difference in the results is mainly due to the poorer performance of the implant users in the NoS0 condition. With NoS600 sec, the cochlear implant subjects demonstrate a threshold intermediate between that of NoS0 and NoSpi.

Tests of implant users and normal-hearing subjects are ongoing to elucidate the mechanisms underlying these effects and the contribution of interaural time and interaural level difference cues.

Based on these results, it seems that speech processors which present envelope information alone can provide sufficient information to allow binaural unmasking to enhance detection. We are currently investigating whether this advantage will generalize to supra-threshold tasks such as speech understanding in noise.

Supported by the Royal National Institute for Deaf People.

RECOGNITION OF SPEECH AT VARIED STIMULUS LEVELS AND IN NOISE BY ADULT RECIPIENTS OF BILATERAL COCHLEAR IMPLANT DEVICES

Jill B. Firszt[1], Ruth M. Reeder[1], Christina L. Runge-Samuelson[1], P. Ashley Wackym[1], Laura K. Holden[2], Margaret W. Skinner[2]

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[2]Washington University School of Medicine, St. Louis, MO, USA

Cochlear implantation of bilateral devices is an important and timely topic, particularly as it relates to benefit for recipients. Subjects who have received bilateral devices typically prefer bilateral compared to unilateral implants. On some measures, a subset of adult recipients has demonstrated improvements in speech recognition in the bilateral condition, supporting the report of users. This significantly higher performance depends on the recorded speech materials used, the levels at which stimuli are presented, and the test conditions with respect to the location of the noise. For determining whether bilateral cochlear implant users' speech recognition is enhanced in the bilateral condition, testing speech in quiet at soft levels (50 dB SPL) and in noise has the potential to reveal loudness summation and/or release from masking effects that may not be evident when speech stimuli are presented at louder levels (e.g., 65 and 70 dB SPL).

The purpose of the current study was to 1) determine mean scores and ranges of bilateral cochlear implant performance for speech stimuli when presented at two intensity levels (60 and 50 dB SPL) and in noise of two types (speech spectrum noise, multi-talker babble), 2) provide information on the variability of scores with test-retest measures, and 3) assess the sensitivity of varied speech recognition measures and test conditions in the evaluation of bilateral cochlear implant performance.

A repeated-measures design was used to compare data collected with speech stimuli in the unilateral and bilateral conditions. Subjects were profoundly hearing-impaired adults who had received recent cochlear implant technology and had used their bilateral devices for at least three months. For each subject, detection thresholds for warble-tones in the sound field were obtained to ensure similar speech audibility for all subjects and between ears within subjects. Speech measures were used to assess sentence recognition in quiet, in fixed noise conditions, and in an adaptive paradigm. Preliminary results indicate that binaural benefit may be evident when speech presentation levels, speech stimuli, and noise conditions reflect the wide range of listening situations encountered by cochlear implant recipients during everyday communication.

Supported by NIH NIDCD, Med-El Corporation.

SESSION 2: SPEAKER 1

COMBINED ACOUSTIC AND ELECTRIC HEARING USING THE SHORT ELECTRODE

Christopher Turner, Bruce Gantz, Mary Lowder, Lina Reiss, Sheryl Erenberg

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Approximately 25 patients with severe high-frequency hearing loss have been implanted with a short-electrode cochlear implant designed to supplement the patients' residual acoustic hearing in our ongoing program. Residual acoustic hearing has been preserved to within 10-15 dB of pre-operative levels for 96% of these patients. Results from the long-term patients (device worn longer than 12 months) indicate that in all cases (including the one case where residual hearing was not preserved) the post-operative speech recognition scores using combined acoustic + electric hearing are better than the pre-operative, acoustic-alone scores; these improvements range from 5 to 70% (mean value of 38%). The residual acoustic hearing also yields an improvement for the recognition of speech in a background of other talkers as compared to traditional cochlear implants.

One question that arises is what factors might explain the variability in post-operative performance and allow a prediction of which individuals will receive the most benefit from the short electrode. One possible factor is the quantity of surviving nerve fibers and/or spiral ganglion cells in the base of the cochlea, which has implications for matching assigned and perceived frequency. Currently, it is not feasible to assess nerve survival with non-invasive techniques. However, a number of these patients (n=8 at the present time) have enough acoustic hearing in the ear contralateral to the implant to allow us to obtain pitch matches between an acoustic tone presented to the contralateral ear and electrical stimulation delivered to the implanted ear. According to the traditional basilar membrane frequency-place map, the most apical electrode of this short device should correspond to approximately the 4400 Hz place along the basilar membrane. In no cases was this prediction supported. The pitch matches for these patients ranged from 1 to 3 octaves lower than that predicted by the Greenwood map. These results suggest that in the highest pitch match cases, the cochlear implant may not stimulate neurons corresponding to the traditional basilar membrane map, but instead stimulates spiral ganglion cells which follow a different frequency-place map. In the lowest pitch match cases, these results suggest that there are few, if any neurons remaining to be stimulated in the base of the cochlea, and the response to the electrical stimulation at the base actually comes from surviving apical neurons. Results to date show a moderate correlation between the pitch match frequency of the most apical electrode and the success of the device for speech recognition, with the lowest pitch match cases tending to perform more poorly with the device.

Supported by the NIH-NIDCD

PRE-IMPLANT PSYCHOPHYSICAL ASSESSMENT OF LOW-FREQUENCY HEARING IN EAS PATIENTS

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The measurement of auditory threshold is very blunt tool for the purpose of assessing the quality of low-frequency hearing in EAS patients before and after implantation. To remedy this situation, we have created a battery of tests to estimate auditory thresholds, frequency resolution, temporal resolution and basilar membrane compression. To date we have tested 12 potential EAS patients and a group of normal-hearing listeners. Auditory thresholds were measured at 100 Hz intervals. Frequency resolution was estimated using a simultaneous masking paradigm and a notched noise method. Temporal resolution was estimated by amplitude modulation detection threshold. Basilar membrane compression was estimated by the difference in masked thresholds for positive and negative Schroeder-phase harmonic complexes. Most generally, the hearing-impaired listeners evidenced poorer performance than normal-hearing listeners. However, as expected, there was a great deal of variability among hearing-impaired listeners with some showing near normal function, e.g., near normal basilar-membrane compression.

Analysis of speech reception thresholds for HINT sentences in steady-state and modulated noise demonstrates that most EAS candidates have lost the ability to hear in the 'dips' in the modulated masker. Others have a limited ability to do so. Post implant the issue will be (i) whether the ability to hear in the 'dips' survives the insertion of the electrode array into the scala tympani and (ii) if so, whether patients with this ability perform better in noise in a EAS condition than patients who do not have this ability.

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SESSION 2: SPEAKER 3

COMPARING AND COMBINING ACOUSTIC AND ELECTRIC STIMULATION: PITCH AND SOUND QUALITY

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Recently a study has commenced in Melbourne in which a small number of people with bilateral steeply sloping audiograms are electing to receive a Cochlear 'Freedom' implant system. These people have near-normal to moderately elevated thresholds at low frequencies (below 500 Hz) and profound to total hearing loss at high frequencies (above 1 kHz). The major aims of the study are to maximize the preservation of acoustic hearing in the implanted ear, and to optimize the programming of the sound processor of the implant. The experimental programming is based on psychophysical comparisons between the pitch perceived with electric stimuli and the pitch of acoustic tones presented in the same (or opposite) ear. The main hypothesis is that perception with combined acoustic and electric stimulation will be most beneficial when sound frequencies are allocated to the electrodes such that their pitch is complementary and compatible with that of sounds heard acoustically.

Underpinning this new study is a series of experiments involving existing implant recipients who have usable hearing in the non-implanted ear. The pitch perceived when constant-rate pulse trains are delivered by selected electrodes has been compared with the pitch of acoustic pure tones using estimation and matching procedures. Preliminary results suggest that the most-apical electrode, when activated at the rate utilized by the speech processor, typically has a pitch corresponding to a tone frequency of about 400 Hz. This is much lower than the frequency indicated by that electrode's position measured using X-ray images. Moreover, it is higher than the acoustic frequency usually assigned to that electrode when the sound processor of the implant is programmed.

Further studies assessed these implant users' ability to recognize melodies when acoustic and electric stimuli were presented either separately or together. Subjective quality ratings were also collected for a range of musical and environmental sounds. In general, the best results for melody recognition were obtained with combined acoustic and electric stimulation, although the scores with the implant and hearing aid used separately were often similar. Perceived sound quality was always highest for the condition in which both modes of stimulation were used simultaneously.

These initial findings suggest that cochlear implants can provide benefits to some people with usable low-frequency acoustic hearing, particularly for pitch perception and improved sound quality.

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SESSION 2: SPEAKER 4

NEURONAL INTERACTIONS OF COMBINED ELECTRIC/ACOUSTIC STIMULATION OF THE COCHLEA IN CAT INFERIOR COLLICULUS

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Using a forward masking paradigm, the present study explores the effects of combined electric and acoustic stimulation (EAS) of the cochlea on neuronal responses in the inferior colliculus (IC). Anesthetized normal hearing cats were implanted with scala tympani electrodes, and an earphone was sealed to the ipsilateral auditory meatus for acoustic stimulation. Neuronal responses were recorded simultaneously at 16 sites along the tonotopic gradient of the central nucleus of the contralateral IC. A 60ms acoustic masker preceded a 20ms electric probe. Masker and probe were systematically varied in intensity and frequency.

At low intensities, electric probe frequencies >1 kHz activated IC locations that corresponded to the probe frequency (*electrophonic* effect). At increasing intensities, there was spread of activation to neighboring recording sites. For any activated recording site, masking of the probe was greatest when the electric probe was preceded by acoustic stimulation of the same frequency. Strength of masking was generally increased by increasing masker intensity.

At higher intensities, the electric probe activated additional IC locations that corresponded to the cochlear site of the stimulating electrode(s) (*electroneural* responses). This activity was masked best by acoustic frequencies that corresponded to the same cochlear site. On neighboring activated recording sites, the characteristic frequency (CF) of the masked tuning curves corresponded to the CF at the individual recording sites.

These results indicate that EAS leads to complex response interactions in the central auditory system. The spatial extent of these interactions is dependent on the intensities and spectral characteristics of both electric and acoustic stimulus components. The results also indicate that electric stimulation of the hearing cochlea evokes both low-threshold acoustic-like *electrophonic* responses and high-threshold *electroneural* responses. It is hypothesized that complex neuronal interactions in the central auditory sytem may influence the overall effectiveness of combined EAS in human subjects.

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SESSION 2: SPEAKER 5

IMPROVED SPEECH RECOGNITION IN NOISE IN COMBINED ACOUSTIC AND ELECTRIC HEARING

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Speech recognition in noise is improved with combined and electric hearing compared to electric hearing alone (e.g., Turner et al., 2004; Kong et al., 2005). It was suggested that with combined hearing, listeners were able to better encode the fundamental frequency (F0) provided by low-frequency residual hearing as a cue to separate various talkers. In our previous study (Kong et al., 2005), we measured both speech recognition in competing noise and melody recognition without rhythmic cues in implant listeners with residual low-frequency (<1000 Hz) acoustic hearing in the nonimplanted ear. All subjects were tested under cochlear implant (CI) alone, hearing aid (HA) alone, and CI+HA conditions for both tasks. Our results showed that while residual low-frequency hearing alone produced essentially no recognition of speech in noise, it significantly enhanced performance when combined with electric hearing. On the contrary, the benefit of combined hearing was not observed in melody recognition and subjects' performance was significantly better with low-frequency acoustic hearing compared to electric hearing.

The mechanisms underlying the enhancement of speech recognition in competing noise is unclear. Kong and colleagues (2005) proposed a sound segregation model in which voice pitch can be better extracted by combining the time fine structure from the residual hearing with the temporal envelope from the electric hearing. However, this model has not been tested. In addition to F0 cues, it is possible that formant frequency information in low-frequency hearing can enhance performance when combined with the speech information in electric hearing.

In our current study, we will test Kong et al's hypothesis by studying speech recognition ability in noise in normal-hearing listeners listening to simulated CI and residual low-frequency hearing situations. The first experiment simulates the speech recognition in noise situation described in Kong et al. (2005), using a lowpass-filtered signal in one ear and vocoder processed speech in the other ear. The masker is time-reversed speech modulated with a speech envelope. The F0 of the monotone target speech is 100 Hz, whereas the masker is 175 Hz. We predict better performance in the combined hearing condition compared to either lowpass speech or vocoded speech alone. Further experiments will determine whether any advantage persists in combined hearing when formant frequency information is removed from the lowpass-filtered signal, and whether this advantage depends on that signal providing appropriate F0 cues.

SESSION 3: SPEAKER 1

INTERFERENCE BETWEEN INTERLEAVED PULSE TRAINS: TEMPORAL EFFECTS ON THRESHOLDS AND MODULATION SENSITIVITY

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A multi-channel cochlear prosthesis is truly "multi-channel" only to the degree that each channel can elicit non-redundant time-varying patterns of CNS activity. If activity on one channel masks acuity on a nearby channel or if the central responses to nearby channels are highly correlated, the benefits of multi-channel stimulation are not fully realized. This presentation will describe the interactions between two interleaved pulse trains in an animal model, focusing on the effects of pulse rate and inter-pulse timing on between-channel interference in thresholds and modulation sensitivity.

The animal model consists of an anesthetized guinea pig with a 6-element banded electrode array implanted in the scala tympani. Stimuli were trains of biphasic electrical pulses at rates of 254 or 4069 pulses per second (pps) per channel. Neural spikes are recorded from the auditory cortex using 16-site recording probes.

One measure of channel interaction was the amount by which a near-threshold pulse train on one intra-cochlear cochlear electrode reduced the threshold for a pulse train on a nearby electrode. In general, two factors resulted in threshold interactions being greater for the higher pulse rate than for the lower rate. First, at 254 pps, pulse trains could be interleaved with a temporal offset of 1966 μs. In that condition, threshold interactions were entirely eliminated. At 4069 pps, temporal offsets could be no longer than 123 μs, and threshold interactions were substantial. Second, at any given temporal offset (up to 123 μs), threshold interactions were significantly greater for the 4069-pps rate. That effect likely is due to temporal integration of electrical fields within the cochlea.

A second measure of channel interaction was the degree by which an unmodulated pulse train on one channel masked detection of amplitude modulation on another channel. In single-channel conditions, modulation sensitivity consistently was greater for a 254-pps carrier than for a 4069-pps carrier. In a condition with a 254-pps carrier, addition of an unmodulated pulse train on a second channel substantially masked detection of modulation when the temporal offset was 82 μs. In contrast, little masking was observed when the temporal offset was 1966 μs.

These physiological results from an animal model will be discussed in the context of implications for speech processor design.

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PHYSIOLOGICAL MEASURES OF COCHLEAR IMPLANT CHANNEL INTERACTIONS

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Contemporary human cochlear implants (CIs) are multichannel devices. Each of these channels is thought to excite a restricted, unique and tonotopically appropriate population of auditory nerve fibers. Psychophysical and clinical studies indicate that these devices are adequate to allow open-set speech reception in many users. Our animal studies seek to understand the physiological mechanisms that underlie this performance. Using deaf animal models and intracochlear electrodes that approximate CI electrodes, we have shown that many factors influence the spatial (spectral) and temporal distribution of neural activity evoked CI stimulation across the tonotopic organization in the central auditory system. Among these factors are: the amplitude of stimulus pulses, the pulse waveform (triphasic or pseudomonophasic), the orientation and separation of the electrode contacts, the mode of stimulation (monopolar, bipolar and tripolar), the number of channels (AN populations) that are activated during any stimulation epoch (simultaneous and forward masking). Our studies make it clear that the spatial and temporal resolution of CI is dependent upon all these parameters. In some cases, the patterns of activation approximate those that are evoked by tonal acoustic stimuli, in other cases they are significantly different.

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SESSION 3: SPEAKER 3

PSYCHOPHYSICS FOR TUNING AND OPTIMIZATION OF COCHLEAR IMPLANT SPEECH PROCESSORS

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A variety of approaches have been considered to improve speech recognition by cochlear implant subjects over the last 20 years. One approach relevant to the work presented here involves using experimental data that probes the status of a particular subject's electrically-stimulated auditory system to assess information bearing capacity, and then using the experimental data to tune a conventional speech processing system. While extensive psychophysical studies on cochlear implant subjects have been performed, to date only a few have shown a relationship between psychophysical measures and speech recognition. While some studies have alluded to the fact that such measures vary across the electrode array, the impact that this variability may have on speech recognition has often not been assessed. In contrast, a few experimental and modeling studies have indicated that this variability does impact speech recognition, possibly as a result of the reduced information-bearing capacity associated with the electrodes for which the psychophysical measures are particularly poor. Specific examples of variables that may play a key role include electrode discrimination, pitch structure, and intensity discrimination.

In this talk, we will review previous work investigating the utility of using experimental, or psychophysical data, to optimally tune individual patient's devices. Specifically, we will review those data that support the hypothesis that such tuning is possible, and also highlight one study which attempted to rank the effect of variables that may impact speech recognition. We will then focus on investigating alternative methods of gathering the experimental data so that data collection can be performed within a clinically-acceptable period of time. Using current psychophysical techniques, assessing each of the psychophysical variables that may be relevant to speech recognition for all of the electrodes in a modern electrode array would be prohibitive in terms of the clinical time required for each patient. In order for psychophysics-based tuning of the speech processor to be clinically relevant, it will be necessary to quickly pinpoint and assess electrodes whose information carrying capacity is somehow limited. We present results from an approach whereby confusion matrices gathered in speech recognition testing are investigated for the purpose of identifying channels performing in an "impaired" or anomalous manner. To provide proof of concept, listening tests are conducted with normal-hearing subjects and acoustic models simulating channel-specific anomalies. Results indicate that the proposed approach successfully identifies impaired channels at a rate significantly greater than chance. Results from speech recognition data collected from cochlear implant subjects are also presented which indicate that the approach does in fact hold promise for identifying electrodes not transmitting information optimally. These analyses have the potential to expedite the identification of impaired channels by providing preliminary information prior to exhaustive psychophysical testing.

SESSION 3: SPEAKER 4

ACROSS-CHANNEL ENVELOPE INTERACTIONS IN COCHLEAR IMPLANT LISTENERS

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Cochlear implant (CI) listeners have particular difficulty in listening to speech in the presence of background noise/ competing speakers. It is therefore of considerable interest to discover how the auditory system processes signals in the presence of fluctuating backgrounds. This talk will summarize the results of a series of experiments that we have conducted over the last few years with the aim of investigating modulation sensitivity in adult CI listeners in the presence of competing modulations on other channels.

In all the experiments, the listener's task involved the detection of envelope modulation in a signal pulse train presented to one channel of the cochlear implant, in the presence of maskers presented to one or two other channels. The masker envelopes were either modulated or steady-state. Results indicated that it was significantly harder to detect modulation in the presence of fluctuating maskers than in the presence of steady-state maskers, even when the steady-state maskers were more intense. The difference in modulation thresholds obtained with fluctuating vs. steady-state maskers is termed "envelope masking" or "modulation detection interference" (MDI). MDI was observed using noise-modulation as well as sinusoidal modulation of the envelope. The electrode separation between the signal and masker also had significant impact. When the masker and signal channels were spatially close, the steady-state masker dominated the masking. When the masker was moved away from the signal, the fluctuating masker dominated and MDI increased. We observed significant MDI even at very wide separations (12 mm) between the signal and masker channels. Modulation tuning was observed at low syllabic rates, but at the high modulation-frequency end the MDI patterns were shaped more like low-pass filters.

Overall, these results indicate that central, across-channel mechanisms, which come into play when stimuli have both slow and fast time-varying envelopes, are important in determining channel-interaction in CI listeners. The effects are large relative to the narrow dynamic range of CI listeners, suggesting that they may severely limit signal processing by the implanted auditory system in real-life listening situations.

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SESSION 3: SPEAKER 5

THE TRIPOLAR ELECTRODE CONFIGURATION REDUCES CHANNEL INTERACTION

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The independence of cochlear implant channels is important for effective information delivery to the implant listener. Subjects with more spatial and temporal interaction among cochlear implant channels have poor speech perception. One method that has been shown to reduce spatial interactions physiologically is use of a more focused electrode configurations such as tripolar. This presentation will summarize several psychophysical measures of one- and two-channel tripolar stimuli and the relationship between these measures and speech perception.

Post-lingually deaf subjects implanted with the Clarion HiFocus I or HiRes 90K cochlear implant were studied. Single- and two-channel thresholds were measured in response to biphasic pulse trains using three different electrode configurations: tripolar, bipolar and monopolar. Pulse rates were 1000 pulses per second with phase durations of 100 microseconds per phase. Each pulse train lasted 500 milliseconds. A two-interval forced choice procedure was used. Single-channel thresholds were highest for the tripolar configuration and decreased as the electrical field size broadened to bipolar and monopolar modes. The thresholds and dynamic ranges were also most variable from channel-to-channel with the tripolar configuration. Furthermore with tripolar, apical channels tended to have lower thresholds and larger dynamic ranges than did basal channels.

Two-channel trains were presented synchronously or interleaved. Channel interaction was quantified by the difference between levels required for one- and two-channel thresholds. Thresholds were usually lower for two-channel compared to one-channel stimuli and the largest shifts occurred for the monopolar and synchronous conditions. Shifts were greatly reduced by using restricted configurations – bipolar and especially tripolar – or by interleaving the pulse trains. For the tripolar configuration, the high single-channel thresholds (relative for each subject) were predictive of large threshold shifts. Large channel-to-channel variability in single channel threshold and synchronous threshold shifts were correlated with poor speech performance with the tripolar mode. One- and two-channel data suggest tripolar is the most sensitive configuration to local, cochlear irregularities and has the lowest channel interactions.

Information obtained with the tripolar configuration regarding local irregularities near each cochlear implant channel could be used to improve speech processing strategies, maximizing the spectral information that can be delivered. Further clinical implications of the present findings will be discussed.

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SESSION 3: SPEAKER 6

FREQUENCY-POSITION FUNCTION RESULTING FROM ELECTRIC STIMULATION

Colette Boëx, Lionel Baud, Mathieu Gani, Gregory Valentini, Alain Sigrist, Maria-Izabel Kós, Marco Pelizzone

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We assessed the frequency-position function resulting from electric stimulation of electrodes in 6 cochlear implant users. One subject presented a normal hearing in his non-implanted ear. The 5 other subjects presented significant residual hearing in their non-implanted ear. They compared the pitch of the auditory sensation produced by stimulation of an intracochlear electrode to the pitch of acoustic pure tones presented to their contralateral ear.

Subjects were implanted with different Clarion™ electrode arrays, all designed to lie close to the inner wall of the cochlea. High resolution radiographs were used to determine the electrode positions in the cochlea. Some subjects presented deep electrode insertions (deeper than 450°).

We used a 2 interval (one acoustic, one electric), 2 alternative forced choice protocol, asking the subject to indicate which stimulus sounded the highest in pitch. Pure tones were used as acoustic stimuli. Electric stimuli consisted of trains of biphasic pulses presented at relatively high rates (higher than 700 pulses per second). Electric stimuli were balanced in loudness across electrodes. Acoustic tones, chosen to approximate roughly the pitch sensation produced by electric stimulation, were balanced in loudness to electrodes.

When electrode insertion lengths were used to describe electrode positions, the pitch sensations produced by electric stimulation were found to be more than 2 octaves lower than predicted by Greenwood's frequency-position function of a normal ear. Part of the discrepancy is due to the fact that electrodes were lying close to the inner wall of the cochlea and, in this condition, electrode insertion length does not correspond to length along the Organ of Corti. When insertion angles were used to describe electrode positions, the pitch sensations were found to be about one octave lower than the frequency-position function of a normal ear. Several physiological phenomena can explain the remaining one octave difference; the most important one being that the site of electrical stimulation in some cochlear implant subjects would be close to the spiral ganglion cell bodies.

On the basis of these data, band-pass filters were designed for sound coding strategies to match the pitch percepts elicited by electrode stimulation. Examples of the effects of these customized strategies will be presented in unilateral and in bilateral cochlear implant users.

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SESSION 3: SPEAKER 7

THE ROLE OF SPECTRAL RESOLUTION IN COCHLEAR IMPLANT SPEECH RECOGNITION IN COMPETING BACKGROUNDS

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High levels of speech recognition are possible with current cochlear implant (CI) devices and speech processing strategies in quiet listening environments. However, speech recognition in CI listeners is highly susceptible to effects of competing backgrounds. Performance varies widely among individuals. The aim of this study was to investigate the role of spectral resolution in the performance of CI listeners in competing speech and competing noise backgrounds.

Spectral resolution was assessed using a direct measure of the ability to resolve spectral peaks in the acoustic signal. The task involves discriminating between two rippled noise stimuli in which the frequency positions of the peaks and valleys are interchanged. The ripple spacing is varied adaptively, and the minimum ripple spacing at which a reversal in peak and trough positions can be discriminated is determined. This test provides the opportunity to directly compare spectral peak resolution across listeners with acoustic hearing, both normal and impaired, and listeners with electric hearing, therefore enabling the direct examination of the following questions: Is the ability to resolve spectral peaks a general requirement for speech recognition in competing backgrounds? What degree of spectral resolution is required for speech perception in competing noise and competing speech backgrounds?

Spectral peak resolution was best on average in normal hearing listeners, poorest in CI listeners, and intermediate in hearing impaired listeners. The CI listeners showed the poorest speech recognition in competing backgrounds generally, and relative to the normal hearing and hearing impaired listeners were particularly susceptible to the effects of the competing speech background. Across the three listener groups there was a significant relationship between spectral resolution and speech recognition both for the competing noise and competing speech backgrounds, indicating a dependence on spectral resolution for speech recognition in competing backgrounds. The results also quantify the degree of spectral resolution required for speech recognition in both backgrounds. In addition, for the CI listeners considered as an individual group, there was a significant correlation between spectral resolution and performance in both backgrounds.

These results indicate that efforts to improve spectral resolution with CIs may result in improved speech recognition in competing backgrounds. The spectral peak resolution test is relatively quick to administer and therefore may also lend itself to clinical applications such as predicting speech recognition in CI listeners in real-world listening environments. .

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INFORMATIONAL MASKING IN SPEECH RECOGNITION: POTENTIAL IMPLICATIONS FOR IMPLANT USERS

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Through research conducted over the course of several decades it has become clear that some competing speech situations create masking processes beyond those that can be attributed to traditional conceptualizations of masking. Informational masking is a term that has been used recently to describe this type of interference, mostly because the pattern of data shares several features with that obtained in non-speech informational masking studies. Given that the field is in the very early stages of understanding how (or, some would argue, whether) informational masking applies to speech recognition, it is much too soon to be sure how listeners with cochlear implants differ from normal-hearing listeners with respect to the impact of this type of speech interference. Nevertheless, several factors lead to a prediction that informational masking will be increased in cochlear implant listening, and at least one factor leads to the opposite prediction. This talk will discuss these factors, and consider which types of improvements in cochlear implants are likely to have the greatest impact on reducing informational masking. Particular attention will be paid to (a) the important role of spatial hearing in overcoming informational masking (and, by implication, the importance of bilateral implants), and (b) the potential contribution of any processing strategy that leads to an increased distinction between the voices of different talkers.

Supported by NIDCD DC01625

SESSION 4: SPEAKER 2

SIGNAL PROCESSING STRATEGIES FOR IMPROVED SPEECH UNDERSTANDING IN NOISY LISTENING CONDITIONS

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Speech understanding in noisy conditions (daily real-life listening environments) is for cochlear implants in general an even bigger problem than for hearing aid users. We have been focussing in our research on multi-microphone configurations combined with adequate signal processing for behind-the-ear (BTE) applications. Using 2 microphones and additional adaptive signal processing with limited complexity (feasible for cochlear implant systems), it has been shown that speech understanding in different types of jammer noises (multiple talkers) and sound scenes (sounds simultaneously from different directions) can be improved. In moderately reverberant rooms improvements of about 10dB can be obtained for cochlear implants and a single jammer source, relative to a single directional microphone. Results and evaluations with cochlear implant subjects obtained with the following adaptive noise reduction strategies will be presented:

i) Adaptive beamforming (or generalized sidelobe cancellers) which provide good results, significantly better than the adaptive zooms implemented in some hearing aids, and using low-complexity algorithms. This technique has recently been implemented in the Freedom cochlear implant system.

ii) Adaptive optimal filtering techniques, which, at the expense of a slightly higher complexity, provides an increased robustness against changes in speaker positions and microphone characteristics.

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SESSION 4: SPEAKER 3

EVALUATION OF THE COMPANDING AND OTHER STRATEGIES FOR NOISE REDUCTION IN COCHLEAR IMPLANTS

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The susceptibility of cochlear implant (CI) listeners to noise is well documented in the literature. Yet, not many noise reduction algorithms have been proposed or evaluated for CI listeners. In this study we evaluate the performance of the companding strategy (Turicchia and Sarpeshkar, 2005) as well as other strategies for noise reduction in cochlear implants. .

The companding strategy models two-tone suppression by performing simultaneous multi-channel envelope compression and expansion using different power exponents. The envelope expansion is used to prevent the compression from degrading spectral contrast in regions close to a spectral peak while allowing the benefits of improved audibility in regions distant from the peak. The companding strategy effectively enhances the spectral contrast between the envelopes in adjacent frequency bands. Further enhancements are made to the companded envelopes by applying an SNR-dependent weight to each channel. The applied weights are set proportional to the effective signal-to-noise-ratio estimated in each channel. The SNR-weighting strategy is used in conjunction with the companding strategy and is also evaluated independently.

Preliminary results obtained with Clarion CII subjects indicated that most subjects benefited in vowel recognition and that some subjects also benefited on sentence recognition in noise with the proposed strategies. The present results are encouraging as they suggest that some CI subjects can benefit from noise reduction algorithms in terms of improved speech intelligibility.

Supported by NIH-NIDCD.

FACTORS AFFECTING IMPLANT LISTENERS' SPEECH UNDERSTANDING IN NOISE

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Listeners who use cochlear implants are surprisingly adversely affected by background noise under certain circumstances. In our work, even when the level of the noise was approximately 10 to 15 dB lower than that of the speech, background noise significantly reduced speech recognition scores. Several reasons have been proposed for this reduction, including: the reliance of implant listeners on speech envelopes which are perturbed by random noise, poor spectral representation from implant processing which causes severe reduction in the redundancy of speech, and poor speech/noise segregation due to weak fundamental frequency representation. Work from our laboratory suggests that each of these may play a role in the adverse effects of noise for cochlear-implant users and for simulation listeners. Evidence for each of these factors will be presented for listeners' understanding of phonemes, words, and sentences in steady and in gated noise. Data will be presented for listeners with cochlear implants and implant simulations.

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EFFECTS OF FREQUENCY MODULATION ON SPEECH RECOGNITION WITH A COMPETING TALKER

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Cochlear implants allow successful communication under optimal listening conditions. However, the amplitude modulation (AM) cue provided by most implants is not sufficient for speech recognition in noise. A series of experiments added slowly-varying frequency modulations (FM) to the existing implant simulation to evaluate FM contributions to speech recognition with competing sentences. Potential FM advantage was evaluated as a function of the number of spectral bands, fundamental frequency (F0) separation of target and competing speech, and FM parameters of depth, rate, and band distribution. Performance improved with the addition of FM both in quiet and noise. The FM cue also allowed gradual improvements with increasing *F*0 separations, a result not found with AM information alone. Performance improved with greater FM depth and rate, which might reflect resolved sidebands under the FM condition. Having FM present in low-frequency bands was most beneficial, and only a subset of bands required FM to achieve performance similar to when all bands had the FM cue. These results provide insight into the relative contributions of AM and FM to speech communication and the potential advantage of incorporating FM for cochlear implant signal processing.

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SESSION 4: SPEAKER 6

ROLE OF F_0 IN SPEECH RECEPTION IN THE PRESENCE OF INTERFERENCE: SIMULATING ASPECTS OF COCHLEAR-IMPLANT PROCESSING

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Despite many significant advances made in the development of cochlear implants, even the most successful cochlear-implant users do not hear as well as normal-hearing listeners. The differences in performance between normal-hearing listeners and cochlear-implant users are especially pronounced in understanding speech in complex auditory environments. For normal-hearing listeners, voice pitch or the fundamental frequency (F0) of voicing has long been thought to play an important role in the perceptual segregation of speech sources. The aim of our studies was to examine the role of voice pitch in speech perception in the presence of background interference, specifically simulating aspects of envelope-vocoder style implant processing. The findings of the studies show that despite reasonable F0 difference limens (< 1 semitone) with 24- and 8-channel vocoder processing, listeners were unable to benefit from F0 differences between competing vowels in the concurrent-vowel paradigm. The F0 information carried in the temporal envelope is weak, susceptible to reverberation, and may not suffice for source segregation. To the extent that vocoder processing simulates cochlear-implant processing, users of current implant processing schemes are unlikely to benefit from F0 differences between competing talkers when listening to speech in complex environments. When low-frequency information was added to envelope-vocoder processed high-frequency information, some F0 segregation benefits returned and the reception of speech in complex backgrounds improved, even when the low frequencies were limited to 300 Hz. Taken as a whole, our findings suggest that low frequency fine-structure information is important to the task of speech segregation, and that every effort should be made to present such information to cochlear-implant users.

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SESSION 4: SPEAKER 7

PRELIMINARY INVESTIGATION OF SPEAKER NORMALIZATION IN COCHLEAR IMPLANT SPEECH PROCESSING

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Because of the limited spectra-temporal resolution associated with cochlear implants, implant patients are more susceptible to acoustic variation among different talkers than normal-hearing listeners, and thus have greater difficulty with multi-talker speech recognition. The present study investigated whether multi-talker speech recognition can be improved by applying speaker normalization techniques to cochlear implant speech processing.

In this preliminary study, a speaker-dependent analysis filter bank design was proposed to normalize the variation of vocal tract length among different speakers. Multi-talker Chinese vowel recognition was tested with normal-hearing Chinese-speaking subjects listening to a 4-channel cochlear implant simulation, with and without speaker normalization. For each subject, speaker normalization was referenced to the speaker that produced the best recognition performance under conditions without speaker normalization. To match the remaining speakers to this "optimal" output pattern, the overall frequency range of the analysis filter bank was adjusted for each speaker according to the ratio of the mean third formant frequency values between the specific speaker and the reference speaker. Results showed that speaker normalization provided a small but significant improvement in subjects' overall recognition performance. After speaker normalization, subjects' patterns of recognition performance across speakers changed, demonstrating the potential for speaker dependent effects with the proposed normalization technique. Further studies using high-quality voice conversion as a pre-processor of cochlear implants will be conducted to test the potential benefits of speaker normalization in real cochlear implant applications.

Supported by NIH-NIDCD]

SESSION 5: SPEAKER 1

PITCH AND AUDITORY STREAM SEGREGATION: NEURAL CORRELATES AND POTENTIAL MECHANISMS

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Pitch is important for music appreciation, for speech perception, and for segregating competing sound sources in complex acoustic environments. Because of its importance, conveying accurate pitch information is one of the greatest remaining challenges for cochlear-implant processing. This talk will review some functional imaging and psychophysical studies designed to help elucidate the nature and neural bases of pitch perception, and its role in stream segregation.

The perceived pitch strength (or salience) of a sound depends on a number of physical parameters, including its temporal (and spectral) regularity. In the first study, temporal regularity was dissociated from pitch salience by using highpass-filtered harmonic complexes (acoustic pulse trains, similar in some ways to the pulse trains provided to cochlear-implant users), which are perfectly periodic (and hence regular), but produce a much weaker pitch percept than do sounds comprising lower harmonics. Using fMRI, reliable differences in brain activation produced by high-salience and low-salience complexes were found only in a very localized region overlapping anterolateral Heschl's gyrus, suggesting that activity in this area may reflect changes in perceived salience rather than physical temporal regularity.

The second study investigates why low-order, resolved harmonics produce a stronger pitch than high-order unresolved harmonics. So-called "transposed stimuli" were used in an attempt to take the temporal firing patterns associated with the fine structure of low-frequency sinusoids and transpose them into the temporal envelope at high-frequency places in the cochlea. The results show that, while the binaural system seems to be able to take advantage of the temporal cues in transposed stimuli, the pitch system does not, suggesting that place, as well as timing, information is necessary for good pitch perception.

A third set of studies investigated the neural bases of sequential stream segregation, whereby a sequence of sounds splits into two perceptual streams, based on differences in frequency or pitch. Using both MEG and fMRI, potential correlates of perceptual stream segregation were identified, which could not be attributed solely to separation on the tonotopic axis. Overall, these studies provide important clues as to how pitch might be processed within the auditory system, which in turn should help in the search for more effective ways of presenting stimuli to cochlear-implant users.

Support provided by the NIH-NIDCD and the Hertz Foundation.

LIMITATIONS ON PITCH PERCPETION BY COCHLEAR IMPLANT USERS

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Modern speech-processing algorithms encode voice pitch by the temporal pattern of activation on one or more electrodes. We study this "temporal" pitch perception by requiring cochlear implant (CI) users to identify which of two pulse trains, differing in rate and applied to the same electrode, has the higher pitch. In addition, we perform analogous experiments with acoustic pulse trains, bandpass filtered to remove low-numbered, resolved, harmonics, and presented to normal-hearing (NH) listeners. Two lines of evidence indicate that listeners do not fully exploit short inter-pulse intervals (IPIs) when estimating pitch.

First, when presented with a pulse train whose IPIs alternate between 4 and 6 ms, both NH and CI listeners report a pitch corresponding to an IPI of just below 6 ms (Carlyon *et al*, 2002). New findings indicate that this is due to pulses occurring after the 4-ms IPI being more prone to refractory effects, leading to an alternation in the amplitude of the compound action potential (CAP) to successive pulses. This in turn causes some 10-ms intervals to be conveyed to a central pitch mechanism. The new findings come from measurements of guinea pig and human CAPs to the same (acoustic) stimuli used in the pitch experiments, and psychophysical evidence from NH and CI users that the 'bias' towards the longer IPI decreases at longer overall IPIs, where refractory effects should be reduced..

Second, discrimination of pulse rate deteriorates for CI listeners above about 300 pps. This has been attributed to refractory effects causing many AN fibers to "miss" even-numbered pulses, as evidenced by an alternating-amplitude pattern in the electrical CAP ("ECAP") to high-rate isochronous pulse trains (Wilson, *et al*, 1977): Neurons respond to the first pulse, are refractory for the second, recovered by the third, and so on. Preliminary results from three different paradigms have, however, so far failed to find evidence that pitch perception at high rates is primarily limited by this alternating pattern: (i) attenuating the odd-numbered pulses in a train (which should reduce alternation) yields a percept that CI users can't distinguish from alternating the even-numbered pulses, (ii) ramping pulse trains on slowly does not differentially improve discrimination at high rates, (iii) presenting a copy of the lower-rate ("standard") stimulus to the contralateral ear in both intervals of a 2IFC trial, thereby providing bilateral users with an interaural timing cue, does not aid discrimination at high rates. Hence, although refractory effects can have a strong effect on pitch perception, we have so far found no direct evidence that a reduction in the AN response to even-numbered pulses provides is primarily responsible for the poor pitch perception at high rates.

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PERCEPTION OF SIMPLE MELODIES WITH PLACE CUES BY NORMAL-HEARING AND COCHLEAR IMPLANT LISTENERS

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The level of spectral resolution required to convey musical pitch is much greater than that required to convey speech information. In this study we presented normal-hearing listeners with spectrally degraded notes to determine the effect of spectral resolution on (i) frequency resolution (ii) identification of melodies without rhythmic cues and (iii) the ability to identify the appropriate note spacing for a single melody.

The notes presented to normal-hearing listeners were either pure tones or spectrally degraded notes produced by methodically randomizing the phase of the tone such that the bandwidth of the resulting tone was a fixed proportion of the frequency. The degraded notes retained a spectral peak at the appropriate frequency, but the bandwidth at the 3 dB down point was widened from 0.1 semitones to 54.6 semitones. Relative to the pure tone condition, frequency resolution and melody identification were not significantly degraded until the 10.5 semitone bandwidth condition. Musical note spacing proved most sensitive to spectral degradation with significant confusion between the correct and incorrect note spacing occurring in the 2.3 semitone bandwidth condition.

The 10.5 semitone noise bands allowed frequency resolution of 1 semitone (comparable to that found in better cochlear implant listeners). In this condition the melody identification for normal hearing listeners was reduced from 100% correct to 70% correct and the ability to determine the appropriate note spacing of a single melody was reduced from 87% to 25% (chance=20%). These results suggest that resolution achieved by most cochlear implant recipients is sufficient for good melody identification, but not for the perception of correct musical intervals.

We also investigated the ability of cochlear implant patients to identify simple melodies and to demonstrate a consistent preference for musical note spacing. The preference for musical note spacing was determined using an adaptive procedure where melodies were presented over a 3 to 6 mm segment of the electrode array. The electric notes were created by stimulating single electrodes of simultaneously stimulating adjacent electrodes (virtual channel). The results were consistent with those of normal-hearing listeners. Specifically, cochlear implant patients were more likely to identify melodies without rhythmic cues than to consistently identify a preference for musical note spacing.

EXPLICIT PITCH ENCODING TO IMPROVE COCHLEAR-IMPLANTS MUSIC PERCEPTION

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Pitch perception depends on the site of stimulation (place pitch) as well as the periodicity of stimulation (rate pitch). Current cochlear implants encode the place pitch by stimulating different location of the cochlea and the rate pitch by temporal envelope with a fixed-rate carrier. Due to frequency-to-electrode mismatch, electrode interaction, and other unknown causes, neither place nor rate pitch is adequately encoded in current implants, producing generally poor music perception, including particularly poor melody recognition.

The present study systematically manipulated the place and the rate of stimulation to improve cochlear implant music perception. In the place-only condition, up to 6 electrodes were stimulated individually with a frequency resolution of ¼ to 1 octave per electrode and a constant stimulation rate (100 or 1000 Hz). In the rate only condition, a single electrode (near apex, middle, or base) was stimulated with the stimulation rate varying linearly as a function of the music note's fundamental frequency. In the combined place and rate condition, the stimulation electrode and the stimulation rate were co-varied to encode pitch. Seven Nucleus-24 subjects participated in a 12-item, closed-set, melody recognition task.

Data so far showed that the subjects achieve an average score of 24% correct with their clinical processors. A significantly improved performance was observed with all three experimental conditions, with an average score of 38% for the rate-only condition, 64% for the place-only condition, and 84% for the combined condition. A novel strategy, which encoded music and voice pitch by the combination of the stimulation electrode and the stimulation rate, has been implemented in a real-time speech processor (SPEAR3). Preliminary data showed that, compared with their clinical processors, the novel strategy significantly improved melody recognition performance while maintaining similar speech performance. The novel strategy also has potential to improve cochlear implant performance in understanding speech in noise and tonal languages.

Supported by NIH-NIDCD.

SESSION 5: SPEAKER 5

TEMPORAL AND SPECTRAL CUES FOR TONE PERCEPTION

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The tone pattern of a monosyllabic word in tone languages conveys lexical meaning. We are interested in understanding what features in the speech signals contribute to lexical-tone perception and the interaction of the features. This information is critical for designing auditory prosthesis speech processors applicable to tone languages, which are spoken by a quarter of the world's population.

Speech signals can be partitioned into the temporal envelope and the fine structure. Smith et al. (2002) paired the envelope of one sound with the fine structure of another and found that, when 4 to 16 frequency bands were used, English speech recognition was dominated by the envelope, whereas melody recognition was dominated by the fine structure. In our study, Mandarin Chinese monosyllables were divided into 4, 8, or 16 frequency bands and the fine structure and envelope of one tone pattern were exchanged with those of another tone pattern of the same monosyllable. In ~90% of the tone-identification trials, subjects based their identification on the fine structure rather than the temporal envelope. Thus, the relative importance of envelope and fine structure for lexical-tone perception resembled that for melody recognition rather than that for English speech recognition. Delivering fine-structure information in auditory prosthesis speech processors could be particularly beneficial for lexical-tone perception.

In another study, we systematically varied the amount of spectral and temporal-envelope information through simulations of cochlear implant processors using a noise-excited vocoder. Spectral information was controlled by varying the number of channels (bandpass filters) between 1 and 16, and temporal-envelope information was controlled by varying the lowpass cutoff frequencies (LPFs) of the envelope extractors from 1 to 512 Hz. We found that tone recognition depended on both the number of channels and the LPF. A tradeoff was observed between the temporal-envelope and the spectral cues for tone recognition, indicating that temporal cues can compensate for diminished spectral cues for tone recognition and *vice versa*. This tradeoff occurred in the range of number of channels between 1 and 12 and LPFs between 1 and 256 Hz. These results were in contrast to those for English phoneme recognition where we found that the tradeoff between temporal and spectral cues occurred in much smaller ranges. Tone perception is more demanding of the temporal and spectral information under cochlear implant stimulations. This result suggests that auditory prosthesis processors for tone languages must effectively deliver more spectral detail (more functional channels) and finer temporal-envelope information than is required for non-tonal languages.

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SESSION 5: SPEAKER 6

ENHANCEMENT OF TEMPORAL CUES TO VOICE PITCH IN CONTINUOUS INTERLEAVED SAMPLING COCHLEAR IMPLANTS

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The limited spectral resolution of cochlear implant systems means that the lower harmonics of speech that give normal listeners spectral cues to pitch are not resolved. In principle, temporal envelope cues to pitch are available in continuous-interleaved-sampling (CIS) processed speech. However, such cues are relatively weak, particularly for fundamental frequencies (*F0*s) at the higher end of the voice pitch range.

A modified processing strategy, aimed at enhancing temporal cues to voice pitch, was compared with standard CIS processing, both in adult users of the Clarion C1 implant and in acoustic simulations. In standard processing either pulse trains (implant users) or noise carriers (simulations) were modulated by 400 Hz low-pass envelopes. In the modified strategy, slow-rate envelope modulations, which convey dynamic spectral variation crucial for speech understanding, were extracted by lowpass filtering (32 Hz). In addition, during voiced speech, higher-rate temporal modulation in each channel was provided by 100% amplitude-modulation by a sawtooth-like waveform whose periodicity followed the *F0* of the input. Channel levels were determined by the product of the lower- and higher-rate modulation components.

Tasks included labelling the direction of pitch movement of synthetic diphthongal glides and using intonation information to identify naturally-spoken sentences as question or statement. In both cases, performance was significantly better with modified processing, both in implant users and in acoustic simulations. Factors contributing to the advantage for modified processing may include increased modulation depth and use of a modulation waveform featuring a rapid onset in each period, resulting in a clearer representation of *F0* in the neural firing pattern.

However, while vowel recognition did not differ across processing strategies in the acoustic simulation, implant users performed worse with modified processing both in vowel recognition and in formant frequency discrimination. It appears that, while enhancing pitch perception, modified processing harmed the transmission of spectral information.

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SESSION 6: SPEAKER 1

CHANGE AND INFORMATION FOR SPEECH PERCEPTION

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All sensorineural systems respond to change and to little else. Perceptual systems do not record absolute level be it loudness, pitch, brightness, or color. Instead, sensory encoding is always relative to ambient levels of energy and/or spatial-temporal context. Emphasizing change serves to overcome limitations upon biological dynamic range, which always is a small fraction of the physical range of energy flux in the environment. Adjusting biological dynamic range, and neglecting absolute levels, serves to maximize the amount of information that can be detected across widely varying levels of physical energy. One consequence of this fact is that veridical recovery - faithful internal reconstruction of the signal or of distal objects or events - is both unnecessary and impossible. The sacrifice of absolute encoding has enormous benefits along the way to maximizing information transmission. Redundant or predictable characteristics, which are relatively uninformative, are perceptually neglected. As a consequence, sensitivity to new, by definition informative, characteristics is maximized. Here, it will be argued that this general principle extends from the earliest levels of processing such as adaptation and contrast, to higher-level perceptual phenomena such as perceptual constancy and categorical perception. Processes for extracting, and perceptually devaluing, redundant or predictable properties of the input simply become increasingly sophisticated with ascending levels of processing. This simple ubiquitous principle of perceptual systems will be applied to exemplary issues concerning speech understanding including perception of coarticulated speech, lack of invariance, categorical perception, and word segmentation. It is hoped that insights into perception by individuals with cochlear prosthetics also will be revealed. For example, within this framework, it is not particularly fruitful to focus upon fidelity. Instead, maximization of information transmitted should be emphasized. Ideally, some new ideas for optimizing processor strategies will be inspired.

Supported by NIH-NIDCD

SESSION 6: SPEAKER 2

GESTURAL SPEECH ORGANIZATION

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Infants have to discover the organization of the speech signal. The patterning of the speech signal is caused by the speech gestures of the speaker. Because the patterning in the signal is caused by phonetic gestures of the vocal tract, and because different gestures pattern the signal differently, the acoustic speech signal provides information about speech gestures. It provides the means by which infants learn to talk. I will present evidence that, well beyond infancy, listeners extract articulatory information from the speech signal. The evidence comes from findings that listeners compensate for coarticulation. That the information that perceivers use to compensate for coarticulation is gestural is shown by the finding of audiovisual compensation. The organization of the speech signal that listeners exploit and that infants and children discover, is the true organization of the signal, the one that talkers provide.

SESSION 6: SPEAKER 3

NOTES ON THE PERCEPTUAL ORGANIZATION OF SPEECH

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A survey of explanations of the perception of speech exposes a widespread reliance on the resolution of acoustic correlates characteristic of each element of a segmental phonetic inventory. Such a normative conceptualization of speech perception is opposed by psychoacoustic studies of ordinary phonetic perception and of perception mediated by a cochlear implant. Despite demonstrable sensitivity to subtle auditory features, a listener is unlikely to identify linguistic properties of speech as if each were one of a family of auditory qualities. Instead, the broad perceptual tolerance for departures from acoustic-phonetic norms encourages an alternative to the customary account appealing to auditory reduction. A brief review of this evidence distinguishes the functions of perceptual organization and perceptual analysis, in which the former establishes the perceptual coherence of a stream of speech and the latter resolves the linguistic properties inherent in its variation. Measures of perceptual tolerance of asynchrony and spatial dislocation in uni- and multimodal instances establish that perceptual organization persists under some impossible conditions, evidence of the abstractness in perceptual attention that results from ordinary perceptual experience. Studies of the bistability of synthetic and sinewave speech signals reveal the independence of perceptual organization of speech and general Gestalt-derived auditory perceptual organization. On this evidence, perceptual organization of speech appears to be keyed to speechlike sensory variation independent of short-term samples; it occurs rapidly and automatically; it is nonsymbolic; and, it reflects sensitivity to coordinate variation within sensory samples despite lack of familiarity and similarity among the elements.

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DISCOVERING THE PERCEPTUAL ORGANIZATION OF SPEECH SIGNALS: IMPLICATIONS FOR CHILDREN WITH COCHLEAR IMPLANTS

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Fifty years of research into the basic mechanisms of human speech perception have focused almost exclusively on the relation between discrete spectro-temporal properties of the signal (known as cues) and the phonetic percepts they evoke. Collectively this approach has failed to identify any single acoustic properties, or combinations of properties, that invariably signal specific phonetic segments. In turn, this failure is largely responsible for the inception of a new theoretical perspective: There must be more to human speech perception than the hunting and gathering of cues in the acoustic signal. Instead it seems that attention to the overall organization of speech signals goes a long way to supporting the recovery of phonetic structure. Because the organization of these signals is language specific children must discover that organization in their first language through early language experience. This process seems to involve learning how much attention to pay to each available acoustic property and determining how these properties fit together to reveal phonetic structure. This presentation will review existing research supporting this proposal, and discuss what is known about the kinds of experiences that best facilitate the discovery of signal organization in one's native language. Finally, the implications of these results for designing intervention programs for children with cochlear implants will be discussed.

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SPEECH PERCEPTION - THE ROLE OF STREAMS OF PROCESSING AND HEMISPHERIC ASYMMETRIES

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Developments in primate neuroanatomy have indicated that the auditory system, like the visual system, can be characterized as having both hierarchical and parallel processing. The hierarchical processing can be seen in the responses to complex sounds. The parallel processing can be seen in multiple streams of processing, running anterior and posterior to primary auditory cortex, and projecting to frontal cortex via different pathways. In my talk I will take this primate model as a framework to consider the results of experiments on speech perception in humans. I will argue that we can identify correlates of both the anterior and posterior streams in humans, and that these have different functional characteristics (namely, what and how pathways). This approach enables us to move beyond simplistic anatomical terminology in our understanding of human speech perception. Finally, I will consider the contributions of hemispheric asymmetries and functional specializations in speech perception.

SESSION 7: SPEAKER 1

DESIGN CONSIDERATIONS FOR NEW IMPLANT ELECTRODES

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New cochlear implant electrodes should be designed to enhance speech perception. A major obstacle to improving speech perception is better temporal coding. This might be overcome by bringing electrodes and auditory nerves into very close proximity, enabling precise stimulation of very small numbers of neurons, and thereby potentially overcoming the problems of synchrony between neurons and deterministic firing. Bringing auditory neurons and electrode into intimate contact may involve placing the electrode within the auditory nerve (an intra-neural electrode), or alternatively "growing" peripheral auditory dendrites towards an intracochlear electrode.

New cochlear implant electrodes should preserve inner ear function, in order to keep residual hearing following implantation and facilitate combined electric-acoustic stimulation of the auditory nerve. They should also maintain the auditory neural population. Anti-oxidants, anti-inflammatory agents (glucocorticosteriods) and neurotrophins may protect the cochlea during and/or after implantation.

Given these considerations, we propose that new cochlear implant electrodes should aim to: (i) promote atraumatic insertion, (ii) make intimate contact with the auditory nerve, and (iii) be capable of drug delivery. We have explored the role for neurotrophins, proteins that rescue auditory neurons from apoptosis following deafness, in achieving some of these aims. The experimental model was the guinea pig, and the method of deafening was a single dose of kanamicin and furosemide. Our key findings were: 1). A bolus of radio-labelled (I^{125}) neurotrophin-3 (NT-3) was distributed to all turns of the cochlea, mostly within the scala vestibuli and scala tympani, with very little signal apparent within the scala media or Rosenthal's canal. NT-3 was never seen *within* auditory neurons. 2) NT-3 and brain derived neurotrophic factor (BDNF), when applied to scala tympani of deafened animals via a mini-osmotic pump, increased the rate of resprouting of peripheral dendrites. The resprouting was preferentially directed towards the spiral limbus. We learnt that the direction of regrowth of peripheral dendrites will need to be controlled if intimate contact between the auditory nerve and the implant electrode is to be achieved. 3) Single auditory neurons from BDNF-treated animals had shorter latencies and smaller dynamic ranges to electrical stimulation (200 pulses/s). Better understanding of the functional effects of neurotrophin treatment is required both from the safety perspective and to probe potential benefits for speech processing. 4) Therapeutic delivery of NT-3 to the cochlea, as determined by an increased survival of auditory neurons, can be achieved with biodegradable, biocompatible polymers such as alginate, applied to either the round window or implanted into scala tympani. This demonstrates that drug-delivery to the inner ear via a polymer-coated electrode seems feasible.

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SESSION 7: SPEAKER 2

FUTURE DEVELOPMENT OF COCHLEAR IMPLANT ELECTRODES

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Optimum performance of future cochlear implants (CI) requires improved interfaces between sophisticated sound processors and auditory neurons. Psychophysical, modeling and electrophysiological data all predict that patient performance will benefit if CI electrodes are consistently inserted without trauma and are optimally positioned. In these studies we examined 64 cadaver temporal bones implanted with 5 different CI electrode arrays with the specific goal of developing strategies that will both minimize trauma and improve electrode positioning.

We observed moderate to severe trauma at one or more locations in 63% of temporal bones studied. Perforation of cochlear partitions, with electrode deviation into the scala vestibuli (SV), occurred in 42% of insertions with electrodes designed to have equal stiffness in vertical and horizontal planes. Similar trauma occurred in only 14% of specimens implanted with electrodes having greater stiffness in the vertical dimension. When electrodes deviated into the SV, perforation occurred at a consistent location opposite the cochleostomy (mean = 196°). In addition to their increased vertical stiffness, electrodes that were least likely to deviate into the SV were pre-curved and were advanced off a stylet insertion tool. However, this tool must be withdrawn at the correct insertion depth for this to be of greatest advantage. Direct temporal bone measurements indicate that this ideal depth is highly variable, but there is currently no method to measure or predict this distance in a CI subject.

From the standpoint of electrode performance, we found that when electrodes deviated into the SV, distances from stimulating contacts to neurons in the spiral ganglion were significantly greater and the relationship of electrode sequence to cochleotopic organization was often distorted. Finally, deviation of electrodes into the SV resulted in decreased depth of insertion limiting stimulation to higher frequencies.

Based on these results we have successfully tested several strategies to better control the mechanical behavior of CI electrode arrays. The advantages of vertically oriented wire and plastic rib assemblies have been reported previously. We have recently fabricated electrodes based on photolithographic metallization of flexible substrates, and we also have tested liquid crystal polymer based electrodes developed in collaboration with Advanced Cochlear Systems (Seattle, WA). The vertical stiffness (1.63 and 4.9 vertical/horizontal stiffness in these two prototypes) and spiral restoration force in each of these designs can be accurately controlled. Moreover, these electrodes can be fabricated with higher contact densities than wire-based arrays and provide additional interior volume to permit the incorporation of optical or ultrasound location sensing technology, active mechanical steering capability and/or drug delivery. We suggest that future application of these design principals will facilitate production of clinical devices with significantly improved performance.

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SESSION 7: SPEAKER 3

IMPLICATIONS OF THE NON-LINEAR TONOTOPIC RELATIONSHIP BETWEEN THE HUMAN SPIRAL GANGLION AND ORGAN OF CORTI

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Since the early days of cochlear implantation the exact site of excitation of the auditory nerve (peripheral process, cell body and/or central axon) has been the subject of research and debate. Animal and model studies suggested that all three can be the case, e.g., depending on electrode configuration. The subject deserves renewed attention in the light of recent observations that place-to-frequency maps of Rosenthal's canal (RC, where the cell bodies are located) and the organ of Corti (OC, the place of the tip of the peripheral processes) are essentially different. This means that, even if the exact intracochlear position of an electrode contact is known, e.g., with high resolution CT-scans, it will excite different fibers, and, consequently, elicit a different pitch, depending on the exact site of stimulation.

To be able to use our computational model to get insight in the functional consequences of the fact that RC ends after 1¾ turn, while the peripheral processes extend to the full 2¾ turns of the cochlea, the fiber trajectories in our human cochlea model had to be redefined accordingly. In addition, the potential influence of the habenula perforate (HP) also became apparent. It was included into the computations, along with a five-fold increase of the number of simulated nerve fibers, in an attempt to further detail the simulations. Now, the fibers are grouped in 80 bundles of 20 fibers each at the level of the HP, while their tips are still evenly distributed along the OC. Furthermore, the nerve fiber model was improved with new human kinetics and a more realistic double cable model representation of the sparsely myelinated human cell body.

As expected, the largest influence of the relatively short RC turned out to occur for deeply inserted electrode contacts. With outer wall positions, the main peak of excitation tended to follow the tonotopy of the OC around threshold, but the excitation pattern shifted towards the apex as it broadened with increasing stimulus level. This is in line with eCAP selectivity curves, which are broader in apical than in basal directions. At the basal end perimodiolar electrodes roughly follow the tonotopy of RC, but beyond 1 turn the center of the broadening area of excitation shifts more and more to lower-pitched fibers. This phenomenon can offer an alternative explanation for the booming sound we previously ascribed to cross-turn stimulation. Furthermore, the model predicts a relationship between the insertion depth of the contacts and the ability to generate intermediate pitch percepts by simultaneous stimulation of neighboring electrodes (so-called current steering).

Generally speaking, the oblique course of apical fibers leads to a reduced selectivity of stimulation for deeply located electrode contacts and to a poorly controllable dependency of the perceived pitch on stimulus level.

Supported by the Heinsius-Houbolt Fund and Advanced Bionics

SESSION 7: SPEAKER 4

ELECTRODE TECHNOLOGY AND DESIGN

Jim Patrick

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The electro-neural interface is a major limitation to the performance of the cochlear implant today. Small number of stimulus sites are used to stimulate large groups of neurons and for patients with significant residual hearing there is the accompanying problem that it is not possible to guarantee that the insertion of an intra-cochlear electrode will not cause further hearing loss.

How many electrodes are needed for optimal performance? It may be possible to manipulate the stimuli from relatively few electrode sites to stimulate small and remote groups of nerves, but differences in anatomy, pathology and electrode position will always mean that clinical implementation will be difficult. The alternative path to improved control over the peripheral nervous system is to have more electrodes in intimate contact with the nerves.

For improved patient benefit we require:

a) An understanding of the mechanism of hearing loss following insertion trauma, and how to minimise it so that electrode arrays can be reliably inserted without hearing loss.

b) The application of clever biology to encourage peripheral processes to grow toward, and potentially to connect with high density electrode arrays.

c) The development of high density active electrode arrays.

The benefit provided by present ABI devices is also far from satisfactory, and research is needed into the merit of stimulation of structures like the Inferior Colliculus, higher up the brainstem.

EVOLUTION OF COCHLEAR IMPLANT ELECTRODES IN THE NEXT DECADE

Claude N. Jolly

MED-EL, Innsbruck, Austria

The implant electrode provides the crucial interface for triggering meaningful action potentials in the remaining auditory neurons of patients affected with neuro-sensory deafness. The first step in interfacing the electrode with the nerve is preservation of the neural tissue and sensory epithelium. The second step consists of placing stimulation contacts in all regions where excitable tissue is located, preferably from base to apex. Atraumatic deep insertion requires continuing effort in developing electrodes and tools that are surgeon friendly and keep the scala tympani as intact as possible. Histology studies using dissection can reveal unforeseen pattern of trauma, and confirm improvement in electrode design and insertion method. .

It is most likely that future electrode arrays will deliver therapeutic agents. Advanced prototypes show that medicine can reach intra cochlea tissue in fluid form at slow flow rates. Coated and eluting electrodes can also deliver a single dose spread over some time and in all or selected cochlea locations. Drugs in nano-particule form could provide a precise targeting. With fluid based drug delivery electrode the patient could benefit of advances in biomolecular engineering some years after implantation. .

Electrodes based on thin film technology have the potential to further enhance effectiveness by reducing the size of the device in the scala tympani and at the cochleostomy and enhancing mechanical characteristics. Trauma could be further suppressed and electrode reliability maximized. Number of true contacts could be increased, which in conjunction with usable virtual channel would provide additional information channels to the patient. A vast variety of electrode parameters, including length, geometry, contact spacing would allow a better treatment for the ossified cochlea, common cavity case, and for the patient needing an auditory brain stem implant. .

For the patient responding to electric and acoustic stimulation the electrode design would be optimum if deep insertion could be achieved with complete preservation of the sensory epithelium. Only basal contacts would be used for the electrical stimulation. Apical contacts would be available to take over the acoustic stimulation in the event of sudden or progressive residual hearing loss. .

Basal perimodiolar electrodes, with deep insertion properties, could also be used. Non pre-shaped electrode designs would be necessary to fit all cochlear size and insertion depth, and introduction angle. Single branch electrode at the cochleostomy is a pre-requisite for safety. .Other desirable features that will be developed in the future are lubricious coating imparting super hydrophilic properties to the electrode, heat sensitive multi-phase material, patterning of the platinum contact to reduce electrode impedance, and middle ear sensing electrode for the measurement of the stapedius reflex. The most important design criteria are long term safety and benefit for the patient cochlea.

SESSION 7: SPEAKER 6

THE ACS VISION OF THE FUTURE COCHLEAR IMPLANT

Scott Corbett, Francis (Sandy) Spelman, Ben Clopton, Tim Johnson, Matt Carson

Advanced Cochlear Systems (ACS), Snoqualmie, WA

Cochlear implants have been one of the dramatic success stories of the bioengineering enterprise. Although these prostheses are used extensively, and their use is growing, there is room for substantial improvement. We suggest high-density cochlear electrode designs will permit field shaping and field steering to an extent not presently possible with the arrays in use today. In conjunction with appropriate signal processing and stimulation strategies, these arrays will make it possible to provide phase information, currently richly available to normal listeners, to the cochlear implant patient. Retaining phase should improve hearing restoration on several levels: music appreciation should be possible, overall speech intelligibility should be higher and binaural implants could preserve the head response transform (HRT), improving localization of sound and intelligibility in noise. Performance improvements, however, will likely require the consumption of additional power by the implant and will require a careful consideration of the tradeoffs for full optimization.

We present an update of our progress over the last decade toward our goal to develop an advanced, integrated new cochlear implant system, including a 72 channel high density array, a new signal processing algorithm (TFM®) which preserves phase information and a transcutaneous optical data link which allows high bandwidth communication to the implant.

SESSION 7: SPEAKER 7

THE FUTURE OF ELECTRODE DEVELOPMENT FOR COCHLEAR IMPLANTS

Mike Faltys and Leonid Litvak

Advanced Bionics Corporation, Sylmar, CA, USA

Commercial electrode designs are a complex exercise in balancing tradeoffs. They must be implantable by all trained surgeons with minimal cochlear trauma, be durable enough to withstand implantation and not degrade for decades, and be manufactured consistently. A key to designing future electrodes will be in evaluating existing electrode designs. We have now deployed thousands of proximal, medial and lateral electrodes and developed new methods of assessing cochlear implant performance. Due to advances in medical imaging, electrode placement can be determined in individual patient. In addition, psychophysical tests that utilize simultaneous stimulation can be used to assess the pattern of the electric fields generated at the neural elements. This talk will give an overview of relevant retrospective data that can be utilized in deciding on optimal electrode design for each target application.

SESSION 8: SPEAKER 1

AUDITORY CORTEX: ORGANIZATION AND RE-ORGANIZATION

Christoph E. Schreiner, Ralph Beitel, Maike Vollmer, Marcia Raggio

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The core or primary regions of mammalian auditory cortex show systematic functional organizations with regard to several stimulus and response properties. Among the parameters that show local gradients and clustering are best frequency, response threshold and latency, and dynamic stimulus characteristics such as amplitude and frequency modulations. We will discuss changes in the functional cortical organization as consequence of hearing impairment and perceptual learning as well as chronic electrical cochlear stimulation.

Supported by NIH N01 DC-3-1006 and P01 34835.

SESSION 8: SPEAKER 2

GRADUAL ADAPTATION TO A MODIFIED PERIPHERAL FREQUENCY MAP BY POSTLINGUALLY DEAF CI USERS

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It is generally believed that CI's impose a basalward shift to the acoustic input, that is, sounds stimulate neurons with higher characteristic frequency than the acoustic frequency of the original stimulus. This frequency misalignment may have a negative influence on speech perception by postlingually deaf CI users. However, a perfect frequency-place alignment may result in the loss of important low frequency speech information. A trade-off may involve a gradual approach: start with correct frequency-place alignment to allow listeners to adapt to the spectrally degraded signal first, and then gradually increase the basalward shift to allow them to adapt to it over time.

Seven pairs of normal hearing listeners underwent 15 hours of speech perception training and testing using a real-time acoustic model of a CI. This 8-channel model simulated a 6.5 mm basalward shift. Subjects were randomized either to the "gradual" group (where the 6.5 mm basalward shift was introduced gradually over the course of ten sessions) or to the "fixed" group, who were exposed to the full 6.5 mm shift since the beginning. Both groups underwent 15 1-hour sessions using audiovisual speechtracking as well as vowel, consonant and sentence recognition tests (with feedback). For the last six pairs of subjects, three fMRI recordings were conducted at the beginning, middle and end of the study to assess changes in cortical activation in response to the CI acoustic simulations with 6.5 mm shift.

Speech perception scores were initially much higher for the "gradual" group, but by the end of the 15 sessions the "fixed" group had almost caught up with them. Imaging results showed some differences that were consistent with the behavioral data. Taken together, these results suggest that gradual exposure to basalward shift may result in faster speech perception improvement by CI users. In this presentation we will also discuss how the gradual approach could be implemented with actual CI users, and the first steps we have taken to achieve this goal.

Supported by NIH-NIDCD grant R01-DC03937.

SESSION 8: SPEAKER 3

PERCEPTUAL LEARNING AND AUDITORY TRAINING IN COCHLEAR IMPLANT PATIENTS

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Large spectral shifts may produce significant speech recognition deficits in cochlear implant (CI) users. Even after several months of exposure, CI users may not completely adapt to the spectral shift. To evaluate whether CI users can better adapt to large spectral shift by gradually increasing the spectral shift over time, frequency-to-electrode assignments were gradually shifted in a Nucleus-22 CI subject. Beginning with the clinically assigned frequency allocation (Table 7), the frequency allocation was gradually shifted every three months toward to Table 1 (a 0.68-octave upshift). Speech performance was evaluated for all frequency allocations just prior to implementation of each shifted allocation; performance with each experimental allocation was evaluated every two weeks over the three-month period of use. Results showed that the degree of adaptation highly depended on the test materials used to evaluate performance. Sentence recognition and voice gender identification were largely unchanged for all frequency allocations. However, phoneme recognition scores gradually declined as the spectral shift was increased. During the gradual adaptation, vowel recognition with Table 1 improved by nearly 20 percentage points by the end of the experiment, nearly 10 percentage points better than when the patient was given only 3 months to adapt from Table 7 to Table 1.

Daily, “passive” listening may not be sufficient to fully adapt to shifted speech, especially at the phonemic level. To see whether moderate speech training can accelerate the adaptation, 16 normal-hearing (NH) listeners were trained with spectrally shifted speech via an 8-channel acoustic CI simulation. Short daily training sessions were conducted over 5 consecutive days. Sentence training provided little improvement in recognition of shifted vowels. However, targeted phoneme training significantly improved the recognition of shifted vowel, as well as consonants and sentences. Targeted phoneme training was further evaluated in 10 CI users. Using a personal computer, auditory training was conducted at home for one hour per day, five days per week, for a period of 1 month or longer. Results showed a significant improvement in all patients' speech perception performance.

These results demonstrated that while gradually exposing CI patients to a spectral shift may help improve the degree of adaptation, targeted phoneme training may significantly accelerate the adaptation process, and that the improved phoneme recognition also generalized to improved sentence recognition. Whether training obviates the need for gradual exposure to shifted speech is unclear, but these results suggest that targeted phoneme training may be an effective tool in improving recognition of spectrally shifted speech by NH and CI listeners.

Supported by NIH/NIDCD.

SESSION 8: SPEAKER 4

FUNCTIONAL BRAIN IMAGING AND AUDITORY CORTEX PLASTICITY IN COCHLEAR IMPLANT USERS

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University of Texas Southwestern Medical Center, Dallas TX

One of the major consequences of long-term deafness is a change in the neural architecture of the central nervous system (CNS). The twofold purpose of this work was to: 1) explore regional cerebral blood flow (rCBF) responses to auditory stimulation that may be associated with the perceptual performance variation in cochlear implant recipients; and 2) investigate the potential benefit of pharmacologically-enhanced aural rehabilitation therapy as a means of increasing speech tracking skills in adult cochlear implant users. Subjects underwent rCBF imaging using Single Photon Emission Computed Tomography (SPECT) by watching a video-taped story under auditory+visual and visual only presentations. Data were normalized, co-registered to Talairach space, and statistical parametric mapping (SPM99) was used. 8 adult cochlear implant participants received either 10 mg d-amphetamine (Treatment group, N=4) or a placebo (Placebo group, N=4) 60 minutes prior to a 1.5 hour intensive aural rehabilitation session occurring twice a week for two months. Treatment consisted of a multi-step rehabilitation program individualized for each participant to develop auditory-only speech tracking skills. Prior to and at the conclusion of the therapy sessions, SPECT rCBF imaging and speech tracking assessments were conducted. Right and left ear monaural stimulation in normal hearing subjects resulted in significant bilateral activation of Brodmann areas 41, 42, 22, 21, and 38. Cochlear implant subjects with relatively high levels of open-set speech perception demonstrated bilateral activation of cortex; however, the extent of activation was significantly less than that observed for normal hearing individuals, particularly in auditory association cortex (Brodmann areas 22, 21, 38). Speech tracking scores of the placebo and treatment groups were similar before the aural habilitation intervention. In the placebo group, speech tracking performance increased 13.5% for visual plus auditory and auditory only presentations as a function of aural habilitation alone. The d-amphetamine-facilitated program resulted in minimal increases in visual plus auditory tracking scores (2%) but led to a 43% increase for auditory-only speech tracking. RCBF imaging indicated no substantial improvement of brain activation in the placebo group. However, both the extent and magnitude of primary and associative auditory cortex activations increased significantly in the pharmacologically-enhanced treatment group. Pharmacologic enhancement supports previous studies in aphasic stroke patients. Data, however, are preliminary and further study is warranted.

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DEVELOPMENT OF SPEECH UNDERSTANDING IN NOISE BY CHILDREN WITH COCHLEAR IMPLANTS

Susan J. Norton

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The majority of adult cochlear implant users report significant difficulty understanding speech understanding in noisy situations. They often avoid noisy situations. Children naturally spend much of their time in noisy environments such as interacting with other children at school and in play situations.

The purpose of this presentation is to examine the speech-in-noise skills of children with cochlear implants. Evaluating speech perception in noise skills of young children in a clinical setting can be challenging. In addition, speech spectrum noise is not representative of the everyday situations children encounter. Our clinic protocol includes a hierarchy of standard speech perception measures based on the child's chronological age as well as their auditory language age. For speech in noise testing the Common Phrases Test and/or the HINT-C sentences are presented via monitored live voice at 50 dB HL in the presence of recorded multi-talker babble from the QuickSIN (Ver.3.1) at a signal-to-noise ratio of +5 dB. The child is seated 1 meter from the speaker at a 0 degree azimuth. Retrospective clinical data were examined for 25 children with unilateral cochlear implants. The median age at testing was 7.0 years (range 3.0-19 years). The median score on the HINT-C sentences presented was 98% and the in noise 93%. Assessment of and factors related to speech-in-noise skills in children with cochlear implants will be discussed.

SESSION 8: SPEAKER 6

LANGUAGE EXPERIENCE OF TYPICAL BABIES IN EVERYDAY LIFE

Todd Risley, PhD.

University of Alaska.

Risley, with his colleague Betty Hart, systematically observed the daily lives of infants and toddlers in typical American families. They collected data – with reliable and repeated samples of daily life – on sufficient numbers of families who were sufficiently representative to estimate average amounts of parent talk received by American babies from their caregivers. They found that from 7 to 36 months of age. a typical American baby hears an average of 340 utterances, containing 1440 words addressed to them by their parents every waking hour of their life -- such that by age three, the average American child will have heard 20 million words addressed to them by their caregivers. And on the child side of the 'language dance', by 28 months children are talking as much as their parents and by age three the average American child will have said 7 million words in expressive language practice. They also found that amount of talking differs from family to family such that by age three some typical children will have heard more than 35 million words addressed to them while others will have heard fewer than 10 million. These observed differences in the amount of language input and language use throughout the waking hours in the everyday lives of these typical American babies accounted for almost all the differences in their observed vocabulary growth, and in their standardized test scores when they were both 3 and 9 years old.

SESSION 8: SPEAKER 7

CHANNEL INTERACTION IN CHILDREN

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Children with cochlear implants differ from adults with cochlear implants in a number of ways. Relevant to the study of channel interaction, children have a more consistent onset of deafness (congenital), duration of hearing loss, and likely a more uniform etiology of deafness. For this purpose, studies of children are typically done separately from studies of adults. Without equivalent pediatric studies, data obtained from adults are extrapolated to children despite these inherent differences. The goal of our work is to define properties of channel interaction common to the pediatric implant population.

We address channel interaction in children from the perspectives of both electrophysiology and psychophysics. Electrophysiologic measure of channel interaction utilizes the Electrically Evoked Compound Action Potential elicited with the masker-probe paradigm. By varying the position of the masker electrode with a fixed probe location, interaction functions result that are then used to quantify interaction. A psychophysical equivalent of channel interaction is addressed by measuring frequency and electrode discrimination using two-interval adaptive forced choice tests with a video game graphical user interface.

Pediatric results of electrode interaction show significant effects of intensity, location and array type. Electrode interaction increases with stimulus intensity. Electrode interaction also increases towards the apical end of the electrode array compared with its basal end. Interaction was consistent across electrode array type; although a small effect was observed with the Clarion Electrode Positioning System.

Our adaptive forced choice software generates acoustic stimuli for frequency discrimination, and electric stimuli through the Clarion CII/HiRes90K or Nucleus 24 implant platforms for electrode discrimination. With this video game platform we are able to determine difference limens for both acoustic frequencies and inter-electrode distances. Adaptive forced choice psychophysics is challenging to test in children less than five years of age, and difference limens are more variable and larger in this young population. Acoustic frequency discrimination is worse for deaf implanted children than for normal hearing children at all ages tested, but both improve with increasing subject age. Frequency difference limens in implanted children approach electrode spacing and signal processing characteristics of the implant. Electrode discrimination improves with stimulus intensity level, and varies with electrode location. In light of these results, we discuss the contribution of electrode interaction to channel discrimination in these subjects.

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SESSION 8: SPEAKER 8

OBJECTIVE MEASURES AND PROGRAM LEVELS: IMPORTANT LESSONS FROM SIMPLE MEASURES

Edward H. Overstreet

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In spite of significant advancements in cochlear-implant technology, clinicians still find themselves confronted with patients who are difficult to program. Moreover, there are situations in which reliable psychophysical responses (usually considered the "gold standard") still may lead the clinician to create programs that result in, at best, sub-optimal performance or, at worst, rejection of the device or explantation. Understanding normative patient programming data is important not only to the clinician but also to the researcher interested in ruling out confounding variables. This presentation will review recent findings from in-house and collaborative studies that provide population norms for electrical compound action potential responses and psychophysical loudness measures. Examples of how such norms can be useful when fitting individual patients will be presented. The practical applications of these data will address issues of adaptation, changes in program levels over time, effective neural stimulation rate, and channel interaction.

SESSION 9: SPEAKER 1

LOCATION OF STIMULATION WITHIN THE INFERIOR COLLICULUS AFFECTS CORTICAL RESPONSES IMPLICATIONS FOR AN AUDITORY MIDBRAIN IMPLANT

Hubert H. Lim and David J. Anderson

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The success and limitations of cochlear implants along with recent advancements in deep brain stimulation and neural engineering have motivated the development of a central auditory prosthesis. Current efforts have focused on the auditory brainstem implant (ABI). However, there is a need for a new implantation site due to the lack of success of the ABI particularly for neurofibromatosis type II patients. A potential site is the inferior colliculus central nucleus (ICC) (Lim and Anderson, 2003). The ICC is a highly organized tonotopic structure and is more surgically accessible than the cochlear nucleus in humans (Lenarz et al., ARO MWM 2004).

To assess the potential for an auditory midbrain implant (AMI), we stimulated different regions along the frequency and isofrequency dimensions of the ICC and recorded the corresponding neural activity along the tonotopic gradient and across different layers of the primary auditory cortex (A1) in guinea pigs using multichannel Michigan electrodes. The stimulus consisted of single, monopolar electrical pulses (200 μsec/phase, negative leading phase). Current source density analysis, acoustic-driven response patterns, and histological techniques were used to identify the location of each site.

Overall, ICC stimulation achieved lower thresholds, greater dynamic ranges, and more localized, frequency-specific activation in A1 layer IV than cochlear stimulation (cochlear data taken from Bierer and Middlebrooks, 2002). However, we observed that location of stimulation within an isofrequency lamina of the ICC affected these A1 responses. Stimulation of more rostral ICC regions elicited higher driven spike rates, larger evoked potentials, greater spreading (along the tonotopic gradient), and lower thresholds of activation in A1. In fact, stimulation of caudal ICC regions did not elicit any A1 activity (even at our maximum level of 56 μA), which may be indicative of greater inhibitory interactions and/or differences in functional projections compared to more rostral regions.

These results suggest that ICC stimulation may enhance both frequency and level discrimination with reduced energy usage compared to cochlear stimulation. Furthermore, location of stimulation within the ICC may affect performance. Stimulation of more rostral ICC regions may achieve lower perceptual thresholds but with a cost of greater frequency channel overlap. The lack of activation via caudal ICC stimulation suggests the possible need for more complex stimulation strategies that may require a three-dimensional electrode array.

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SESSION 9: SPEAKER 2

ELECTROPHYSIOLOGICAL VALIDATION OF THE AUDITORY MIDBRAIN IMPLANT

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The non-tumor (NT) ABI patients exhibit speech recognition performance comparable to the good CI performers, an outcome rarely seen in the more than 400 NF2 ABI patients currently implanted. Preliminary results suggest that the difference in outcomes between NF2 and NT ABI patients may be due to physiological damage to the cochlear nucleus during tumor removal, and in particular, to a neural structure/pathway that is essential for recognition of the amplitude modulation in speech (1).

We hypothesize that stimulation of the inferior colliculus (IC) in the auditory midbrain may bypass the damaged part of the auditory brainstem in NF2 patients and provide a better alternative for hearing restoration in these patients.

The goal of this stuy was to validate the electrophysiological characteristics of the Auditory midbrain implant (AMI) and demonstrate the feasibility of this implant as an alternative auditory prosthesis for hearing restoration in NF2 patients.

Matherial and Methods

In acute experiments, a multichannel solid state Michigan electrode was implanted along the tonotopic gradient of the primary auditory cortex (A1), in guinea pigs. The AMI electrode was implanted stereotaxicly along the tonotopic axis of the central nucleus of the IC (ICC). Both electrodes were placed along the simillar tonotopic gradients in ICC and A1. The AMI electrode was then stimulated with biphasic charge balanced pulses (200µs/phase), and multiunit recording of the nueral activity were performed in A1 (2,3).

Results and discussion

The stimulation threshold for initiating spike activity in the closest best frequency sites in A1 was in average 27µA with an average latency of 5 ms. ICC stimulation in low frequency regions induced activity in low frequency regions of A1, and similar trends were seen in the high frequency. ICC stimulation apears to be specific and causes minimal spreading of activity across A1 sites. These results indicate that AMI electrode may be a good alternative to auditory brainstem implant for hearing restoration in NF2 patients (4).

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SESSION 9: SPEAKER 3

USEFUL SIGNALS FROM MOTOR CORTEX

Andrew B. Schwartz

University of Pittsburgh

Over the years, we have shown that detailed predictive information of the arm's trajectory can be extracted from populations of single unit recordings from motor cortex. Using drawing movements as a behavioral paradigm, these signals have been shown to contain instantaneous velocity information and many of the invariants describing animate movement. Furthermore, this technique can be used to study visuo-perceptual processes taking place as objects are drawn. By developing techniques to record these populations and process the signal in real-time, we have been successful in demonstrating the efficacy of these recordings as a control signal for intended movements in 3D space. Having shown that closed-loop control of a cortical prosthesis can produce very good brain-controlled movements in virtual reality, we have been extending this work to robot control. We are using an anthropomorphic robot arm with our closed-loop system to show how monkeys can control the robot's movement with direct brain-control in a self-feeding task. The animals control the arm continuously in 3D space to reach out to the food and retrieve it to their mouths. Since the recorded signals are a high fidelity representation of the intended behavior and contain features of animate movement, neural prosthetic devices derived from this technology are capable of producing agile, natural movement.

SESSION 9: SPEAKER 4

CHRONIC MULTI-SPECIES STUDIES OF VESTIBULAR PROSTHESES

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Disorders of the peripheral vestibular system are relatively common and often result in severely impaired mobility, blurred vision and debilitating attacks of vertigo and motion sickness. Presently, little can be done to resolve these symptoms when they are chronically present. While data are limited, prevalence of profound vestibular problems appears about the same as profound hearing loss. Early research in the area of vestibular neuroprosthetics alongside the success of the cochlear implant, provides hope that providing motion cues via electrical stimulation may eventually help some patients suffering severe vestibular impairment. Conceptually, vestibular prostheses are similar to cochlear implants and consist of 4 principal elements: a power source, motion sensors, a microcontroller, and an electrode. We have developed and tested a vestibular prosthesis that senses yaw angular head velocity and uses this information to modulate the rate of current pulses applied to the vestibular nerve via an electrode *chronically*.

This device has been tested in three species. In squirrel monkeys, the lateral canals were plugged bilaterally and our prosthesis was secured to the head with the angular velocity sensor parallel to the axis of the lateral canals. The stimulating electrode was placed near the ampullary nerve of one lateral canal. When rotated in the dark, the animals responded with an appropriate horizontal vestibulo-ocular reflex (VOR), which adapted over time, providing evidence that the CNS was utilizing the information provided electrically. Data also show that the artificial rotational cue provided by the prosthesis is combined with normal sensory cues measuring the relative orientation of gravity. In another experiment, guinea pigs were provided chronic constant-rate stimulation and responded with a brisk nystagmus that adapted away after about a day. When the stimulation was removed, a brisk nystagmus in the opposite direction was measured, again lasting about a day. These findings demonstrate adaptation to constant-rate stimulation. When the stimulation was alternately turned on and off weekly, the nystagmus response began to decay more rapidly, eventually decaying just a few seconds after the device was turned on or off. This indicates that, with repetitive application of chronic stimulation, the animal learned to adapt rapidly to the present state (on or off) of stimulation. Such "switching" will be important for users of vestibular prosthetics so they don't feel disoriented when they remove the device to sleep, shower, etc. In studies with rhesus monkeys, we inserted an electrode into the right posterior canal. We have found that that the application of prosthetic stimulation to a posterior canal yields perceived tilt illusions consistent with predictions for normal semicircular canal stimulation. While all of this preliminary work suggests clinical potential, many questions remain unanswered, and many challenges must be addressed prior to clinical use.

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SESSION 9: SPEAKER 5

DEVELOPMENT OF A MULTICHANNEL IMPLANTABLE PROSTHESIS FOR RESTORATION OF 3D VESTIBULAR FUNCTION

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Bilateral absence of vestibular sensation and consequent failure of vestibulo-ocular and postural reflexes can cause significant disability due to oscillopsia (apparent motion of visual fields during head movement), impaired postural stability and chronic disequilibrium. While the prevalence of this disorder is not precisely known, about 7% of candidates for cochlear implantation (CI) and 10% of CI recipients exhibit profound bilateral loss of vestibular sensation on quantitative testing. There are no adequate treatment options for people who, despite rehabilitation exercises, fail to compensate for this loss. An implantable vestibular prosthesis that encodes head movement in all 3 dimensions (3D) and conveys that information via selective electrical stimulation of the vestibular nerve could significantly improve quality of life for these patients. We describe animal studies supporting this approach, discuss stimulation selectivity and other design considerations, and present a new multi-channel vestibular prosthesis that encodes head movement in 3D.

To develop an assay of stimulus selectivity for subsequent experiments, we used 3D scleral search coils and 3D binocular video-oculography to examine eye movements in response to transient canal-plane-specific head rotations of awake chinchillas in darkness. Eight normal chinchillas exhibited responses like those of normal humans, with gain (eye/head acceleration) near -1 in each canal plane. Eight chinchillas treated unilaterally with intratympanic gentamicin exhibited findings typical of similarly treated humans, with decreased gain for head movements exciting each canal of the treated labyrinth. Histologic exam confirmed persistence of vestibular nerve afferent fibers in treated canal cristae.

In chinchillas made bilaterally vestibular deficient through semicircular canal plugging and otolith disruption, biphasic current pulse trains delivered via an electrode implanted in one horizontal canal and pulse-frequency-modulated by head rotation in the horizontal plane elicited an almost perfectly compensatory 1D VOR in that plane. However, 3D oculography revealed evidence of spurious current spread to other vestibular nerve branches, indicating a need to refine electrode design and stimulus protocols to increase selectivity.

Drawing on these findings, we have designed and constructed a head-mounted, multi-channel vestibular prosthesis comprising 3 MEMS rotational accelerometers, a 6 MHz microcontroller, and a current source able to select any pair of 8 electrodes for bipolar stimulation. The device is able to encode head rotation in all 3 dimensions as continuous-interleaved, pulse-frequency-modulated and/or amplitude-modulated, biphasic pulsatile stimulation of three or more vestibular nerve branches.

Supported by NIDCD K08-DC006216 and R01-DC002390

SESSION 9: SPEAKER 6

THE PERCEPTUAL EFFECTS OF RETINAL ELECTRICAL STIMULATION

Ione Fine[1], Alan S. Horsager[2], Scott Greenwald[3]

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Photoreceptor loss due to severe retinitis pigmentosa or macular degeneration is one of the major causes of blindness in the Western world,and the prevalence of these diseases is likely to increase dramatically as the population ages. Currently there are several groups trying to develop retinal prostheses, analogous to cochlear implants, in which photoreceptor input is replaced by direct electrical stimulation. Recently six patients have been implanted chronically with simple 4x4 retinal prostheses lying over the inner retinal layer. We report here psychophysical data examining the perceptual consequences of electrical stimulation on a single electrode. These data include (1) how thresholds decrease with pulse duration and decrease as a function of electrode height above the retinal surface, (2) how brightness increases as a function of stimulation intensity, and (3) how pulses interact over time.

SESSION 9: SPEAKER 7

DESIGN OF A HIGH-RESOLUTION OPTOELECTRONIC RETINAL PROSTHESIS

Daniel V. Palanker[1,2], Alexander Vankov[2,1], Philip Huie[1,2], I. Chan[2], A. Butterwick[2], Alon Asher[1], Stephen A. Baccus[3], Michael F. Marmor[1], Mark S. Blumenkranz[1];

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Electrical stimulation of the retina can produce visual percepts in blind patients suffering from macular degeneration and retinitis pigmentosa. However, current retinal implants provide very low resolution (just a few electrodes), whereas at least several thousand pixels would be required for functional restoration of sight.

We present a design of an optoelectronic retinal prosthetic system with a stimulating pixel density up to 2,500 pix/mm^2 (corresponding geometrically to a maximum visual acuity of 20/80). Design of such prosthesis presents several major challenges: (a) To activate thousands of microelectrodes while avoiding cross-talk between pixels, metal erosion and overheating of tissue, the electrodes need to be located very close to the target cells; (b) To allow for natural eye scanning of images, information delivered to the implant should be coupled to eye movements; (c) To adjust the stimulation map to retinal architecture, real-time location-dependent image processing will be required.

Intimate proximity between electrodes and cells (~ 10 µm) is achieved by promoting the migration of retinal cells into 3-dimensional subretinal implants. Microfabricated arrays consist of either chamber electrodes with apertures 10-15 µm in width and 20-50 µm in depth or pillar electrodes 10 µm in diameter and 50 - 70 µm in height. Information from the video camera and signal processor is delivered to the implant by projection from a goggle-mounted pulsed infrared display onto the retina, thus activating the photosensitive pixels in the retinal implant. Each pixel has a photodiode connected to a common bi-phasic pulsed power line and thus converts local light intensity into a biphasic pulse of current. An eye tracking system mounted on the same goggles monitors the position of the retinal implant and adjusts the image processing between the camera and the IR goggles at a rate of 30 frames/s.

In summary, we present a design of a retinal prosthetic system that would solve some of the major problems associated with the realization of a functional retinal stimulation: high pixel density, proximity of electrodes to target cells, natural eye scanning capability, and real-time image processing adjustable to retinal architecture.

Support provided by AFOSR and VISX Corp.

POSTERS CATEGORIZED BY AREA OF RESEARCH

Session 1:
Bilateral Implants, Bimodal Hearing, and Electrophysiology
8AM, Sunday, July 31 - 8AM AM, Monday, August 1, 2005

1. ELECTRIC ACOUSTIC STIMULATION OF THE AUDITORY SYSTEM – SURGICAL ISSUES AND CLINICAL RESULTS by Oliver Adunka, Wolfgang Gstoettner, Jan Kiefer
2. PRECEDENCE EFFECT IN BILATERAL COCHLEAR IMPLANT USERS IN FREE-FIELD AND UNDER DIRECT STIMULATION by Smita S. Agrawal1, Ruth Y. Litovsky1, Gary L. Jones Richard Van Hoesel
3. A MULTI-RESONANT TRANSDUCER FOR A COMPLETELY IMPLANTABLE BIONIC EAR by Mark Bachman, Tao Xu, Fan-Gang Zeng, G.-P. Li
4. ARTEFACT REDUCTION BY A TRI-PHASIC STIMULUS FOR NEURAL RESPONSE IMAGING (NRI) by Battmer R.-D., Gärtner L. , Frohne-Büchner C., Brendel M., Büchner A., Litvak L., Emadi G., Alabashyan H., Lenarz Th.
5. CHARACTERISTICS OF NRTTM RECOVERY FUNCTIONS FOR DIFFERENT STIMULATION PARAMETERS by Joerg Pesch, Waikong Lai, Norbert Dillier, Matthijs Killian, Thomas Lenarz, Rolf D Battmer
6. TEMPORAL INTERACTIONS IN THE INFERIOR COLLICULUS: RESPONSES TO INTERLEAVED ELECTRICAL PULSE TRAINS by Steven M. Bierer, Ben H. Bonham, Russell L. Snyder
7. MUSIC PERCEPTION UNDER BIMODAL STIMULATION by Michael Buechler, Waikong Lai, Norbert Dillier
8. ECAP FOR DUAL ELECTRODE STIMULATION USING THE NUCLEUSÒ CI24RE COCHLEAR IMPLANT by Peter A. Busby, Rolf-Dieter Battmer, Joerg Pesch
9. INTRACOCHLEAR EVOKED POTENTIAL RESPONSES TO BIPHASIC PULSES WITH AN INTERPULSE GAP by Lianne A. Cartee1, Charles C. Finley, Chris van den Honert, Dewey T. Lawson, Blake S. Wilson
10. LOWS ARE THE NEW HIGHS: IMPROVING SPEECH INTELLIGIBILITY WITH UNINTELLIGIBLE LOW FREQUENCY SOUNDS by Janice E. Chang, John Y. Bai, Martin Marsala, Helen E. Cullington, Fan-Gang Zeng
11. SPREAD OF EXCITATION IN THE COCHLEA by Louise C Craddock, Huw R Cooper
12. USING THE EARLAB SIMULATION ENVIRONMENT TO STUDY ELECTRICALLY EVOKED ACTIVITY IN THE AUDITORY NERVE by Socrates G. Deligeorges, David Anderson, V. Vajda, Allyn E. Hubbard, David C. Mountain
13. MEASUREMENTS OF NEURAL ADAPTATION EFFECTS DEPENDENT ON RATE OF STIMULATION by Norbert Dillier, Waikong Lai, Rolf D. Battmer, Joerg Pesch, Matthijs Killian
14. EFFECTS OF TEMPORAL FINE-STRUCTURE ON LATERALIZATION AND THE BMLD OF SPONDEES IN BABBLE AND STEADY-STATE NOISE by Ward R. Drennan, Jong Ho Won, Jay T. Rubinstein
15. NOISE BAND VOCODER SIMULATIONS OF ELECTRIC ACOUSTIC STIMULATION by Tom Francart, Jan Wouters
16. RECORDING THE NEURAL RESPONSE EVOKED BY A BURST STIMULUS by Lutz Gaertner, Andreas Buechner, Carolin Frohne-Buechner, Martina Brendel, Timo Stoever, Thomas Lenarz

17. MEASUREMENT OF INTERAURAL TIME AND AMPLITUDE DIFFERENCE SENSITIVITY ON SUBJECTS WITH BILATERAL COCHLEAR IMPLANTS by Matthieu Gani, Colette Boëx, Christoph Schmid, Martin Kompis, Mattheus Vischer, Rudolf Häusler, Marco Pelizzone
18. METHODS FOR EVALAUTING BILATERAL ADVANATGES IN CHILDREN WITH COCHLEAR IMAPLANTS AND/OR HEARING AIDS by Soha N. Garadat, Ruth Y. Litovsky
19. RESIDUAL HEARING CONSERVATION AND ELECTRO-ACOUSTIC STIMULATION WITH THE NUCLEUS 24 CONTOUR ADVANCE by Chris James1, Bernard Fraysse1, Ángel Ramos Macías, Olivier Sterkers, Sandro Burdo, Richard Ramsden, Klaus Albegger, Didier Bouccara, Olivier Deguine1, Michel Gersdorff, Roland Laszig, Thomas Lenarz, Manuel Manrique Rodriguez, Erwin Offeciers, Ernst Von Wallenberg
20. SPEECH INTELLIGIBILITY IN NOISE FOR CHILDREN WITH BILATERAL CIs: THE EFFECT OF BILATERAL EXPERIENCE by Patti M. Johnstone, Ruth Y. Litovsky, Shelly Godar, Aaron Parkinson
21. EFFECT OF STIMULATION RATE AND INTERAURAL ELECTRODE PAIRING ON ITD SENSITIVITY IN BILATERAL COCHLEAR IMPLANT USERS by Gary L. Jones, Ruth Y. Litovsky, Smita S. Agrawal and Richard Van Hoesel
22. INFLUENCE OF MICROPHONE DIRECTIONALITY AND MICROPHONE POSITION ON SPEECH UNDERSTANDING IN NOISE IN BILATERAL COCHLEAR IMPLANT USERS by Martin Kompis, Matthias Bettler, Mattheus Vischer, Joachim Müller, Marco Pelizzone, Rudolf Häusler
23. BINAURAL HEARING USING TWO COCHLEAR IMPLANTS OR ONE COCHLEAR IMPLANT AND ONE HEARING AID by Jane R. Madell, Nicole Sislian, Lori Markoff, Lisa Rosenberg
24. INTERAURALTIME DIFFERENCES IN FINE STRUCTURE AND ENVELOPE IN BILATERAL ELECTRICAL AND ACOUSTICAL HEARING by Piotr Majdak, Bernhard Laback, Wolf-Dieter Baumgartner
25. AUDITORY NERVE SINGLE-FIBER RESPONSES TO COMBINED ELECTRIC AND ACOUSTIC STIMULATION OF THE COCHLEA by Charles A. Miller, Paul J. Abbas, Barbara K. Robinson, Kirill V. Nourski, Fuh-Cherng Jeng, Heil Noh
26. A COMPUTATIONAL STUDY OF COCHLEAR IMPLANT CODING USING MULTIPLICATIVE NOISE by Robert P. Morse, Nigel G. Stocks
27. ACOUSTIC-ELECTRIC INTERACTIONS IN THE AUDITORY NERVE: MASKING OF THE ELECTRICALLY-EVOKED COMPOUND ACTION POTENTIAL BY ACOUSTIC NOISE by Kirill V. Nourski, Paul J. Abbas, Charles A. Miller, Barbara K. Robinson, Heil Noh
28. CLINICAL RESULTS WITH HYBRID (ELECTROACOUSTIC) STIMULATION by Aaron J. Parkinson, Bruce J. Gantz, Christopher W. Turner, Dave Fabry
29. SIMULATING TIME-VARYING ELECTRICAL STIMULATION OF THE AUDITORY NERVE by Mark E Robert
30. MODELING THE INFLUENCE OF FITTING PARAMETERS ON LOCALIZATION IN CI USERS by Peter Schleich, Peter Nopp, Erwin Hochmair
31. INFLUENCE OF STIMULATION PULSE SHAPE ON NERVE EXCITATION THRESHOLD: INVESTIGATIONS USING A STATE-SPACE MODEL AND PRELIMINARY RESULTS PULSARCI100 USERS by H. Schösser, A. Nobbe, S. Brill, P. Spitzer, C. M. Zierhofer

32. BINAURAL MEASURES OF COCHLEAR IMPLANT LISTENERS by Bernhard U. Seeber, Ervin Hafter
33. THE RESPONSE OF THE AUDITORY NERVE TO ELECTRCAL STIMULATION FOLLOWING DEAFNESS by David J. Sly, Leon F. Heffer, Mark M. White, Robert K. Shepherd, Stephen J. O'Leary
34. ASSSESSMENT OF SPATIAL UNMASKING AND SOUND LOCALIZATION IN BILATERAL IMPLANTS USING DIRECT INPUT by Sigfrid D. Soli, Jenny C. Y. Chan, Andrew J. Vermiglio, Daniel J. Freed, Dorcas Kessler
35. SOUND LOCALIZATION IN BILATERALLY IMPLANTED CHILDREN BELOW 7 YEARS OF AGE by Lieselot Van Deun, Astrid van Wieringen, Tim Van den Bogaert, Fanny Scherf, Paul Van de Heyning, Andrzej Zarowski, Ingeborg Dhooge, Naïma Deggouj, Leo De Raeve, Christian Desloovere, Jan Wouters
36. COMBINED ELECTRIC ACOUSTIC STIMULATION OF THE AUDITORY SYSTEM: RESULTS OF A CLINICAL STUDY by K. Vermeire, P.H. Van de Heyning, I. Anderson, P. D'Haese, M. Flynn
37. PATIENT-SPECIFIC ELECTRO-ANATOMICAL MODELS OF THE COCHLEAR IMPLANT: COMPARISONS WITH EMPIRICAL DATA by Darren M. Whiten, Donald K. Eddington
38. EFFECTS OF ELECTRIC STIMULATION ON ACOUSTICALLY-EVOKED RESPONSES IN INFERIOR COLLICULUS by Jihwan Woo, Paul J. Abbas, Charles A. Miller, Heil Noh Kirill V. Nourski, Barbara K. Robinson

Session 2:
Psychophysics and Signal Coding
8AM, Monday, August 1 - 8 AM, Tuesday, August 2, 2005

1. THE COCHLEAR IMPLANT ELECTRODE-PITCH FUNCTION by Uwe Baumann, Tobias Rader, Andrea Nobbe
2. COMPANDING TO IMPROVE COCHLEAR IMPLANTS' SPEECH RECOGNITION IN NOISE by Aparajita Bhattacharya, Fan-Gang Zeng
3. RESULTS OF A PSYCHOACOUSTIC-MODEL-BASED ACE STRATEGY (PACE) FOR THE NUCLEUS-24 DEVICE by Andreas Büchner, Waldo Nogueira, Bernd Edler, Rolf D. Battmer, Thomas Lenarz
4. HIGH-RATE CARRIERS IMPROVE PITCH DISCRIMINATION BETWEEN 250 AND 1000 Hz by Jeff A Carroll, Hongbin Chen, Fan-Gang Zeng
5. THE EFFECT OF PULSE BURST DURATION ON LOUDNESS IN COCHLEAR IMPLANTS, IN LIGHT OF ECAP AMPLITUDE by Lawrence T. Cohen, Robert S.C. Cowan
6. AUDITORY STREAM SEGREGATION AND CHANNEL DISCRIMINATION IN COCHLEAR IMPLANT LISTENERS by Huw R Cooper, Brian Roberts
7. MUSIC PERCEPTION BY COCHLEAR IMPLANT USERS AS MEASURED USING THE MONTREAL BATTERY FOR EVALUATION OF AMUSIA by William B. Cooper, Kalyan S. Kasturi, Emily A. Tobey, Philip Loizou
8. GROWTH OF MASKING FUNCTIONS FOR INTERLEAVED PULSE TRAINS by Gail S. Donaldson, David A. Nelson, Heather A. Kreft

9. INVESTIGATION ON IMPROVEMENT OF THE FREQUENCY RESOLUTION VIA CURRENT STEERING by C. Frohne-Büchner, A. Büchner, M. Brendel, T. Stöver, Th. Lenarz
10. MUSIC PERCEPTION BY COCHLEAR IMPLANT LISTENERS by John J. Galvin III , Qian-Jie Fu, Geraldine Nogaki
11. EFFECTS OF FREQUENCY ON AUDITORY STREAM SEGREGATION IN COCHLEAR IMPLANTS by Robert S. Hong, Christopher W. Turner
12. PSYCHOPHYSICAL AND PHYSIOLOGIC FORWARD MASKING PATTERNS IN COCHLEAR IMPLANTS by Michelle L. Hughes, Lisa Z. Stille, Kelly R. Barrow
13. OPTIMIZING VIRTUAL CHANNEL SELECTION by Kalyan Kasturi, Philip C. Loizou
14. CURRENT STEERING AND SPECTRAL CHANNELS IN HiRESOLUTION BIONIC EAR USERS: COCHLEAR-IMPLANT PLACE/PITCH PERCEPTION by Dawn Burton Koch, Mark Downing, Leonid Litvak
15. ENCODING ADDITIONAL FREQUENCY INFORMATION VIA VARIABLE PULSE RATE FOR IMPROVED SPEECH UNDERSTANDING IN COCHLEAR IMPLANT SUBJECTS by M. Selin Kucukoglu, Leslie M. Collins
16. AUDITORY GROUPING ON THE BASIS OF SPATIAL CHANNELS BY IMPLANT LISTENERS by Bom Jun Kwon, Chris van den Honert
17. FINE STRUCTURE AND GATING INTERAURAL TIME DIFFERENCES IN ELECTRICAL AND ACOUSTICAL HEARING: EFFECT OF STIMULUS DURATION by Bernhard Laback, Piotr Majdak, Wolf-Dieter Baumgartner
18. USING AMPLITUDE MODULATION TO DELIVER FINE TEMPORAL INFORMATION by David M. Landsberger, Colette M. McKay
19. FREQUENCY MAP FOR THE HUMAN COCHLEAR SPIRAL GANGLION by Patricia A. Leake, Olga Stakhovskaya, and Divya Sridha
20. MUSIC PERCEPTION OF COCHLEAR IMPLANT USERS COMPARED TO HEARING AID USERS by Valerie W Looi, Hugh J McDermott, Colette M McKay, Louise M Hickson
21. EFFECTS OF DELAYING THE CHARGE-RECOVERY PHASE OF A PSEUDO-MONOPHASIC PULSE ON THRESHOLD AND COMFORT LEVELS IN COCHLEAR IMPLANTS by Olivier Macherey, Astrid van Wieringen, Robert P. Carlyon, John M. Deeks, Jan Wouters
22. THE LOUDNESS OF AMPLITUDE MODULATED STIMULI by Colette M. McKay, Katherine J. Henshall
23. MODELING SUBJECT RESPONSES IN A REPRODUCIBLE NOISE MASKING TASK: PRELIMINARY FINDINGS WITH COCHLEAR IMPLANT USERS by Ted A. Meyer, John E. King, Abby C. Connell, Jenelle R. Stahlke, Victoria C. Lawrence
24. ENCODING FINE TIME STRUCTURE WITH CHANNEL SPECIFIC SAMPLING SEQUENCES by Andre Mitterbacher, Clemens Zierhofer, Reinhold Schatzer, Mathias Kals
25. FREQUENCY DISCRIMINATION WITH PARALLEL AND SEQUENTIAL STIMULATION by Andrea Nobbe, Peter Schleich, Clemens Zierhofer, Peter Nopp
26. EFFECTS OF CARRIER PULSE RATE ON MODULATION DETECTION IN SUBJECTS WITH COCHLEAR IMPLANTS by Bryan E. Pfingst, Li Xu, Catherine S. Thompson, Chenfei Ma
27. SPECTRAL MODULATION TRANSFER FUNCTION IN COCHLEAR IMPLANT LISTENERS by Aniket Saoji, Leonid Litvak, Gulam Emadi, Tony Spah

28. THE RELATIVE LOUDNESS OF ONE, TWO AND THREE CHANNEL STIMULI by Kara C. Schvartz, Monita Chatterjee
29. SPATIAL DISTRIBUTION OF EFFECTS OF SINGLE PULSE STIMULI: SPREAD OF EXCITATION AND FORWARD MASKING by Benjamin A. Milczarski1, Robert L. Smith1, Mohamed Bingabr
30. QUANTIFYING THE CO-MODULATION EFFECT IN FAST-ACTING DYNAMIC RANGE COMPRESSION WITH AN IMPLANT SIMULATION by Michael A. Stone, Brian C. J. Moor
31. PITCH-RANKING SUNG VOWELS WITH STRATEGIES PROVIDING ADDITIONAL TEMPORAL CUES by Brett A. Swanson, Hugh J. McDermott, Colette M. McKay, Jim Patrick
32. ELECTRODE INTERACTIONS IN COCHLEAR IMPLANTS by Qing Tang, Fan-Gang Zeng
33. MELODY IDENTIFICATION AND CHANNEL INTERACTIONS: ACOUSTIC MODEL PREDICTIONS by Chandra S. Throckmorton, Leslie M. Collins
34. TEMPORAL PITCH PERCEPTION IN COCHLEAR IMPLANTEES by Andrew E. Vandali, Cathy Sucher, David J. Tsang, Colette M. McKay, Jason W. D. Chew, Hugh J. McDermott, Richard van Hoesel
35. USE OF PSYCHOACOUSTIC MASKING IN SOUND PROCESSING: EFFECT ON PERFORMANCE IN NOISE by Luc Van Immerseel, André Goedegebure
36. SPATIAL EXCITATION PATTERNS OF DIFFERENT PULSE SHAPES AND ELECTRODE CONFIGURATIONS IN COCHLEAR IMPLANTEES by Astrid van Wieringen, Robert P. Carlyon, Jan Wouters
37. FREQUENCY DISCRIMINATION FOR ELECTRICAL NOISE-MODULATED PULSE TRAIN STIMULI AND SINUSOIDAL STIMULI WITH HIGH-RATE CARRIERS by Yifang Xu1, Leslie M. Collins
38. AN ALGORITHM TO COMPENSATE FOR CHANNEL INTERACTIONS WITH SIMULTANEOUS PULSATILE STIMULATION IN COCHLEAR IMPLANTS by Clemens Zierhofer, Andre Mitterbacher, Reinhold Schatzer

Session 3:
Speech, Language, amd Learning
8AM, Tuesday, August 2 - 8 AM, Wednesday, August 3, 2005

1. PHONETIC CONTEXT EFFECTS IN ADULTS WITH COCHLEAR IMPLANT by Radhika Aravamudhan, Andrew J. Lotto
2. SPEECH RECOGNITION IN SENSORINEURAL HEARING LOSS AS A FUNCTION OF SPECTRAL CHANNELS: IMPLICATIONS FOR COCHLEAR IMPLANTS by Deniz Başkent
3. THE ROLE OF FINE TEMPORAL STRUCTURE IN THE EFFECT OF TALKER VARIABILITY IN COCHLEAR IMPLANTS by Yi-ping Chang and Qian-Jie Fu
4. IMPORTANCE OF TEMPORAL FLUCTUATION IN VOICE GENDER IDENTIFICATION AS A FUNCTION OF COCHLEAR PLACE by Sherol Chinchilla, Qian-Jie Fu, Geraldine Nogaki
5. AUDITORY-VERBAL LIST MEMORY PERFORMANCE IN CHILDREN WITH COCHLEAR IMPLANTS byMiranda Cleary, Richard G. Schwartz, Jane Madell, Deena Wechsler-Kashi

6. TOWARDS A CONCEPTUAL FRAMEWORK FOR UNDERSTANDING COCHLEAR IMPLANT OUTCOMES by Richard C Dowell PhD
7. PERCEPTUAL ADAPTATION TO A BINAURALLY-MISMATCHED FREQUENCY-TO-PLACE MAP: WHAT IS LEARNED? By Andrew Faulkner, Stuart Rosen and Lucinda Saul
8. INFORMATIONAL MASKING AND SPECTRAL RESOLUTION IN COCHLEAR IMPLANT USERS by Rabia Farooquee, Ginger S. Stickney, Ruth Y. Litovsky
9. SPEECH EVOKED CORTICAL POTENTIALS AS A FUNCTION OF COCHLEAR IMPLANT CHANNEL NUMBER by Lendra M. Friesen, Kelly L. Tremblay, Neeru Rohila, Richard D. Wright, Robert V. Shannon, and Deniz Baskent
10. AUDIOVISUAL ASYNCHRONY SKILLS IN ADULT COCHLEAR IMPLANT RECIPIENTS: SOME PRELIMINARY FINDINGS by Marcia J. Hay-McCutcheon, David B. Pisoni
11. ACOUSTIC PHONETICS OF SPEECH PRODUCTION BY PRE-LINGUALLY DEAFENED CHILDREN WITH COCHLEAR IMPLANTS by Dana Ide Helvie, Andrew J. Lotto
12. EFFECT OF FREQUENY BOUNDARY ASSIGNMENT ON SPEECH RECOGNITION WITH THE ACE SPEECH CODING STRATEY, PART II by Laura K. Holden, John W. Hawks, Marios S. Fourakis, Margaret W. Skinner, Timothy A. Holden
13. IMPORTANCE OF LOW-FREQUENCY INFORMATION FOR UNDERSTANDING INTERRUPTED SPEECH by Su-Hyun Jin1 and Peggy B. Nelson
14. MORPHOLOGICAL CHANGES OF ERPS TO THE PERCEPTION OF VOWELS AND CV SYLLABLES IN THE POST-IMPLANTATION PERIOD IN ONE COCHLEAR IMPLANT USER by Damir Kovačić, Evan Balaban
15. ADAPTATION TO SPECTRALLY SHIFTED SPEECH BY UNSUPERVISED LEARNING by Tianhao Li, Qian-Jie Fu
16. SMOOTH GMM BASED SPEAKER ADAPTATION FOR SPECTRAL DEGRADED SPEECH by Chuping Liu, Qian-Jie Fu
17. LINGUISTIC AND AUDIOLOGICAL FACTORS IN COCHLEAR IMPLANT SPEECH PERCEPTION by Michelle AuCoin McGuire, Fan-Gang Zeng
18. CHRONIC EVALUATION OF A STIMULATION STRATEGY WITH INCREASED NEURAL RESPONSE EFFICIENCY by Sheena McLaren, Sonelle McDonald, Terry Nunn, Filiep Vanpoucke, S. Peeters
19. EXPLAINING DIFFERENCES IN SPEECH RECOGNITION ABILITY IN COCHLEAR IMPLANT USERS – SPECTRO-TEMPORAL DISCRIMINATION AND COGNITIVE CAPACITY by A. E. Elisabet Molin, Arne Leijon, Helene Wallsten
20. THE DEVELOPMENT OF SYLLABLES IN CHILDREN FOLLOWING COCHLEAR IMPLANTATION by Jan A. Moore
21. PRELIMINARY LANGUAGE, SPEECH RECOGNITION & PSYCHOSOCIAL RESULTS IN THE CHILDHOOD DEVELOPMENT AFTER COCHLEAR IMPLANTATION (CDACI) STUDY by Laurie S. Eisenberg, Alexandra L. Quittner, Emily A. Tobey, Nancy E. Fink, Nae-Yuh Wang, John K. Niparko, the CDaCI Investigative Team
22. AUDITORY TRAINING WITH SPECTRALLY SHIFTED SPEECH: EFFECTS OF TRAINING FREQUENCY by Geraldine Nogaki, Qian-Jie Fu, John J Galvin III
23. THE PERCEPTION OF STRESS AND INTONATION BY CHILDREN WITH COCHLEAR IMPLANTS by Rosemary O’Halpin, Andrew Faulkner, Stuart Rosen, Laura Vian

24. BENEFITS OF ADAPTIVE BEAFORMING:SPEECH RECEPTION WITH COCHLEAR IMPLANTS IN A “CAFETERIA” by Lionel Baud, Nicholas Reyren, Matthias Bettler, Martin Kompis, Marco Pelizzone
25. PERCEPTION OF QUESTION-STATEMENT CONTRASTS USING SUPRASEGMENTAL INFORMATION IN PRELINGUALLY DEAFENED CHILDREN WITH A COCHLEAR IMPLANT by Shu-Chen Peng, Chris Turner, Bruce Tomblin
26. Theory of Mind and Language Development in Children with Cochlear Implants by Kimberly A. Peters, Ethan R. Remmel
27. EFFECTS OF REVERBERATION AND VARIOUS MASKERS ON SENTENCE INTELLIGIBILITY IN COCHLEAR IMPLANT SIMULATIONS by Sarah F. Poissant, Nathaniel A. Whitmal III and Richard L. Freyman
28. EVALUATION OF HIGHER STIMULATION RATES IN THE NUCLEUSÒ RESEARCH PLATFORM 8 SYSTEM by Kerrie L. Plant, Laura K. Holden, Margaret W. Skinner, Lesley A.Whitford, Jennifer Arcaroli, Esti Nel, Colleen Psarros
29. LONG-TERM PERFORMANCE OF CLARION 1.0 COCHLEAR IMPLANT USERS by Chad V. Ruffin, BS, Richard S. Tyler, Ph.D., Shelley A. Witt, M.A., Camille C. Dunn, Ph.D., Bruce J. Gantz, M.D., Jay T. Rubinstein, Ph.D., M.D.
30. SPEECH PERCEPTION SCORES MATCHED IN QUIET AND IN NOISE: WHICH COCHLEAR IMPLANT DEVICE IS BETTER, “A” OR “B”? by Elad Sagi, Mario A. Svirsky, and Heidi Neuburger
31. EFFECTS OF TRAINING ON THE PERCEPTION OF SPECTRALLY SMEARED ENVIRONMENTAL SOUNDS by Valeriy Shafiro, Christopher Spankovich, Erin Maierle
32. A BANDPASS SIGNAL DECOMPOSITION MODEL TO IMPROVE SIGNAL PROCESSING STRATEGY IN COCHLEAR IMPLANTS by Jayaganesh Swaminathan, Ramdas Kumaresan
33. PERCEPTION OF EMOTION IN SPEECH BY YOUNG COCHLEAR IMPLANT USERS: A PILOT STUDY by Rosalie M. Uchanski, Amanda R. Shinall
34. FREQUENCY RESOLUTION AND ITS RELATIONSHIP TO THE SPEECH PERCEPTION OF ADULT COCHLEAR IMPLANTEES by Cila Umat, Colette M. McKay, Hugh J. McDermott
35. NAMING AND VERBAL-FLUENCY ABILITIES IN CHILDREN WITH COCHLEAR-IMPLANTS by Deena Wechsler-Kashi, Richard G. Schwartz, Miranda Cleary, Jane R. Madell
36. SPECTRAL AND TEMPORAL CUES IN MANDARIN TONE PERCEPTION BY POST-LINGUALLY DEAFENED COCHLEAR IMPLANT USERS by Chaogang Wei, Keli Cao, Xin Jin, Xiaowei Chen, Fan-Gang Zeng
37. SPECTRAL AND TEMPORAL CUES FOR PHONEME RECOGNITION IN NOISE: IMPLICATIONS FOR COCHLEAR IMPLANTS by Yunfang Zheng, Li Xu
38. COMMUNICATION DEVELOPMENT IN CHILDREN WHO RECEIVE THE COCHLEAR IMPLANT UNDER 12 MONTHS: RISKS VERSUS BENEFITS by Shani J. Dettman, Richard C. Dowell1, Darren Pinder, Robert J. S. Briggs

Session 4:
Electrode Design, Novel Prostheses, and Clinical Outcomes
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ELECTRIC ACOUSTIC STIMULATION OF THE AUDITORY SYSTEM – SURGICAL ISSUES AND CLINICAL RESULTS

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Objective: The purpose of this investigation was to evaluate clinical parameters in patients implanted for the combined, ipsilateral electric-acoustic-stimulation of the auditory system (EAS).

Methods: Twenty fife patients with residual deep frequency hearing were implanted with a Comi 40+ or Combi 40+ M Cochlear Implant, manufactured by MED-EL between January 1999 and July 2004. All patients had substantial low frequency hearing and complete loss of cochlear function in frequencies above 1.000 Hz. Patients were implanted with an adapted surgical procedure and limited 360° insertions to contribute to hearing preservation. Pure-tone-audiometric thresholds and speech discrimination data were measured pre- and postoperatively. All subjects were fitted with the cochlear implant (CI) only 3-4 weeks after implantation and remained without further acoustic amplification for 3 months to offer appropriate CI alone training for that period. Then, EAS fitting followed and patients underwent a battery of speech discrimination tests to document the benefit of EAS.

Results: Preservation of low frequency hearing was accomplished in 23 of 25 subjects (92%). Ten patients (40%) had complete and 13 patients (52%) showed partial preservation of residual low frequency hearing. Speech discrimination scores of all tested patients documented a vast increase in intelligibility when compared to either the cochlear implant alone or the acoustic alone condition in background noise with signal-to-noise ratios of 10 and 15 dB. With the cochlear implant alone, above average speech discrimination scores were evaluated, when compared to a cohort of fully inserted regular cochlear implant users.

Discussion: Using a modified surgical technique, low frequency hearing preservation in cochlear implant surgery is possible. 360° insertions provide an industry standard CI with stimulation of sufficient neural structures for above average discrimination scores with the implant alone. The synergistic effect of electric and acoustic stimulation modes leads to high discrimination scores, especially in background noise.

SUNDAY, POSTER 2

PRECEDENCE EFFECT IN BILATERAL COCHLEAR IMPLANT USERS IN FREE-FIELD AND UNDER DIRECT STIMULATION

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Precedence Effect (PE) is an auditory phenomenon that occurs when a pair of sounds is presented from different locations with a brief delay, and a single auditory event is heard, whose perceived location is dominated by the leading source, with minimal contribution by the lagging source. One measure of the PE is known as *discrimination suppression*, whereby listeners' ability to discriminate changes in the location of the leading and lagging sources can be evaluated. In adults with normal hearing the PE is strong at brief delays (<10 ms) and weakens as delays increase. This manifests itself as follows: the ability of listeners to discriminate changes in location of the leading stimulus is nearly as good as their ability to perform the task with a single source stimulus (i.e., the lagging source interferes to a minimal extent due to active PE). In contrast, due to inhibition of directional information contained in the lagging source, discrimination of the lagging source position is very difficult at brief delays and improves as delays increase (i.e., as the PE weakens). Physiological correlates of the PE have been reported in the binaural circuits in the brainstem, and psychophysical evidence also suggests that the binaural system contributes significantly to the PE.

We recently evaluated the PE in adult subjects with bilateral cochlear implants (BICI) who had adult onset of hearing loss. In one study, using the SPEAR processor to deliver direct electrical stimulation of pulsed signals, discrimination suppression was investigated by varying binaural cues (interaural level and timing differences; ILDs and ITDs) in the leading and lagging sources. In a second study, discrimination suppression was evaluated in free field by varying the locations of the lead and lag in azimuth. Preliminary results indicate that subjects with bilateral cochlear implants not only exhibit PE but also follow the trend seen in normal hearing adults. In free-field as well as under direct stimulation, they are able to perform the lead discrimination task even at short delays but lag discrimination is more difficult. There is a large variability in the lag suppression task with some subjects recovering at brief delays (<10 ms) while other subjects require much longer delays (>30 ms). Performance under direct stimulation appears to be co-related with that seen in free-field.

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A MULTI-RESONANT TRANSDUCER FOR A COMPLETELY IMPLANTABLE BIONIC EAR

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Cochlear implants have been remarkably effective in improving speech intelligibility for hearing-impaired listeners; however, miniaturization and cosmetics present a challenge for acceptance. While mechanical parts of the middle ear can be surgically replaced with artificial counterparts, (e.g., ossiculoplasty, stapedectomy), no completely implantable solution exists for correcting or replacing the human cochlea. All cochlear implant devices rely on the use of a large, power hungry, externally worn speech processor that must process sound, encode it, and deliver it to an implanted electrode array by wireless means via a coil attached to the patient's head. The need for digital analysis and wireless transmission limits the number of electrodes that can be addressed.

We propose a technology that can enable a completely implantable bionic ear. The basis of the technology is a recently developed small transducer that can be designed to mimic the function of the human cochlea. The transducer, built upon polymer MEMS (micro-electrical mechanical systems) technology, consists of an array of resonating cantilevers or beams which is capable of receiving sound and filtering it into many narrow frequency bands. The resonator effectively performs a mechanical Fourier transform, requiring no digital conversion nor electrical power to do so (a small amount of power is required to amplify the resulting signals). Such a device can deliver multiple electrical signals to the cochlea for stimulation of the auditory nerve without the need for external digital units. The mechanical, parallel nature of the frequency filtering enables large numbers of frequency channels to be simultaneously generated for direct auditory stimulation. If such a device can be shown to be effective in mimicking the natural function of the human cochlea, it will offer tremendous potential for totally implantable, bionic ear applications. Initial targets for the technology will be improved cochlear implants with the benefit of low cost, small size (less than 2 cm), low power, and high channel number. Ultimately, we envision that the multi-resonant device may be used to directly stimulate the auditory nerve via an intra-neural electrode array, truly mimicking the human cochlea function.

Initial four-channel proof-of-concept transducers have been built and tested. The polymer micro-resonators were 7 mm and shorter, exhibited excellent narrow-band frequency response, sensitivity and linearity with low harmonic distortion. Ongoing efforts are focused on developing packaged, high channel count devices for comparison with traditional DSP-based cochlear devices.

SUNDAY, POSTER 4

ARTIFACT REDUCTION BY A TRI-PHASIC STIMULUS FOR NEURAL RESPONSE IMAGING (NRI)

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Although the recording of the compound action potential via a cochlear implant system is a well-accepted method, the proper method of artifact reduction is still under discussion. After the electrical stimulus some residual charge remains on the electrode contacts and in the tissue close to the contacts that drives the amplifier into saturation. The artefact may be reduced by sucking off remaining charge at the end of the stimulus, thus introducing a third phase after the normally bi-phasic stimulus.

The research software "Bionic Ear Data Collection System" (BEDCS) for the Advanced Bionics implants CII and HiRes90K permits the neural response imaging (NRI) response to flexible stimulation patterns to be recorded. BEDCS was used within a study comparing artefact reduction with alternating stimulus polarity and with masker and probe technique, both with additional reduction of a third phase stimulus. Responses were recorded at sub-threshold and supra-threshold levels as a function of amplitude of the third phase relative to the two initial phases. The influence of the third phase on loudness perception was also assessed subjectively.

Our preliminary data indicate that the amplitude of the third phase needs to be optimized individually to reduce the stimulus artifact effectively. Thus, the first negative peak, N1, is less distorted and the latency as well as amplitude can be defined more reliably. The overall NRI response is of better quality and, therefore, may allow further insight into auditory nerve properties.

SUNDAY, POSTER 5

CHARACTERISTICS OF NRT™ RECOVERY FUNCTIONS FOR DIFFERENT STIMULATION PARAMETERS

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The recently released Nucleus® CI24RE cochlear implant contains an improved amplifier for Neural Response Telemetry (NRT™). This new amplifier has a low noise floor of 1µV rms and allows for faster and more accurate NRT recordings. In our investigation the enhanced NRT capabilities of the new implant were used to gain deeper insight into the NRT recovery function.

The recovery functions were measured with varying Masker Probe Intervals (MPI) between 100µs and 10000µs making use of the Masked Response Extraction (MRE) method and a reference MPI of 300µs. The recordings were done on different electrodes using different probe current levels (CL) with a fixed Masker-Probe-Offset of +10 CL. In a further set of recordings the Masker Probe Offset was changed from +20 CL to –20CL.

The measured data were fitted with an exponential model that assumes that at short MPIs all auditory nerve fibers are in their absolute refractory state and no neural response can be recorded. The model is defined by three parameters reflecting the absolute refractory period (T_0), the time constant of recovery during the relative refractory period (α) and the maximal amplitude of the neural response at saturation level (A). The measurements on different electrodes and at different stimulation levels were compared by means of their T_0 and α.

Interestingly, NRT responses could also be recorded for very short MPIs (MPI below reference MPI). In the recovery functions with a negative Masker-Probe-Offset a supraexcitability peak was found at the end of the relative refractory period before the function reaches it's saturation level. The Amplitude and MPI of the peak varied between subjects.

The results show that the time constants T_0 and α vary with different CLs: with increasing CLs T_0 decreases and α increases. All findings were confirmed by control measurements using a different recording technique (Artifact Reduction Pulse) to make sure that the effects were not related to the MRE method.

The responses at very short MPI and the supra-excitability peak are not covered by the current exponential model and open new opportunities for describing of the nerves refractory behavior. The variability of the parameters show that an analysis of the recovery function should rather take into account measurements at different levels of loudness instead of using a single set of stimulation parameters. This may help to predict optimal map stimulation rates for individual subjects.

SUNDAY, POSTER 6

TEMPORAL INTERACTIONS IN THE INFERIOR COLLICULUS: RESPONSES TO INTERLEAVED ELECTRICAL PULSE TRAINS

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The temporal aspects of a stimulus can greatly influence the response of neurons in the central auditory system. In the inferior colliculus (IC), for instance, a neuron's response to a brief tone can be suppressed or facilitated by the occurrence of a preceding tone. Relatively little, however, is known about interactions in the IC produced by electrical stimulation of the cochlea. Such processing may play a fundamental role in cochlear implant perception.

We evaluated temporal interactions in the IC of acutely deafened guinea pigs in response to interleaved pulse trains from one and two cochlear implant channels. Multi-unit activity in the IC's central nucleus was recorded with a 16-channel silicon-substrate electrode spanning several octaves of the tonotopic axis. The stimuli were biphasic pulses delivered via an 8-electrode implant inserted into the contralateral scala tympani. Pulses were delivered bipolarly between neighboring electrodes and presented as trains of 5 pulses at a rate of 50 Hz. Trains were temporally interleaved, with train A (the masker) occurring 2 to 10 ms earlier than train B (the probe).

With the probe stimulus fixed at a level 3-5 dB above threshold, a masker presented 10 ms earlier and of the same channel and intensity caused a reduction in response at most IC recording sites. This suppression was cumulative over the duration of the stimulus, being greatest for the last probe pulse. Facilitation occurred less commonly and affected only the first probe pulse. For some neurons, suppression was evident even with a sub-threshold masker. The degree of suppression at a given IC recording site was strongly correlated with neighboring sites. Suppression was generally greater at sites non-optimally stimulated, producing an effective narrowing of activity across the IC.

As the interval between masker and probe was shortened, the degree of suppression increased. At intervals as short as 2 ms, the total response to a super-threshold masker plus probe was not significantly different than that of the masker alone. An "off-channel" masker (delivered to a channel other than the probe channel) could also suppress the response to a probe stimulus. The degree of suppression was typically proportional to the magnitude of response produced by the masker alone, indicating that cross-channel interactions are mainly a result of an adaptive mechanism similar to that of same-channel interactions. In several cases, however, an off-channel masker was found to be a more effective suppressor than a same-channel masker.

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MUSIC PERCEPTION UNDER BIMODAL STIMULATION

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Objective: For many CI recipients, listening to music, namely the perception of pitch and timbre, is still not satisfactory. However, CI users with some residual hearing in the contralateral ear report that the sound quality is significantly improved when they use a hearing aid in conjunction with the CI (bimodal stimulation). Typically, these persons have some aided residual hearing in the lower frequencies, which, although providing minimal benefit for speech intelligibility, augments the mid-to-high frequency sounds from the CI in a way to improve the subjective sound quality. The aim of this study was to assess in greater detail how music perception can be improved by bimodal stimulation. Therefore, a test battery with objective and subjective tests was put together.

Tests: The objective tests consisted of three tasks: (1) discrimination of pitch, melody, and rhythm, (2) recognition of musical instruments, and (3) song recognition. The subjective tests included quality judgment of single instruments and of complex music pieces.

The test battery was evaluated in a pilot trial with eight subjects for the three conditions CI alone, hearing aid alone (where possible), and CI plus hearing aid. It has been proposed by Ching et al. to fit the hearing aid of bimodal users in a standardized way [Ching, T.Y.C., Incerti, P., Hill, M. (2004). “Binaural benefits for adults who use hearing aids and cochlear implants in opposite ears,” Ear Hear. 25 (1), 9-21.]. Consequently, four of the subjects were fitted with a new, digital high power hearing aid, and four of them used their own hearing aid for the tests.

Results: Preliminary results show poor pitch and melody perception for most subjects with the CI alone, whereas improved scores were achieved for some of the subjects in the bimodal condition. Rhythm perception was already satisfying for most of the subjects in the condition CI alone and did not change significantly in the bimodal condition.

From the four newly fitted subjects, only one accepted the new hearing aid in the end. The other three subjects preferred their old devices even after four weeks of acclimatization.

Conclusions: The test battery proved to be a valuable instrument for the evaluation of music perception with CI and/or hearing aid, although some tasks turned out to be too challenging for some of the subjects. Music perception can be significantly improved when using a hearing aid in addition to the CI, provided that some residual hearing is present.

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ECAP FOR DUAL ELECTRODE STIMULATION USING THE NUCLEUS® CI24RE COCHLEAR IMPLANT

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The Nucleus® CI24RE receiver-stimulator can deliver dual electrode stimulation by electrically coupling two adjacent intracochlear electrodes, with two extracochlear electrodes serving as the return. This makes available 21 additional electrodes for stimulation on the 22-electrode array. The objectives of this study were to develop methods to measure the electrically evoked compound action potential (ECAP) for dual electrode stimulation, and determine whether ECAP characteristics for dual electrode stimulation differed from those for single electrode stimulation, in particular the amplitude growth function and spread of excitation in the cochlea.

ECAP for dual and single electrode stimulation was measured using the forward masking (subtraction) paradigm, as also used in the Nucleus Neural Response Telemetry (NRT™) software. In this study, research software was used to generate dual electrode stimuli and record the ECAP. The amplitude growth function studies investigated the effects of different single electrode maskers and different recording electrodes on the ECAP for a dual electrode probe. The spread of excitation studies compared excitation pattens along the cochlea for dual and single electrode stimulation. A fixed dual or single electrode was used as the probe and a series of single electrodes were used as the maskers. The recoding electrode was fixed with respect to the probe. Spread of excitation was measured using electrodes at the apical, mid, and basal positions.

Preliminary results from a small number of subjects showed that ECAP can be effectively measured for dual electrode stimulation. The amplitude growth functions for dual electrode probes were generally similar to those for single electrode probes. There also were no marked effects of masker and recording electrodes on the growth functions for the dual electrode probes. The spread of excitation patterns for dual and single electrode probes showed overlap in the position of the peak and the width of excitation pattern.

INTRACOCHLEAR EVOKED POTENTIAL RESPONSES TO BIPHASIC PULSES WITH AN INTERPULSE GAP

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To achieve charge balance with intracochlear stimuli, equal-amplitude biphasic current pulses are the most common shape employed by cochlear implant speech processors. Because the two phases of a biphasic pulse counteract each other, the threshold level with a biphasic pulse is generally higher than that of a cathodic pulse alone. By introducing an interpulse gap (IPG) within a biphasic pulse, it is possible to reduce the stimulus magnitude necessary to reach a desired loudness.

To determine the differences between the neural response to a biphasic pulse with an IPG from that of a traditional biphasic pulse, intracochlear evoked potentials (IEPs) were recorded in response to each pulse shape. IEPs were measured through percutaneous electrodes. Electrical stimuli were delivered through an implant electrode using the implant ground electrode as a return. Intracochlear potentials were measured differentially between an unstimulated electrode and an electrode placed on the mastoid with a wrist electrode present for measuring the reference body potential. A series of 4 stimuli separated by 20 ms intervals were initiated consisting of each of the following: an anodic-leading biphasic pulse, a cathodic-leading biphasic pulse, an anodic-leading biphasic pulse with 3 ms IPG, and a cathodic-leading biphasic pulse with 3 ms IPG.

For biphasic pulses without pulse separation, the IEP recordings are similar indicating similar modes of stimulation and implying that both pulse polarities stimulate on the cathodic phase at a similar site. The anodic-first configuration produces a larger negative phase implying a lower response threshold than the cathodic-first stimulus. The isolated anodic stimulus produces a large negative waveform followed by a positive waveform. This response differs from the isolated cathodic stimulus which produces a positive waveform only. The result implies different modes and sites of stimulation for isolated stimuli.

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SUNDAY, POSTER 10

LOWS ARE THE NEW HIGHS: IMPROVING SPEECH INTELLIGIBILITY WITH UNINTELLIGIBLE LOW FREQUENCY SOUNDS

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Current cochlear implants (CI) provide mainly temporal envelope information at high frequencies but discard temporal fine structure information, including voice pitch information at low frequencies. While such a coding strategy is sufficient for understanding speech in quiet, it largely limits speech recognition in noise and music appreciation. The aim of this study was twofold: (1) to investigate the role and mechanisms of low-frequency cues in speech recognition, and (2) to optimize cochlear implant performance by combined acoustic and electric stimulation.

Both normal-hearing and cochlear-implant subjects participated in the study. Normal-hearing subjects listened to a four-channel CI simulation with residual acoustic hearing at either low frequencies (<250, 500, or 1000 Hz) or high frequencies (>2000, 4000, or 6000 Hz). The acoustic sound was combined with the CI simulation either monaurally to simulate the standard electro-acoustic-stimulation or dichotically to simulate the CI and hearing aid stimulation. HINT sentences, at the presence of a competing voice, were used to measure the speech reception threshold (SRT), in terms of signal-to-noise ratio (SNR). An additional control simulating a five-channel CI was used to assess whether potential improvement associated with acoustic hearing was equivalent to the result of a CI simulation simply with more channels.

Although extreme low- (<500 Hz) and high-frequency (>4000 Hz) acoustic sounds had negligible intelligibility when presented alone, they both significantly improved CI performance, including bilateral implant simulation. While the fashion how acoustic hearing was combined with electric hearing had no significant effects, the degrees of improvement were different between low- and high-frequency sounds. Performance of low-frequency sound conditions significantly surpassed that of the 5-channel CI control, whereas high-frequency sound produced similar performance to 5-channel CI. These results suggest a unique mechanism underlying the improvement of cochlear implant performance by addition of low-frequency sounds. Identical experiments are being conducted to see whether these simulation results can be extended to actual bimodal and bilateral cochlear implant users.

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SUNDAY, POSTER 11

SPREAD OF EXCITATION IN THE COCHLEA

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The degree of interaction between neighbouring populations of auditory nerve fibres stimulated by electrodes in a multi-channel cochlear implant is likely to contribute to the variability in speech discrimination performance that is seen between implant users. The Neural Response Telemetry (NRT TM) system available with the Nucleus 24 cochlear implant system enables the recording of a measure of the spread of excitation in the cochlea. The forward-masking paradigm for recording the evoked compound action potential (ECAP) involves stimulation with probe and masker pulses, which are delivered to the same active electrode in normal recording conditions in order to record the maximum ECAP amplitude. If the masker and probe pulses stimulate different electrodes, the response to the probe depends on the degree of overlap in the neural populations stimulated by each. As the masker electrode is moved away from the probe, the size of the ECAP response reduces as the degree of overlap reduces.

ECAP responses recorded in 20 adult CI24 users using this method are described. The stimulus active electrode was kept constant, in the middle of the electrode array. The masker active electrode was then moved progressively towards the apical and basal ends of the array and the amplitude of the response for each position of the masker recorded. The width of the NRT response profile at 75% of maximum amplitude was measured, and this provided a measure of the spread of excitation in the cochlea. Considerable variability in the both the amplitude of the responses and the width of the excitation profiles were observed. There was no significant difference in the spread of excitation measure between 'contour' and straight electrode arrays. There was a weak but significant relationship between dynamic range and maximum NRT response amplitude. There was no relationship between the NRT spread of excitation measure and open-set speech discrimination performance measured in quiet with sentences.

The significance of these findings and the potential for relating these profiles to other performance measures is discussed. Future studies will examine a) NRT spread of excitation along different sections of the electrode array ; b) the relationship between the spread of excitation measure and more specific perceptual tasks.

USING THE EARLAB SIMULATION ENVIRONMENT TO STUDY ELECTRICALLY EVOKED ACTIVITY IN THE AUDITORY NERVE

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There are many factors that can influence cochlear implant performance. Some of these factors relate to hardware differences such as the method for electrode activation or the acoustic signal processing method used to modulate stimulating pulse trains. Other factors are more biological in nature such as patient-specific differences in cochlear electro-anatomy, electrode location, and numbers and locations of surviving nerve fibers.

Understanding how these factors impact performance is challenging because data need to be integrated from a wide variety of human and animal experiments. To assist in this effort, we have adapted the EarLab simulator for use in cochlear prosthetic research. The EarLab simulation environment uses a modular architecture where different anatomical structures are simulated using plug-in modules. The modules are designed to use species-dependent or patient-dependent parameters that can be easily manipulated. EarLab modules are currently available that simulate auditory structures in the auditory periphery, brainstem and midbrain. Neural activity can be represented either as average firing rate or in terms of the times of occurrence of individual action potentials. The modular approach also allows one to upgrade specific modules as more physiologically accurate modules become available.

To specifically support cochlear implant research, we have developed three new types of EarLab modules. These modules represent hardware speech processors, electrical current spread, and neural excitation. These modules are designed to replace the modules that represent middle-ear and cochlear mechanics and hair-cell physiology in simulations of normal hearing. The simulation environment can use standard audio files as input to facilitate the simulation of responses to standard speech and speech in noise test sets.

Simulations will be presented comparing acoustically evoked auditory nerve responses in normal ears to electrically evoked responses in implanted ears. The target stimuli are sentences from the Hearing In Noise Test (HINT) lists and results for several common speech-processing strategies will be compared.

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MEASUREMENTS OF NEURAL ADAPTATION EFFECTS DEPENDENT ON RATE OF STIMULATION

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Recordings of compound action potentials are increasingly used in the clinical environment as valuable tools to assist in the fitting of speech processors. The correspondence of neural response thresholds with psychophysical thresholds and levels of comfortable loudness perception however diminishes greatly with increasing differences between the stimulation rates used for electrophysiological response measurements and those used for the speech processing algorithm. For higher stimulation rates, neural adaptation and fatigue effects have to be considered and seem to be an important factor for the observed differences and variations between objective and subjective threshold values. With the Nucleus Research Platform 8 (RP8/System 4) which includes an improved Neural Response Telemetry (NRT) system, featuring higher sampling rates, longer sampling windows, an amplifier with improved linearity, saturation recovery and noise immunity, it has become possible to determine detailed temporal response patterns when stimulating the auditory nerve with long pulse trains in most subjects.

Two methods were used to investigate rate dependent neural adaptation properties in this study. The first method consisted of continuous stimulation on one electrode at a time (electrode numbers 22, 16, 11, 6 and 1 were used) during 12 minutes. During the first two minutes the stimulation rate was set at 10 stimulus repetitions per second. During the next two minutes, a higher stimulation rate ranging from 100 to 495 pps was used and for the last eight minutes the rate was again lowered to 10 pps. Averaged responses were sampled every 20 seconds. Results for 20 subjects have been analyzed until now and show various short time adaptation and recovery time constants depending on the rate of stimulation, electrode position and additional subject variables.

The second method was adapted from Wilson et al. (1997) and consists of recording neural responses to each pulse in a pulse train by varying the number of masker pulses preceding a probe stimulus. Pulse trains with 100, 500, 1000 and 2000 pps were used with pulse train durations up to two seconds in six subjects. Characteristic time courses of response amplitude values were observed for pulse trains with rates above 100 pps whereby the response to the first stimulus was always largest and the responses to the subsequent stimuli varied in a regular oscillatory pattern which usually was changed into a more stochastic stationary amplitude fluctuation after 200 milliseconds. The time constants for the fading of these oscillations again were dependent on rate, electrode position and subject variables.

The neural response properties apparent in the rate adaptation observed for stimulation rates up to 495 pps as well as the amplitude variations within pulse train stimulation studied up to 2000 pps point to the possibilities of achieving less deterministic and more natural stochastic firing patterns with stimulation rates below 2000 pps.

SUNDAY, POSTER 14

EFFECTS OF TEMPORAL FINE-STRUCTURE ON LATERALIZATION AND THE BMLD OF SPONDEES IN BABBLE AND STEADY-STATE NOISE

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The inability to deliver temporal fine structure is a significant limitation of current cochlear-implant technology. Successful delivery could improve speech recognition in noise, tonal speech recognition and music perception. Additionally, in binaural hearing, encoding of temporal fine structure is essential for evaluation of interaural time differences (ITDs). Thus, tasks which depend on the detection of ITDs can serve as a psychophysical measure of the extent to which temporal fine-structure is delivered. Using cochlear implant simulations, the present experiment evaluated the effect of fine-structure in two practical binaural tasks.

Spondees were passed through a 6-channel cochlear implant simulation using Hilbert transforms. A random component was added to the angle of the Hilbert transform using the following equation in which x(t) is the output of one of the 6 band-pass filters: $X_{FS}(t) = abs(H(x(t)))*cos(angle(H(x(t))) + 2\pi nr)$. The number r is a uniform random number ranging from -0.5 to +0.5 and n is a "noise factor" which can vary from 0 to 1, establishing the extent of randomization of the fine structure. Using this approach, psychophysical abilities can be evaluated as a function of the noise factor ranging from 0 (no randomization, i.e. the original wave) to 1 (complete randomization, i.e. a traditional cochlear implant simulation).

Two binaural tasks were used: 1) a lateralization task and 2) a BMLD task. In the lateralization task, listeners lateralized "padlock" and "stairway" based on +/- 750, 500, 250 and 0 microsecond ITDs. In the BMLD task, a one-up, one-down adaptive tracking procedure was used (Turner, 2004) in which listeners identified one of 12 spondees in a closed-set task. The noise level was tracked in 2-dB increments to evaluate speech reception thresholds (SRTs). Two noise backgrounds were used: two-speaker babble, and steady-state, speech-shaped noise. The BMLD was the difference between the SRT for spondees with 0 ITD and the SRT for spondees with a 700-microsecond ITD.

The R-squared values for lateralization ranged from 0.9 for the original wave (n=0) to 0 - 0.4 for complete randomization (n=1). R-squared values remained high for noise factors up to about 0.75. BMLDs in babble noise ranged from 0 to 3 dB for n=0, to 0 dB for n=1. In steady-state noise, BMLDs ranged from 6-9 dB for n=0 to 0-2 dB for n=1. BMLDs remained large up to n=0.5. The results indicate that good lateralization ability can be retained based on ITDs with delivery of only a small percentage of fine structure. BMLDs required more fine-structure. Lateralization ability and small BMLDs were observed with completely random fine-structure. Supported by VM Bloedel Hearing Research Center, NIH grant DC00242, the Korean Science and Engineering Foundation (KOSEF), and Hanyang University.

SUNDAY, POSTER 15

NOISE BAND VOCODER SIMULATIONS OF ELECTRIC ACOUSTIC STIMULATION

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Noise band vocoders are often used to simulate performance of cochlear implant (CI) users. We extended this for simulating Electric Acoustic Stimulation (EAS), the combined use of a cochlear implant and a hearing aid.

We examined speech recognition performance in different noise conditions, using different signal processing schemes and with different speech materials.

The signal processing schemes were: (1) simulation of a CI using overlapping synthesis filters and with tonotopic mismatch as a reference condition; (2) simulation of EAS, stimulating one ear with both the electric and acoustic signal (ipsilateral), without any tonotopic mismatch; (3) idem as 2, but now one ear was stimulated with the simulated electric and the other ear with the acoustic signal (contralateral); (4) idem as 3, but now *with* tonotopic mismatch; (5) idem as 1, but with the amplitude envelope of the LP signal modulated on a sinusoidal carrier; (6) unprocessed as a reference condition

The two noise conditions were speech weighted steady noise and a single competing talker. Sentences, especially made for speech in noise tests with CI users and numbers (1-100) were used as speech materials.

First, several pilot experiments were carried out to determine possible training effects for each of the conditions. Based on these findings, several training runs were included for each condition.

The experiments were carried out with several normal hearing subjects, with the following results:

(1) Adding the acoustic signal is very advantageous in competing talker noise.
(2) A small advantage of EAS is present in the speech weighted noise condition.
(3) A small disadvantage is noticed for the conditions with tonotopic mismatch.
(4) No significant difference between the ipsi- and contralateral conditions was found.

In a second set of experiments, the ability to use ITDs and ILDs with EAS users was analysed. It was found that in the default EAS configuration (CI on the one side, HA on the other, with residual hearing <500Hz), with realistic stimuli, the use of ITDs and ILDs for localisation was difficult.

However, when the ILDs were artificially increased, or overlap was introduced between the two ears, localisation was possible to a certain extent.

The measurements, results and interpretation of both sets of experiments will be presented in the poster.

RECORDING THE NEURAL RESPONSE EVOKED BY A BURST STIMULUS

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It is often claimed that high stimulation rates, i. e. above 1500pps, introduce a stochastic response pattern of the auditory nerve. If individual fibres cannot follow a high stimulation rate a tune-in process should occur at the onset of a burst. This process should be visible if the neural response is recorded in response to bursts of different numbers of pulses.

Several studies already showed that the optimal stimulation rate is not necessarily the highest possible rate. Recently it was found that the loudness for a given stimulus level does not increase monotonically with the stimulation rate but has a maximum at a rate that corresponds roughly to the optimal rate.

Neural Response Imaging (NRI) may serve as an objective indicator in this matter. Therefore a study was initiated to record the response of the auditory nerve following stimulation with a burst signal of various high rates. The response decreases with increasing number of pulses in the burst. This decrease is not monotonic but shows some oscillating effect, e. g. an odd number of pulses leads to a bigger response than an even number. This zigzag pattern could be recorded in 9 out of 13 subjects. In four of these subjects this zigzag pattern disappears for higher stimulation rates. Preliminary data indicate that the rate range, in which the zigzag disappears corresponds to the optimal stimulation rate. Details of the measurement and results will be presented.

SUNDAY, POSTER 17

MEASUREMENT OF INTERAURAL TIME AND AMPLITUDE DIFFERENCE SENSITIVITY ON SUBJECTS WITH BILATERAL COCHLEAR IMPLANTS

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One of the major benefits of wearing two cochlear implants is an improved ability to localize the source of a sound. This ability stems from the differences between the sounds at each ear: the ear closer to the sound source will receive the sound earlier and louder compared to the other ear. Thus, sensitivity to interaural time and amplitude differences (ITD, IAD) is a fundamental parameter to assess on users of two cochlear implants.

We conducted ITD and IAD sensitivity measurements on four subjects with bilateral Med-El cochlear implants. Measurements were always conducted following the same protocol: First, pairs eliciting binaural fusion at the most comfortable level were identified. Second, basal, medial and apical pairs that fused well were loudness balanced across ears. Third, ITD/IAD sensitivity measurements were performed using a 2I-2AFC procedure, with three different types of stimuli: unmodulated 200 and 1562 pulses per second (pps) pulse trains as well as amplitude modulated 1562 pps pulse trains.

ITD sensitivities were found to range between 50 - 300 µs in three out of four subjects for unmodulated 200 pps pulse trains. None of the subjects was sensitive to ITD with unmodulated 1562 pps pulse trains. For amplitude modulated 1562 pps pulse trains, ITD sensitivities ranged from 100 – 800 µs. To get insight into the mechanisms of ITD sensitivity upon amplitude modulated pulse trains, we further tested two variations of these stimuli: (1) we delayed the pulses, keeping synchronous AM envelopes across ears and, (2) we delayed AM envelopes, keeping synchronous pulses across ears. These additional experiments revealed that subjects were only sensitive to envelope delays, and not to pulse delays.

IAD sensitivities were better than 0.6 dB on all electrode pairs and with all types of stimuli in three out of four subjects. We observed no effect of electrode place or stimulation rate on IADs.

These measurements will be extended to more subjects, and in particular to users of cochlear implants systems from other manufacturers. We also plan to retest ITD and IAD sensitivities on the same subjects after an extended period of adaptation to binaural speech processing strategies based on measurements of electrode positions inside the cochlea. These measurements might reveal if brain plasticity affects binaural processing.

Supported by the Swiss National Science Foundation.

SUNDAY, POSTER 18

METHODS FOR EVALAUTING BILATERAL ADVANATGES IN CHILDREN WITH COCHLEAR IMAPLANTS AND/OR HEARING AIDS

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For most cochlear implant (CI) users, speech perception in complex environments is very challenging. Bilateral cochlear implants, however, have been suggested to improve CI users' abilities to understand speech in background noise. While there are several methods that can be incorporated to evaluate the advantages of bilateral CI in adults, few are available to quantify such benefit in children, possibly due to lack of age appropriate testing tools.

This presentation will include two tests (CRISP and CRISP-Jr) that are being used in our lab to measure speech reception thresholds (SRTs) in children in free field. CRISP is aimed for children 4 years and older, while CRISP-Jr can be used for children as young as 2.5 years old. The tasks involve a 4-AFC paradigm, such that children view a display containing four pictures and are asked to identify the picture that matches an auditory target word. Sound level is varied adaptively and SRTs are measured using a 3-down/1-up algorithm. These tests are unique in that they offer computerized child-friendly interactive games with age-appropriate reinforcement. This presentation will include results obtained from children with normal hearing and children who use CIs and/or hearing aids (HA). In addition, computerized demonstration of the evaluation tools will be available.

Normal hearing children have been evaluated in a number of studies that measured auditory functioning in complex acoustic environments. SRTs are measured in quiet, and in the presence of different types of interferes. Masking is calculated for different locations of the maskers, and spatial release from masking (SRM) is calculated by comparing masking when the target and masker are spatially near or spatially separated; SRM serves to evaluate developmental changes in sound source segregation. Results from a number of studies to date have shown that very young children are able to exploit cues arising from spatial separation of the target and maskers in sound source segregation.

Having shown that these tools are powerful for measuring SRTs and SRM in normal hearing children, similar measures were extended to children with bilateral CIs, or children who wear one implant and a HA. Relatively little is known about the ability of bilaterally fitted children to function in acoustically complex environments, and the extent to which they are able to combine information from two listening devices effectively. Results to date suggest that the ability of children with two devices to combine inputs from bilateral devices varies. Overall, children with two CIs perform better under bilateral than monaural conditions, whereas children with CI+HA often perform worse with the HA added to the CI than with the CI alone. The tests described here may provide powerful tools for evaluating fitting strategies in pediatric clinical settings.

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SUNDAY, POSTER 19

RESIDUAL HEARING CONSERVATION AND ELECTRO-ACOUSTIC STIMULATION WITH THE NUCLEUS 24 CONTOUR ADVANCE

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We describe interim findings from a multi-centre prospective study of conservation of residual hearing in recipients of the Nucleus 24 Contour Advance electrode array and the benefits of combined electrical and acoustic stimulation.

Subjects were adult candidates for cochlear implantation. A "soft" surgery protocol was defined including 1-1.2mm cochleostomy anterior and inferior to the round-window, and the perimodiolar electrode array inserted 17mm using the "advance-off-stylet" technique. Pure tone thresholds were measured pre-op and post-op at intervals. To asses the benefits of combined electrical and acoustic (El-Ac) stimulation, patients who retained thresholds up to 80dBHL at 125 and 250 Hz and 90dBHL at 500Hz were fitted with an ITE hearing aid. Speech recognition was tested for cochlear implant alone for all patients and combined with an ipsi-lateral hearing aid for El-Ac patients.

Data were available for 27 patients. Hearing threshold levels were conserved within 20dB of pre-op levels for 9(33%), 7(26%) and 5(19%) of patients for 125, 250 and 500Hz. However, analysis of surgical questionnaires showed that in only 12 of 27 cases was the recommended soft-surgery protocol closely followed. For these 12 cases hearing thresholds were conserved within 20dB for 6(50%), 6(50%) and 4(33%) of cases. Median threshold increases were 40dB (250-500Hz) for the whole group and 23dB for the strict soft-surgery group. Ten patients retained sufficient hearing threshold levels to enter the El-Ac user group, in nine of these cases soft-surgery was well observed.

For the El-Ac user group, mean recognition scores (N=9) for words presented at 65dBSPL were 45% for CI alone, and 55% for cochlear implant plus ipsilateral hearing aid (Diff. 10% pts, $P<0.05$, Paired-T). For sentences presented in multi-talker babble at 5dBSNR, mean word scores were 46% CI alone, and 56% CI+ipsiHA (Diff. 10% pts, $P<0.01$, Paired-T). Group mean word recognition scores for 9 El-Ac users were about the same as those for 7 CI-only users (62%). However CI-only users performed much worse in noise with a mean sentence scores of 27% at 5dBSNR.

Hearing could be conserved to within 20dB of pre-operative levels for conventional candidates for cochlear implantation provided that soft-surgery techniques were closely observed and cochleostomy hole size was limited to 1.2mm. There were considerable benefits for speech recognition in noise using combined ipsi-lateral electrical and acoustic stimulation for those patients retaining thresholds up to 90dBHL up to 500Hz.

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SUNDAY, POSTER 20

SPEECH INTELLIGIBILITY IN NOISE FOR CHILDREN WITH BILATERAL CIs: THE EFFECT OF BILATERAL EXPERIENCE

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Bilateral cochlear implants (BICIs) are somewhat experimental since the advantages are difficult to quantify. Improvements with BICIs on measures of sound localization and speech understanding in noise have been reported in adults. Our work is aimed at determining whether children, who receive bilateral implants in sequential procedures, exhibit similar effects. Results are compared with those from a group of children who wear a single implant plus a hearing aid in the non-implanted ear (CI+HA). We recently reported that sound localization abilities in children with BICIs is very poor upon initial activation of the second implant, and improves gradually for up to 2 years post activation of the second CI (Litovsky et al., 2005). This is in contrast with findings in adults, who are generally able to localize sounds significantly better with BICIs than with a single implant within 3 months of bilateral experience.

On speech intelligibility tasks, children with BICIs demonstrate considerable improvement in recognizing speech in noise within 3 months after activation of the second CI (Litovsky et al., 2004). It is not known if these skills plateau early or continue to improve over time. This study presents data from two groups of children, 8 with BICIs and 8 with CI+HA. Performance is compared for two listening modes: monaural (single CI) and bilateral (2 CIs or CI+HA). Children with BICIs have had bilateral experience ranging from 3 to 23 months. Speech intelligibility was measured using the CRISP test, which utilizes a 4-alternative forced choice picture-pointing task. Speech reception thresholds (SRTs) were obtained using a 3-down/1-up adaptive algorithm that estimates performance at 80% correct. SRTs were measured in quiet, and with background speech consisting of two-talker interferers. The target speech was in front (0°). The locations of the interferers were either coincident in space with the target (0° front) or separated (90° right/left).

A bilateral advantage was seen in the bilateral CI group but not for the group using a CI and a HA. Children with bilateral CIs tend to show rapid improvement in speech recognition in noise. This performance does not improve much with increased bilateral experience. However, maturational factors may influence performance in quiet over time.

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EFFECT OF STIMULATION RATE AND INTERAURAL ELECTRODE PAIRING ON ITD SENSITIVITY IN BILATERAL COCHLEAR IMPLANT USERS

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We are studying the effects of place of stimulation and pulse rate on ITD sensitivity in adult subjects with bilateral cochlear implants (BICI-N24). In previous work (Litovsky et al., 2005; *Assoc. Res. Otolaryng.*) we examined the effect of place of stimulation (e.g., pitch-matched electrode pairs that are basal, medial or apical) in 11 adult subjects at a low pulse rate of 100 pps. Each subject generally showed better ITD sensitivity at certain places along the cochlea, but the "best" place was variable across subjects (some showing better sensitivity near the base, others near the apex). In addition, the best performers were people with adult-onset hearing loss while the worse performers had experienced hearing loss during childhood.

In the current experiments we examined the combined effects of rate and place of stimulation on ITD sensitivity of the best performers. Results suggest that: 1) discrimination thresholds generally worsen as the rate of stimulation is increased, 2) several subjects are able to discriminate ITDs (d' > 1) at rates as high as 1000 pps, 3) the electrode pairs with best thresholds do not differ much across rates, 4) in a number of instances, electrode pairs that had worse sensitivity at 100 pps were more susceptible to degraded ITD sensitivity with increasing rate of stimulation, 5) occasionally discrimination thresholds were observed to be substantially better at 500-600 pps than at lower pulse rates. We also noted that in many cases subjects were able to use onset and/or offset ITDs for accurate left-right discrimination when the ongoing timing difference between the two signals was either zero or ambiguous; however, in some instances performance was nonmonotonic at large ITDs. We will also present data on ITD discrimination of amplitude modulated stimuli presented at a high pulse rate (6,000 pps).

Current speech processing strategies rely on high rates of stimulation, but at the present time they do not provide binaurally-synchronized inputs to BICI users. As the field advances in those directions, it is important to establish whether binaural cues can be extracted at high rates. Findings in this area can influence decisions about whether and how to incorporate ITD cues in speech processing strategies for BICI users.

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INFLUENCE OF MICROPHONE DIRECTIONALITY AND MICROPHONE POSITION ON SPEECH UNDERSTANDING IN NOISE IN BILATERAL COCHLEAR IMPLANT USERS

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In this study we investigated the influence of position and the directionality of different microphone systems on speech understanding in noise with cochlear implant (CI) users using either one or two cochlear implant systems.

So far, 6 bilaterally implanted adult cochlear implant (CI) users were included in the study. Four used MED-EL COMBI 40+ implants bilaterally, two used a MED-EL COMBI 40 implant in one ear and a MED-EL COMBI 40+ in the other ear. The subjects used Tempo+ head level speech processors in everyday life and modified Tempo+ speech processors during the experiments.

All CI users were tested with three different microphone systems: (i) omnidirectional microphones placed above the ear as in BTE hearing aids, (ii) omnidirectional microphones placed in the ear as in ITE hearing aids, and (iii) two-microphone directional microphone systems (Phonak Audio-zoom) placed above the ear. All test were performed in two different listening conditions using (a) both cochlear implant systems and (b) only the CI with the better speech understanding, as determined by speech tests in quiet.

Speech reception thresholds (SRT) in noise was measured using an adaptive German speech test in noise (Oldenburger Sentence test). The test sentences were presented in a moderately reverberant room (average reverberation time 0.34 s) from a loudspeaker in front of the listener, while speech babble noise was presented either the left, from the right, or from the same loudspeaker in front of the listener as the test sentences.

On average, the two-microphone directional system and the omnidirectional microphones placed in the ear outperformed the omnidirectional microphones placed above the ear by 2.5 dB (SRT). The differences between the directional system and the ITE-microphone were small and not statistically significant. If noise was presented from the side of the ear with the better speech understanding or from the front, an average bilateral advantage of 6.7 dB or 1.1 dB, respectively, was found ($p<0.01$). There was no significant interaction between the microphone system used and the unilateral or bilateral use of cochlear implants. Our results suggest that speech recognition in noise can be optimized for both unilateral and bilateral CI users by choosing the microphone placement and directionality adequately.

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BINAURAL HEARING USING TWO COCHLEAR IMPLANTS OR ONE COCHLEAR IMPLANT AND ONE HEARING AID

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Beth Israel-New York Eye and Ear Cochlear Implant Center

The advantages of binaural hearing have well documented for people with normal hearing and for people using hearing aids. It is been more difficult to demonstrate a binaural advantage for patients using cochlear implants because the number of bilaterally implanted patients is small. As patients with more residual hearing are being implanted, it is becoming possible to demonstrate binaural benefit for patients who use a cochlear implant in one ear and a hearing aid on the unimplanted ear. Previous research on this topic at our center and at other centers, has demonstrated binaural benefit for patients using a cochlear implant and a hearing aid by measuring speech perception in quiet and in noise and localization (minimal audible angle). The current study is evaluating speech perception skills for two groups of patients. The first group are patients using bilateral cochlear implants and the second group are patients using an implant and a hearing aid. Testing includes speech perception results for normal and soft speech in quiet and in the presence of competing noise (four talker babble). Suggestions for determining when a hearing aid should be considered for the unimplanted ear as well as when bilateral cochlear implants might be considered will be discussed.

INTERAURALTIME DIFFERENCES IN FINE STRUCTURE AND ENVELOPE IN BILATERAL ELECTRICAL AND ACOUSTICAL HEARING

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Localization of sound sources is partly based on interaural time differences (ITDs). For lower frequencies, the neural stimulation pattern is synchronized to the phase of the carrier signal. Interaural difference of the phase, so called fine structure ITD, is important for determining the lateral position of the sound source. Bilateral cochlear implant (CI) listeners currently use stimulation strategies which encode ITD in the temporal envelope but which do not transmit ITD in the fine structure, due to the constant phase in the electrical pulse train. The arbitrary interaural phase difference between the pulse trains causes uncontrolled fine structure ITD.

To determine the necessity for encoding ITD in the fine structure, ITD-based lateralization was investigated systematically with CI listeners and normal hearing (NH) subjects. Lateralization discrimination was tested at different pulse rates for various combinations of independently controlled envelope ITD and fine structure ITD. Special stimuli were used whose basic parameters are based on speech signals.

Results for electrical hearing show that the fine structure ITD had the strongest impact on lateralization at lower pulse rates, with significant effects for pulse rates up to 800 pulses per second. At higher pulse rates, lateralization discrimination depended on the envelope ITD only. It is concluded that bilateral CI listeners benefit from transmitting fine structure ITD at lower pulse rates. A comparison of the performance between CI and NH listeners reveals sufficient comparability for the better performing CI listeners. Preliminary results of a lateralization positions tasks performed by NH listeners show the effects of fine structure and envelope ITD on the magnitude of lateralization for stimuli used in the lateralization discrimination tests.

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AUDITORY NERVE SINGLE-FIBER RESPONSES TO COMBINED ELECTRIC AND ACOUSTIC STIMULATION OF THE COCHLEA

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The combined presentation of acoustic and electric stimuli can enhance speech perception in ears with residual (acoustic) hearing. Acoustic-electric interactions can occur with both monaural and binaural stimulation and can take place at different levels of the mammalian auditory system. This presentation examines monaural interactions at the auditory-nerve level. Our recent work has had two goals: (1) to describe acoustic-electric interactions occurring within single auditory nerve fibers and (2) to relate those responses to patterns evident in the electrically evoked compound action potential (ECAP). The latter effort is needed to interpret the complex and nonmonotonic course of recovery from adaptation that is present in ECAP measures (Nourski et al., 2005, Hear. Res.).

An acute feline preparation was used in which intracochlear electric stimuli were delivered by a minimally invasive monopolar electrode. Bursts of wide-band acoustic noise (100-400 ms duration) were presented during an ongoing, low-rate (250 pps), electric train that provided probe stimuli. Time permitting, we obtained within-fiber comparisons across electric levels, acoustic levels, and acoustic masker durations. Best frequency was also determined in some fibers.

In nearly all fibers, the electric stimulus evoked an α response, reflecting direct membrane depolarization of a wide population of fibers. However, fibers exhibited several different α response patterns. Most demonstrated either sustained or slowly adapting responses, while others showed relatively fast (within 50 ms) rate adaptation. A third group had an unusual "build-up" response, with per-pulse firing rate increasing across the train. Electric responses were complex in the minority of fibers that exhibited a clear β (electrophonic) response. The β response could exhibit faster rate adaptation than the α response, creating a transient change in the temporal code. We suggest that these multiple mechanisms for differential rates of adaptation may have perceptual consequences, as they occur over time courses comparable to speech tokens.

Unlike acoustic probes and CAP measures, the ECAP has revealed unusual non-monotonic patterns of nerve recovery after presentation of either an electric or acoustic probe (see poster by Nourski et al.). From our single-fiber data, we hypothesize that this pattern may be due to unequal rates of spike-rate recovery and changes in spike jitter, with reduced jitter resulting in a brief (few ms) period of ECAP enhancement. We will discuss two possible mechanisms for this: (1) a transient suppression of spontaneous activity and (2) a transient change in the state of the membrane at the site of electrical depolarization.

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A COMPUTATIONAL STUDY OF COCHLEAR IMPLANT CODING USING MULTIPLICATIVE NOISE

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We have previously advocated the deliberate addition of noise to cochlear implant signals [1]. The artificial noise mimics the natural additive noise in the healthy ear (e.g. originating from Brownian motion of hair-cell stereocilia) that is largely absent in a deafened ear. The normal ear, however, also contains multiplicative noise sources that result from the quantal nature of synaptic transmission: each nerve fibre is excited by the product of a hair-cell signal and noise. Crucially, auditory models that exclude multiplicative noise fail to predict the physiological response to certain stimuli, such as low-frequency sinusoidal stimulation [2]. Furthermore, at high stimulus levels, these models predict a reduction in spike-time variability that is not observed in physiological data.

Because profound deafness is associated with the loss of inner hair-cells, the multiplicative noise sources are completely absent in the deafened ear. The response of the cochlear nerve to standard cochlear implant stimulation, with or without additive noise, would not therefore be expected to resemble the response to normal acoustic stimulation.

Here, using a computational model, we show that the response to cochlear implant stimulation more closely resembles that to normal acoustic stimulation if each electrode signal is the product of a Gaussian noise waveform and the filtered, compressed and half-wave rectified input signal. The results are from a computational model of cochlear implant stimulation. The simulated cochlear nerve fibres had leaky integrate-and-fire dynamics and modelled refractory and accommodation effects by a threshold dependency derived from the sodium-inactivation dynamics of the Frankenhauser-Huxley equations for myelinated nerve. We show that multiplicative noise leads to a fundamental change in the coding mechanism and can lead to a marked increase in transmitted information compared with additive noise, or a control condition with no noise. We therefore expect this new form of stochastic resonance to lead to increased speech comprehension when used in cochlear implant coding.

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ACOUSTIC-ELECTRIC INTERACTIONS IN THE AUDITORY NERVE: MASKING OF THE ELECTRICALLY-EVOKED COMPOUND ACTION POTENTIAL BY ACOUSTIC NOISE

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Combined electric and acoustic stimulation (EAS) is a promising approach to improve the performance of cochlear implants in patients with residual hearing. In such patients, there may be auditory nerve fibers responsive to both acoustic and electric stimuli. Understanding of possible interactions between the two types of stimuli at the level of the auditory nerve is important for developing EAS paradigms. In the present study, we investigated the time course of simultaneous and post-stimulatory effects of acoustic noise on the auditory nerve electrically evoked compound action potential (ECAP).

Adult guinea pigs with normal hearing were used in acute experimental sessions. Broadband acoustic noise (duration 400 ms), presented directly to the ear canal by an earphone coupled to a speculum, was used as a masker. Biphasic electric pulses, delivered through an intracochlear wire electrode, were used as probes. The onset of the probe was varied relative to the onset of the masker. ECAPs were recorded from the auditory nerve trunk. Masking of the ECAP by acoustic noise was measured as a decrease in the ECAP amplitude relative to a control (unmasked) condition.

Simultaneous masking featured an onset (maximum) effect followed by a decrease in the amount of masking to a steady state. The time course of the simultaneous effects was characterized by a two-component exponential function. The amount of masking increased with both masker and probe level. Post-stimulatory ECAP recovery was non-instantaneous and often featured a non-monotonic time course, particularly at longer masker durations. In such cases, forward masking functions featured a rapid recovery phase, followed by a transient depression in the ECAP amplitude. This effect was characterized by a three-component exponential function with two positive and one negative component. A high-rate (5000 pps) electric pulse train masker produced similar post-stimulatory effects on the ECAP in response to probe pulses.

Acoustic stimulation affects the auditory nerve responses evoked by electric stimuli in a level- and time-dependent manner. Simultaneous masking follows a time course that is comparable to that of the adaptation to an acoustic stimulus. Forward masking functions suggest a multi-component process with refractoriness, spontaneous activity and neural adaptation possibly contributing to the time course of recovery.

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SUNDAY, POSTER 28

CLINICAL RESULTS WITH HYBRID (ELECTROACOUSTIC) STIMULATION

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Cochlear implant technology has evolved over the last several years such that patients with considerably more residual hearing are now candidates for cochlear implantation. Of particular interest in recent years are those patients with severe to profound high-frequency sensorineural hearing loss but significant low-frequency acoustic hearing (i.e., ski-slope type losses). This presentation describes clinical results for subjects using the Nucleus Hybrid cochlear implant. For patients with severe and profound high frequency hearing losses, this device, with its 10mm 6-electrode array, allows electric stimulation of high-frequency hearing, while permitting low-frequency residual hearing to be stimulated acoustically.

A total of 31 patients have received the Nucleus Hybrid cochlear implant system in the US and Europe. Results to date demonstrate that a short-electrode array can be inserted into the cochlea without total loss of residual low-frequency hearing. This permits the continued use of a hearing aid to stimulate residual low-frequency hearing while providing electrical stimulation to the basal portion of the cochlea. With electroacoustic stimulation patients show improved open-set perception of CNC words as well as improved speech perception in noise as measured by the BKB-SIN test. The results of this study, when completed, will be used to assess the viability of developing a speech processor that is capable of processing and stimulating patients electrically and acoustically.

SIMULATING TIME-VARYING ELECTRICAL STIMULATION OF THE AUDITORY NERVE

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The work presented here is from the ongoing development of the first stage of a proposed network model designed to simulate the electrically-stimulated auditory system. The underlying unit model, an integrate-and-fire model (XI&F), predicts neural activity in response to applied extracellular currents. Its guiding principle is to use the simplest biologically-realistic configuration that can simulate responses for the full range of electrical stimulation strategies employed by auditory prostheses with the objective of restoring normal hearing.

A strategy commonly used in implant psychophysics modulates the amplitude of a fixed-rate pulse train using the envelope extracted from the input signal. Steady rate electrical stimulation such as this can produce phase-locking of the neural response to the frequency of the carrier signal. That is, fibers in the stimulated region of the auditory nerve are thought to be collectively in the same refractory state and as a consequence are essentially unresponsive to any weak or irregularly time-varying components of the signal. Signal processing and stimulation strategies have been proposed to preserve the presence of and possible information contained in these envelope components. Such strategies may benefit from testing with models that can realistically simulate how the electrically-stimulated auditory system processes time-varying stimuli.

Previously reported XI&F results computed for sinusoidal electrical stimulation show poor quantitative accordance but better qualitative agreement with animal data that report declining phase-locking with frequency. The model also suggests that variation in adaptation rate between cells may underlie the reported variability among fibers in the degree of phase-locking at higher frequencies. I will present results of recent efforts directed at improving the quantitative performance and also work that compares sinusoidal simulation to the functionally more efficient pulsatile stimulation waveform.

SUNDAY, POSTER 30

MODELING THE INFLUENCE OF FITTING PARAMETERS ON LOCALIZATION IN CI USERS

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Binaural auditory models usually consist of three blocks: peripheral processing, binaural processing and central processing. In most models of the auditory processing, the peripheral processing block includes models for the outer and middle ear, the basilar membrane, the inner hair cells, and neuronal adaptation. In the present model, this processing stage has been replaced by a simulation of the signal processing of the COMBI 40+ cochlear implant (CI) system, i.e. an automatic gain control (AGC), preemphasis filtering, 12 finite impulse response Hilbert envelope extractors, and the logarithmic map-law. Several parameters of signal processing can be adjusted for each side, e.g. the compression onsets of the AGCs, the distribution of cut-off frequencies of the filter bands, or map-law coefficients.

The binaural processing stage in the present model is based on the Jeffress delay line and contains attenuation lines. The binaural processing is based on contralateral inhibition and has been shown to work in a number of psychoacoustic experiments.

The central processing stage of the present model remaps 12 interaural time differences (ITD) and level differences (ILD) as functions of time extracted from the binaural processing stage, to azimuths. The central processing stage provides the output of the model, which is the energy weighted average of 12 azimuths.

In the present model, remapping of ITDs and ILDs to azimuths is probably the most critical part. In models of normal hearing, ITD and ILD maps are sometimes generated using a white noise signal which is filtered with head related transfer functions (HRTF) measured in the horizontal plane around the head. The resulting set of stereo signals serves as an input to the model. Stationary ITDs and ILDs are extracted from the binaural processing stage and stored as functions of azimuth and frequency band. These functions are used as ‘inverse functions’ for the remapping of ITD and ILDs to azimuths. In models of normal hearing this approach is successful because compression and adaptation processes are assumed to be band specific.

The signal processing in a CI system usually contains two compression and adaptation stages: the front-end AGC compressing the audio signal, and the map-law compressing the envelope signals of each filter band. In a bilateral CI system, the compression and thus the ILD in each filter band is a function of azimuth and the spectral energy distribution of the signal, whereas in models for normal hearing the ILD in each filter band is only a function of azimuth. Different approaches for generating ITD and ILD maps will be used in the present model, e.g. 12 band-pass filtered noise signals each exciting one of the CI system filter bands for calculating ILD and ITD maps.

Applying the above-described model, two localization experiments with bilateral CI users are modelled: In experiment 1 the influence of different AGC settings and different signal levels have been studied in five subjects. In experiment 2 an effect of different map-law settings has been shown in three subjects.

Differences between localization results and predictions of the model will be discussed. The model reveals new insights into the signal processing in CI system and shows up possible concepts for future CI signal processing.

INFLUENCE OF STIMULATION PULSE SHAPE ON NERVE EXCITATION THRESHOLD: INVESTIGATIONS USING A STATE-SPACE MODEL AND PRELIMINARY RESULTS PULSARCI^{100} USERS

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Usually biphasic pulses are used for the stimulation of the auditory nerve. However, the use of other pulse shapes like triphasic stimulation pulses might be advantageous for the reduction of channel interaction and – during ECAP measurements – for the reduction of stimulation artifacts. In addition to that, the variation of pulse inter-phase-gaps could allow a further reduction of stimulation thresholds and thus contribute to saving stimulation power.

A state space model, implemented in MATLAB® and incorporating the Hodgkin-Huxley membrane equations, has been developed to investigate the influence of pulse shape parameters on the excitation threshold of myelinated nerve fibers. Simulations with triphasic pulses of various phase proportions and with biphasic pulses of variable inter-phase gaps have been carried out.

Since the PULSARCI^{100} cochlear implant provides biphasic and triphasic stimulation pulses and offers the possibility of inter-phase-gap variations, psychoacoustic experiments with PULSARCI^{100} users have been performed for the evaluation of the simulation results.

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BINAURAL MEASURES OF COCHLEAR IMPLANT LISTENERS

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The Simulated Open Field Environment creates realistic auditory scenes with simulated sources and echoes inside an anechoic chamber. By using 48 loud-speakers arranged horizontally around the subject the patient can listen with his own device in the free-field which by definition assumes the correct HRTFs.

A visual display is used for localization responses and provides a simulated 3D-scene. We are in the process of compiling a binaural hearing test suite for CI listeners consisting so far of the following experiments:

1) A 360° horizontal localization test allows for measures of front/back confusions. Responses are taken on a continuous scale which provides better resolution that e.g. speaker identification. Synthetic (low-pass and wide-band noise) as well as natural sounds (noises, speech, police siren, dog bark) allow predictions of performance in every day conditions.
Results: One bilateral CI listener shows no localization ability with the single, newer implant, but only 26.6° rms-error for both CIs if front/back confusions are resolved. Front/back confusions are 52% which is far higher than for a normal hearing subject (2%). Another patient with CI and hearing aid in combination showed 36.6° rms-error if 33% confusions were resolved.

2) Frontal localization: A test for localization of frontal targets with a light pointer method allows for accurate estimates of localization performance.

3) Impact of echoes on localization: Localization is studied for wide-band and speech sounds in situations of summing localization and precedence. Previous studies showed that the excellent localization ability of a CI-patient was entirely based on the evaluation of interaural level cues (ILDs) (Seeber and Fastl, DAGA 2003, 2004). As interaural timing cues play a crucial role in precedence we suppose that CI-patients do not show the precedence effect. Instead, we assume that the localized direction is determined by the ILD-sum of source and echo which would lead to a shift towards the direction of the echo as in summing localization. In this case echoes would destroy the localization information for CI patients. Results from a monaural CI patient with residual hearing on the contralateral side showed no effect of echo delay time on localization.

4) The echo threshold was studied by adjusting the delay time between source and echo pairs to find the time at which the echo becomes audible and thus disturbing. Results of a bilateral CI patient show echo thresholds for clicks similar to thresholds of normal hearing subjects which can be attributed to gap detection. The patient was not able to give consistent threshold estimates for a CVC word because he could not parse source and echo apart, suggesting reduced precedence.

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THE RESPONSE OF THE AUDITORY NERVE TO ELECTRCAL STIMULATION FOLLOWING DEAFNESS

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Just above threshold electrical stimulation of the auditory nerve produces probabilistic discharge responses in individual auditory neurons. It has recently been shown that loudness perception in cochlear implant patients can be predicted from stimulus-response models incorporating probabilistic responses of the auditory nerve. The primary aim of this study was to investigate the effect of hearing status upon probabilistic firing of the auditory nerve, in the hope that this knowledge may improve our understanding of loudness perception with the cochlea implant and its relation to deafness.

We therefore examined how sensorineural hearing loss (SNHL) affects the response of single auditory nerve fibres (ANF) to electrical stimulation of the cochlea. Single unit recordings were made from adult guinea-pigs anaesthetized with ketamine/xylazine. The electrical stimuli were monopolar, biphasic, charge-balanced current pulses. ANF responses were compared across groups of either undeafened animals, and those deafened one or six months prior by a single dose of kanamicin and furosemide. Stimulus pulses (50 μs/phase, 10 μs inter-phase interval) were delivered at rates of 20 and 200pps (pulses per second) via an electrode implanted into scala tympani just prior to the single unit recording.

Spike latency decreased progressively with the duration of SNHL. The dynamic range (against stimulus current) increased with SNHL following 200pps electrical stimulation, but was unaffected following stimulation at 20pps. That the influence of SNHL upon dynamic range is observed only at higher rates, suggests that interaction effects between spikes are likely to be present, and affected by, SNHL. This may be due to an increase in the time-course and/or magnitude of a short duration membrane recovery. Subsequent analyses revealed that at near-threshold levels of stimulation, neural activity is suppressed soon after the onset of the pulse train *even if* spikes are not generated in response to the first pulse of the train. This might explain the reduction in perceptual threshold observed as pulse-rate increases; the number of pulses delivered prior to the onset of the suppression increases with pulse rate, so the probability of firing is likely to rise and the threshold decrease. Furthermore, the time-constant of the physiological suppression is similar to the perceptual measures of threshold-change associated with cochlear implant non-simultaneous electrode interactions, and this may therefore be the physiological basis for this phenomenon.

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SUNDAY, POSTER 34

ASSSESSMENT OF SPATIAL UNMASKING AND SOUND LOCALIZATION IN BILATERAL IMPLANTS USING DIRECT INPUT

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A prototype instrument to assess the binaural abilities of bilateral cochlear implant (CI) users via delivery of signals directly to the auxiliary inputs of their processors has been developed and evaluated. Sets of calibrated head-related transfer functions (HRTFs) from sources at various azimuths in the horizontal plane were measured through CI microphones at the entrance of the ear canal, in the ear level module, and on the transmitter. The Hearing In Noise Test (HINT) speech and noise materials were processed with HRTFs for 0º, 90º, and 270º azimuths for use in assessment of spatial unmasking. An impulse noise from the Source Azimuth Identification in Noise Test (SAINT) was processed with HRTFs for 12 azimuths from 90º to 270º in 15º increments to assess sound localization.

The adaptive rule for measuring the speech reception threshold in noise with HINT was modified for use with CI subjects who do not achieve 100% intelligibility in quiet. The scoring rules for SAINT were also modified for use with CI subjects who are unable to identify all of the source azimuths.

Both the HRTF simulations and the modified testing procedures were validated first in with 17 acoustic hearing (AH) subjects and subsequently with 5 bilaterally implanted CI subjects. Signals were delivered via soundfield speakers (SF) and via direct connect (DC) input. For AH subjects, headphones were used to deliver DC signals. For CI subjects, DC signals were delivered to the auxiliary inputs of their processors. Briefly, the HRTF simulations for HINT and SAINT produced nearly identical SF and DC results for both the AH and the CI subjects. These results were obtained using the modified testing procedures for both HINT and SAINT. DC test scores were often slightly better than SF scores for the CI subjects.

The bilateral CI subjects differed widely with respect to their spatial unmasking and sound localization abilities, and, in most cases, these abilities did not fall within the range of performance for AH subjects. However, in all cases, it was possible to make accurate DC assessments of these abilities that can be compared directly with those of normally-hearing individuals. This poster will present detailed information about the modified testing protocols and the monaural and binaural test results. Results suggest that well-controlled measures of CI binaural hearing abilities may be readily obtained in clinical settings using DC tests.

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SOUND LOCALIZATION IN BILATERALLY IMPLANTED CHILDREN BELOW 7 YEARS OF AGE

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Studies with implanted adults have indicated that bilateral cochlear implantation can offer important benefits compared to monaural implantation in terms of speech intelligibility. However, adults benefit mainly from head shadow and summation effect, but a real binaural advantage (binaural squelch) is minimal. As a result of neural plasticity it is possible that the auditory system can learn to exploit binaural cues if the second implant is given at a sufficiently young age.

In 2003, the Belgian National Health Insurance Institute financed a second implant for 42 children, aged between 2 and 12 years, in Belgium. These children were implanted at the five centres mentioned above ([1,2,3,4,5]) and a research project was started to investigate several issues related to (the development of) binaural processing.

The adult localization test procedure was modified in such a way that it is feasible with very young children. As in adult testing, the test setup consisted of 13 loudspeakers positioned in the frontal horizontal plane from -90° to +90°. A broadband telephone signal served as the stimulus in a game where children indicated the picture under the loudspeaker where the phone was ringing. Seventeen normal hearing children aged between 3;8 and 6;11 years participated in the evaluation of the test procedure. A mean localization error (RMS) of 13.7° was observed, with a large variance between subjects. The setup proved to be useful for testing most of the children aged 4 years and older and with some but not all younger children. With hearing-impaired children (wearing bilateral hearing aids or cochlear implants) the results were more variable. In an attempt to bypass task difficulties, also a lateralization task was carried out. First results of localization and lateralization will be presented at the conference.

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SUNDAY, POSTER 36

COMBINED ELECTRIC ACOUSTIC STIMULATION OF THE AUDITORY SYSTEM: RESULTS OF A CLINICAL STUDY

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Introduction: Combined electric and acoustic stimulation (EAS) of the auditory system is a new therapy for patients with severe to profound high- and mid-frequency hearing loss but remaining low-frequency hearing.

Objective: The objective of this study was to assess the results of electric acoustic stimulation in a group of patients

Methods: In a prospective study, 5 patients with low-frequency hearing of better than 60 dB below 1 kHz were implanted with a MED-EL COMBI 40+ cochlear implant. Pure tone thresholds as well as monosyllabic word scores and Plomp sentences in quiet and in noise were measured with hearing aids, cochlear implant alone and in the combined stimulation mode (EAS) in the same ear. To evaluate the benefit of EAS in everyday situations, patients were asked to fill in an APHAB questionnaire. Their perception of music was assessed by means of the MuMu questionnaire and a computer controlled music test.

Results: Hearing could be (partially) preserved in all 5 patients. One patient retired after 3 months post-implantation because of depression. Speech reception results will be discussed in 3 different modes: 1) ipsilateral hearing aid alone, 2) CI in full frequency range, 3) CI in EAS frequency range and 4) EAS. Results of the APHAB and the music tests will also be discussed.

Conclusion: Combined EAS is feasible and effective in patients with remaining low-frequency hearing. Large synergistic effects can be observed especially in conditions with interfering noise, where patients using CI alone still have large difficulties in understanding.

SUNDAY, POSTER 37

PATIENT-SPECIFIC ELECTRO-ANATOMICAL MODELS OF THE COCHLEAR IMPLANT: COMPARISONS WITH EMPIRICAL DATA

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Striking differences in cochlear anatomy and pathology are clearly evident in the histologically-processed temporal bones from cochlear implant users. Since all of these differences (e.g. the total number, and distribution of surviving spiral ganglion cells; the proliferation of new bone and soft tissue; the shape of the cochlear duct; and the type and position of the implanted electrode) are likely to influence the pattern of neural activation elicited by electric stimulation, understanding the relative influence of each may be an important step in determining whether peripheral differences contribute to the wide range of performance measured across cochlear implant users.

We hypothesized that patient-specific models of the implanted cochlea that incorporate individualized anatomy might prove a useful tool in investigating how, and to what extent, the peripheral anatomy influences electric hearing. To investigate the feasibility of these models, the histologically-processed temporal bones of two implanted patients (one Ineraid, one Nucleus) were used to construct separate 3D electro-anatomical models incorporating each patient's unique anatomy. Using an iterative finite-difference algorithm, the electric field in the model cochlea can be solved in response to an arbitrary stimulus waveform applied to an arbitrary electrode configuration. Coupling these field estimates to a single-neuron model allows for the prediction of (1) the neural activation pattern, (2) the electrically-evoked compound action potential recorded from intra-cochlear electrodes, and (3) an estimate of the relative perceptual threshold across electrodes for a given stimulus configuration.

To test the predictions of these models we compared model predictions with two sources of empirical data. First, a generalizible model (one without patient-specific features) was used to predict the neural activation pattern in response to two novel stimulus waveforms. These model predictions suggested a difference in pitch discrimination for which we subsequently found evidence in a number of current implant subjects.

Second, the patient-specific models were used to calculate estimates of perceptual threshold for stimulation by each model electrode (6 for the Ineraid patient, 20 for the Nucleus patient). These were compared with psychophysical thresholds measured on the respective patients during life.

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SUNDAY, POSTER 38

EFFECTS OF ELECTRIC STIMULATION ON ACOUSTICALLY-EVOKED RESPONSES IN INFERIOR COLLICULUS

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Combined electric and acoustic stimulation of the auditory system is a new therapy for patients with severe-to-profound high- and mid-frequency hearing loss, but with remaining low-frequency hearing. Speech perception data indicate synergistic benefit with such combined stimulation. What is lacking, however, is a good understanding of the neural sites of acoustic-electric interactions that give rise to improved performance. Work at Iowa has been studying interactions at both the peripheral (nerve) and central (inferior colliculus, IC) levels. This presentation focuses on preliminary results obtained with central (IC) measures obtained from acute guinea pig preparations.

Two different studies, one investigating monaural acoustic-electric measures and another investigating binaural (across-ear) acoustic-electric interactions are described. Both approaches used invasive thin-film multi-channel electrode arrays to record either field potentials or spike activity from the IC. Biphasic electric pulses, delivered through an intracochlear wire electrode placed in the basal turn of the cochlea, were used as masker stimuli. A masking electric pulse was followed by binaural or monaural acoustic probe with varied delay. Responses evoked by the probe stimulus were determined based on their latencies and analyzed using custom-designed software.

Acoustic frequency tuning curves (FTCs) obtained for each recording site confirmed the electrode array's placement along the IC tonotopic axis. Electric stimulation yielded FTCs similar to those in response a high frequency tone, consistent with the basal placement of our minimally invasive intracochlear stimulating electrode. In forward-masking experiments, we observed a suppression of acoustic probe-evoked responses. This masking data will be presented as function of recording site and acoustic stimulus frequency.

With binaural stimulation, our measure of across-ear interaction of acoustic and electric stimuli was based upon an extension of the binaural interaction potential first measured with ABR's. Our interaction measures demonstrate a non-monotonic function of the interaural time delay. Preliminary interaction functions obtained across different stimulus levels indicate that they are relatively robust and can be insensitive to level changes. Such a measure may therefore find application to clinical questions.

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THE COCHLEAR IMPLANT ELECTRODE-PITCH FUNCTION

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The cochlear frequency-place function in normal hearing ears has been investigated for human cadavers and a wide variety of other species and an exponential relationship has been proposed (Greenwood, 1990). Although it seems reasonable to assume a similar function for electrical stimulation by means of an intra-cochlear electrode array, the exact frequency-place function for this special type of stimulation needs to be investigated.

Six users of the MED-EL Combi 40+ (C40+) cochlear implant device with moderate to profound hearing loss between 125 and 1000 Hz in the non-implanted ear took part in a binaural pitch matching experiment. The C40+ electrode array provides a deep insertion into the tympanic scala and a wide spatial separation of the stimulating electrodes. Insertion depth was controlled by Stenver's view plain radiographs and the insertion angle was estimated. The task of the subjects was to adjust the frequency of a sinusoid presented at the non-implanted ear by means of an adjusting knob until they perceived the same pitch that was elicited by a reference stimulus at the implanted ear. Acoustical and electrical stimuli were presented in an alternating order. Electrical stimulation was carried out with a fixed pulse rate of 800 pps at apical electrodes. Ten fixed starting frequencies were chosen randomly between 125 and 1000 Hz for the acoustical stimulus. For each electrode and each starting frequency two adjustments were collected. The average adjustment for each reference electrode was calculated as the median of 20 adjustments.

The results show that the two most apical electrodes were matched to nearly the same pitch by four of the six subjects whereas all subjects adjusted more basally located electrodes to higher and statistically different frequencies. The average electrode-pitch function increased in an orderly fashion with an a slope of 98 Hz for each change of electrode location (equal to 40 Hz/mm). In contrast to the exponential predictions according to Greenwood for normal hearing, the electrode-pitch function shows a more linear relationship. A comparison with results obtained from a similar study with Nucleus CI24 subjects will be presented (work in progress).

COMPANDING TO IMPROVE COCHLEAR IMPLANTS' SPEECH RECOGNITION IN NOISE

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The performance of the available cochlear implant processors in noise is still far below that of the biological cochlea. The ability of the human ear to sharpen the spectral peaks by two-tone suppression is thought to be one of the reasons for its outstanding performance in noise. Two-tone suppression is characterized by a decrease in response to a tone in the presence of a second tone. Recently, Turicchia and Sarpeshkar proposed a companding strategy, or compression-then-expansion, to simulate two-tone suppression, which leads to simultaneous spectral contrast enhancement and multi-channel syllabic compression. The present study uses their architecture to improve cochlear implant speech performance in noise.

The companding strategy is implemented using a broad pre-filter bank, a compression block, followed by a narrowly tuned post-filter bank and an expansion block. Both the compression and expansion block consist of an envelope detector and a non-linear unit followed by a multiplier manipulating the filter output by the non-linear block output. This architecture was implemented in Matlab 7. To evaluate the performance of the companding strategy, vowel recognition experiments were conducted in both normal subjects and cochlear implant subjects. Twelve vowels in /hVd/ format were presented in quiet and in speech-spectrum-shaped noise at different signal-to-noise ratios (SNR). The normal-hearing subjects listened to the stimuli processed with the companding strategy alone or with the companding strategy followed by an acoustic simulation of an 8-channel cochlear implant.

Preliminary results showed that the normal-hearing subjects derived relatively small benefits from the companding strategy in quiet and in noise, but both the simulated and actual cochlear implant subjects significantly improved their performance with the companding strategy. The average improvement was 27 percentage points at 0 dB SNR and 13 at -5 dB SNR in the simulated cochlear implant users. Similar or even greater improvement was observed in actual cochlear implant subjects. These preliminary data showed that the companding strategy has the potential to improve cochlear implant performance in noise. Parameter optimization and technical implementation in cochlear implants will be discussed.

RESULTS OF A PSYCHOACOUSTIC-MODEL-BASED ACE STRATEGY (PACE) FOR THE NUCLEUS-24 DEVICE

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Based on the ACE (Advanced Combination Encoder) strategy for the Nucleus 24 implant, a new strategy with an advanced maxima selection has been developed. All currently available *n of m* strategies select the stimulating channels on the basis of the energy or amplitude in the specific filter band. Any psychoacoustic processes are not considered. In normal-hearing listeners masking occurs depending on frequency, amplitude and energy of specific signals. Those processes have been investigated in detail, i.e. by the Fraunhofer Institute and the TNT[2], and are already implemented into well-known coding schemes such as mp3 (MPEG1 layer 3). If the selection of stimulated channels in cochlear implant systems is based on a similar psychoacoustic model, information which is masked in normal-hearing listeners could be neglected, providing more bandwidth for signal components which are perceived by normal-hearing individuals.

The new PACE (Psychoacoustic Advanced Combination Encoder) strategy indeed utilizes a psychoacoustic model for the maxima selection and has already been implemented on the Cochlear research processor L34 in cooperation with Cochlear Corp. for chronic use in cochlear implant patients. A long-term cross-over study is currently being carried out to compare three different conditions: a) 8-channel ACE, b) 8-channel PACE, c) 4-channel PACE.

Acute tests from a pilot study with eight cochlear implant subjects yielded encouraging results. Seven of the eight study patients showed statistically significant improvement with the psychoacoustic-model-based strategy. Mean scores in the HSM sentence test in noise increased from 51 % correct to 67 % correct when comparing a 4-channel ACE with a 4-channel PACE. Moreover, patients achieved equal results with a 4-channel PACE vs. an 8-channel ACE, which indicates that the psychoacoustic model-based strategy may select more relevant signal components and thus patients are able to achieve good perception with a smaller number of selected channels. Details of the new strategy and results of the ongoing chronic study will be presented.

HIGH-RATE CARRIERS IMPROVE PITCH DISCRIMINATION BETWEEN 250 AND 1000 Hz

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While cochlear implant subjects can perform well for speech recognition in quiet, they obtain limited benefits in challenging conditions, such as speech recognition in noise and music recognition. One possible reason for this limitation is poor pitch discrimination in cochlear implant users. Previous studies showed that a high-frequency carrier modulated by a halfwave-rectified lower frequency stimulus, known as transposed tones, will generate the same neural response as a pure tone at the low frequency. A temporal model of pitch perception would suggest similar pitch discrimination between the pure tone and the transposed tones.

This study compares pitch discrimination of 4 different stimuli in 6 Nucleus-24 cochlear implant users. The stimuli included standard pulse trains, sinusoidally-amplitude-modulated (SAM) pulses, transposed tone pulses, or logarithmic transposed tone pulses. The carrier rate was 5000 Hz in the latter 3 stimuli. The logarithmic transposed tone pulses were identical to the transposed tone pulses except that the sinusoidal modulation was performed on a logarithmic scale in amplitude. A 3-interval, forced choice, adaptive procedure with a 2-down 1-up decision rule was used to measure the difference limen. Standard frequencies were tested at 20, 64, 125, 250, 500, and 1000 Hz.

Using the standard pulse stimulus, subjects were able to discriminate pitch based on rate changes up to 250 Hz, agreeing with known psychophysical data. Using SAM pulses, subjects performed identically with rate discrimination. Compared with the standard or the SAM pulses, transposed tone stimuli produced similar performance at low standard frequencies but significantly better performance at standard frequencies between 250 and 1000 Hz. For example, the logarithmic transposed pulses could typically be discriminated at a 5-10% difference at these frequencies. As a comparison, subjects were virtually unable to perform pitch discrimination using the standard and SAM pulses above 250 Hz.

While it is clear the transposed tones are not good models for pitch discrimination in normal-hearing listeners (Oxenham et al., PNAS, 2004), the present result suggests that they could be incorporated in cochlear implants to improve pitch discrimination. The mechanisms for the observed benefit of the high-rate carriers are not clear and might be related to the pseudo-spontaneous activity caused by the high-rate stimulation (Rubinstein et al, Hear Res, 1995). Data are being collected and will be reported for pitch ranking and functional melody recognition using the high-rate carriers.

Support provided by the NIH-NIDCD

MONDAY, POSTER 5

THE EFFECT OF PULSE BURST DURATION ON LOUDNESS IN COCHLEAR IMPLANTS, IN LIGHT OF ECAP AMPLITUDE

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In order to consider the variation of loudness with the duration of a burst of stimulation pulses, it is relevant to measure the neural responses to the individual pulses comprising the burst. Our objective was to study burst duration effects, in the first instance, at a pulse rate sufficiently low that refractory effects would be small, employing both psychophysical and neurophysiological measures.

The loudness of bursts of monopolar biphasic pulses was determined for burst duration varying from a single pulse to 300 ms, in five subjects using the Nucleus cochlear implant (three with straight and two with Contour electrode arrays). The pulse rate of 250 pps was chosen so that refractory effects would be small. Initially, a magnitude estimation task was used to obtain a function relating the loudness of a 300 ms burst to current. This function allowed us to determine currents corresponding to 20, 50 and 80% of the loudness at MCL for 300 ms burst duration. Loudness was measured as a function of burst duration at each of these currents, for three electrodes (6, 12 and 18). The loudness of a burst of a particular duration, the "test burst", was measured using the 300 ms loudness growth function. The current of a 300 ms burst was adjusted to achieve loudness balance against the test burst. That current allowed the equivalent loudness of the test burst to be calculated from the 300 ms growth function.

Using Neural Response Telemetry (NRT), the ECAP was recorded associated with a representative subset of the pulses comprising a 300 ms burst. These responses were obtained by recording the NRT response to the last pulses of bursts of various durations, and using the "Miller" method. NRT data files were processed using custom software that calculated the latency of peak N_1, in addition to the amplitude of the N_1-P_1 complex. The NRT data showed a modest level-dependent reduction of the ECAP peak amplitude throughout the bursts, and a corresponding increase in N_1 latency. Thus, for this pulse rate, refractory effects were indeed small and the ECAP amplitude could be approximated as constant throughout the burst.

The temporal loudness summation window describing loudness as a function of burst duration indicated a longer time-constant than for normal hearing. This finding is not unreasonable, as the synapse between inner hair cell and auditory neuron has been shown to have a profound effect on temporal summation, at least at threshold. In addition, we found that the contribution of the first pulse to the loudness of a burst was of the order of ten times stronger than those of subsequent pulses. This finding indicates that the loudness of bursts should be interpreted with considerably greater care than has been the case.

AUDITORY STREAM SEGREGATION AND CHANNEL DISCRIMINATION IN COCHLEAR IMPLANT LISTENERS

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Experiment 1 investigated stream segregation in 8 Nucleus CI24 cochlear implant listeners using alternating tones in a repeating ABA- sequence, stimulating each of the 22 channels. The sequences were presented at four different rates, corresponding to Tone Repetition Times (TRTs) of 50, 100, 150 and 200 ms. Tone 'B' always stimulated channel 11; Tone 'A' stimulated at random each of the other electrodes. Listeners reported when they heard two streams and when they heard one stream. Although reported segregation was consistently greater for stimuli with increased channel separation, there was no significant effect of TRT. This suggested that the judgments may have reflected simple channel discrimination rather than the effects of auditory stream segregation.

Experiment 2 used pitch ranking to investigate channel discriminability in 11 implant listeners. Each of the 22 electrodes was randomly chosen and compared with stimulation of channel 11. Listeners judged which tone was higher in pitch and also rated their confidence. 8 out of the 11 listeners showed a tonotopic arrangement of pitch. The number of electrodes that was not perceived as different in pitch from channel 11 varied between listeners. Two listeners showed an apparently disordered pitch perception, but still obtained good open-set speech recognition. Overall, there was some relation between the results for the two experiments, but an individual's judgments of segregation were not entirely predictable from their pitch ranking results.

Experiment 3 investigated the ability of implant listeners to hear distinct auditory streams when listening for an easily recognisable tone sequence interleaved with distractor tones. In normal listeners, interleaved melodies can be heard as distinct auditory streams provided there is no overlap in pitch range between them. Following training, 5 experienced implant users identified 1 of 2 simple tone sequences in a 2-AFC presentation. All 5 showed 100% correct identification when the sequences were heard without any distractors. Distractors were then introduced that stimulated either: a) the identical part of the electrode array as the target tones, b) a non-overlapping but adjacent part of the array or c) a spatially distinct part of the array (either at the apical or basal end). No listeners were able to score above chance in identifying the target sequence when the distractors stimulated the same part of the electrode array. The ability to ignore the other distractors varied between listeners. Some were unable to score significantly above chance even when the distractors stimulated electrodes spatially remote from the target sequence.

These results imply that cochlear implant listeners often do not achieve auditory stream segregation, even in relatively unchallenging tasks. The relationship between listeners' judgments of streaming are discussed in relation to channel discrimination, open-set speech recognition, and neural response telemetry (NRT) spread of excitation.

MUSIC PERCEPTION BY COCHLEAR IMPLANT USERS AS MEASURED USING THE MONTREAL BATTERY FOR EVALUATION OF AMUSIA

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Music perception is currently an important topic of cochlear implant research. Because no standardized measure of music perception exists, it is difficult to accurately assess both the current state and progress in the technological development of devices designed to assist cochlear implant (CI) users in music perception. Familiar melody identification tasks and pitch perception tests are the dominant methods for evaluating music perception by CI users. However, familiar melody identification and pitch perception tasks are limited in their ability to evaluate music perception by CI users. Further, the methods and stimuli used for these measurements vary across researchers and laboratories.

The assessment of music perception by CI users would be improved by the use of standardized measure of music perception. The present study attempts to address this problem by measuring music perception of CI users with a test battery developed in the fields of music cognition and neuropsychology: the Montreal Battery for Evaluation of Amusia (MBEA, Peretz, Champod, & Hyde, 2003). The MBEA is a measure of music perception that is theoretically driven and has been developed in the neuropsychology and brain imaging research fields over the last ten years. It is the most current standardized music perception measure and has been normalized with over 160 normal controls. The battery of six tests (scale, contour, interval, rhythm, meter, and incidental melody memory) uses novel melodies to test individual processing components in the pitch and temporal domain of a proposed music processing model (Peretz & Coltheart, 2003). Its introduction to cochlear implant research as a standard for music perception assessment is timely and important.

The present investigation uses the MBEA to assess music perception of ten adult postlingually deafened CI users who receive a high level of speech perception benefit from their CI device (≥50% CNC and ≥80% HINT). Its aim is to determine how CI users who receive "good" benefit from their device perform on the MBEA, as compared to normal hearing (NH) controls, and whether their performance is accurately predicted by findings from previous studies.

Preliminary results from this study indicate that performance on the MBEA is consistent with other findings in the literature. Mean CI user scores for the three pitch domain tests (scale, contour, and interval) are near chance; mean CI user scores for the two temporal domain tests (rhythm and meter) are in the range of NH controls. As would be predicted, based on the presence of a rhythmic cue, the mean CI user score for the melody memory test is higher than the pitch domain tests and lower than the temporal domain tests. As expected, CI users demonstrate considerable inter-subject variability.

GROWTH OF MASKING FUNCTIONS FOR INTERLEAVED PULSE TRAINS

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For cochlear implant listeners who utilize pulsatile stimulation strategies, decoding of speech and other complex sounds involves the detection and discrimination of signal components represented as interleaved pulse trains. To better understand the factors that limit sound perception in these users, it is important to understand the perceptual interactions that occur when pulse train stimuli are interleaved in time.

The present study evaluates a simple, within-channel measure of pulse train interaction, namely the detection threshold for one pulse train (the probe) in the presence of a second pulse train (the masker), when the two pulse trains are presented to the same electrode. The data were collected as growth of masking (GOM) functions by measuring probe thresholds for several levels of the masker distributed over the masker dynamic range.

In the first experiment, GOM functions were obtained in five Clarion C-I users for pulse trains with rates of 100, 500, 1000, 1625 and 2600 pps. Masker and probe pulse trains were 300 ms in duration, and probe pulses were temporally centered between masker pulses. Probe detection thresholds, expressed as the ratio of probe amplitude to masker amplitude (A_p/A_m), were larger for the 100-pps stimuli than for stimuli with higher pulse rates. Thresholds did not vary systematically with pulse rate for rates between 500 and 2600 pps.

In the second experiment, GOM functions were obtained in five Clarion C-I and five Nucleus-22 users for 300-ms, 100-pps masker and probe pulse trains. Probe pulses were either coincident with the masker pulses (0-delay condition) or temporally delayed by 1, 5 or 9 msec relative to masker pulses. Large intersubject differences were observed in the effect of probe delay on thresholds (A_p/A_m), possibly indicating differences in the short-term temporal window.

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INVESTIGATION ON IMPROVEMENT OF THE FREQUENCY RESOLUTION VIA CURRENT STEERING

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The majority of CI-users are able to discriminate the pitch produced by two adjacent electrodes; recently it was shown that also distinct pitch percepts can be produced by steering the current between two adjacent contacts. This means the frequency resolution of a cochlear implant strategy, currently limited by the number of contacts, can be significantly improved.

In a clinical study a current steering strategy was tested. In this strategy the acoustic signal is decomposed into 15 bandpass filters corresponding to the 15 intermediate regions of the electrode array. Within each of the 15 bands the location of stimulation, i. e. the current distribution between the two adjacent contacts, is defined by the frequency of the highest spectral peak in each band. Thus, in each cycle 15 stimuli are presented, one in each band. The strategy was implemented on a research processor and used by each subject for one month.

Preliminary data indicate that frequency resolution of acoustic stimuli can be improved by current steering. A trend was found towards better speech perception in noise when using current steering. Four out of the six subjects tested so far achieve a better score in the HSM sentence test in noise. The averaged result is 42% in Current Steering vs. 37% in HiRes. Subjects report that Current Steering allows them to better identify voices and follow a voice in a noise environment. The strategy of fitting the program parameters (such as T, M) does not need to be changed, but the same parameters can be used in HiRes or Current Steering.

MONDAY, POSTER 10

MUSIC PERCEPTION BY COCHLEAR IMPLANT LISTENERS

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Familiar melody identification (FMI) is often used to test cochlear implant (CI) patients' music perception. However, FMI may not accurately assess the CI's and/or speech processor's ability to convey music because of differences in subjects' past and present musical listening experience. In the present study, a musical sequence identification (MSI) task was used to objectively assess 11 CI users' music perception via patients' clinically assigned speech processors. Musical sequences were comprised of 5 notes that corresponded to frequencies used in the musical scale. The duration of each note was 250 ms, and the duration between notes was 50 ms. The interval between successive notes in the sequences was varied between 1 and 5 semitones. The "base note" of the musical sequences was also varied (220, 440 or 880 Hz). Nine distinct musical patterns were generated for each note interval and base note, resulting in a total of 135 musical sequences. These combinations of test conditions allowed performance to be assessed for a wide range of musical notes.

Performance was highly variable among CI subjects, ranging from 14 to 91 % correct; there was no clear advantage among the CI devices and speech processing strategies tested. Performance was generally lowest for the 220 Hz base note sequences. Performance generally improved as the number of semitones between successive notes was increased. Top performers scored better than 90 % correct with only 2 semitones between melodic intervals while the poorest performers scored below 40 % correct with 5 semitones between intervals. The identification of 12 familiar melodies was also measured in the same subjects. Mean performance was 63 % correct when rhythmic cues were preserved, and 29 % correct when rhythmic cues were removed. MSI was not correlated with FMI, and phoneme recognition performance was not significantly correlated with either MSI or FMI.

To see whether MSI performance could be improved by regular but minimal training (1/2 hour per day, every day), several subjects were trained using custom software. As the training progressed, the number of response choices was increased and/or the number of semitones between successive notes in the sequence was reduced. Preliminary results showed that regular training improved all subjects' MSI performance; the amount of improvement ranged from 22 to 45 percentage points. FMI performance also improved after MSI training; the amount of improvement ranged from 4 to 29 percentage points. While subjective quality ratings may be the ultimate arbiter of CI users' music appreciation, the MSI task may be a useful tool in objectively comparing performance across patients as well as performance within patients for a variety of speech processing conditions.

Work supported by NIH/NIDCD.

MONDAY, POSTER 11

EFFECTS OF FREQUENCY ON AUDITORY STREAM SEGREGATION IN COCHLEAR IMPLANTS

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Cochlear implant patients often have difficulty understanding speech in background noise, particularly if the background is other talkers. One way to study the mechanisms responsible for this difficulty is to examine auditory stream segregation. Auditory streaming is the grouping of sounds into different perceptual streams—for example, the segregation of a target speech into one group and background into another. Theoretically, a better ability to perform auditory stream segregation would be associated with a better ability to understand speech in various backgrounds. Such a relationship has been found in hearing-impaired listeners (Mackersie et al., 2001), although this has not been studied to our knowledge in cochlear implant patients.

This study examines the ability of cochlear implant and normal hearing subjects to perform auditory stream segregation based on pure-tones. Normal hearing listeners are able to segregate two rapidly alternating tones into different streams more easily as the frequency difference widens between the two tones. Our hypothesis is that cochlear implant patients will demonstrate relatively poorer auditory stream segregation, because they have poorer frequency discrimination ability (Dorman et al., 1996; Gfeller et al., 2002). Therefore, we would expect if cochlear implant patients perform more poorly on stream segregation of pure tones, they would then have trouble understanding speech in background noise; spectral resolution is especially important for understanding speech in noise (Fu et al., 1998).

To measure stream segregation, we use an adaptive 2AFC rhythmic discrimination task (adapted from Roberts et al., 2002), with each interval containing a sequence of rapidly alternating pure tones. The listener is asked to select the interval with an irregular, unsteady rhythm formed by the two tones. A poorer ability to segregate the two tones makes the task of detecting the irregular rhythm easier. Results to date are in agreement with the idea that cochlear implant patients perform better at this task (detecting the inter-tone rhythm) than normal hearing listeners, suggesting that many cochlear implant users have a poor ability to accomplish auditory stream segregation based on frequency cues. Furthermore, our results suggest that the performance of cochlear implant and normal hearing listeners on this rhythmic discrimination task is relatively monotonic with respect to frequency.

Support provided by the NIH.

MONDAY, POSTER 12

PSYCHOPHYSICAL AND PHYSIOLOGIC FORWARD MASKING PATTERNS IN COCHLEAR IMPLANTS

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The amount of channel interaction between electrodes in a cochlear implant can be assessed using a forward masking paradigm with varied spatial separation between masker and probe. Psychophysical spatial forward masking patterns indicate the amount of perceptual overlap between electrodes, whereas physiologic spatial forward masking patterns indicate the amount of physical overlap between neural populations recruited by different electrodes. We hypothesize that physiologic and psychophysical forward masking patterns should vary similarly as a function of spatial separation between masker and probe. The purpose of this study was to assess the relation between psychophysical and physiologic spatial forward masking patterns.

For all measures, the probe electrode was fixed while the masker electrode varied in location along the array. Physiologic forward masking patterns were measured for the electrically evoked compound action potential (ECAP). Psychophysical pulse train forward masking (PTFM) patterns were obtained with a 300-ms masker, 20-ms probe, and 2-ms masker-probe delay. Psychophysical single pulse forward masking (SPFM) patterns were measured at various masker-probe delays with the same 25- or 50-usec/phase biphasic pulse that was used to elicit the ECAP. ECAP forward masking patterns were then compared to PTFM patterns as well as to SPFM patterns.

To date, PTFM and ECAP data have been collected on 14 adult cochlear implant users (N = 6 Clarion CII/90K, N = 8 Nucleus 24R(CS)). Three probe electrodes representing basal, middle, and apical regions were tested for each subject. Five masker electrodes were used for each probe electrode. Normalized amount of masking was calculated for both PTFM and ECAP. Results showed a significant correlation between the two measures ($r = 0.55$, $p < 0.00001$). Significant correlations remained when data were analyzed for each electrode region, with the strongest correlation occurring for basal and middle electrodes. For each subject, the PTFM-ECAP correlation coefficient was compared to speech perception performance on three different measures (sentences in noise [BKB-SIN], CNC words-quiet, CNC phonemes-quiet). Subjects with the best speech perception performance typically had the weakest correlation between the PTFM and ECAP masking patterns and subjects with poorer speech perception performance had the strongest correlation coefficients.

SPFM patterns have been collected for only two subjects to date. Little or no masking effect was observed for masker-probe delays of 300 ms, 100 ms, or 40 ms. For a delay of 2 ms, the overall amount of masking was similar to that measured with pulse trains; however, the SPFM patterns showed more masking at larger masker-probe electrode separations when compared to PTFM patterns.

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OPTIMIZING VIRTUAL CHANNEL SELECTION

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Several studies reported that a number of subjects can perceive distinct pitches between pairs of adjacent electrodes via simultaneous delivery of current to pairs of electrodes. This outcome is encouraging as this method provides the means for potentially increasing the number of channels available to the implant users, beyond the number of electrode contacts. Identifying the number of perceived intermediate pitches or virtual channels, however, is only the first step. Further research is needed before implementing virtual channels in current implant processors.

For one, given processor constraints (e.g., power consumption, stimulation rate, etc), we need to know the minimal number of virtual channels needed to improve speech understanding. We would also like to know how to best select and place the virtual channels along the electrode array. The answers to these questions can not be easily obtained with cochlear implant listeners due to the large number of confounding factors that might influence the outcome.

We can however address the above questions using cochlear implant simulations and normal hearing (NH) listeners. In the reference condition, IEEE sentences were synthesized using 4 channels and presented to NH listeners for identification. Virtual channels were implemented by the addition of an extra sine wave corresponding to the frequency (place) of the virtual electrode. To investigate the effect of spectral resolution (between electrodes) we varied the number of virtual channels from 1 to 4. The virtual channels were either fixed in frequency or selected based on the maximum envelope amplitude. The above conditions were applied independently to three different frequency regions: low, mid and high frequency. Results indicated that the place of stimulation (i.e., the frequency region) had a significant effect on word recognition. The spectral resolution (number of virtual channels) had a smaller effect on speech understanding. Adding virtual channels in the low frequency region yielded no significant benefit on word recognition. Significantly higher recognition scores were obtained when virtual channels were introduced in the mid-frequency region. In one condition, adding one additional virtual channel in the mid-frequencies produced recognition performance equivalent to that of 8 channels.

The present results suggest that having access to a small number of virtual channels can bring significant benefits to speech understanding. More specifically, the addition of 1-2 virtual channels if placed and selected appropriately can potentially *double* the number of effective channels of frequency information transmitted by current cochlear implants.

Supported by NIH-NIDCD.

MONDAY, POSTER 14

CURRENT STEERING AND SPECTRAL CHANNELS IN HiRESOLUTION BIONIC EAR USERS: COCHLEAR-IMPLANT PLACE/PITCH PERCEPTION

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This multi-center clinical investigation (13 study sites) is determining the number of spectral channels (or different pitches) that can be resolved by postlinguistically deafened adults who use the HiResolution Bionic Ear. The number of spectral channels is defined as the number of distinct pitches that can be heard as current is delivered to distinct locations along the cochlea. In the CII and HiRes 90K implants, the number of sites of stimulation can be increased beyond the number of electrode contacts. Through simultaneous delivery of current to pairs of adjacent electrodes, stimulation can be "steered" to sites between the contacts by varying the proportion of current delivered to each electrode of the pair.

Subjects are CII or HiRes 90K cochlear-implant users. After loudness balancing and pitch ranking electrode pairs (2-3, 8-9, 13-14), a 2AFC paradigm is used where subjects identify the tone with the higher pitch while current is varied proportionally between electrodes in each pair. Data from 65 implanted ears indicate that the number of spectral channels that can be distinguished is, on average, 4.5 for the basal electrode pair, 7.1 for the mid-array electrode pair, and 5.9 for the apical electrode pair. Assuming that the numbers of spectral channels for these three electrode pairs are representative of the entire array, the potential number of spectral channels overall can be calculated. For subjects in the study as of April 2005, the potential number of channels ranges from 7 to 451.

There is a significant relationship between sentence perception in noise and word recognition, and the number of potential spectral channels in these subjects. Individuals who perceive high numbers of spectral channels (>200) always have high speech-perception scores. Subjects with fewer numbers of spectral channels exhibit a range of scores. Nonetheless, subjects with fewer spectral channels who score above 30-40% on speech-in-noise tests must be able to use the spectral information provided by the current implementation of HiRes. Therefore, enhancing spectral resolution may provide even better speech perception for those listeners, especially in noise. Moreover, subjects with poor speech scores and few spectral channels also should benefit from current steering because of the ability to direct stimulation toward areas of greater neural survival. There do not appear to be significant relationships among the potential total number of spectral channels and demographic factors such as age at implant, duration of hearing loss, and duration of implant use.

These results indicate that enhanced spectral resolution can be created using current steering. Current steering will be incorporated into future HiRes sound-processing algorithms in order to provide higher fidelity frequency resolution to Bionic Ear users.

ENCODING ADDITIONAL FREQUENCY INFORMATION VIA VARIABLE PULSE RATE FOR IMPROVED SPEECH UNDERSTANDING IN COCHLEAR IMPLANT SUBJECTS

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In a normally functioning auditory system, frequency information is encoded by the place and the rate of stimulation within the cochlea. In contrast, current cochlear implant signal processors use a single pulse rate to modulate the envelope information. This technique encodes frequency using only the place information for a limited number of frequency bands. Although this strategy often provides sufficient speech recognition in quiet environments, speech recognition performance degrades in noisy environments at a greater rate with cochlear implant subjects than with normal-hearing subjects. Providing additional frequency coding in terms of pulse rates may increase the robustness of speech recognition for implant subjects.

It is well known that varying the pulse rate in electrical stimulation changes the perceived pitch of a signal. With an aim towards mimicking the normal-hearing auditory system, while still working within the limitations of a cochlear implant system, we propose to vary the pulse rates applied to an electrode. This approach is motivated by the FAME algorithm proposed by Nie et al. (2005) that encodes the slowly varying frequency modulated signal along with the envelope. Our approach differs in that we present one of a discrete set of pulse rates in each channel as opposed to the continuum of rates used by Nie et al. (2005). In our work with acoustic models, we have evaluated this approach by studying speech recognition performance with 2, 4, and 8 simulated pulse rates per analysis band as a function of noise level. Our results have shown that performance increases as the number of carrier frequencies increases. Also, we find that increasing the number of carrier frequencies better represents the speech in the spectral domain with as few as 2 simulated pulse rates.

This initial study assumed that each channel provides a discrete set of discriminable pulse rates. However, some channels may suffer from poor pulse rate resolution, leading to the chosen pulse rates being indiscriminable. A follow-on study investigated whether, under these circumstances, the advantage of having multiple pulse rates per channel still exists. To investigate the impact of indiscriminable pulse rates within a channel, we create four new models based on the previous model with 2 pulse rates per channel. In each of these new models, low, mid-low, mid-high, or high frequency analysis bands use a single simulated pulse rate to modulate the envelope, while other bands continue to have 2 simulated pulse rates. An experiment with normal-hearing subjects has been performed measuring speech recognition using these new models at different noise levels. Our results indicate that the speech recognition performance degrades the most when the additional information in the mid-frequencies are missing, suggesting that a multi-rate speech processing strategy for cochlear implants should consider the psychophysical measures associated with each electrode channel.

MONDAY, POSTER 16

AUDITORY GROUPING ON THE BASIS OF SPATIAL CHANNELS BY IMPLANT LISTENERS

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Cochlear implant listeners often demonstrate good speech understanding ability with only 8 channels when using a CIS-like strategy. They seem to be able to extract speech information from a signal with coarse spectral representation (or to restore the information through a perceptual re-organization of a coarse signal). The ability is significantly compromised if background noise is present, indicating that the re-organization of information is effectively impeded with noise. We wondered whether this perceptual restoration of information would be affected if the noise were presented in channels spatially different from speech channels; for example, if speech were presented in a 10-channel CIS strategy in odd-numbered channels and noise was presented in even-numbered channels. If auditory grouping for implant listening takes place in a similar manner to acoustic listening, the existence of noise added to different channels to speech might not highly affect speech understanding, as a human listener is well capable of separating two streams of signal presented in different frequency bands. It is difficult to expect, however, that auditory grouping occurs in electrical hearing as readily due to channel interactions. Two different stimulation channels may overlap neural population, and that would interfere with each neural response, resulting in unexpected response patterns. Thus, the noise channels adjacent to speech channels would be as effective a masker as it exists in the same channels, making auditory grouping more challenging than acoustic hearing.

Consonant identification was measured to address the above question. Speech and speech-shaped noise were processed with 10-channel CIS and speech and noise channels were spatially alternated: even- and odd-numbered channels, as described above (alternating condition; AC). For a reference condition, speech and noise were added and processed with 10-channel CIS and presented at odd-numbered channels (mixed condition; MC). It should be noted that for a given signal-to-noise (SNR) ratio, the masker of MC could be more effective because separate current field is generated by noise and is prone to interact with existing speech channels.

Results measured with four Nucleus 24 patients to date show that for a poor SNR (0 dB in our experiment) the identification scores with MC are significantly higher, implying that implant listeners are capable of grouping auditory objects successfully on the basis of spatial channels, overcoming the adversity from channel interactions. The results are particularly striking because the effect is observed at a poor SNR, where the current field generated from noise could overwhelmingly mask the current field from speech channels.

MONDAY, POSTER 17

FINE STRUCTURE AND GATING INTERAURAL TIME DIFFERENCES IN ELECTRICAL AND ACOUSTICAL HEARING: EFFECT OF STIMULUS DURATION

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The relative potencies of ongoing and gating interaural time difference (ITD) cues in left/right discrimination were studied in electrical and normal hearing. Previous studies using unmodulated pulse trains do not reveal to what extent cochlear implant (CI) listeners extract ITD information from the ongoing signal (referred to as fine structure) and the onset and offset (gating portions).

Lateralization discrimination thresholds (JNDs) were measured for three CI and five NH listeners using constant-amplitude pulse trains with various pulse rates. The first and last pulse represented, per definition, the gating portions, and the remaining pulses represented the fine structure. In different experimental conditions, ITD was carried either in the onset, offset, both onset and offset (gating ITD), fine structure, or in the entire pulse train. In experiment I, four pulses were used at all pulse rates (100, 200, 400, and 800 pulses per second, pps), allowing to hold the amplitude constant. For the NH listeners and one CI listener, the JNDs for fine structure ITD increased, for gating ITD remained constant, and for onset ITD decreased with growing pulse rate. For the other two CI listeners, the overall trends were similar, except that high sensitivity to fine structure ITD was observed even at 800pps. Experiment II verified that none of the listeners made use of monaural cues for any of the stimulus conditions tested in experiment I. Experiment III (one CI listener and four NH listeners participating in experiments I and II) used stimuli with constant durations across all pulse rates of either 40ms or 300ms. Constant amplitudes across both durations at each pulse rate (100, 400, and 800pps) were applied.

For the 40 ms duration and at 400pps, the sensitivity to fine structure ITD increased and for gating ITD decreased, relative to the stimuli used in experiment I, indicating temporal integration of ongoing fine structure ITD information (both CI and NHs). At 800pps, an overall decrease in performance was observed, most likely due to the reduced signal amplitude relative to the four-pulse condition, as a consequence of the requirement to preserve constant energy and loudness.

For the 300ms duration, sensitivity to fine structure ITD increased, relative to the 40ms condition, at 100pps (CI listener) and at pulse rates up to 400pps (NH listeners). No significant change in performance was observed at 800pps.

Overall, the data indicate that CI listeners can extract ITD information from the temporal fine structure. For long signals (300ms), fine structure ITD cues dominate up to 400pps and gating ITD cues dominate at the highest pulse rate (800pps), consistent with the “onset dominance” effect reported in the NH literature [e.g. Hafter and Dye, 1983, JASA 73].

Supported by Med-El Corporation

MONDAY, POSTER 18

USING AMPLITUDE MODULATION TO DELIVER FINE TEMPORAL INFORMATION

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Despite excellent speech perception in quiet situations, cochlear implant users have great difficulty with both understanding of speech in background noise and perceiving music. Current commercial speech processing strategies provide little fine temporal information to the listener. If a method of improving the delivery of fine temporal information to the listener is developed, then this information will presumably be useful to improving an implantee's ability to understand speech in noise as well their pitch perception. We propose that amplitude modulation of the outputs of speech processing strategies can be used to convey fine temporal information. In commercial strategies, there is some modulation information but it is often presented out of phase across channels. This is likely to explain why it has not been a useful cue for implantees.

Two experiments examine the ability of implantees to either detect an amplitude modulation or discriminate a rate of amplitude modulation from higher rates. In the modulation detection experiment, stimuli consisted of stimulation on 5 apical to medial electrodes. Subjects were required to determine which of 4 sounds was different. The target stimulus was different in that it had amplitude modulations at 100Hz on 1, 3, or 5 of the electrodes. An adaptive 4IFC procedure was used to estimate of the minimal detectable modulation depth for each stimulus. In the modulation rate discrimination experiment, a similar procedure was followed. The reference stimuli had amplitude modulation at 100Hz on 1, 3, or 5 of the electrodes. The target stimulus had amplitude modulation on the same electrodes as the reference but at higher modulation rate. The procedure was repeated until an estimate of the rate just detectably different from 100Hz was measured.

Results of both experiments suggest that a subject's ability to detect and discriminate in-phase amplitude modulation is better when the modulation presented on multiple electrodes. However, no improvements in performance were measured when the number of electrodes with amplitude modulations was increased from 3 to 5 electrodes. We can conclude that in-phase amplitude modulation on multiple electrodes could be a useful method of delivering fine temporal information. Additionally, it seems that it is not important to present these modulations on all electrodes to get the performance improvement.

Currently, we are testing the hypothesis that common amplitude modulation on electrodes conveying formant information will improve vowel identification. Pilot data will be presented.

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MONDAY, POSTER 19

FREQUENCY MAP FOR THE HUMAN COCHLEAR SPIRAL GANGLION

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Greenwood's frequency-position function (Greenwood, 1990, JASA 87) for the organ of Corti (OC) is widely used to estimate represented frequencies for cochlear implant (CI) stimulation sites both in temporal bone studies and in imaging studies of living CI recipients. However, many contemporary CIs position the stimulating electrodes near the modiolus to target the spiral ganglion (SG), and the SG frequency map may be significantly different from that of the OC, especially in the apical cochlea.

The main goal of this study was to develop a more accurate method for estimating represented frequencies in the human SG that can be applied in both temporal bone and imaging studies. Further, since OC length is a required metric for application of the frequency-position function, a specific goal was to develop a method for estimating OC length that can be applied in both temporal bone and imaging studies. Cadaver cochleae (n=9) were fixed <24 hours postmortem, stained with osmium tetroxide, microdissected, decalcified briefly, embedded in epoxy resin and then examined in surface preparations. In digital images, the OC and SG were measured, and the radial nerve fiber trajectories were traced to define a series of frequency-matched coordinates along the two structures. These data showed that whereas the distance along the OC that corresponds to a critical bandwidth is constant throughout the cochlea, the critical bandwidth distance in the SG changes significantly along the spiral.

The mean OC length was 33.13 mm. In contrast, the mean SG length (at the center of Rosenthal's canal) was only 13.69 mm. OC length was significantly correlated with SG length ($r^2=0.76$; $p<0.005$). The mean length of the inner modiolar wall adjacent to the SG (closest possible position of a CI electrode) was 15.49 mm. Frequency-matched points along the SG and OC, expressed as percent of length, showed a highly consistent intersubject correlation that was best fit by a cubic function. This function allows derivation of SG frequency by substitution into Greenwood's equation. Further, OC and SG length each showed significant correlation ($r^2=0.78$ and 0.86 respectively; $p<0.005$) with cochlear size (average of the maximum diameter of the basal coil and the orthogonal diameter). This finding should enable us to estimate OC length in imaging studies (by measuring cochlear diameter) and thereby to infer represented frequency in living subjects.

The positions of individual CI electrodes in the cochlea can be correlated with psychophysical measures such as pitch perception, threshold and dynamic range. More accurate frequency maps for the OC and SG should permit better matching the filter band for each CI processor channel to its stimulation site, potentially increasing clinical benefits (e.g., especially for music appreciation).

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MONDAY, POSTER 20

MUSIC PERCEPTION OF COCHLEAR IMPLANT USERS COMPARED TO HEARING AID USERS

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Most existing studies of the music perception abilities of cochlear implant (CI) users have compared them to normally-hearing listeners. No research has yet been published to investigate the speculation that CI users perform differently to hearing aid (HA) users. This study aimed to compare the music perception skills of CI users to HA users who meet the cochlear implantation criteria.

15 *Nucleus* CI users were compared to 15 HA users on a music test battery. All subjects were postlingually deafened adults with at least 1 year's experience with their device. Stimuli were presented directly to the device, bypassing the microphone, at comfortable presentation levels.

The music test battery comprised: 1) Rhythm test - comparing 48 rhythm pairs as same or different; 2) Pitch test - pitch ranking one-octave, half-octave, and quarter-octave sung vowel intervals with fundamental frequencies ranging from 98 to 740 Hz; 3) Instrument test – closed-set identification of 12 single musical instruments, 12 solo instruments accompanied by an orchestra, and 12 music ensembles; 4) Melody test – closed-set identification of 10 familiar melodies, with intact rhythm and pitch cues. Quality rating scores were also obtained for the stimuli in the instrument test.

Results indicated that there was no significant difference between the groups on the rhythm test. In the pitch-ranking test, the HA subjects were significantly better than the CI subjects for all 3 interval sizes (2-way ANOVA: $p < 0.001$ for group and interval size). The HA subjects were also significantly better on the melody recognition test (t-test; $p < 0.001$). For the instrument test, a 2-way ANOVA showed no significant difference between the identification scores of the two groups. However, there was a difference between performance across the 3 subtests ($p < 0.001$), with the scores for the single instrument subtest being higher than for the other 2 subtests. This is indicative of subjects finding instrument identification more difficult with increased stimuli complexity. Although there was no significant difference between CI and HA users in their quality ratings of the different stimuli in the instrument test, it was interesting to observe that mean CI ratings were higher than HA ratings in all 3 subtests. In summary, HA users performed equal to, or better than, CI users on these music perception tasks.

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MONDAY, POSTER 21

EFFECTS OF DELAYING THE CHARGE-RECOVERY PHASE OF A PSEUDO-MONOPHASIC PULSE ON THRESHOLD AND COMFORT LEVELS IN COCHLEAR IMPLANTS

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Existing cochlear implant devices stimulate the auditory nerve with trains of symmetric biphasic pulses. Recent behavioral data have shown that modifying the pulse shape while maintaining charge balance, may be beneficial in terms of reducing power consumption, increasing dynamic range, and/or improving spatial selectivity. We measured the sensitivity of five cochlear implantees to a novel "delayed pseudo-monophasic" stimulus consisting of an anodic phase followed by a cathodic phase (8 times longer and smaller than the anodic), separated by an interphase gap. The length of the interphase gap was set so that two adjacent phases of opposite polarity were as far as possible from each other. Monopolar coupling was used in the three experiments listed below.

In Experiment 1 threshold and comfort levels were measured for a 100-pps delayed pseudo-monophasic stimulus as well as for other 100-pps pulse-shapes studied previously [1]. The delayed pseudo-monophasic stimulus produced thresholds that were more than 10 dB lower than those obtained with symmetric biphasic pulses. Importantly, this reduction was much greater than the 2-3 dB drop obtained with "standard" pseudo-monophasic pulses.

Experiment 2 compared threshold and comfort levels for a standard biphasic and a delayed pseudo-monophasic stimuli at different rates and phase widths. This was done to study the possible benefits of modifying the pulse-shape for implementation in a speech processor. The threshold drop was still greater than 4 dB using an 892-pps rate and an 11 µs phase width.

Experiment 3 investigated which of the two parts of the delayed pseudo-monophasic pulse was most effective. In other words, it was examined whether neural discharges occurred during the big/short phase, the long/low one or both. The results suggested that both phases contributed to threshold values, but that stimulation at a comfort level was dominated by the big/short phase.

This study showed major threshold reductions using a delayed pseudo-monophasic stimulus compared to the widely used biphasic one. These reductions, which were predicted by the linear filter model described in [2], might lead to considerable power savings.

[1] van Wieringen et al. "Effects of waveform shape on human sensitivity to electrical stimulation of the inner ear". Hearing Research 200 (2005) 73-86.

[2] Carlyon et al. "Effect of inter-phase gap on the sensitivity of cochlear implant users to electrical stimulation". Hearing Research, in press.

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THE LOUDNESS OF AMPLITUDE MODULATED STIMULI

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A recent loudness model by McKay et al. [2003, J Acoust Soc Am **113**: 2054-2063] provided a practical method of predicting the relative loudness of arbitrary current pulse trains. In brief, the method involves applying a current-to-loudness function for each pulse, and adding up the loudness contributions within a temporal integration window of several milliseconds. The simple loudness model has been validated with arbitrary steady-state electrical stimuli. The method has also been used to implement a processing strategy (SpeL) in which the acoustic specific loudness of the incoming stimulus (the loudness contributions from different places along the cochlea) is mapped onto the electrical specific loudness produced by pulses on different electrodes. Subjects using this strategy perceived the loudness of sounds of differing bandwidth more similarly to normally-hearing subjects, compared to when they were using SPEAK or ACE.

The aim of the present study was to test whether the simple loudness model was also successful in predicting the loudness of amplitude-modulated pulse trains. Previous studies measuring the loudness of amplitude modulated pulse trains have suggested that there was a level-dependency, with the peak level determining the loudness at high levels in the dynamic range, and the RMS current determining the loudness near threshold. The loudness model predicts a similar level dependency, due to the shape of the current-to-loudness function. However, the model predicts that the level dependency is based on absolute currents, rather than on level within the dynamic range. Six subjects who were users of the CI24M or CI24R implants participated in the study. The amplitude modulated stimuli had three different carrier pulse rates (500, 1000, and 8000 Hz), two different modulation rates (250 and 500 Hz), four modulation depths (5, 10, 15, & 20 current steps), and at three levels within the dynamic range (threshold, 60%DR and 90%DR). Subjects loudness balanced the stimuli to fixed-current pulse trains.

The results were consistent with the predictions of the loudness model. That is, at low current levels (near threshold, and all levels of the high-carrier-rate stimuli) the current of the balanced fixed-current pulse train was close to the RMS current of the modulated stimuli. As the current level increased (i.e. as rate was decreased, or the level in the dynamic range was increased for lower carrier rates) the current of the balanced fixed-current pulse train moved from the RMS level towards the peak level. The adjustment required to loudness balance the modulated stimuli was dependent on the absolute current level, rather than the level within the dynamic range, in keeping with the predictions of the loudness model.

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MODELING SUBJECT RESPONSES IN A REPRODUCIBLE NOISE MASKING TASK: PRELIMINARY FINDINGS WITH COCHLEAR IMPLANT USERS

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Performance by cochlear implant users on difficult listening tasks has improved greatly over the past 20 years with recent advances in processing speed and stimulation strategies. Improving spectral resolution, better understanding channel interaction, and enhancing temporal fine structure are areas of rapid development. Much of this growth has evolved from an increased understanding of the perceptual capabilities of CI users on molar psychophysical tasks. In this study, we utilize a molecular psychophysical approach to examine detection of a tone in a reproducible noise masking task by CI users.

Jeffress (1967, 1968) postulated that signal detection in a background noise could be explained by an energy detection model (EAM). A two-parameter, single-channel EAM (Gilkey & Robinson, 1986) consisting of a bandpass filter (30-70 Hz-wide) centered at the signal frequency (500 Hz), a half-wave rectifier, and a leaky integrator (40-125 ms decay constant) was used to predict subject responses on a diotic tone-in-noise yes-no task with 25 reproducible noise samples (overall d' = 1.0). For three listeners with normal hearing, the EAM explained approximately 60% of the variance in their individual responses. A multiple-channel EAM consisting of a weighted sum of seven spectral channels explained an additional 10% of the variance, suggesting that listeners with normal hearing might utilize information in bands away from the signal frequency.

To date, we have collected data from a single CI user (Nucleus-22, 3G, SPEAK). The CI user required an 18-dB increase in the signal level to achieve a similar overall performance level (d' = 1.0) as the listeners with normal hearing. A modified single-channel EAM was implemented by utilizing SCILAB (Lai et al., 2003) to obtain the subject's electrodograms for the various stimuli. The speech processor determined the bandpass filter width (160 Hz), and for the channel containing the signal frequency, the electrodograms from SCILAB were passed through a leaky integrator. The time constant of the integrator was varied as the free parameter of the model. The EAM explained 60% of the variance in the subject's responses. However, the time constants were considerably longer than those for the listeners with normal hearing, and a wide range of time constants fit the data well. When the responses to the 25 different noise samples were plotted in ROC space, the distribution for the CI user was again vastly different than the distribution for the listeners with normal hearing. Furthermore, a multiple-channel model did not improve predicted variance suggesting that across-channel listening for CI users, especially through older processors, does not appear to be helpful for tone-in-noise detection. Predictions with the latest speech processors and coding strategies will be discussed.

ENCODING FINE TIME STRUCTURE WITH CHANNEL SPECIFIC SAMPLING SEQUENCES

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In normal hearing, action potentials of auditory nerve fibers are phase-locked to audio input signals up to frequencies around 5 kHz. Thus, the fine time structure of the audio signal is directly reflected in the neural activation pattern and can be utilized by the central structures to detect the stimulus frequency (i.e., the so-called "temporal pitch mechanism"). In cochlear implant users, temporal pitch perception seems to be restricted to frequencies below a “pitch saturation limit” of about 300 Hz in most subjects, but as high as 1000 Hz in some instances.

Speech processors for multichannel cochlear implants use a bank of bandpass filters to split up the incoming signal frequency range. The continuous interleaved sampling (CIS) stimulation strategy utilizes only the envelope of the bandpass output signals to determine the stimulation amplitude for each channel. Information about the fine time structure is discarded and thus not represented in the stimulation pattern. CIS has been highly successful in restoring speech perception for listeners of western languages. In these languages, a remarkable amount of information is conveyed in the speech envelope alone. However, for music or tonal languages, the fine time structure of the signal plays an important role. A presentation of fine structure information in a processor in a way that it can be perceived by implant patients is likely to provide better melody recognition and speech reception for tonal languages.

The channel specific sampling sequence (CSSS) strategy was designed to represent fine time information up to about 1 kHz. For higher frequencies, standard CIS is used. For each band pass filter in the CSSS frequency range, a burst of high-rate stimulation pulses with a programmable amplitude profile can be defined. For stimulation, the onsets of the sampling sequences are derived from the zero crossings, and the amplitude weights from the instantaneous envelopes of the filter output signals. Thus, in a CSSS channel both the fine time and the envelope information are represented.

In a first evaluation of the CSSS strategy, the following experiments have been conducted:

(1) Single channel tests: The just noticeable difference (JND) in pitch was measured at different carrier rates and CSSS sequence repetition rates in an adaptive interval forced choice procedure. The pitch percept for CSSS sequences at repetition rates from 100 Hz to 1 kHz was evaluated in a pitch scaling experiment.

(2) Processor comparison: A CSSS processor was compared to a standard CIS processor in another pitch scaling task. Pure tones (sine wave) and complex tones (musical instruments) from 110Hz up to 1244Hz (in three semi-tone intervals) were presented. A test procedure where stimulus frequency and the two different processing strategies were fully randomized was adopted. First results show a benefit for the CSSS strategy especially for low frequencies.

FREQUENCY DISCRIMINATION WITH PARALLEL AND SEQUENTIAL STIMULATION

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In cochlear implants the spectral information is analysed by a multi-channel filter bank. In the Med-El cochlear implant the filter band outputs are then transmitted to twelve independent channels located at different sites inside the cochlear. That means that the just noticeable frequency difference is limited by the number of filter bands. For the perception of music, tonal languages and speech in noisy background it is necessary to provide a transmission of the fine spectral information. However, the filter in the signal processing of the Med-El implant overlap in a way that the amplitudes of the electric pulses for two neighboured electrodes are weighted dependent on the position of the analysed frequency between the according filter bands.

In an adaptive two alternative forced-choice procedure, the just noticeable frequency difference for sinusoids with frequencies near the cut-off frequencies of two neighboured filter bands was measured. Tests were performed for apical, middle and basal electrode pairs. Testing was done using the CIS+ signal processing strategy whereby the two electrode sites were stimulated sequentially with the normal CIS+ stimulation rate of 1515 pps. It was also performed using parallel stimulation of the two electrode sites using the same stimulation rate.

The results show that the overlapping filter bands result in a weighting of stimulation amplitudes which even allows discrimination of sinusoids within one filter band. This works not only for parallel but also for sequential stimulation as is currently implemented in the Med-El cochlear implant system.

EFFECTS OF CARRIER PULSE RATE ON MODULATION DETECTION IN SUBJECTS WITH COCHLEAR IMPLANTS

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Most modern cochlear-implant speech-processors function by filtering the auditory stimulus into discrete bands of frequencies, extracting the envelopes of the filtered signals, and using these envelopes to amplitude modulate trains of interleaved pulses. In the electrical signal, the carrier pulse rate limits the temporal detail with which the modulation waveform is sampled. Higher carrier pulse rates allow more accurate representation of high-frequency components in the modulation waveform. For this reason, it has been assumed that higher carrier pulse rates will result in better information transmission. However, in the case of the prosthesis, neural response features such as adaptation and refractory properties must be taken into account. In studies of modulation encoding in guinea pig auditory cortex, Middlebrooks (ARO 2005 and CIAP 2005) found that the representation of the modulation waveform in the activity of cortical neurons activated by cochlear implant stimulation was better when low-rate (254 pps) carriers were used than when high-rate (4,069 pps) carriers were used.

We studied detection of phase-duration modulation in human subjects as a function of level for two carrier rates: 250 pps and 4 kpps. Subjects were adults with Nucleus 24M or 24R(CS) implants. Phase duration of symmetric biphasic pulses was modulated sinusoidally at 40 Hz with a starting phase duration of 50 μsec. A two-interval forced choice procedure with flanking cues was used with a two-down one-up tracking procedure. Modulation detection thresholds were determined for monopolar stimulation at one to three sites (site 11 or sites 4, 11 and 18) and 5 stimulus levels (10, 30, 50, 70 and 90% of the dynamic range in dB). Modulation detection thresholds decreased (improved) as a function of level, but the rate and pattern of increase varied from subject to subject as previously observed by Fu (NeuroReport, 2002). Dynamic ranges were consistently smaller for 250 pps carriers. At a given sensation level, modulation-detection thresholds were lower for 250 pps carriers than for 4 kpps carriers in most cases. At levels expressed as percent of dynamic range in dB or linear μAmps, the differences in functions for the two carrier rates varied as a function of level, with some subjects showing differences in modulation-detection thresholds at low levels, some at middle levels, some at high levels, and some at all levels within the dynamic range. Mean modulation-detection thresholds for all 5 levels were smaller (more sensitive) for the 250-pps-carrier signals in about 70% of the conditions tested. These data suggest a distinct disadvantage to using carrier pulse rates as high as 4 kpps.

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SPECTRAL MODULATION TRANSFER FUNCTION IN COCHLEAR IMPLANT LISTENERS

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One of the factors limiting speech understanding in cochlear implant listeners is their ability to perceive complex spectral envelopes. Spectral envelope perception can be characterized by measuring the spectral modulation transfer function (SMTF), which is the minimal spectral contrast required to detect sinudoidal spectral modulation (measured in cycles/octave) as a function of spectral modulation frequency. In this study, SMTFs were obtained in normal hearing and cochlear implant listeners at spectral modulation frequencies of 0.25, 0.5, 1, and 2 cycles/octave and compared with their vowel and consonant recognition scores. As compared to the normal hearing listeners, SMTFs obtained for the cochlear implant listeners indicated a wide range of variability. The cochlear implant listeners needed greater spectral contrast to detect high spectral modulation frequencies than the low modulation frequencies. These findings are consistent with the limited spectral resolution commonly reported in cochlear implant listeners. Modulation detection thresholds at 0.25 and 0.5 cyc/oct were highly correlated with vowel and consonant recognition scores ($r = 0.76$ and $r = 0.9$, respectively). Thus the SMTF can be used to relate spectral envelope perception to vowel and consonant recognition in cochlear implant listeners.

THE RELATIVE LOUDNESS OF ONE, TWO AND THREE CHANNEL STIMULI

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In normal hearing listeners, the loudness of a two-tone complex is known to increase with frequency separation between stimuli (loudness summation). Relatively little is known about loudness summation effects in cochlear implant listeners other than the common observation that the loudness of multi-channel stimuli is greater than that of a single-channel stimulus.

Previous investigations have found two additional factors, pulse rate and refractoriness, to also contribute to the overall perceived loudness when interleaved pulse trains are use in a two-channel paradigm. (McKay, C.M., Remine, M.D., and McDermott, H.J., J. Acoust. Soc. Am. 2001, 110(3): 1514-1524). The aim of this study is to quantify multi-channel loudness in CI listeners in greater depth, and further establish how these three factors interact to contribute to the overall loudness.

Ongoing experiments in our lab are exploring this issue using two- and three-channel stimuli in Nucleus-22 and Nucleus-24 cochlear implant listeners. A double-staircase adaptive method is used for all loudness-balancing procedures. First, all single-channel stimuli are loudness- balanced to the 50% dynamic range point of a reference channel. Next, the loudness of a multi-channel reference stimulus containing two or three interleaved pulse trains, R1, R2 and R3, is compared with the loudness of a fixed single-channel stimulus. In the two-channel paradigm R1 remains at a constant apical, basal or medial position while R2 varies from most basal to most apical. For example, R1 remains constant at electrode pair (2,5) (basal) while R2 is varied in location from (2,5) (basal) to (18, 21) (apical). In the three-channel paradigm R1 and R2 are fixed in location and R3 is varied. For example, R1 and R2 remain constant at electrode pairs (2,5) and (10,13), respectively, while R3 is varied in location from (2,5) to (18,21). The listener adjusts the level of the experimental single-channel stimulus until its loudness matches the loudness of the multi-channel complex.

Preliminary results obtained with a single CI listener suggest that, other than the three factors listed above, the relative pitches of the individual channels also determines the overall loudness. When the individual channels are widely spaced, the two pitches may be so different that the listener is able to perceptually segregate them: the loudness judgment may then be based largely on the more dominant of the two channels. Implications for perceived loudness of multi-channel stimuli for cochlear implant listeners in everyday listening situations will be discussed.

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SPATIAL DISTRIBUTION OF EFFECTS OF SINGLE PULSE STIMULI: SPREAD OF EXCITATION AND FORWARD MASKING

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Spatial effects of a bipolar, biphasic current pulse were evaluated by determining the spatial distribution of its forward masking of a probe pulse as a function of probe location, and the spatial distribution of equivalent excitation at each probe location that was necessary to produce the same forward masking. Spatial profiles were constructed for the masked probe thresholds; for the equivalent excitation; and for the spatial distribution of probe threshold shifts. Profiles were measured at several masker levels spanning the dynamic range at the central masker electrode location. Data were obtained from six Nucleus 22 or 24 implant users. Maskers and probes were presented using a bipolar +1 mode, with maskers centrally located at electrodes 10,12; and probes either at location 10,12 or various basal and apical locations. Masker and probe stimuli consisted of single 200-µs/phase biphasic current pulses, and the probe was presented at a short time delay of 2 msec from the masker in order to emphasize peripheral effects presumably due to neural refractoriness. All stimuli were specified in terms of current, or change in current, in microamps.

Masked threshold profiles and equivalent excitation profiles generally had similar shapes in a given subject. The effects of the masker on the probe pulse typically decayed with distance from the masker with a maximum effect at or near the masker location. Three of the subjects revealed spatial non-monotonicities and greater masking in the basal direction of masking spread, while two others showed greater masking in the apical direction. The decay was typically approximated better in the apical rather than the basal direction using an exponential function, suggesting a passive decay of electrical activity and uniform electrical length constant in this direction. The relationship between masker level and probe threshold was observed to be linear, and this proportionality seemed to account for the similarity between the two profiles. However, when data were replotted in terms of threshold shift significant changes in profile shape often occurred, caused by the subject-specific irregular distribution of thresholds across electrode location. Furthermore, sub-threshold effects were observed for one subject, such that a sub-threshold masker actually produced an improvement in detection of the probe. It was concluded that the various spatial profiles obtained could potentially reveal insights into different processes, such as the instantaneous physical spread of the stimulus in the equivalent excitation profiles, and temporal interactions at the neural level in the forward-masked threshold shifts. Both of these processes would be expected to play important roles in the perception of complex dynamic stimuli.

QUANTIFYING THE CO-MODULATION EFFECT IN FAST-ACTING DYNAMIC RANGE COMPRESSION WITH AN IMPLANT SIMULATION

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Using a noise-excited vocoder to simulate a cochlear implant (Shannon *et al.* 1995), Stone and Moore (2003) demonstrated that, for a mixture of speech signals, slow-acting dynamic range compression produced speech intelligibility the same as for unprocessed stimuli, but fast-acting compression degraded intelligibility. Stone and Moore (2004) demonstrated that this was at least partly due to single-channel fast-acting compression introducing "co-modulation" between the previously independent target and background signals. Having identified the effect, we aimed to quantify its existence and variation in the region between a 'slow' and a 'fast' compressor.

In experiment 1, we measured intelligibility as the speed of the multi-channel compression varied from 'slow' to 'very fast'. For both an 8- and a 12-channel simulation, intelligibility decreased as the speed of compression increased. For the 12-channel simulation, intelligibility was not degraded until modulation rates above 2 Hz were compressed. For the 8-channel simulation, the boundary was lower than 2 Hz. This appears inconsistent with the results of Drullman *et al* (1994a, 1994b), who found that there was no information in the temporal envelope of speech for envelope modulation rates of less than 2 Hz.

Experiment 2 was like experiment 1 but used higher degrees of spectral resolution, similar to those found with moderate to severe hearing impairment. The number of compression channels, between 1 and 12, was varied separately from the spectral resolution, using 12 and 18 channels. For each combination of spectral and compression channels, four different speeds of compressor were assessed. The results are plotted as a 3-dimensional surface to investigate the trade-offs possible. As the number of compression channels doubles, the compression speed needs to be slowed by a factor of about 0.67 to maintain intelligibility.

The influence of co-modulation, even for surprisingly low modulation rates, has implications for the front-end design of cochlear implants.

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MONDAY, POSTER 31

PITCH-RANKING SUNG VOWELS WITH STRATEGIES PROVIDING ADDITIONAL TEMPORAL CUES

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Five Nucleus 24 recipients pitch-ranked pairs of sung vowels with fundamental frequencies in the range 98 to 277 Hz. Performance with a base-line ACE strategy (using quadrature envelope detection) was compared to performance with three experimental strategies that were designed to provide additional temporal cues to pitch:

- half-wave rectification (HWR)
- temporal peak sampling (TPS)
- explicit F0 modulation (F0M)

The processing strategies were implemented on a PC using the Nucleus MATLAB Toolbox, and the stimuli were delivered by Nucleus Implant Communicator Stream software via the SPrint processor.

The subjects could be divided into two groups on the basis of performance. For the three poor performers, tested with six-semitone intervals:

- Pitch reversals (scores significantly lower than chance) were common. Many of these pitch reversals could be explained by examining the centroids of the electrode stimulation patterns, implying that the poor performers attended more to place cues and less to temporal cues.
- The HWR and TPS strategies provided a small improvement over ACE.
- The F0M strategy provided the best performance below 200 Hz, but performance degraded for higher frequencies.

For the two good performers, high scores were obtained both at six-semitone and one-semitone frequency intervals, and there was no significant difference between any of the strategies tested (ceiling effect). The two good performers were also tested with a modified ACE strategy that had a 10 Hz low-pass filter applied to the envelopes to deliberately suppress F0 modulation. The resulting score patterns were similar to those of the poor performers, further supporting the hypothesis that the poor performers were not making use of the temporal cues to pitch in the sung vowel task.

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MONDAY, POSTER 32

ELECTRODE INTERACTIONS IN COCHLEAR IMPLANTS

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Cochlear implant performance is at least partially limited by electrode interaction and inaccurate loudness mapping derived from single-electrode stimuli. Electrical field interaction and loudness summation are two of the greatest contributors to electrode interaction.

This study systematically evaluated electrode interaction as a function of stimulation rate and electrode separation at threshold and suprathreshold levels, with simultaneous and interleaved stimulation, and in monopolar and bipolar configurations. Five Clarion C-II cochlear implant users participated in this study. Thresholds were measured by a three-alternative forced choice (3AFC) adaptive procedure with a two-down, one-up rule. Loudness was balanced between single-electrode and dual-electrode stimulation at the comfortable level. A probe and an either in-phase or out-of-phase masker were presented to two different electrodes, at 4 masker levels (±20% and ±60% of the masker threshold) and three electrode separations (1-3, 1-9, and 1-15). The threshold difference between the probe alone and the probe plus the masker was used to quantify the degree of electrode interaction.

The results showed that monopolar stimulation always produced electrode interaction with the interaction increasing with decreasing electrode separation and increasing masker level. On the other hand, bipolar stimulation only produced electrode interaction with shortest electrode separation. Stimulation rate did not affect electrode interaction in either electrode configuration. Preliminary data showed a more complex pattern of electrode interaction at suprathreshold levels, including contributions from both electrical field interaction and loudness summation. The present data can be used to model the electrical field distribution and delineate its contribution from loudness summation. A complete electrode interaction model should be incorporated into the speech processor to improve cochlear implant performance.

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MELODY IDENTIFICATION AND CHANNEL INTERACTIONS: ACOUSTIC MODEL PREDICTIONS

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Although cochlear implants provide a high level of speech perception for some recipients, the benefit provided by the implant varies across subjects. One possible cause of this variability may be related to perceptual anomalies that can be assessed by measuring pitch structure or channel interactions. Non-monotonic pitch structures, indiscriminable electrodes, and forward masking effects when masker and probe are not the same electrode have been well-documented (e.g. Townshend et al., 1987; Zwolan et al., 1997; Shannon 1983). Some studies have linked these perceptual anomalies to speech recognition performance (e.g. Henry et al., 2000; Throckmorton and Collins, 1999). Using acoustic models, Throckmorton and Collins (2002) measured the relative effect on speech recognition of each these anomalies. Their results suggested that pitch anomalies, especially in the lower frequency region, were most detrimental to speech recognition. This is supported by studies in implant subjects (Henry et al., 2000) as well as acoustic modeling work (Shannon et al., 2001; Kasturi et al., 2002).

However, as interest increases in not only providing excellent speech recognition for implant recipients but also increasing music perception, a question arises as to whether the factors that are important to speech recognition are also the important factors for melody identification. Using an acoustic model, Kong et al. (2004) studied the effects of limited spectral information on melody identification, both with and without rhythm. Under the adverse condition of having no rhythm information, their study determined that normal-hearing subjects may need as many as 32 spectral channels to achieve the highest performance.

This study expands on the research of Kong et al. (2004), with the focus reflecting that of the Throckmorton and Collins (2002) study on speech recognition: which perceptual anomalies most affect melody identification? Using the same easily recognizable melodies as those used by Kong et al. (2004), this study uses acoustic models to compare melody identification for an unimpaired 8-channel system, indiscriminable electrodes, missing spectral information, non-monotonic pitch structure, and forward masking.

The results from these models suggest that, as with speech recognition, spectral anomalies cause the greatest degradation in melody identification. However, unlike the speech recognition results, pitch reversals had a much milder effect on melody identification than missing spectral information or indiscriminable channels. This may be indicative of the difference between music and speech, where harmonics may provide the information necessary to compensate for misplaced fundamental frequencies.

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TEMPORAL PITCH PERCEPTION IN COCHLEAR IMPLANTEES

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Temporal pitch perception was investigated in three adult Nucleus 24 cochlear implant users using amplitude modulated stimuli presented on multiple electrodes (up to 9) in quick succession. Pitch difference limens (DLs) were measured in a two alternative forced choice (2AFC) procedure which required subjects to identify which of a pair of stimuli differing in modulation frequency was higher in pitch. Place of stimulation was held constant and intensity cues to pitch were randomized by roving the stimulus level by up to 6 dB. Results showed that modulation depths of at least 10-40% of the subjects electrical dynamic range resulted in pitch DLs as low as 1 to 2 semitones (or 6 to 12 %) for modulation frequencies up to approximately 300 Hz. These results are consistent with data from previous modulation studies using single electrodes. The effect of introducing phase differences in the modulation envelopes applied to different regions within a fixed group of 9 adjacent electrodes was also examined. Phase differences of 90 or 180 degrees were found to be detrimental to the task when regions of identical phase comprised approximately 3 or less adjacent electrodes.

In most sound coding strategies currently used clinically, the depth of fundamental frequency (F0) modulation within each channel and the phase relationship between modulation in neighboring channels can vary substantially across channels and with signal thereby providing inconsistent, or poorly coded, temporal cues to pitch. To overcome these analysis/coding problems, a number of experimental processing techniques were developed (based on the above data) that provided deeper modulation cues to F0 in the stimulus envelope coincidentally in time across all activated electrodes. Pitch ranking abilities were measured in five subjects using these strategies as well as clinical strategies ACE and CIS. A 2AFC procedure was employed using sung vowel stimuli separated in F0 by half an octave. Small but significant benefits in pitch ranking for F0's less than approximately 300 Hz were found for the experimental strategies compared to ACE and CIS. In addition, results of speech recognition tests conducted in quiet and noise demonstrated equivocal performance between ACE and one of the experimental strategies. However, it was not clear from these data whether similar benefits to pitch perception could be expected in everyday situations, such as when following speaker intonation, when listening to music, or when discriminating between lexical contrasts in tonal languages. Investigations in this area are in progress.

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MONDAY, POSTER 35

USE OF PSYCHOACOUSTIC MASKING IN SOUND PROCESSING: EFFECT ON PERFORMANCE IN NOISE

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Cochlear implant users often perform very well in situations with little background noise, but their performance degrades fast with increasing noise levels. One of the possible reasons for the detrimental effect of noise is that cochlear implants provide all information to the implanted ear while some sound components are masked in the normal ear. The sound-processing methods proposed here use psychoacoustic simultaneous-masking curves to limit the information provided to the electrically stimulated auditory nerve in order to improve speech perception in noise.

Two types of psychoacoustic masking algorithms are implemented. Type I algorithms apply masking to the acoustic input and synthesize the result to obtain a sound that can be used in a free-field experiment. Algorithms with high or low spectral resolution are evaluated. Type II algorithms are a modification of the HiRes strategy and apply masking in the front-end, or before or after the filter bank. All algorithms support shifting the masked threshold to change the masking level, and are implemented in Spaide, the PC-based research platform for the CII implant.

Type I algorithms are evaluated in subjects using their normal cochlear implant settings. First, the masking level is increased until scores for CVC words without noise drop by no more than 10% relative to the condition where no masking is applied. Next, short sentences are presented in stationary speech-shaped noise to find the speech-reception threshold (SRT). Type II algorithms are evaluated with different masking levels, and CVC phoneme scores as a function of signal-to-noise ratio are determined.

The evaluation results of the type I algorithms demonstrate that applying masking can effectively decrease the SRT by 4 or more dB in all subjects. However, the decrease depends on subject, algorithm, and noise level. Evaluation of type II algorithms shows that applying masking in the front-end, similar to the type I algorithms, is not the most effective in improving speech perception in noise. Which algorithm is the most efficient depends on subject, noise level, and masking level. In case of clean speech it is always best not to apply masking. The lower the SNR the higher the performance gain can be if masking is used, up to 20% increase in phoneme score at 0 dB SNR. In general it is better to use moderate masking levels, a compromise between masking the noise and preservation of speech components.

SPATIAL EXCITATION PATTERNS OF DIFFERENT PULSE SHAPES AND ELECTRODE CONFIGURATIONS IN COCHLEAR IMPLANTEES

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Thresholds for 100-pps biphasic pulse trains can be significantly reduced by either increasing the inter-phase gap (IPG) up to 2900 µs or 4900 µs (Carlyon et al., 2005)., or by presenting the anodic and cathodic phases in an alternating pattern with 5 ms between phases ("ALT-m" condition; van Wieringen et al., 2005) Thresholds are also known to b elower for monopolar than for bipolar stimulation. The present study examined whether these threshold differences are accompanied by differences in the pattern of spatial excitation. To do this, we measured forward-masked excitation patterns for different masker types whose levels were adjusted to produce equal masking when the signal was presented on the masker channel. In all three experiments the signal was a 20-ms alternating biphasic pulse train (1000 pps) in bipolar mode. The maskers in experiment 1 were 200-pps ALT-m and 200-pps biphasic maskers pulse trains in bipolar mode. In the second experiment, the maskers were alternating-polarity biphasic pulse trains with IPGs of 8 µs or 2900 µs. In the third experiment, the inter-phase gaps of the alternating biphasic masker were 8 µs in both conditions, but the electrode configuration was either bipolar or monopolar 1+2.

Results: although the ALT-m waveform and the longer inter-phase gaps yielded significantly lower detection thresholds than the standard biphasic waveform or the shorter in-phase gaps, they did not yield sharper forward-masked excitation patterns in experiment 1 or experiment 2, respectively. In experiment 3 the monopolar electrode configuration shows broader spatial pattern for some, but not all, implantees.

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MONDAY, POSTER 37

FREQUENCY DISCRIMINATION FOR ELECTRICAL NOISE-MODULATED PULSE TRAIN STIMULI AND SINUSOIDAL STIMULI WITH HIGH-RATE CARRIERS

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Two approaches have been proposed to reduce the synchrony of the neural response to electrical stimuli in cochlear implants. One is to add noise to the pulse-train carrier, and the other is to use a high-rate pulse-train carrier. The effectiveness of additive noise or high rate carriers has been considered in modeling, physiological, and psychophysical studies. Unluckily, the results of these studies have been mixed in terms of overall effectiveness of the competing strategies. Our approach to testing the efficacy of the two approaches is to use computation models of neural responsiveness prior to psychophysical studies to pinpoint those measures which might be most demonstrative of the anticipated effects. In our previous work, we have used such models to examine the effects of adding noise to threshold, dynamic range, and intensity discrimination [Xu and Collins, 2002, 2003, 2004].

Several new speech processing techniques have also been considered recently in the literature. One intriguing approach, both because of its reported potential and because of its potential link to psychophysical data is a strategy called FAME proposed by Nie et al. [2005]. FAME is based on the hypothesis that encoding both frequency and amplitude modulations in the underlying speech signal will provide better speech understanding than clinically-used amplitude-based speech coding algorithms. In a study utilizing acoustic models, Nie et al. [2005] report that utilization of the FAME strategy can improve speech recognition by as much as 71% in normal hearing subjects listening through an acoustic model in noise. Such an approach may be of limited utility if frequency discrimination abilities vary as a function of electrode, and such limitations are not considered within the context of the coding strategy. Kucukoglu et al. [2005] demonstrated this effect using a discrete-rate version of FAME. It is possible that adding noise or using high rate stimulation could improve frequency discrimination, thus to some degree addressing this issue. In this study, we consider the effect of noise and high rate stimulation on frequency discrimination using a computational Auditory Nerve (AN) model [Bruce et al., 1999]. The effect of the stimulus level and the frequency of the stimulus on frequency discrimination are predicted via signal detection theory and the statistics of the neural response of the AN model. The theoretical predictions are compared with psychophysical studies when they are available. Theoretical prediction indicates that noise does not improve frequency discrimination. Instead, the model demonstrates better discrimination ability for sinusoidal stimuli with high-rate pulse-train carriers.

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AN ALGORITHM TO COMPENSATE FOR CHANNEL INTERACTIONS WITH SIMULTANEOUS PULSATILE STIMULATION IN COCHLEAR IMPLANTS

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In multichannel cochlear implants, simultaneous stimulation across electrodes results in a summation of current fields. This is presumed to exacerbate interactions among channels and adversely affect speech intelligibility. Sequential pulsatile stimulation paradigms, such as the continuous interleaved sampling (CIS) stimulation strategy, are specifically designed to minimize such channel interactions.

An algorithm devised to compensate for channel interactions with simultaneous pulsatile stimulation is presented. The algorithm is based on a simple model of an exponentially decaying current field in proximity of an electrode stimulated in monopolar configuration. Two decay constants, alpha and beta, model the drop-off of the intracochlear field potential towards the apex and base, respectively. For a number N of electrodes stimulated simultaneously, the algorithm yields reduced pulse amplitudes y_i such that the overlapping current fields approximate the exponentially decaying field distribution that would result in proximity of the same electrodes if they were stimulated non-simultaneously with amplitudes x_i. The channel interaction compensation (CIC) algorithm was implemented in a real-time speech processor prototype.

Preliminary results from acute speech reception tests with consonants and vowels in noise, comparing a sequential CIS to the proposed simultaneous stimulation paradigm with CIC, are presented. Findings are encouraging in that for the large majority of subjects tested, model parameters could be found such that no significant difference in the performance with sequential and simultaneous stimulation was observed. A relatively broad range of model parameters alpha and beta was observed to support robust speech reception scores, facilitating parameter selection. CIC also inhibited loudness summation effects with simultaneous pulsatile stimulation.

The application of the proposed algorithm in a cochlear implant speech processor supports higher pulse rates per channel as are feasible with sequential stimulation, while at the same time largely circumventing the problems typically associated with simultaneous stimulation. This might be of particular interest for stimulation strategies aimed at presenting temporal fine structure information with high-rate carriers, in addition to the channel envelope information presented in most of the current processor designs.

PHONETIC CONTEXT EFFECTS IN ADULTS WITH COCHLEAR IMPLANT

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The perception of speech is complicated by the fact that the acoustic realization of a phoneme varies as a function of the surrounding speech sounds (the phonetic context) and by characteristics of individual speakers. Normal hearing (NH) listeners have the ability to accommodate this acoustic variability through context-dependent perception of speech sounds. One question of practical and theoretical interest is whether listeners with cochlear implants (CI) also show context-dependent speech perception. Previous research (e.g., Lotto & Kluender, 1998) has demonstrated that many of these context effects are the result of interactions between the spectral patterns of the context and target sounds. It is likely that if the spectral representations of speech sounds are changed (as happens with cochlear implants), phonetic context effects will be affected. To test this hypothesis, we examined two types of context effects with NH and CI adult listeners. 1) Spectral-based context effects: Listeners identify a consonant or vowel that is preceded by phonemes that differ in their spectral pattern. NH listeners show a shift in responses that is predicted by the spectral relations of target and context. 2) Temporal-based context effect: Listeners identify a target consonant distinction that is temporal (e.g., /b/ vs. /w/) that is followed by a context vowel that varies in duration. NH listeners show a contrastive shift in target identification based on vowel duration.

As predicted, CI and NH listeners demonstrated a similar effect of context for only the temporal based effect. For the two spectral-based effects, CI listeners either showed no effect or one that was in the opposite direction as for NH listeners. Because these context effects are usually considered hallmarks of the ability to accommodate acoustic variability in speech, the lack of normal spectral context effects for CI listeners may have practical implications for situations in which there is substantial variability (e.g., heavily coarticulated speech or switching between multiple speakers.

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SPEECH RECOGNITION IN SENSORINEURAL HEARING LOSS AS A FUNCTION OF SPECTRAL CHANNELS: IMPLICATIONS FOR COCHLEAR IMPLANTS

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Speech recognition by normal-hearing listeners improves with increasing number of spectral channels when tested with a noiseband vocoder simulating cochlear implant processing. Speech recognition by implant users, however, saturates around eight channels and does not improve as the number of active electrodes increases (Friesen *et al.*, 2001). One of the main limiting factors is believed to be the current spread and the resulting channel interactions. In sensorineural hearing loss the auditory filters are broadened due to the lack of the cochlear nonlinearity, which might also result in reduced number of effective spectral channels (Turner *et al.*, 1999). The present study investigates whether the limitation in the spectral information transmission in implants comes partially from the physiology of the damaged cochlea combined with the crude implant processing. If some limitation occurs due to the damaged auditory system rather than purely due to the device signal processing then simply increasing the number of the channels of the device (such as by adding more electrodes physically) would not increase information transmission.

Normal-hearing and hearing impaired subjects with moderate sensorineural hearing loss participated in the study. The speech stimuli were processed with noiseband vocoder with varying number of channels and presented in background noise of varying level. The stimuli were amplified (without frequency shaping) to comfortable listening levels for hearing impaired subjects, where all speech spectrum was above the hearing threshold. To minimize the effect of audibility, NH listeners were tested at similar levels above their hearing thresholds, rather than the most comfortable level of 65 dB SPL. The normal hearing group was also tested at quiet and loud levels to observe the effects of stimulus level, and with wide vocoder filters in an attempt to simulate broad auditory filters.

Normal-hearing and hearing impaired groups performed similarly for low noise levels. In high background noise levels, however, a limitation in the performance by hearing impaired group was observed, which was similar to performance by implant listeners and which could not be explained by limited audibility only.

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THE ROLE OF FINE TEMPORAL STRUCTURE IN THE EFFECT OF TALKER VARIABILITY IN COCHLEAR IMPLANTS

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It has been well demonstrated that there is a significant effect of talker variability on speech recognition performance in normal-hearing listeners. However, in spectrally degraded speech with cochlear implants, due to the potential confusion between different talker characteristics and distinct phonemes, the underlying mechanism of talker variability effects on recognition performance is still not clear. Previous studies have demonstrated that the discrimination of talker identity may not be the main factor causing the effect of talker variability in normal-hearing subjects listening to an acoustic simulation of cochlear implant processing. Instead, the fine temporal structure may be responsible for the significant effect of talker variability. The purpose of this study is to further investigate the role of fine temporal structure in the effect of talker variability in cochlear implants.

The effect of talker variability was assessed by measuring vowel recognition performance in both single- and multi-talker (4-talker) conditions by cochlear implant users. The fine temporal structure was gradually destructed by increasing the noise level from 15 dB SNR to 5 dB SNR. Preliminary results showed that there was a significant effect of talker variability in quiet condition, consistent with the previous studies. When small amount of noise was added to speech (10-15 dB SNR), the performance difference between multi- and single-talker was still significant. Interestingly, the largest performance difference between multi- and single-talker was observed in the 10-dB SNR condition. However, when the noise level was further increased, no significant performance difference was observed in the 5-dB SNR condition. These results suggest that a 5-dB SNR or lower is needed to destruct the fine temporal structure and remove the significant effect of talker variability.

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IMPORTANCE OF TEMPORAL FLUCTUATION IN VOICE GENDER IDENTIFICATION AS A FUNCTION OF COCHLEAR PLACE

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It has been well documented that both temporal and spectral cues can contribute to voice gender identification for spectrally degraded speech with no fundamental frequency available. Previous studies have also found that periodicity cues are particularly important in identifying voice gender for cochlear implant (CI) patients due to limited spectral resolution associated with cochlear implants. The present study further investigated the importance of temporal fluctuation in voice gender identification as a function of cochlear place.

Voice gender identification was measured in both CI patients with a custom 4-channel processor and normal hearing (NH) subjects listening to a 4-channel acoustic simulation of cochlear implant processing. The periodicity cues were either preserved by using 160-Hz envelope filter or removed by a 20-Hz envelope filter. Six processors, with either periodicity cues preserved in all 4 channels, in one of 4 channels, or removed in all channels, were implemented. Speech materials consisted of 12 vowels in an h/V/d format as spoken by 5 female and 5 male talkers. Talkers were selected to span typical ranges of fundamental frequency (F0) for adult males and females. There was a 50 Hz separation between the mean F0 of the highest-pitched male voice and the lowest-pitched female voice.

Near chance level preliminary results were observed when periodicity cues were removed from all 4 channels for both NH and CI subjects. Voice gender identification increased to about 90% when the periodicity cues were preserved in all channels. When periodicity cues were preserved only in one of 4 channels, the identification score was highly dependent on the place of channels. Highest scores were observed when periodicity cues were preserved in the apical channel. The identification score gradually decreased when the channel with periodicity cues was shifted to the basal location. Acoustical analysis of speech sounds revealed that the long-term amplitudes were significantly different across the four channels. The highest amplitude was observed in the most apical channel and lowest amplitude was observed in the most basal channel. These results suggest that voice gender identification is mainly dependent on periodicity cues in the channel with the highest amplitude for spectrally degraded speech.

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TUESDAY, POSTER 5

AUDITORY-VERBAL LIST MEMORY PERFORMANCE IN CHILDREN WITH COCHLEAR IMPLANTS

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In the last five years several different centers have investigated short-term memory for auditory lists in children who use cochlear implants. Cognitive skills such as verbal short-term memory, it is theorized, may contribute to the individual differences in spoken language acquisition observed among early-implanted children. This unique clinical population may also help illuminate the role of early auditory-verbal experience in normal short-term/working memory development.

Although past research has reported memory differences between groups of CI and normal-hearing children for simple verbal materials, it is still unclear exactly why children with CIs demonstrate lower levels of performance even when the stimuli are familiar and audible. The present study takes a more detailed look at the children's behavior during list recall. We examine word recognition both with and without a memory load, and attempt to identify which steps in the list recall process are performed differently by the two groups.

A pretest procedure was used to select recordings of familiar CVC words correctly identified in isolation by each individual child. Lists composed of these recorded words were then presented, ranging in length from 3 to 6 items. In this word span task, listeners repeated each item in the list as it was presented, and then, after a brief delay, were cued to recall the list in order in its entirety.

We tabulated the number of lists correctly recalled, the length of the longest list recalled, the improvement in performance seen as a function of list repetition, and the error types observed. We also noted if word identification errors were made under memory load conditions and whether or not the child spontaneously engaged in audible auditory-verbal rehearsal.

Six children 7 to 11 years of age with CIs have participated in the study, three of whom completed the stimulus identification pretest at levels that allowed administration of the word span task. Data from additional children should be available by the conference date. Data from 30 normal-hearing children and 10 normal-hearing adults are reported for comparison.

All of implanted children tested thus far had more difficulty with the memory span task than normal-hearing children matched for age, gender, and nonverbal IQ, despite being able to correctly identify the target words both in isolation and under a memory load. Two of the three implanted children displayed spontaneous verbal rehearsal behavior for list lengths that were challenging for them. Audio recordings of rehearsal behaviors from both groups of children will be demonstrated.

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TOWARDS A CONCEPTUAL FRAMEWORK FOR UNDERSTANDING COCHLEAR IMPLANT OUTCOMES

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This presentation will use published studies and new data to support an information processing model of auditory perceptual outcomes for people using cochlear implants. The model attempts to provide an explanation of many of the relationships observed between predictor variables and speech perception scores for implant users.

Following the ideas of Blamey et al (1996), it is postulated that a series of primary factors including ganglion cell survival, central auditory processing, properties of the electro-neural interface and signal processing, are directly related to speech perception outcomes for adults using cochlear implants. Our ability to measure these primary factors is limited in most cases so we must rely on secondary characteristics that have some hypothesised relationship to the primary factors.

For instance, longer duration of deafness has been identified in many studies to have a negative effect on speech perception outcomes. Spiral ganglion cells are known to degenerate over time when deprived of input, so it is reasonable to assume that a relationship exists between duration of deafness and spiral ganglion numbers. Hence, the relationship between duration of deafness and outcomes can be used to support a link between ganglion cell numbers and outcomes.

On the other hand, duration of deafness may also be related to outcomes through the loss of processing ability within the central auditory system. So we could argue that reduced speech perception following a lengthy period of deafness is due to the loss of auditory processing ability. One easily identified primary factor is the type of signal coding scheme used for a cochlear prosthesis. Multiple studies have confirmed the improvement in outcomes that have flowed from more sophisticated signal processing.

In expanding these concepts to include children and early deafened adults there is a need to consider additional primary factors that contribute to outcomes. It is suggested that these could be characterised by a) *auditory experience prior to implantation*, b) *language learning opportunity in childhood*, and c) *general and specific cognitive skills*.

Results from existing studies of outcomes have been analysed with an attempt to quantify the relative importance of different primary factors for predicting outcomes. These analyses suggest that the relationship between speech perception outcomes and many of the primary factors is non-linear. For instance, auditory experience in the first 3 to 4 years of life may be of crucial importance with negligible effect later on. Ganglion cell survival, as suggested by Blamey et al (1996), may also have a significant effect on outcomes only if it falls below a certain level. Signal processing improvements produced rapid increases in perceptual abilities between 1985 and 1995, but only incremental changes for a proportion of implant users in the last decade. The limitations of the current electro-neural interface may be implicated in this apparent slowing in the rate of improvement of results. These ideas will be expanded upon and existing outcome data will be used to support the concepts presented.

PERCEPTUAL ADAPTATION TO A BINAURALLY-MISMATCHED FREQUENCY-TO-PLACE MAP: WHAT IS LEARNED?

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Both normal hearing listeners and implant users are able to adapt to a substantial frequency-to-place mismatch in monaurally presented speech. In optimizing the use of bilateral cochlear implants and the use of a single implant with a contralateral hearing aid, it is of interest to know whether adaptation can allow the integration of spectral cues from two ears with *different* acoustic frequency to cochlear place maps. This was examined through the use of a dichotic sine-carrier vocoder simulation of CI processing. The processing used a limited spectral resolution of 6 spectrally-adjacent bands. Numbering bands from apex to base, bands 1, 3 and 5 were presented to one ear with a 6 mm basalward shift, while bands 2, 4 and 6 were presented to the contralateral ear without a shift. Normal hearing listeners were trained for some three hours with this processor using auditory-visual and auditory-alone connected discourse tracking. Sentence intelligibility showed significant improvements after training, but did not exceed the intelligibility obtained when listeners heard only the unshifted bands 2, 4 and 6. Thus listeners appear to improve their performance with the dichotically-shifted presentation through learning to ignore the information from the ear with the frequency-to-place mismatch. This finding implies that optimal use of spectral cues in binaural speech recognition requires the use of similar frequency-to-place maps in both ears.

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INFORMATIONAL MASKING AND SPECTRAL RESOLUTION IN COCHLEAR IMPLANT USERS

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Cochlear implant users have a limited number of electrodes to code a wide range of frequencies. Due to their poor spectral resolution, it is difficult for implant users to distinguish between the target speech and a competing talker. Perceived target/masker similarity can cause greater masking even without the overlap of acoustic energy, a phenomenon known as informational masking. A second form of informational masking occurs when the masking stimulus varies from one trial to the next as opposed to being fixed across trials. Informational masking interferes with the listener's ability to form a mental auditory image that can aid in grouping distinct components of the target and masker.

Two experiments used competing sentence stimuli to investigate masker uncertainty in cochlear implant users and normal hearing listeners presented with unprocessed speech or an implant simulation. In the first experiment, the masking sentence varied from one trial to the next, keeping the competing talker constant (Linguistic Uncertainty). In the second experiment, the talker varied, keeping the competing sentence constant (Talker Uncertainty). In a control condition, the same masking sentence and talker were repeated each trial. The simulation was used to control the degree of spectral resolution available to the normal hearing listeners. Each simulation condition was presented in blocks of 20 sentence pairs processed into 8, 16, or 32 temporal envelope bands with a sinusoidal carrier set to the center frequency of each band. In addition, normal hearing listeners received a block of 20 sentences that were left unprocessed, and all stimuli were left unprocessed for the cochlear implant listeners. The competing sentence was presented at a 0 dB TMR so that gross differences in loudness would not contribute to segregation.

In the Linguistic Uncertainty experiment, both cochlear implant users and normal hearing listeners showed greater masking when the masking sentence varied across trials. In the Talker Uncertainty Experiment, greater masking was also observed with the randomized talker. These results demonstrate how ambiguous auditory information transmitted from the periphery can disrupt central information processing mechanisms. Together, masker uncertainty and perceived target/masker similarity interfere with grouping mechanisms and contribute to the poor speech recognition abilities of cochlear implant users in realistic listening environments.

TUESDAY, POSTER 9

SPEECH EVOKED CORTICAL POTENTIALS AS A FUNCTION OF COCHLEAR IMPLANT CHANNEL NUMBER

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Studies exploring the relationship between cortical auditory evoked potentials (CAEPs) and perception in cochlear implant (CI) listeners are generally based on waveform morphology, often without mention of implant parameters. This is potentially problematic because device factors could contribute to CAEP morphology. For example, the number of active channels could be a confounding variable since the number of channels affects spectral and temporal information being delivered to the CANS. As the number of CI channels decrease, frequency resolution becomes poorer in the output signal from the device. If the number of active channels in the implant evokes different neural responses, erroneous conclusions could be made about auditory system development or the auditory systems ability to represent sound.

The purpose of this study was to determine if the number of active CI channels used affects the latencies and amplitudes of CAEPs and perception. For behavioral testing, 20 presentations of 12 CVC tokens from the Hillenbrand vowel test were presented to 7 normal hearing monolingual adults. Conditions consisted of unprocessed spoken words and processed versions simulating 2, 4, 8, 12, and 16 implant channels. Subjects were asked to select the token they heard. For the purpose of comparing perceptual and physiological responses, percent correct scores for the words /hid/ and /heed/ were extracted from the overall performance score. Then, those same stimuli were used to evoke the P1-N1-P2 responses. These responses were evoked in six stimulus conditions (2, 4, 8, 12 and 16 channels, as well as the unprocessed version). For both speech tokens, CAEP waveform morphology differed as a function of channel number. Similar to our previously published findings, perception also changed as a function of channel number (Friesen et al. 2001). The relationship between perception and physiology, as a function of channel number, will be addressed.

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AUDIOVISUAL ASYNCHRONY SKILLS IN ADULT COCHLEAR IMPLANT RECIPIENTS: SOME PRELIMINARY FINDINGS

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Recent evidence has suggested that normal hearing individuals who have good audiovisual speech perception skills also have a narrow window over which they identify auditory and visual signals as being synchronous in time. This finding suggests the timing of the presentation of auditory and visual signals can be used as a cue for speech understanding. The detection of asynchrony in audiovisual speech and the impact that this has upon speech perception in the cochlear implant population has not been examined. In the present study, younger and older adult cochlear implant recipients were evaluated to determine their precision with the detection of audiovisual asynchrony. This study also assessed the effect that asynchrony detection skills have on speech perception.

Two groups of cochlear implant recipients, one between the ages of 40 and 55 and the other over the age of 65, were examined in this study. The CNC word test and the HINT and CUNY sentence tests were administered to all study participants. The CUNY test was given in auditory-alone, visual-alone and audiovisual modalities. In addition, study participants were asked to judge whether or not the auditory and visual signals of words were presented synchronously.

Results showed that both the older and younger group of participants performed similarly on the speech perception and audiovisual asynchrony tasks. Speech perception skills were not correlated with the ability to detect small temporal differences between the auditory and visual signals. Similar to the findings of previously published data, the younger adult cochlear implant recipients were better speechreaders than older cochlear implant recipients. The speechreading skills, however, were not correlated with audiovisual asynchrony skills.

The present findings suggest that cochlear implant recipients do not rely upon the synchrony cues within an audiovisual signal for speech understanding to the same extent that normal hearing listeners do. It is possible that for these deafened individuals alternate cues for speech understanding (e.g., contextual cues) were more salient than synchrony cues, and therefore, more heavily relied upon for speech perception.

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ACOUSTIC PHONETICS OF SPEECH PRODUCTION BY PRE-LINGUALLY DEAFENED CHILDREN WITH COCHLEAR IMPLANTS

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The speech production skills of many children with cochlear implants (CI) have progressed to the point where gross differences in speech acoustics are no longer observed. However, given the major differences in the nature of the input signal, it is likely that systematic differences between the phonetic systems of CI and normal hearing (NH) children exist. Detailed acoustic analyses at the phonetic level (as opposed to phonological transcriptions or intelligibility measures) allow us to quantify similarities and subtle differences.

Words produced sentence-level reading tasks were recorded from NH and CI children (7-14 years of age) in both normal and clear speech conditions (instructions to produce the "best, clearest speech"). Measures of a variety of acoustic features were obtained such as vowel space size, voice onset time, fundamental frequency, and segment durations. These measures allow us to compare the relationship of feature values to phonetic categories as well as the correlations between features. For this sample of children, there was remarkable similarity in the NH and CI phonetics, including correlations between features, such as between fundamental frequency and voice onset time. Differences between the groups appear to be related to the nature of the signal and differences in strategies to enhance intelligibility as opposed to differences in motor control development.

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TUESDAY, POSTER 12

EFFECT OF FREQUENCY BOUNDARY ASSIGNMENT ON SPEECH RECOGNITION WITH THE ACE SPEECH CODING STRATEY, PART II

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The ACE strategy as implemented on the Nucleus 24 Cochlear Implant filters incoming sound into a maximum of 22 frequency bands. These bands are assigned to each active electrode in tonotopic order and can be varied by using different frequency boundary tables provided by the clinical software. In an earlier study (Fourakis et al., 2004), speech perception with an "experimental" versus the manufacturer's default table was compared using the SPrint™ processor. The experimental table dedicated one or two more electrodes in the F1 and F2 speech regions and limited high frequency information to ~6000 Hz. Vowel identification was significantly improved with the experimental table and seven of the eight adult subjects preferred its sound quality.

For the current study, a SPEAR3 research processor was used allowing greater flexibility of frequency band manipulation than with the SPrint™. Eight adults were evaluated with three different frequency assignments. The first assignment (OLD EXP) was based on the earlier study's experimental assignment, the second (NEW EXP) provided finer resolution in the F1 and F2 frequency ranges while sacrificing some resolution in the 1100-1900 Hz and 3000-7000 Hz ranges, and the third (BARK) divided the entire 200-7000 Hz range into equal bark intervals. Subjects used each assignment for several weeks before completing a number of speech perception tasks and a questionnaire evaluating their daily listening experiences. Speech perception tasks included: 1) *identification* of CNC words, TIMIT sentences, medial vowels, and synthetic stop-vowel transitions, and 2) *formant discrimination* in synthetic vowels. All stimuli were presented at 60 dB SPL.

For the group, there were no statistically significant differences between frequency assignments for words, sentences, transitions, and formant discrimination. Using repeated measures ANOVA, there were significant main effects for talker gender and frequency assignment for vowels produced by men, women, boys and girls (Hillenbrand et al., 1995). Bonferroni-adjusted post-hoc pairwise tests showed a significant advantage for the NEW EXP over the OLD EXP assignment for women's and girls' voices, and a marginally significant advantage ($p=.049$) for BARK over OLD EXP for men's voices. In addition, there were significant effects of assignment for individual subjects on some tasks. The questionnaire responses indicated no clear group preference but some individuals did prefer NEW EXP or BARK over OLD EXP. Individuals' results will be discussed in relation to electrode position estimated from spiral CT scans.

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IMPORTANCE OF LOW-FREQUENCY INFORMATION FOR UNDERSTANDING INTERRUPTED SPEECH

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In a recently completed study of hearing-impaired (HI) listeners' speech perception in noise (Jin and Nelson, 2004), two factors emerged as highly related to amplified sentence recognition in the presence of modulated noise: low frequency audibility and auditory filter bandwidths. Nine young adult listeners with sensorineural hearing loss and eight young adults with normal hearing (NH) sensitivity as controls participated in the series of experiments. Amplified speech recognition performance of the HI listeners was equal to that of the NH listeners in quiet and in steady noise, but was significantly poorer in modulated noise. Thus, even when amplification was adequate for full understanding of speech in quiet and in steady noise, HI listeners experienced significantly less masking release from the modulated maskers.

The results indicated that those listeners with greatest hearing losses in the low frequencies were poorest at understanding amplified sentences in modulated noise. In addition, those HI listeners with wider auditory filters (in the 2k – 4k Hz region) were poorer than HI listeners with near-normal auditory filter bandwidths. These two findings are consistent with the hypothesis that strong spectral representation of voice pitch is necessary for auditory segregation of speech from noise (e.g., Qin and Oxenham, 2003). Additional results from HI and NH listeners will be presented, in which we systematically vary the audibility of different frequency regions of speech by filtering. Sentences are interrupted by either speech-shaped noise or silence gap while measuring the percent of sentence recognition. The purpose of the current study is to examine contribution of different spectral regions to the auditory segregation/integration of interrupted speech. Implications for noise-reduction signal processing algorithms will be discussed.

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TUESDAY, POSTER 14

MORPHOLOGICAL CHANGES OF ERPS TO THE PERCEPTION OF VOWELS AND CV SYLLABLES IN THE POST-IMPLANTATION PERIOD IN ONE COCHLEAR IMPLANT USER

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Restoration of hearing after cochlear implantation is based principally on two factors: i) degree of bypassing damaged structures in the inner ear by the surgical insertion of a neuroprosthetic device and ii) intrinsic properties of the neural auditory system for processing novel auditory sensory input (plasticity). The exploration of the mechanisms underlying auditory perception in altered auditory systems can contribute to the understanding of both fundamental principles of human auditory perception and human brain dynamics.

This study explores morphological changes of the event related brain potentials associated with the auditory perception of vowels and consonant-vowel (CV) syllables following a cochlear implantation (CI) in a profoundly deaf adult. The participant was tested in the phonological discrimination of /a/ vs /e/, /u/ vs /i/, /fa/ vs /sa/ and /pa/ vs /ta/ contrasts in a pseudo-odd ball task once a month for a period of 5 months. During this period, the participant underwent a speech rehabilitation program based on the verbotonal method and his CI sound processor was adjusted according to clinical rules in several fitting sessions. In order to avoid data artifacts caused by the cochlear implant which was located on the right side of the head, we restricted ERP recordings to the left side of the head.

Data analysis focuses on the morphological changes of the ERP waves across different stimulation patterns caused by vowels and CV syllables at 5 time points. In addition, data on the relationship between implant stimulation patterns and ERP waveform output will be presented.

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TUESDAY, POSTER 15

ADAPTATION TO SPECTRALLY SHIFTED SPEECH BY UNSUPERVISED LEARNING

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It has been well documented that normal-hearing listeners are able to partly adapt to spectrally shifted speech after short-term training. The training methods used in previous study were technically “supervised” training where the training words were explicitly specified by either preview or feedback. However, it is still not clear whether the adaptation to spectrally shifted speech can be achieved by unsupervised training where the training words are not explicitly expressed. The present study is to investigate the adaptation to spectrally shifted speech through unsupervised training. Two kinds of spectral shift are used to investigate whether the nature of this kind of adaptation depends on the extent of spectral shift. Understanding the nature of learning process will help design the effective training methods for cochlear implant users and understand the underlying mechanisms of speech pattern recognition in electric hearing.

Two eight-channel noiseband processors were implemented to generate spectrally shifted speech. The extent of spectral shift was manipulated by the frequency mismatch between analysis and carrier filters. For processor 1, the speech information in the frequency of 75 Hz - 5.4 kHz was mapped to 150 Hz - 10.8 kHz while the speech information in the range of 200 Hz - 7 kHz was upwardly shifted to 1 kHz - 12 kHz for processor 2. Baseline vowel recognition scores were measured prior to the training, during, and after the training. Each subject completed three or four short training sessions each day for five consecutive days. Each training session included 5-minute unsupervised training of shifted speech and a follow-up baseline test. For unsupervised training, the labels of all 12 tokens were replaced with 12 symbols (A-L) during training period. Preliminary results showed that the post-training vowel recognition performance was significantly higher than the pre-training baseline performance for processor 1. However, no significant improvement was observed after the training for processor 2.

The results showed that the adaptation to spectrally shifted speech could also be achieved by unsupervised learning. However, the efficiency of unsupervised training is highly dependent on the extent of spectral shift. When the spectral shift is not severe, unsupervised training can accelerate the adaptation to spectrally shifted speech. However, the benefit of unsupervised learning is limited in the condition of large spectral shift. These results suggest that some cochlear implant patients may not be able to adapt to electrically stimulated speech due to the large spectral shift if only unsupervised learning is available. Supervised training (e.g. targeted phoneme training) may be necessary for these cochlear implant patients to improve their speech performance over time.

Supported by NIH/NIDCD

SMOOTH GMM BASED SPEAKER ADAPTATION FOR SPECTRAL DEGRADED SPEECH

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Due to the nature of sub-band analysis and spectral degradation associated with cochlear implants, cochlear implant (CI) patients may have some difficulty in adapting to varying characteristics, such as different prosodic characteristics, spectral envelope and vocal tract length, during multi-talker conversations, and thus have greater difficulty with multi-talker speech recognition. Previous studies revealed that multi-talker speech recognition could be significantly improved by applying a simple speaker normalization technique to cochlear implant processing (Luo and Fu, 2005, IEEE-BME in press). However, the linear frequency warping method used in the previous study may not be sufficient to normalize the speech pattern of individual talkers to the optimal reference patterns.

Voice conversion is a technique to transform a speaker's sound to another speaker's sound. It has been well documented that advanced voice conversion techniques can effectively reduce the talker distortion between different talkers without spectral degradation. The present study is to investigate whether the speech patterns of a worse talker can be modified to match to those of a better talker by using smooth Gaussian Mixture Model (GMM).

A male to female speaker conversion is conducted in the present study. All sentence materials are selected from the MOCHA-TIMIT database. Several noiseband processors are implemented to process the original and converted sentences to simulate the cochlear implant processing. Talker distortion before and after the speaker conversion is measured for the spectrally degraded speech. Preliminary results show that GMM based speaker adaptation could significantly reduce the talker distortion for the spectrally degraded speech with the number of channels varying from 4 to 16. Also this kind of speaker conversion can be achieved with relatively small training data and small number of GMM components. The results from the present study suggest that GMM based spectral conversion may help to reduce talker variability and improve the overall perception in CI users.

Support provided by NIH/NIDCD.

TUESDAY, POSTER 17

LINGUISTIC AND AUDIOLOGICAL FACTORS IN COCHLEAR IMPLANT SPEECH PERCEPTION

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Although cochlear implant (CI) users average 70-80% for sentence recognition in quiet, they are extremely challenged by understanding speech in noise in their native language. Similarly, normal-hearing, non-native listeners experience about the same degree of difficulty as native CI users understanding a second language in noise. These observations suggest that two mechanisms are responsible for the imperfect perception of distorted speech: A central mechanism, which is responsible for the non-native listeners' difficulty and a peripheral mechanism, which is responsible for the hearing-impaired listeners' difficulty. The present study used acoustic simulation of cochlear implants to assess the relative contributions of central and peripheral mechanisms to cochlear implant speech performance.

Twenty normal-hearing native and non-native speakers of English participated in this study. Non-native speakers had acquired English in adulthood and had been using the language on a regular basis for at least four years. Three types of stimuli--phonemes, words, and sentences--were used to assess three types of linguistic functions: acoustic-phonetic identification, lexical recognition, and segmentation of continuous speech into words. Two types of distortions were introduced in the stimuli. The stimuli were either presented in quiet and in speech-spectrum-shaped noise at +20, +10, 0, and –10 signal-to-noise ratios (SNR) or processed to simulate a 2, 4, 8, 16, or 32- channel cochlear implant.

Preliminary results showed that, while the non-native and native speakers produced similar performance in quiet, the non-native speakers' performance declined disproportionately in noisy and lower band conditions. For example, the non-native score was 20% points lower than the native score at 0 SNR and 25% points lower at 4 channels. This disproportionate decline cannot be attributed to audiological factors. Rather, it suggests that non-native speakers have inaccurate or inefficient syntactic processing. Data are being collected on phoneme and word recognition to determine whether processing of distorted speech is slowed down by phoneme identification due to first language interference and/or lexical familiarity due to phoneme mismatch and knowledge of word. Because a significant portion of CI users uses another language in everyday listening situations, assessing the central (linguistic) and peripheral (audiological) contributions to cochlear implant speech perception is of clinical significance. Knowing which speech process is influenced by linguistic factors will allow audiologists to establish the reasons behind a non-native cochlear implant subject's performance and to develop proposed clinical protocols for improved performance.

CHRONIC EVALUATION OF A STIMULATION STRATEGY WITH INCREASED NEURAL RESPONSE EFFICIENCY

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The standard clinical stimulation mode of a cochlear implant consists of amplitude-modulated monopolar biphasic pulses spatially distributed along the electrode array. Charge balancing the pulses is crucial for safety reasons. However this still leaves a considerable freedom in the pulse shape, e.g. triphasic or asymmetrically balanced pulses can be selected as well.

This study evaluates the speech performance and sound quality of a strategy designed towards reduced power consumption. Using the flexibility of the CII electronic platform a stimulation strategy has been designed with pulses featuring a +/- 100 ms inter-phase gap. Such pulses have the potential to increase the efficiency of the neural response. Therefore stimulation levels can be reduced offering lower power consumption and longer battery life. However at the same time there is a risk for more channel interaction and worse speech understanding.

In this study a group of 6 subjects, all having at least 3 months experience with a fast-rate HiResolution program, participated in a one-month chronic trial. Their baseline program was compared to the research strategy programmed with the BEDCS and BEPS research software. Power consumption was determined by comparing fitting levels. Speech understanding was evaluated before the switch-over and after one month. The test material was the BKB sentence test taken at 70 dB_A in quiet and in noise. Potential changes in sound quality were assessed with a questionnaire.

The low-power strategy reduced the power consumed by the implanted stimulator by a factor of +/-10. The speech understanding and quality results were more variable. The first three subjects showed a significant increase in speech understanding, especially in noisy conditions. SRT shifts of more than 5 dB were observed. In terms of overall speech quality, no major differences were found. The last three subjects showed degradation in performance, and also their overall speech quality scores degraded.

As a preliminary conclusion the research strategy reached its goal in terms of power reduction due to a combination of stimulation rate reduction and increased neural efficiency. The factors underlying the differences in speech understanding are at this moment still not well understood. One observation is that the latter group had worn the HiResolution strategy for a longer time. Further analysis will be needed in order to capture the effect of differences in each of the factors involved: i.e. fitting methodology, rate, channel ordering and inter-phase gap duration.

EXPLAINING DIFFERENCES IN SPEECH RECOGNITION ABILITY IN COCHLEAR IMPLANT USERS – SPECTRO-TEMPORAL DISCRIMINATION AND COGNITIVE CAPACITY

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Several studies have shown that the benefit of Cochlear Implants (CI), for instance regarding speech understanding, shows great variations among individual CI users. Are these differences mainly correlated with psychoacoustic or cognitive test results?

A psychoacoustic spectro-temporal discrimination test has been developed and tested on a group of CI users. The users have also been tested with a cognitive test developed at Linköping University, Sweden, and with an ordinary word recognition tests.

Results of 20 CI users show near normal performance on the spectro-temporal discrimination test for 2 and 4 spectral bands but severely impaired discrimination ability for 8 or more spectral bands.

The spectro-temporal test is constructed using Gaussian white noise shaped as the long-term spectrum of speech. This noise is then filtered to give alternating increased and decreased spectrum levels in a number of frequency bands. At the middle of the stimulus duration the band levels are shifted.

The goal is to measure the required level difference between spectral peaks and valleys in order for the listener to detect the spectro-temporal modulation, for stimuli with 2, 4, 8, 16, and 32 spectral bands. The test procedure is a transformed adaptive 3I3AFC(6) method, converging at 71% correct responses, which corresponds to a detectability index d'=2.2.

The spectro-temporal test can be used to indirectly estimate the limitation in speech recognition of the CI user. A model of the electrical signal transmission and neural excitation in the peripheral hearing system has been constructed. By observing the neural patterns created by two different sounds a difference index d' between these neural patterns can be calculated. This index can be compared to the results on the spectro-temporal discrimination test. The electrical model can be tuned to reproduce the results of the actual CI user. The tuned model can then be used to estimate the amount of phonetic information in a speech signal presented to the ear that is successfully transferred to the neurons in the auditory nerve.

THE DEVELOPMENT OF SYLLABLES IN CHILDREN FOLLOWING COCHLEAR IMPLANTATION

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This study investigates the beginning stages of speech acquisition following cochlear implantation. Consonant-vowel (CV) syllable shapes were evaluated at yearly intervals post-implant. Fifty-seven children who received their cochlear implant between 12 months of age and 14 years of age participated in the study. They all received Cochlear Corporation cochlear implants. Yearly speech samples were obtained in both free play and through an elicited task. The speech samples were transcribed an entered into the Logical International Phonetics Program or LIPP. Consonant and vowel repertoires were obtained at yearly intervals up to 4 years post-implant. In addition, the intrasyllabic patterns of consonant-vowel pairs (CV) in words and babbling were also analyzed. The children were grouped by age-of-implant.

The data were analyzed within the perspective of the Frame-Content Theory. This theory of typical sound development in infants predicts that the serial organization of syllables is most dependant on the motor constraints of the oral cavity. Consonant and vowel pairs are most influenced by the rhythmic oscillation of the jaw rather than independent movement of the tongue. Preferred CV patterns emerge in typical infants regardless of ambient language. These patterns include coronal consonants and front vowels (CF), labial consonants and central vowels (LC) and dorsal consonants and back vowels (DB). Specific questions driving this research included the following: 1. Do children receiving cochlear implant organize their syllables in the first four years post implant in a way that resembles typically developing children? 2. How does age-of-implant influence the patterns of syllable organization? 3. What other variables may affect the patterns of CVs in babbling and words?

Analysis of CV productions showed the youngest group of children implanted prior to 30 months-of-age demonstrated patterns of syllable organization most like typically developing infants. However, they also showed a statistically significant preference for other CV syllable types not seen in typical infants. Children implanted after 30 months of age showed patterns of organization distinctly different from typical children. These results suggest that the pattern of syllable organization is more normal when the child is implanted earlier. These results do not support the notion that children will gain speech skills in a typical way post-implant. Many children gain highly intelligible speech over time; however, these results suggest the pattern of serial organization of speech following cochlear implantation is different.

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PRELIMINARY LANGUAGE, SPEECH RECOGNITION & PSYCHOSOCIAL RESULTS IN THE CHILDHOOD DEVELOPMENT AFTER COCHLEAR IMPLANTATION (CDACI) STUDY

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Objectives: CDaCI is a prospective study designed to identify predictors of cochlear implant outcomes over a 3 yr period in young children receiving a cochlear implant (CI) compared to a group of similarly aged normal hearing (NH) peers. To specifically assess the impact of clinical measures and parent-child interactions on oral language development, four domains are addressed: A. Oral language level; B. Speech recognition; C. Psychosocial & behavioral correlates of oral communication; D. Parental proxy of quality of life (QoL). Here we report baseline and observations from year 1 of evaluative follow-up.

Methods: CDaCI participants include children enrolled between 9mo-5yr prior to CI (n=188; mean age 2.2yrs±1.2yr; 51% girls) or as hearing (NH) controls (n=97; mean age 2.3yrs±1.1yr; 61% girls). Domain-specific measures are as follows: A. The Reynell Developmental Language Scales (RDLS) is the 1° measure of language. Auxiliary measures address basement effects in youngest subjects (MacArthur); ceiling effects due to age (>7yr) are addressed with OWLS testing. B. Tests of the ability to recognize speech & speech-in-noise are performed using a hierarchical battery. C. Joint attention is measured in videotaped interactions with parents: free play, puzzle-solving, and Art Gallery. D. Health utility metrics are assessed through parent-proxy.

Results: A. At baseline, there are large differences in language levels between the deaf (CI) and NH children (RDLS: 63.2 v. 100.1). Baseline measures also suggest differences in cognition between the CI & NH children, requiring adjustment in analysis. B. At 1 year, approximately half of the CI group demonstrated closed-set word and sentence identification. C. CI children at baseline spent significantly more time in supported and coordinated-joint attention than NH controls, but significantly less time in symbol-infused joint attention. Deaf children also spend significantly more time in solitary play with objects, *not* interacting with caregivers, than hearing children. D. Despite similar levels of hearing loss among CI children, QoL scores vary considerably and correlate best with the child's age.

Conclusions: Preliminary results highlight important differences between the deaf (CI) cohort and NH controls. The extent to which the CI experience closes baseline disparities in language will be a primary focus. CDaCI data will support a multivariate model of language trajectory and the impact carried by audiologic, cognitive, family-interaction, (re)habilitative training, and device variables.

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AUDITORY TRAINING WITH SPECTRALLY SHIFTED SPEECH: EFFECTS OF TRAINING FREQUENCY

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Auditory training has been shown to improve speech recognition among hearing aid (HA) users, cochlear implant (CI) patients, and normal-hearing (NH) subjects listening to spectrally shifted speech. While previous studies have shown that protocols used in the training have a significant effect on the outcome of the training, it remains unclear how often the training should be conducted to maximize the benefit of auditory training. To see whether the frequency of training will affect NH listeners' adaptation to spectrally shifted speech, 12 NH listeners were trained with spectrally shifted speech via an 8-channel acoustic simulation of CI speech processing. Five short training sessions (1 hour per session) were completed by each subject at one of the following training frequencies: 5 sessions/week, 3 sessions/week or 1 session/week. Subjects were trained to identify monosyllable words from a list of choices in a c/V/c format with targeted vowel contrasts.

Baseline vowel, consonant, and sentence recognition were measured before and after training, as well as at regular intervals during the training period. Preliminary results showed that pre-training vowel recognition scores were relatively low for all subjects due to the severe spectral shift. After five sessions of targeted vowel contrast training, there was a significant improvement of shifted vowel recognition in all NH listeners. The mean improvement was comparable (~ 15 percentage points) at all training frequencies even though there was significant inter-subject variability in pre- and post-training baseline performance. While not explicitly trained in the protocol used in the present study, shifted consonant and sentence recognition also improved by about 20 percentage points from their pre-training baseline scores in all NH listeners. Similarly, the improvement of shifted consonant and sentence recognition was largely unaffected by the frequency of training.

The results demonstrated that the frequency of training has little effect on NH listeners' adaptation to spectrally shifted speech, at least within the proposed time period. The outcome of auditory training is largely dependent on the amount of training (e.g. total number of training sessions) instead of the training frequency (e.g. daily or once a week). While more frequent training may help accelerate NH listeners' adaptation to spectrally shifted speech, there may be benefit from training as little as once a week. The results of the present study also suggest that appropriate training schedules can be developed to maximize the time and effort associated with hearing-impaired patients' auditory rehabilitation.

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THE PERCEPTION OF STRESS AND INTONATION BY CHILDREN WITH COCHLEAR IMPLANTS

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Because of the limitations of current implants in delivering adequate pitch information and poor spectral resolution, users rely on relatively weak cues to pitch carried in the temporal modulation pattern. The interdependence of perceptual cues to stress (pitch, timing and loudness) in English is well documented and it is evident that pitch makes syllables stand out and seem more prominent to normal hearing listeners. These issues are investigated for a group of 17 implanted (CI) children aged 5;7 to 16;11 and using ACE or SPEAK strategies.. The aims are to establish

(i) the extent to which stress and intonation are conveyed to CI children in synthesised bisyllables (BAba vs. baBA) involving controlled changes in F_0, duration and amplitude (Experiment I), and in natural speech stimuli involving compound vs. phrase stress and focus (Experiment II).
(ii) when pitch cues are missing or are inaudible to the listeners, do other cues such as loudness or timing contribute to the perception of stress and intonation?

Results of Experiment I show variability in performance across the CI group. Some subjects were unable to reliably hear pitch differences even at the maximum difference presented (almost an octave). Those who were hearing differences needed a large (0.5 octave) difference relative to a normal hearing group of children presented with a cochlear implant simulation. Some of the CI children who could not discriminate F_0 differences in Experiment I nevertheless scored above chance in tests involving focus in natural speech. Results suggest that CI children may not necessarily rely on F_0 cues to stress, and in the absence of F_0 or amplitude cues, duration may provide an alternative cue.

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TUESDAY, POSTER 24

BENEFITS OF ADAPTIVE BEAMFORMING: SPEECH RECEPTION WITH COCHLEAR IMPLANTS IN A "CAFETERIA"

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Poor speech reception in noise is a major problem for most cochlear implant users. One of the most effective approach in noise reduction techniques is the use of adaptive beamforming. This technique demonstrates promising results when tested in the laboratory, but practical benefits are not clear in more demanding real conditions. We therefore tested a custom beamformer in a "cafeteria" during lunch time and compared these results to data obtained in the laboratory.

We measured consonant identification in noise with five cochlear implant users in two conditions: with unprocessed omnidirectional microphone input and, with an adaptive beamformer with two AudioZoom™ microphones. A Kemar (Bruel&Kjaer) manikin was placed in the large (about 500 people) cafeteria of our hospital during lunch time. The signal source was placed one meter in front of the manikin while the ambient noise level was monitored online. This installation allowed us to record on digital tape several randomizations of 56-consonant blocks at various signal-to-noise levels (S/N ≥40, 15, 10, 5, 0, -5, and -10 dB). These signals were then used to evaluate patients via the auxiliary input of their processor. Each patient responded to at least three (different) 56-consonant blocks at each signal-to-noise level.

Results can be summarized as follows: (1) The adaptive beamformer provided better consonant recognition at all signal-to-noise levels, except in quiet. The Speech Reception Threshold (SRT) with the beamformer was 2.9 dB in cafeteria noise, an improvement of about 5.5 dB compared to the single microphone. (2) Tests made with the same patients in the laboratory (with CITT speech shaped noise, fixed spatial distribution of signal and noise sources in a sound proof room) yielded an impressive 14 dB SRT improvement between the adaptive beamformer and the single microphone input. (3) For comparison, normal hearing subjects showed similar SRT improvements (6.3 and 15 dB) between cafeteria and laboratory tests. Normal subjects however reached their SRT at negative S/N levels.

In conclusion, adaptive beamforming can markedly improve speech reception in the most demanding real life situations. Cochlear implant users are able to pick up almost all the benefits that the noise reduction technique can offer. Cochlear implant manufacturers should consider to offer such a noise reduction means because it would be readily available to all. Laboratory testing of beamformers usually overestimates benefits because it is difficult to properly mimic the temporal and spatial fluctuations of the noise found in a real environment.

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PERCEPTION OF QUESTION-STATEMENT CONTRASTS USING SUPRASEGMENTAL INFORMATION IN PRELINGUALLY DEAFENED CHILDREN WITH A COCHLEAR IMPLANT

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It has been widely demonstrated that cochlear implant (CI) devices are effective in facilitating spoken language development in prelingually deafened children. However, these devices can be limited in encoding fundamental frequency (F0) or voice pitch information which may be critical to the perception of prosodic components of speech such as lexical tones and sentence intonation. In the literature, data on pediatric CI recipients' perception of contrasts in speech intonation, as determined by its acoustic correlates of F0, intensity and duration cues, with F0 as the primary cue are very limited. It remains unclear how the suprasegmental information available via an implant can potentially allow prelingually deafened children to perceive speech intonation contrasts that mark different utterance types.

The present study aimed to examine how suprasegmental information presented in utterances may contribute to pediatric CI recipients' accurate identification of two utterance types – question and statement. Twenty prelingually deafened children and young adults with a CI and 10 age-matched peers with normal hearing (NH) served as participants. The speech stimuli were composed of 120 utterances produced by six adult speakers with NH (3 per gender). The target utterances were syntactically matched questions and statements that were contrasted in their speech intonation. These utterances were presented to each participant at 70 dBA in a random order using a computer program. The participants' accuracy in identifying different utterance types (statement vs. question) was compared both between the CI and NH groups and within the CI group. The acoustic properties of each utterance were characterized to evaluate how CI participants were able to utilize the suprasegmental information to achieve accurate identification of the utterance type of each utterance.

Preliminary results, obtained from 15 CI and three NH participants, indicated that although overall accuracy for the majority of CI participants (N = 13) was significantly above the chance level (50%), their performance was poorer than NH participants' (77% vs. 100%). No significant difference in the CI participants' accuracy in identifying different utterance types was observed (79% for statements; 76% for questions). Among the target utterances, 20% were accurately identified by all of these CI participants and 15% were accurately identified by less than half of these CI participants. Item analyses are being performed and a detailed description of the acoustic properties of target utterances will be provided on the basis of CI participants' group accuracy on each utterance. These results can help us better understand pediatric CI recipients' perception of contrasts in utterance types using suprasegmental information via an implant. These findings have implications for the improvement of CI technology and for the development aural (re)habilitation strategies associated with the perception of speech intonation and other prosodic components of speech in pediatric CI users.

THEORY OF MIND AND LANGUAGE DEVELOPMENT IN CHILDREN WITH COCHLEAR IMPLANTS

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Theory of mind (ToM) involves reasoning about mental states to explain people's behavior. Developmental research shows that typically-developing hearing children make significant strides in theory of mind during the preschool years (Flavell & Miller, 1998). Specifically, between age 3 and age 5, children develop an understanding that people's behavior is motivated by their mental states (beliefs, desires, emotions, etc.). This understanding allows children to predict and explain people's behavior more accurately. Without this knowledge, children would have difficulty navigating the social world successfully.

Research shows ToM development is delayed in deaf children of hearing parents, possibly due to late exposure to mental state talk and/or delayed acquisition of requisite syntax. No previous research has systematically examined ToM in children with cochlear implants. Our goal was to examine the impact of early cochlear implantation on theory of mind development in a group of pre-linguistically deafened children. Subjects were 31 oral children with cochlear implants (mean age at CI = 2.9 years) and 33 children with normal hearing. Tasks included a five-item ToM scale developed by Wellman and Lui (2004) and a nonverbal measure of false belief understanding. Understanding of photographs, ability to explain anomalous actions using mental state verbs, and memory for propositional complements were also tested. Language measures included story re-telling, and sentence use and comprehension.

Implanted children showed delayed ToM relative to peers with normal hearing; however children with cochlear implants out-performed non-implanted deaf children of hearing parents in previous research. Statistical analyses showed that chronological age and language ability were the best predictors of theory of mind development. Use of complement syntax alone was not a significant predictor. Implant users understood and used complement syntax, indicating that such understanding may be necessary but insufficient for the development of ToM. Children with cochlear implants, as a group, showed age appropriate language use and comprehension when compared with peers with normal hearing, suggesting intervention strategies used with these children may emphasize language development over social cognitive development.

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EFFECTS OF REVERBERATION AND VARIOUS MASKERS ON SENTENCE INTELLIGIBILITY IN COCHLEAR IMPLANT SIMULATIONS

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Cochlear implants (CI) have helped many recipients with severe-to-profound hearing losses to live, learn and work successfully in mainstream environments. Despite their successes, many CI users have difficulty hearing and functioning in noisy, reverberant conditions. To date, there has been no systematic study of the impact of the characteristics of natural settings on speech perception in CI recipients. This paper presents results from two experiments which model the effects of reverberation and noise on speech intelligibility when varying amounts of spectral information are available.

In Experiment 1, 16 young adults with normal hearing listened to and repeated lists of topic-based sentences (Helfer & Freyman, 2004) that were first subjected to reverberation simulation (Zurek, Freyman & Balakrishnan, 2004) and then CI simulation (Qin & Oxenham, 2003). Condition/list pairings for the subjects were determined by a 16 x 16 Latin square. Levels of reverberation were determined by varying the uniform absorption coefficients (α) of the modeled room (α =.25, .4, .7, and 1) to produce reverberation times of .152 s, .266 s, .425 s and 0 s, respectively. The CI simulations used amplitude modulated sine wave carriers in either 6, 12, 24, or an infinite number (i.e., no processing) of spectral channels. Sentence intelligibility scores for both 24- and 12-channel processors indicated that speech perception remained nearly as good as unprocessed speech across all reverberation times. In contrast, performance for the 6-channel processor deteriorated markedly as reverberation increased. This substantial deviation suggests that reduced frequency resolution is a primary cause of decreased intelligibility in the presence of reverberation.

Experiment 2 measured the combined effects of reverberation and noise on speech produced by the 6- and 12-channel CI simulations of Experiment 1. Ten subjects listened to speech processed with reverberation simulation with α = 0.4, 0.7, or 1.0, both in quiet and in the presence of either steady-state speech spectrum noise or two-talker babble at signal-to-noise ratios of +18 dB and +8 dB. As in Experiment 1, the combination of noise and reverberation significantly reduced intelligibility scores when the number of spectral channels was restricted. The number of channels, the level of reverberation, and signal-to noise ratios were all significant factors. Of particular interest in the data was an apparent absence of an interaction effect between noise and reverberation which has been found in listeners with normal hearing and hearing impairments listening to unprocessed speech. Potential reasons for the lack of such an interaction will be presented.

TUESDAY, POSTER 28

EVALUATION OF HIGHER STIMULATION RATES IN THE NUCLEUS® RESEARCH PLATFORM 8 SYSTEM

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The Nucleus® Research Platform 8 comprises the CI24RE receiver-stimulator with the Contour™ Advance electrode array, the L34SP body worn speech processor and the Nucleus Programming Environment fitting software. This system provides the platform for evaluation of a range of new speech coding strategies, with the possibility of using higher stimulation rates and the ability to program 22 electrodes into 43 output channels by combination of single electrode and dual electrode stimulation.

The effect of using higher stimulation rates was assessed in a clinical study with fifteen adult subjects, using an ABAB experimental design to control for order effects. Each of the subjects used the standard ACE strategy, with a total stimulation rate of between 12.0 and 14.4kHz, for the first three months after initial device activation. After evaluation with this strategy, each subject was switched to a higher rate ACE strategy. At this time two different high rate programs were provided; one with a total stimulation rate of 24kHz and one with a total stimulation rate of 32kHz. After a six-week period of optimisation the preferred high rate program was evaluated. Subjects then repeated their use of each of the strategies in turn for a further three-week period, prior to a second evaluation with each. The test materials were monosyllabic CNC words presented in quiet and CUNY sentences in noise. Preference was assessed via a questionnaire.

There were no significant differences in speech perception scores between the programs for the group of subjects, however individual subject effects were observed. For testing in quiet significantly higher scores were observed for five subjects with the higher rate ACE strategy, while one subject obtained significantly higher scores with the standard ACE strategy. The same findings were observed in noise, however the subjects showing individual benefit differed between the studies. Only two subjects obtained significantly higher scores for the higher rate program on both speech perception tests. These findings are consistent with the preference outcomes, in that the preferred program differed across subjects. Eight subjects reported overall preference for the higher rate ACE program, five preferred the standard ACE program and two reported that there was no difference between the programs. The preference for stimulation rate within the higher rate strategy also varied across subjects, with ten subjects preferring the 24kHz rate and five preferring the 32kHz rate program.

This data suggests that the provision of a higher rate option may provide improved outcomes for some but not all subjects. It is important that the rate be optimized for individual subjects to ensure maximum benefit.

TUESDAY, POSTER 29

LONG-TERM PERFORMANCE OF CLARION 1.0 COCHLEAR IMPLANT USERS

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Since the inception of cochlear implantation, patients have undergone implantation with little knowledge of long-term stability of speech performance gains. Examining performance over time is significant because of the need to verify the long-term effects of electrical stimulation on the auditory system and to be able to counsel potential subjects of the stability of their initial improvements. The few longitudinal studies that exist suggest that the initial improvements in speech perception remain stable for at least 6 years post-implantation. Factors confounding the evaluation of long-term performance include the evolution of speech processing strategies and processors, both which may mask declines in performance. This was a retrospective longitudinal study of 135 months that examined the declines or improvements in monosyllabic word discrimination that may have occurred after performance reached the usual 24 months post-implantation asymptote. The 31 subjects used the Clarion 1.0 cochlear implant with identical speech processors programmed with continuous interleaved sampling for the duration of the study. The mean length of follow-up was 93 months (median = 96m). There were no internal device failures or other adverse events requiring subsequent explanation or reimplantation of the device. The study was significant for three findings (1) There was no significant growth or decline in speech perception after 24 months post-implantation unless the individual experienced adverse medical/physiological events. (2) There is a significant inverse relationship between age at implantation and maximum performance. (3) There is a slight negative correlation between age at implantation and time to maximum score.

TUESDAY, POSTER 30

SPEECH PERCEPTION SCORES MATCHED IN QUIET AND IN NOISE: WHICH COCHLEAR IMPLANT DEVICE IS BETTER, "A" OR "B"?

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A recent study by Spahr et. al. (2003) has demonstrated significant differences in some speech perception scores between users of two cochlear implant devices. Users were first matched according to their performance in a given speech task, and then tested for differences in a selection of other speech tasks. After subjects were matched according to their word recognition scores in quiet, users of 'device A' obtained higher scores than users of 'device B' in tests of vowel identification and recognition of sentences in noise. This result has important implications for the evaluation of speech processing strategies, or CI devices, because it shows convincingly that differences may or may not emerge depending on the specific test that is used. However, this outcome has been misinterpreted by some as indicating that device A is better than device B in terms of absolute levels of speech perception. We demonstrate that such a conclusion cannot be ascertained from the matching procedure outlined above.

To simulate the results of Spahr et. al., we assume that performance with device A remains approximately the same in conditions of quiet and noise, and that performance with device B drops significantly in the presence of noise. Let us define the robustness index as the ratio of performance in a difficult listening situation (e.g. in noise) to performance in an easier listening situation (e.g. in quiet). In our theoretical example, device A would have a significantly higher robustness index than device B. With this property in mind, we simulate two scenarios where percent correct scores are generated using normally distributed pseudorandom numbers. For each scenario, percent correct scores are generated with enough spread to allow matching of scores between devices in either quiet or noise. In the first scenario, random numbers are generated so that the mean percent correct score for device A is significantly greater than the mean percent correct score for device B, i.e. device A performs better on average. Conversely, in the second scenario, device B performs better on average.

When simulated percent correct scores from device A and B are matched in one listening condition, the relative performance of the matched pairs in the other listening condition persists irrespective of which device performs better on average. For example, like the study of Spahr et. al., device B performs worse in noise when simulated scores were matched in quiet. However, this result occurs both in the scenario in which device A performs better, and the scenario in which device B performs better. Furthermore, for both scenarios, device B performed better in quiet when simulated scores were matched in noise. Hence, a high robustness index is not necessarily good or bad in absolute terms.

In summary, the matching procedure used in the present study cannot be used to conclude that one CI device is better than another.

EFFECTS OF TRAINING ON THE PERCEPTION OF SPECTRALLY SMEARED ENVIRONMENTAL SOUNDS

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Environmental sounds play an important role in maintaining the listener's awareness of the objects and events in the immediate environment. They can warn of potential dangers (e.g., alarms, collisions) or provide aesthetic satisfaction (e.g., babbling brook, bird song). Accurate identification of the sources of environmental sounds provides a basis for adequate behavioral responses in a dynamic environment, and, in addition to speech perception, is a major concern for cochlear implant users. Although research indicates that decreased spectral resolution has a negative effect on environmental sound identification, little is known about the processes underlying perceptual adaptation to spectrally smeared environmental sounds. The goal of the present research was to examine a change in the ability to identify spectrally smeared environmental sounds in response to training.

First, a comprehensive test of 160 sounds was developed. It consisted of 40 unique sound sources, each represented by 4 different tokens. Twenty one normal hearing listeners identified the undistorted sounds in a 60 alternative closed set response task with the average accuracy of 98%. Next, in a pretest-posttest design, 6 naïve normal hearing listeners, were asked to identify the spectrally smeared test items obtained with a 4 channel noise-based vocoder. Five training sessions were administered between the initial and the final test. The items on the training test were selected individually for each subject and comprised one half of the sound sources that were misidentified in the pretest. Each sound source used in training was represented by 2 different tokens. During training, subjects were given trial and block feedback, and could replay each sound up to 5 times.

Overall mean identification performance improved by 30%, from 33% correct on the pretest to 63% on the posttest. The largest improvement of 86% was obtained for the sounds used during training. However, increases in identification accuracy of 34% and 30% were also observed for alternative tokens of the sound sources used during training, and sound sources not represented during training. Among those, the greatest improvement was found among sounds with prominent dynamic energy patterns with broadband (e.g., clock ticking, helicopter) and harmonic (doorbell, laughter) spectra. These results indicate positive effects of training on the identification of environmental sounds, and suggest that learning effects can generalize to other sounds as well. These findings provide a preliminary basis for incorporating environmental sounds into auditory rehabilitation programs for cochlear implant patients.

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A BANDPASS SIGNAL DECOMPOSITION MODEL TO IMPROVE SIGNAL PROCESSING STRATEGY IN COCHLEAR IMPLANTS

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Most of the current Cochlear Implant (CI) speech processing strategy extracts and encodes envelope modulation information from a limited number of channels. While envelope encoding has allowed CI users to achieve good speech recognition in quiet, their performance degrades significantly when speech is presented with interfering signals, background noise, reverberation and other acoustically challenging conditions. Here, we propose a novel speech signal processing strategy that encodes amplitude, frequency and spectral tilt information in order to improve CI performance in acoustically challenging conditions.

Initially we process the speech signal through a bank of band-pass filters. We then analyze the envelope and phase modulations at the output of each filter. Each filter output is then processed to extract its instantaneous frequency and instantaneous amplitude. It is further decomposed into minimum-phase and maximum-phase parts. The minimum and maximum phase parts of filter outputs characterize the spectral tilt of the bandpass components.

We attempt to reconstruct the original signal from decomposed bandpass signal components. We are able to achieve good signal reconstruction with as low as four bands. This early result is promising and motivates us to incorporate this signal decomposition strategy into CI’s.

PERCEPTION OF EMOTION IN SPEECH BY YOUNG COCHLEAR IMPLANT USERS: A PILOT STUDY

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Pilot experiments were performed to investigate the perception of emotion in speech by young cochlear implant (CI) users. New stimuli were created by two female talkers recording multiple tokens of several sentences with each of the four emotions, 1) angry, 2) fearful (or scared), 3) happy, and 4) sad. For these experiments, three tokens of a single sentence for each emotion from each talker were employed (4 emotions × 1 sentence script × 3 tokens = 12 stimuli per talker). All stimuli were normalized in level prior to presentation in a sound-treated booth via a loudspeaker at approximately 65 dB SPL (audio-only presentations).

Emotion discrimination and emotion identification experiments were performed by three groups of listeners: i) eight normal-hearing, pre-school-age children (3–6 yrs old), ii) two pre-school-age CI users (4–5 yrs old), and iii) three elementary-school-age CI users (8–11 yrs old). For both the pre-school-age and elementary-school-age CI users, discrimination performance was highly variable (range: 42–100% correct; chance = 50% correct), and did not seem to be correlated with age. Identification performance for these listeners was much less variable, and only at chance levels or somewhat above (range: 29–50% correct; chance = 25% correct). For the normal hearing pre-school-age listeners, both discrimination and identification performance were highly variable, with ranges of 46–100 and 29–100% correct, respectively.

The data from children with normal hearing are roughly consistent with results from others, in that development of emotion perception is in-progress at these ages. E.g., results from a study by Morton & Trehub (2001) indicate that young children, even at 9 or 10 years old, are still learning emotion perception – that is, learning to consider *how* something is said in addition to *what* is said. Amongst the CI users, some children could not discriminate emotion, and hence, also could not identify the emotion of the speech signal. While other CI users could discriminate these emotions (not perfectly, but substantially above chance levels of performance), they could not identify these four emotions. Thus, difficulties with emotion perception in young children with CIs may be a combination of a) the not-yet-fully-developed emotion perception in children of this age, and b) poor coding in cochlear implants of the signal characteristics relevant to emotion perception.

TUESDAY, POSTER 34

FREQUENCY RESOLUTION AND ITS RELATIONSHIP TO THE SPEECH PERCEPTION OF ADULT COCHLEAR IMPLANTEES

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This study examined the perception of vowel-like stimuli by cochlear implantees using a multidimensional scaling (MDS) technique. It was hypothesized that the variation in perceiving these stimuli may explain some of the variation seen in the speech perception performance of adult cochlear implantees.

Nine stimuli were generated from pairs of narrow band noises (NBNs) with three different F1 and F2 frequencies. Thirteen users of the Nucleus-22 cochlear implant system and SPEAK strategy were tested using their own speech processors. All stimuli were presented at a comfortable level in a sound-field condition. Speech perception was measured using the Speech Intelligibility Test (SIT) sentences and the vowel scores from the Consonant-Nucleus-Consonant (CNC) monosyllabic word lists.

The results showed no significant correlation between subjects' ability to resolve the F1 and F2 frequencies of vowel-like NBN stimuli and their speech perception measures ($r = 0.330$, $p = 0.271$ for the correlation with the mean SIT scores; $r = 0.046$, $p = 0.882$ for the correlation with the mean CNC vowels), in spite of some implantees' difficulty in perceiving the F1 frequencies. However, subjects' uncertainty in performing the MDS dissimilarity judgment task was significantly correlated with the speech perception measures ($r = 0.579$, $p = 0.038$ for the correlation with the mean SIT scores; $r = 0.868$, $p < 0.001$ for the correlation with the mean CNC vowels). A higher degree of response variability in performing the MDS task was associated with lower speech perception scores. The findings from the present study imply that cognitive abilities may explain some of the variation seen in the speech perception performance of adult cochlear implantees.

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TUESDAY, POSTER 35

NAMING AND VERBAL-FLUENCY ABILITIES IN CHILDREN WITH COCHLEAR-IMPLANTS

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The purpose of this study was to examine lexical organization in children using cochlear-implants (CI). We were interested in assessing whether there are differences in speed or quality of lexical processing in children with CIs compared to typically developing (TLD) hearing children. Furthermore, we wished to examine whether there are differences in the organization of the lexicon at the semantic level or the phonological level in these populations. We used two tasks to examine word retrieval abilities: a timed picture-naming task and a verbal-fluency naming task.

In the picture-naming task, drawings of objects were presented on a computer screen. The child was asked to name, as quickly as possible, objects that appeared on the computer screen. Two seconds after the child named the picture, a new picture appeared. Reaction time measures were obtained using a voice key.

In the verbal-fluency naming task, the child was asked to say, as many words as possible that belong to a certain category or that begin with a given sound. This task included two parts, a verbal-fluency semantic task and a verbal-fluency phonological task. In the verbal-fluency semantic task, the child was asked to name animals and, in a separate trial, to name foods. In the verbal-fluency phonological task, the child was asked to generate as many words as possible that begin with the sounds /t/, /f/, and /l/ in each of three trials. The child was given one minute to respond for each trial.

Results from 4 children with CIs and 8 TLD hearing children were included in this preliminary analysis. The age range of the CI children was 9;2 to 11;4 and of the TLD hearing children 7 to 11;11. Hearing impairment onset (for children in the CI group) was before the age of 2;7. The children had at least 3;4 years of experience with their cochlear-implant.

In the picture-naming task the CI children had longer response times than the comparison group of TLD hearing children. Thus, lexical access and retrieval is longer for CI compared to hearing children, even when stimulus is presented visually and their naming response is correct. However, some individual children with CIs had response-times that were similar to those of the hearing children. We will explore factors that may differentiate these children from the other children in the CI group.

A preliminary analysis of verbal fluency results indicated that CI children as a group performed more poorly compared to TLD hearing children. The total number of words they generated on these tasks was fewer than the total number of words generated by the TLD hearing children.

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SPECTRAL AND TEMPORAL CUES IN MANDARIN TONE PERCEPTION BY POST-LINGUALLY DEAFENED COCHLEAR IMPLANT USERS

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Despite the success in speech recognition in quiet, current cochlear implant users still face a great deal of difficulty in recognizing tones in tonal languages. The present study evaluated relative contributions of spectral and temporal cues to Mandarin tone perception by varying the number and the place of active electrodes in cochlear implant users. A functional measure of spectral and temporal resolution was also obtained by pitch discrimination and temporal gap detection.

Six post-lingually deafened adult subjects using Nucleus CI24M implants participated in this study. The subjects used their clinical processors to perform temporal gap detection as well as pitch discrimination at 250, 500, 1000, 2000 and 4000-Hz standard frequencies. The subjects also performed a 4-alternative, forced-choice Mandarin tone recognition task, in which 100 words consisting of 25 syllables with 4 tonal variations were presented in quiet and in the presence of speech-spectrum-shaped noise. The signal-to-noise ratio (SRN) was +10, +5, 0, and -5 dB. In addition to the subject's clinical map, experimental processors were constructed to remove 7 or 14 most apical, middle, or basal electrodes.

Gap detection threshold was 8.9±3.5 msec (mean±standard deviation). Weber's fraction in pitch discrimination was 0.40, 0.22, 0.06, 0.06 and 0.03 at 250, 500, 1000, 2000, and 4000-Hz standard frequency, respectively. Average tone recognition score was in quiet 85±11% and decreased from 66% at +10 dB SNR to chance performance at –5 dB SNR. Reducing the number of active electrodes decreased the performance by 10-20% points, with apical electrodes producing slightly better performance than basal electrodes. Statistical analysis showed significant correlation between pitch discrimination and tone recognition, but insignificant correlation between gap detection and tone recognition. The present data suggest that current implant users rely more on spectral cues than temporal cues to recognize tones. Implications to future speech processor design will be discussed.

SPECTRAL AND TEMPORAL CUES FOR PHONEME RECOGNITION IN NOISE: IMPLICATIONS FOR COCHLEAR IMPLANTS

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Cochlear implant users only receive limited spectral and temporal information compared to normal-hearing subjects. Their speech recognition performance deteriorates dramatically in noise conditions. The purpose of this study is to determine the relative importance of two speech cues, the temporal and the spectral cues, for speech recognition in noise. The temporal information is represented by the lowpass cutoff frequencies (LPFs) of the envelope extractor that varied from 1 to 512 Hz. The spectral information is represented by the number of channels (NCs) that varied from 2 to 32. Six normal-hearing native-English-speaking subjects were recruited to listen to acoustic simulations of cochlear implants under three conditions, i.e., in quiet and in noise with signal-to-noise ratios of +6 and 0 dB, respectively. Consonant and vowel recognition were measured as a function of the NCs and the LPFs. We found that the spectral cues exert a more dominant effect on speech recognition than the temporal cues. Speech-recognition performance deteriorates in noise. An increasing of the NCs improves vowel perception in noise. To reach performance plateau the number of channels increases from 12 in quiet to 16-24 in noise. However, for consonant recognition, no further improvement in performance is evident when NCs is ≥ 12 in all three conditions. The contribution of the temporal cues for phoneme recognition shows a similar pattern in both quiet and noise conditions. Finally, as in the quiet condition, there is a tradeoff between the temporal and the spectral cues for speech recognition in noise.

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COMMUNICATION DEVELOPMENT IN CHILDREN WHO RECEIVE THE COCHLEAR IMPLANT UNDER 12 MONTHS: RISKS VERSUS BENEFITS

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The advent of universal neonatal hearing screening in some countries and the availability of screening programs for *at risk* infants in other countries has facilitated earlier referral, diagnosis, and intervention for infants with hearing loss. Improvements in device technology, two decades of clinical experience with the cochlear implant in paediatric populations, a growing recognition of the efficacy of cochlear implants for young children, and the recent change in the USA Food and Drug Administration's age criteria to include *infants* with profound hearing loss has lead to increasing numbers of young children receiving cochlear implants. It is hypothesized that earlier implantation leads to greater speech perception, and faster rates of language acquisition as the child is still within the critical period for their development.

A retrospective review was completed for 16 infants aged between 0.61 and 1.07 years (mean 0.90, SD 0.15) and 84 toddlers between 1.15 and 2.00 years (mean 1.60, SD 0.23) who received the Nucleus multichannel implant at the Royal Victorian Eye and Ear Hospital, Melbourne, Australia. Pre-implant audiological assessments for these children included, aided and unaided audiograms, ABR, ASSR, and OAE's, and indicated profound to total hearing loss in all cases. Communication assessment included completion of the Rossetti Infant-Toddler Language Scale (RI-TLS) and educational psychologists' cognitive and motor assessment. CT scan and surgical records for each case were reviewed. Post-implant communication assessment included open-set word and sentence testing, formal language tests (Peabody Picture Vocabulary Test of receptive vocabulary, and/or Clinical Evaluation of Language Fundamentals [Pre-school or CELF-3], and/or RI-TLS), and educational psychologists' review. Testing was completed, where appropriate, pre-implant and at 1, 2, 3, and 5 years post-implant, but owing to clinical constraints and duration since implant, not all materials were completed for all child participants.

Results demonstrated that cochlear implantation may be performed safely in very young children with excellent communication outcomes. The mean rates of receptive (1.13) and expressive (1.05) language growth for children implanted less than 12 months was significantly greater than the rates achieved by children implanted between 12 and 24 months, and matched growth rates achieved by normally hearing peers. Mean open-set speech perception scores of 73% (phoneme score) and 46% (word score) are comparable with previous reports for children and adults who use cochlear implants.

DELAYED BDNF TREATMENT IN COMBINATION WITH BRIEF ELECTRICAL STIMULATION IN A GUINEA PIG DEAFNESS MODEL

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Several studies indicate that electrical stimulation (ES), even very briefly, can enhance spiral ganglion cell (SGC) survival in deafened guinea pigs. Also, intracochlear application of neurotrophins like BDNF enhances ganglion cell survival. When neurotrophins were applied together with ES, a synergistic effect was found. We are especially interested in enhancing SGC survival in animals which have been deaf for a period which might be clinically relevant. We applied in the current study a period of two weeks when in deafened guinea pigs a significant SGC loss starts to occur. We investigated the remaining cochlear function and degeneration pattern of SGCs in three groups of deafened guinea pigs. These groups were: A) untreated, B) treatment with BDNF, C) BDNF treatment + daily brief ES.

In group A, guinea pigs, implanted with a round-window electrode, were deafened by co-administration of kanamycin (400 mg/kg sc) and furosemide (100 mg/kg, iv). Compound action potentials (CAPs) were recorded before and at various times after treatment (immediately, 1, 2, 4, 7 days, 2-8 weeks). Acoustical stimuli were broadband clicks and tone pips of various frequencies (2-16 kHz). Animals were sacrificed after 1-8 weeks for histology.

In groups B and C, 2 weeks after the deafening procedure, the right cochleas were implanted with an electrode and cannula. The cannula was attached to a mini-osmotic pump (flow rate: 0.25 μl/h) and filled with BDNF (100 μg/ml). BDNF was administered to the cochlea for 4 weeks. In group C, the animals received additional ES in order to record eABRs. These animals received ES approximately 30 minutes per day, 6 days per week, for 4 weeks. The stimulus current amplitudes were 100-1000 μA, pulse width was 20 μs, interstimulus period was 99 ms. All animals were sacrificed for histology immediately after the 4 weeks of BDNF treatment.

The animals in group A (no BDNF) showed considerable diversity in the way their CAP thresholds changed over time after the deafening procedure. Whereas half showed monotonically deteriorating thresholds, the others showed intermittent improvement, especially after 1 day. However, all later deteriorated again. Changes in thresholds were seen up to 14 days. Thus, a relatively long delay after deafening is needed to obtain a stable condition. SGC densities started to decrease noticeably between 2 and 4 weeks and reached a 70% loss, 8 weeks after treatment. We will compare the SGC densities between the three experimental groups and relate the histological findings to functional measures derived from CAPs and eABRs.

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A HIGH-DENSITY ELECTRODE ARRAY FOR A COCHLEAR PROSTHESIS

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Since the 1980's cochlear prostheses have gained worldwide market approval and have become the most successful neural prosthesis with the number of users currently exceeding 80,000 worldwide. Over time, patient performance has improved considerably through advancements in speech processing algorithms, solid-state electronics, packaging and electrode design. This abstract addresses an alternative to traditional wire bundle electrode arrays and presents a silicon-substrate high-density cochlear electrode array. By employing a thin-film fabrication technique, stimulating sites can be placed 250μm apart (center-to-center) in a very precise and repeatable fashion. With the site density at least two times closer than commercial devices, this approach serves to better focus the electrical stimulation on the target neural elements and therefore activate a more confined neural population. As a result, channel interaction may be reduced and frequency resolution increased leading to enhanced speech perception.

To assess the efficacy of high-density arrays in a guinea pig, a shallow insertion device (10mm length, 500-200μm taper) has been fabricated and tested in the first cochlear turn. Thirty-two iridium-oxide stimulating sites (180μm-diameter) are placed at a 250μm pitch on a thinner (2-4μm) portion of the substrate, while a thicker (14μm) back-end portion remains outside the cochlea to support electrical connections and the option for integrating commercially fabricated circuitry. Aluminum conducting traces are sandwiched between stress-balanced oxide-nitride dielectrics. In-vivo testing revealed auditory thresholds of 50μA and 300μA for monopolar and bipolar stimulation, respectively. Measured back-voltages indicate that stimulation with up to 1mA for up to 40nC of delivered charge is possible from a 3V supply. The thin-film process enables the integration of eight segmented polysilicon strain gauges, which can sense curvature, as well as a wall-contact sensor at the array's tip. Output from the curvature sensors can determine array position to better than 50μm.

Directly coupled to the benefits of a high-density array is modiolar proximity. Silicon-substrate arrays exhibit considerable in-plane flexibility and have been tailored to maintain a perimodiolar resting state, but this compliancy requires an articulated backing or insertion tool for successful device insertion. To that end, Michigan Technological University is actively fabricating a backing device consisting of multiple fluidic chambers that provide localized curvature control along the length of an attached array.

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STANDARD MAP PROGRAMMING WITH THE MED-EL COMBI 40+ SYSTEM

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Recent investigations (Boyd, in press) on users of the MED-EL COMBI 40+ system have confirmed anecdotal clinical experience that the setting of the electrical thresholds during the fitting process is not critical. This work has been extended to look at the relative importance of the upper programming setting. The approach taken in the present study has been to test levels of performance obtained by subjects using "standard" programs (maps) rather than their everyday "customized" maps.

Psychometric fitting data were examined for a group of 90 long-term users in order to determine the average upper programming setting on each electrode. Using these data, standard maps were generated and tested on subjects in acute trials (i.e. a few minutes experience only) and compared to performance levels obtained using each subject's normal customized map. The degree of "imbalance" of each standard map was assessed by having the subject indicate the perceptual loudness of each channel at MCL using a visual-analogue scale.

Average sentence discrimination score in quiet for 8 subjects was found to be 67% for customized maps and 53% for the standard map (statistically significant). However, while the standard map produced lower scores it is very likely that scores would be higher if users were able to gain experience and familiarity with the new settings.

Additional trials for a group of subjects tested at the "switch-on" session, in order to clarify this issue, are currently in progress in this department and will also be presented. Results to date show a much less obvious difference between the benefits obtained by standard and customized maps than those indicated by the acute series.

These results demonstrate that very acceptable levels of performance can often be obtained from standard maps, which is information of considerable value when programming young children where behavioural or objective fitting data are not available. It is likely that these findings will also be of value in the design of simplified devices for use in developing countries.

WEDNESDAY, POSTER 4

IMPLICATIONS OF NEURAL DEGENERATION FOR ELECTRODE DESIGN: CLINICAL OBSERVATIONS AND INSIGHTS FROM COMPUTATIONAL MODELING

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In spite of the fact that multi-channel cochlear implant electrode arrays have been inserted into the scala tympani for over 20 years, there is little agreement between both researchers and manufacturers on the optimal position of the array within the scala tympani. Some groups report the most favorable results with an array placed against the outer wall over its full length, others argue that a position close to the medial, modiolar, wall is most favorable with respect to the threshold and spatial selectivity. How and to what extent the clinical outcome in terms of speech understanding is influenced by lateral-to-medial variations of the electrode position is even less clear. Our group observed a significantly better speech perception in a group of 25 patients with the CII cochlear implant system (HiFocus I electrode) with a partially inserted positioner, compared to a demographically identical group of 20 patients with the same implant and array but with the entire array in an outer wall position. Thus, although the amount of evidence favoring a peri-modiolar position is growing, it is still unclear if these positive effects can be expected for all contacts along the array. Moreover, very little is known about the functional consequences of neural degeneration, which is considered a common phenomenon, starting with the loss of peripheral processes.

The present study applied a realistic 3D-computational model of the human cochlea to predict the effects of a lateral-to-medial shift and insertion depth of each contact of a model of the HiFocus I electrode array. The simulations were performed with completely intact nerve fibers and with fibers without peripheral processes to simulate neural degeneration. For the basal end of the cochlea the model predicted reduced thresholds, and increased dynamic range and spatial selectivity values for the peri-modiolar position, with minimal influence of neural degeneration. At the apical end of the cochlea, neural degeneration was expected to reduce the functional dynamic range and the spatial selectivity considerably for perimodiolar contacts, while outer wall electrodes turned out to be less sensitive in this respect. This lead to the conclusion that the ideal electrode should be perimodiolar at the base of the cochlea, while the apical contacts should reside along the outer wall. The HiFocus 4L electrode is a one-piece electrode meeting these design criteria. It is currently tested in temporal bones. Initial results will be shown.

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EFFECTS OF POST-DEAFENING GROWTH FACTOR TREATMENT ON ELECTRICAL DETECTION THRESHOLDS

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Sensorineural hearing loss (SNHL) involves damage to one or more components of the auditory pathway, including hair cells, spiral ganglion cells (SGC), the auditory nerve central processes and more central auditory nuclei. Cochlear implants (CI) have been widely successful in restoring partial hearing to patients with SNHL. Since these implants function by stimulation of the auditory nerve, it is probable that promoting survival of auditory neurons could enhance CI performance. Upregulation of growth factors, including brain-derived neurotrophic factor (BDNF) and ciliary-derived neurotrophic factor (CNTF), have been shown to enhance SGC survival. In this study we examined the effect of these growth factors on CI detection thresholds in guinea pigs.

After deafening the ear by local infusion of neomycin, growth factors were introduced into the cochlea via an adenovirus containing a gene insert that encoded for either BDNF or CNTF. In Experiment I, animals were inoculated with a combination of both BDNF and CNTF. Experiment II animals received an inoculation of only BDNF. Psychophysical electrical detection thresholds were measured using tripolar, bipolar, and monopolar configurations. An apical and a basal site of stimulation within the basal turn of the cochlea were tested for each of these configurations, giving a total of 6 configuration and site conditions. When compared to control animals that received either artificial perilymph or empty adenoviral inoculations, Experiment I animals had lower average detection thresholds in five of the six conditions. Specifically, there was a difference between control and treatment animals in all conditions with the exception of the apical tripole. Experiment II animals showed a lower average detection threshold when compared to controls for all three apical conditions, but did not show any difference for the three basal conditions. The results of this study suggest growth factor upregulation as a possible means of enhancing cochlear implant performance.

A FULLY IMPLANTABLE MIDDLE EAR HEARING DEVICE USING THE DIFFERENTIAL ELECTROMAGNETIC TRANSDUCER

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The fully implantable middle ear hearing device (F-IMEHD) using the differential electromagnetic transducer (DET) has been studied and developed for 3 years by Korean research team. Through this paper, we show the function and test results of the developed F-IMEHD and related accessories such as battery charger and remote controller.

The developed F-IMEHD are composed of five main parts of a vibration transducer, an implantable microphone, a sound signal processor with adjustable filter characteristics, a control signal transmitting and receiving module for the communication with remote controller and battery charger, and a recharging circuit for an internal battery of F-IMEHD. As the vibration transducer, the DET has been designed to produce a maximal vibration and implemented into the appropriate size for implanting in the middle ear. And the vibration characteristics have been tested using the various material of DETs' membranes. The sound signal processor has the function of digitally selectable filter with various frequency characteristics and adjustable sound gain controlled by a low power consumption micro-controller. For the recharge and wireless control of the F-IMEHD, a transcutaneous battery charger using inductively coupled coils and a RF type remote controller with LCD interface have been designed and implemented.

Through the circuit designing and power management by micro-controller, the F-IMEHD can work for about 6 days when the average usage time a day is assumed to 15 hours. The small size and the low power consumption of our F-IMEHD have been improved to be enough for implant.

The DET vibration experiment of developed F-IMEHD has been carried out. Also, in order to demonstrate the function and usefulness of our F-IMEHD, *in-vitro* and *in-vivo* experiments have been carried out using an ossicular chain of a cadaver and animal such as a guinea pig and a dog. The experimental results, it is verified that the developed F-IMEHD using a DET has a suitable performance for the replacement of conventional hearing aids.

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WEDNESDAY, POSTER 7

MODELING OF ELECTRIC FIELD IMAGING TECHNIQUE AND IMPEDANCE MODELS OF COCHLEAR IMPLANTS USING FINITE ELEMENT METHOD

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Typically, the impedance measurements between neighboring cochlear implant (CI) electrodes are used for diagnostic purpose. Impedance measurement within working ranges is an indicator of the integrity of the electrodes. The electric field imaging technique (EFI) has been used to measure the intracochlear potential of electrodes and the current flow from the active electrodes. An impedance matrix can be created based on the potential and current measurements. This extends the impedance measurement of neighboring electrodes only, which is typically done, to measure the impedance measurements of all the electrodes. Recent research shows that EFI data can be used to compute and provide insight to the current flow in the cochlea and study the integrity of the whole electrode array. A better understanding of intracochlear mechanism might be provided by the impedance matrix from EFI technique.

In this paper, the impedance matrix of EFI is modeled by using a realistic model of a single turn spiral tapered human cochlea, an implant electrode array and a new electrode-tissue interface model using finite element method. The results of the finite element analysis of the cochlear implant electrodes generate impedance values across the electrode array which can be used to generate an impedance matrix. Due to discrepancy in the Warburg capacitor in the active and non-active electrode contacts and power lost along the cochlea, the diagonal terms of the impedance matrix is larger than the off diagonal terms, which represent the impedance values of the non-active electrode contacts.

The simulation result was compared with the measurement results. It is found that the electrode-tissue interface is important to the accuracy of the model. It is crucial to incorporate electrode-tissue interface layer to cochlea models in order to obtain accurate results. It also shows that the anatomy, tapering of the cross section area of the cochlea, is important to the solution of the model, though spiraling of the cochlea model is not. This model result also shows us that electric power is leaking along the cochlea.

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DISTRIBUTION OF ELECTRICAL ARTIFACTS ON THE SCALP

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The primary goal of this project is to obtain a deeper understanding of the functional operation of the cochlear implant by objectively testing these devices in individual patients. A generic approach has been developed to monitor and evaluate any clinical implant system "in situ" while it is actively stimulating by recording scalp electrical artifact potentials generated by the device. Our work extends the initial work done in this field (Mens) by looking also at scalp potential distributions at different points on the head. We hypothesize that these distributions can provide information about both the functional operation of the implanted device and the routes by which stimulation currents enter and leave the implanted cochlea.

A custom-designed, biological-potential amplifier, a hand-held electrode-probe, a flexible head cap, and recording software were developed. Patient data were obtained from Med-EL C40+, Clarion C-I, Clarion C-II, and Clarion High Resolution 90K devices. A flexible head cap is worn by patients to provide a grid of the standard 10-20 EEG system electrode locations. Using the probe, surface artifact potentials were recorded from points on the head corresponding to coordinates of the extended international 10-20 system. Artifact potentials are analyzed on the basis of their temporal structure and spatial distribution on the scalp. Software tools developed in MatLab and Visual Basic decompose multi-channel data into single channels of coded information, and can extract anomalies in these data sets, if present. The spatial distributions are quantified by peak-to-peak amplitudes and mapped using MatLab.

Results indicate that in general differences do exist in the spatial distribution in addition to variations in the distribution based on the electrode being stimulated. These observations lead us to believe that there are differences in current spread along the cochlear tissues, which arise due to variations in the anatomy and electrode position. Data from patients with suspected case fractures have been obtained and analyzed. Specifically, the spatial electrical field distribution in the vicinity of the implanted device was studied in greater detail for evidence of possible current leakage due to a case fracture. A mathematical model of the system is being developed to characterize the potentials and help provide more insight into these surface potential distributions. The poster will describe the methodology in detail and present examples of several applications of the tools.

CLINICAL AND SUBCLINICAL FACIAL NERVE STIMULATION IN CHILDREN WITH COCHLEAR IMPLANTS

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Background: Cochlear implants restore hearing through direct electrical stimulation of the primary auditory nerve. Given the nature of the stimulus, spread of current to surrounding structures such as the facial and vestibular nerves is of concern.

Purpose: 1) to identify auditory from facial nerve stimulation in the auditory brainstem evoked potential; 2) to examine the incidence of both clinical and subclinical facial nerve stimulation and its characteristics in children with cochlear implants;

Methods: Auditory evoked potential recordings were done in combination with electromyographic monitoring of multiple branches of the facial nerve. Intraoperative measures were made in children immediately following implant insertion and the presence of myogenic responses was confirmed by paralysis. The incidence of electrically evoked facial nerve stimulation was measured both prospectively, in a group of 25 children who had at least one year of implant experience, and retrospectively, in a separate group of 100 children.

Results: Intraoperative recordings showed large non-auditory responses at a number of sites including the auditory evoked potential. Under paralysis, the responses were absent and clear auditory brainstem responses were recorded. Similar electromyographic responses were found in experienced cochlear implant users indicating that facial nerve stimulation occurred at comfortably loud levels in 50% of a cross-sectional group of 25 implant users. Different patterns of stimulation of the branches of the facial nerve were seen across individuals. Retrospective analysis of previously recorded auditory brainstem responses demonstrated a 36% incidence of facial nerve stimulation.

Conclusions: 1) Facial nerve potentials can be recorded using electrophysiologic measures in a number of cochlear implant users at high levels of stimulation. 2) The auditory brainstem response can be obscured in the presence of facial nerve stimulation. 3) Electrophysiologic recording of facial nerve stimulation provides an additional objective measure to ensure the safe and comfortable use of cochlear implants in children.

WEDNESDAY, POSTER 10

AUTOMATED FITTING SOFTWARE STUDY

Wendy S. Parkinson[1], Pamela W. Dawson[2], Gregory H. Wakefield[3], Sean K. Lineaweaver[1], Chris van den Honert[1], Yetta Abrahams[4]

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The process of "custom" fitting a cochlear implant to the needs and preferences of its recipients is a clinical challenge for cochlear implant audiologists. Processor MAP parameters may be combined into literally thousands of programs, and asking a recipient to exhaustively evaluate each of these is impractical at best. Moreover, direct investigation of individual parameters is also difficult because they tend to interact non-monotonically with one another. Therefore, clinicians typically defer to choosing from default suggested settings or from preferences based upon personal experience or clinical intuition. If the recipient is performing "at expected levels", most clinicians tend to be satisfied that the selected parameters are appropriate. If the recipient isn't performing well, some clinicians may search further to evaluate a limited set of parameters hoping the effect of the parameter changes will be positive. In any case, the task of the clinical professional to choose a MAP that will provide the best possible outcome is time-consuming and potentially unreliable.

The purpose of this investigation is to evaluate an Automated Fitting procedure that allows an implant recipient to rapidly find his or her "best" speech processor MAP. The fitting software is based on a mathematical model of biological evolution called the Genetic Algorithm (GA) (Wakefield, G. H., Parkinson, W., Lineaweaver, S. and van den Honert, C. (2005). "Genetic algorithms for adaptive psychophysical procedures: Recipient-directed design of speech-processor MAPs," *to appear in* Ear & Hearing.) The software provides a means for individual cochlear implant recipients to search iteratively over multiple MAP parameters using the GA in order to identify the one MAP they prefer. As the software progresses, MAP parameters including channel number, maxima, stimulation rate, frequency allocation table, threshold emphasis, Q-value, and input/output filtering, are varied simultaneously until a final "GA MAP" is selected for both quiet and background noise conditions.

This study involves twenty experienced subjects, both "good" (3-18 months experience) and "poor" (6-18 months experience) performers, from Cochlear's research laboratories. Specifically, comparisons between two "GA" MAPs (one evolved in quiet, and one evolved in noise, from among 1024 possibilities) with two "standard" (designed with clinical default parameters) MAPs will be made. These MAPs will be evaluated through both speech perception testing and take-home questionnaires. Another aim of the study is to characterize how well these two experienced groups use the automated fitting software. Preliminary data will be presented.

SINGLE ELECTROPHYSIOLOGICAL RECORDING SESSION IN INFANTS CANDIDATE TO COCHLEAR IMPLANTATION

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Early cochlear implant application in infants suffering from bilateral profound sensorineural hearing loss ensures maximal amount of auditory information during a very critical period, thus reducing the effects of auditory deprivation. One of the possible drawbacks of early implantation is the uncertainity in the diagnosis of deafness.

The present investigations reports our experience with estimation of severe to profound hearing loss in infants using both classical auditory brainstem responses (ABR) and round window electrocochleography (RW ECoG). The diagnostic efficiency of both techniques is analysed and its reliability in the candidacy process to cochlear implant assessed. The technique of round window electrical stimulation (RW ES) to evaluate the responsiveness of the auditory neurons and integrity of the auditory nerve is also illustrated.

From November 1998 to December 2004, over 386 children with a suspect of hearing loss have been tested while under general anesthesia to a single recording session including ABR, RW ECoG, RW ES as a one-day procedure. Standard ABR with click stimulation at 21 per second was first tested. Thereafter, under otomicroscopy, a miringotomy was perfomed from the umbus to the posterior anulus of the tympanic membrane and the round window niche visualized. A gold-ball electrode was thus placed under direct view in the round window niche. RW ECoG was thus performed using click stimuli and tone burst (0.5, 1 and 2 kHz). After being utilized as a recording electrode for ECoG, the same gold-ball electrode placed on the round windo was used to perform RW ES to test the viability of cochlear nerve fibers by means of contralaterally eABR recording.

The presence of ABR was invariably associated with recordable RW ECoG. On the other hand, responses at RW ECoG were found in 15 to 25% of patients in whom ABR was absent. The reliability of ECoG in estimating the hearing threshold was validated in 45 children in whom it was possible to perform subjective tonal audiometry 1 to 3 years after the electrophysiological testing. When calculating the diagnostic efficiency of the ECoG to predict a profound hearing loss, a score of 98% were obtained. Seventy-nine of the 386 children showed a severe-to-profound hearing loss and received a cochlear implant. Thirteen children aged less than 1 year, 41 between 12 and 23 months, and 25 between 24 and 36 months. Additional 12 children showed no response at the RW ES and various type of malformations at MR and CT scan (cochlear nerve aplasia, cochlear malformation or both), and received an auditory brainstem implant (ABI).

In conclusion, RW ECoG is a reliable technique to establish the auditory level in infants furnishing useful indications for candidacy to cochlear implantation. RW ES is also performed in the same session, utilizing the round window electrode, yielding an estimate of the conduction along the peripheral and brainstem auditory pathways. A single electrophysiological recording session greatly contributes to speed up the diagnosis of deafness contributing to very early auditory rehabilitation.

WEDNESDAY, POSTER 12

PERIPHERAL PHYSIO-ANATOMICAL FACTORS IN COCHLEAR IMPLANT OUTCOMES

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Because large variation in outcome is observed across patients with the same cochlear implant system, yet mean performance levels across different devices are highly similar, we hypothesize that patient-dependent factors play a significant role in determining outcome in individual cochlear implant patients. More specifically, we seek to determine how well the peripheral factors of (1) cochlear size and shape, (2) electrode insertion depth and scala tympani position and (3) neural survival and physiological responsiveness as measured in individual implant subjects account for the performance variation seen across the same subjects.

Because CT metal electrode artifact contamination interfers with identification of the electrode array and obscures fine anatomical features of the cochlea, we employ a two-step imaging procedure to determine electrode position in the cochlea. Using well-defined anatomical landmarks, we coregister a pre-op CT image voxel space optimized for anatomical detail with a post-op CT image space optimized for resolution of the electrode. The electrode is then segmented and copied into the pre-op image space to provide a composite image of electrode placement within an individual's cochlea. Procedures to reduce the artifact contamination by post processing of image raw data and to enhance anatomical detail using a micro-CT reference data set are also being developed.

Peripheral physiological responsiveness is measured grossly by obtaining I/O growth and spatial distributions of intracochlear evoked potentials (IEP) along the electrode array. These measures are augmented with ad hoc two-pulse forward masking measures to determine if measured potentials are due to passive spread within the cochlea or originate from neurons local to the masking electrode.

Finally, this project seeks to estimate the combined influence of physiological responsiveness and variable neural survival in an individual subject by comparing IEP measures against a reference electro-anatomical-neural computational model that assumes full neural survival and uniform neural characteristics. The electro-anatomical reference model is based however on the cochlear anatomy and electrode placement as determined by the CT images of each individual subject. Multiple linear regression analysis is used to examine the relative and combined contributions of each of these factors in accounting for the variance in the performance outcomes of eight Clarion C-II and 90K subjects. Use of this information has proven highly useful in modifying standard clinical maps to produce improvements in receptive speech outcomes.

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ATYPICAL CORTICAL ACTIVITY IS ASSOCIATED WITH POOR SPEECH PERCEPTION IN CHILDREN WITH COCHLEAR IMPLANTS

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Background: Obligatory responses from the auditory cortex in children who use cochlear implants may differ in both morphology (Ponton and Eggermont, 2001) and latency (Sharma, et al., 2005) from age matched peers who have normal hearing. It is not clear, however, how these responses compare to responses from more peripheral levels of the auditory pathway, how they vary across experienced paediatric cochlear implant users, and how they might relate to behavioral outcomes.

Purpose: 1) to examine auditory pathway activity from the brainstem to cortex in children using cochlear implants; 2) to assess the relationship between electrophysiologic measures of auditory activity and behavioral measures of hearing in these children.

Methods: Evoked potential responses from the auditory brainstem, thalamo-cortical pathways and cortex were recorded in 23 children who were 6.4 ± 2.9 years of age at activation and who had 5.8 ± 0.6 years of implant experience. Measures were made at center mid-line (CZ) referenced to the ipsilateral earlobe for early and middle latency responses and to linked ipsilateral and contralateral earlobes for later latency responses. Separate responses were evoked by single pulses or pulse trains delivered either from an electrode at the apical or at the basal end of the implanted array at comfortably loud levels. If visually detectable, responses were categorized as typical or atypical (as compared to previously reported waveforms). Markers were blinded to all demographic data. Wave categories and latencies across children were compared and possible relationships with behavioral measures were analysed.

Results: Typical brainstem and thalamo-cortical responses were found in all but 1 child and atypical cortical responses were observed in 6 of the 23 children. Analyses of responses from these 6 children suggested trends toward differences in brainstem and thalamo-cortical responses and significantly poorer speech perception scores ($p<0.05$). The children with atypical cortical responses ranged in age at the time of implant activation from 5.0 to 12.3 years whereas the children in the other group were 2.9 to 11.0 years at activation.

Conclusions: Atypical patterns of activity in the auditory cortex: 1) might be associated with differences at more peripheral levels of the pathways, 2) relate to poorer speech perception outcomes, and 3) indicate immaturity in the auditory cortex or abnormal cortical processing of auditory input.

ELECTROPHYSIOLOGICAL RESEARCH TOOLS FOR THE FREEDOM™ COCHLEAR IMPLANT

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To support electrophysiological research with the Nucleus® Freedom™ cochlear implant, the next generation of the Nucleus Implant Communicator (NIC™) suite of tools has been developed. The Freedom implant is very attractive for electrophysiological research as it has a significantly improved Neural Response Telemetry (NRT™) system. This is ideal for early-latency response research where decreased amplifier noise, a higher sampling rate of 20 kHz and up to 64 samples all contribute. The NIC tools provide a framework to control this functionality in conjunction with the generation of stimulation. The NRT measurements are specified in the same fashion as the stimulation, allowing precise control of both stimulation and measurement. The NIC tools are hardware independent, with stimulation and measurement parameters expressed in familiar units.

For other types of electrophysiological research involving mid-latency responses (EABRs) and late-latency responses (CERA), the NIC tools also provide for synchronisation of external recording equipment. This synchronisation is bi-directional and provides for either a trigger in or out to suit the external recording equipment. Multiple operating modes are possible including synchronisation to the start of stimulation, synchronisation to individual stimuli or even to a fixed point in time during the stimulation.

The NIC tools can also support synchronised bilateral stimulation for either electrophysiological or speech coding research. This is achieved through the use of two speech processors and suitable connection of the trigger signal. The basic stimulation functionality available with the NIC tools will typically be used for electrophysiological research. However, where an audio signal is the test signal, MATLAB® and the Nucleus MATLAB Toolbox (NMT) are more suited. The toolbox provides a speech coding research framework and has been extended to include synchronisation trigger control. The trigger can be controlled relative to the test signal and therefore the desired response can be recorded. This is ideal for use in late-latency response research where audio signals are often used as the test input signals.

MEASUREMENT OF THE ELECTRICALLY EVOKED AUDITORY BRAIN STEM AND CORTICAL RESPONSES USING THE NUCLEUS® FREEDOM™ COCHLEAR IMPLANT

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Objective measures such as the electrically evoked auditory brainstem response (EABR) and cortical evoked response (CEP) hold great potential for cochlear implant recipients unable to provide behavioural feedback regarding the performance of their cochlear implant. Unfortunately, detection of either the EABR or CEP currently requires the use of externally placed scalp electrodes and specialised recording equipment.

The objective of this study was to evaluate the technical feasibility of recording both the EABR and CEP using the neural response telemetry (NRT™) amplifier of the Nucleus Freedom cochlear implant. In such a system, the electrodes used to detect the EABR or CEP consist of two extra-cochlear electrodes.

All recordings of the EABR and CEP were performed in 4 guinea pigs acutely implanted with an 8 electrode scala tympani array. The guinea pigs were deafened with the co-administration of kanamycin and furosemide. The potentials were recorded from a pair of extra-cochlear transcutaneous needle electrodes inserted at the nape of the neck and vertex respectively. Electrical potentials present at the extra-cochlea electrodes were amplified using the Freedom implant's NRT amplifier and subsequently telemetered via RF to an L34SP research speech processor.

Results indicated that both the EABR and CEP of the deafened guinea pigs could be recorded using the Nucleus Freedom cochlear implant NRT amplifier via two extra-cochlea electrodes. Future testing will attempt to record the EABR and CEP using the conventionally implanted extra-cochlear electrodes in human recipients of the Freedom cochlear implant.

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WEDNESDAY, POSTER 15

ELECTRODES AND STIMULATORS FOR STRIAL PRESBYCUSIS

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Many elderly people experience age-related hearing loss extending from low to high frequencies. The relationship between increased hearing thresholds and the corresponding reduction in the endocochlear potential generated by the stria vascularis in the cochlea is well documented (*strial presbycusis*). Some estimates suggest that between six and seven million elderly suffer from strial presbycusis in the U.S. No treatment, other than hearing aids, is available for them at the present time.

Recent research on animals demonstrates that increasing the endocochlear potential (EP) to its normal value results in bringing hearing thresholds near their normal values. Advanced Cochlear Systems (ACS) is developing a hearing assist device based on this new research. The implanted device will maintain the endocochlear potential at near normal values in the ears of strial presbycusis patients. The device will likely reverse their hearing impairment. This device may also arrest deterioration of the scala media.

ACS is following a phased approach to develop the therapeutic device. We have prototyped a Valve Rectifier System (VRS) to test in animals for durations of a few hours to two weeks. The system is being evaluated at the Medical University of South Caolina, using gerbils as subjects.

We have tested several surface treatments of electrodes: Pt, Ir and IrO. The prototype uses activated iridium oxide film (AIROF) surface treatments. We are testing sputtered iridium oxide film (SIROF) and electrodeposited iridium oxide film (EIROF) as well (EIC Laboratories, Norwood, MA). The rectifier has been fabricated in a half-wave version; two half-wave rectifiers combine to make a full-wave device.

We continue to study electrode surfaces, test the rectifier system in animals, and plan to produce a miniaturized version of the system.

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WEDNESDAY, POSTER 16

USING NRT TO PREDICT STIMULATION LEVELS: PEDIATRIC CONSIDERATIONS

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Although improvements in cochlear implant technology are associated with significant increases in speech perception ability, accurate setting of stimulation levels remains critical for optimal performance. For Nucleus patients, clinicians must determine appropriate stimulation levels for both threshold (T) and comfort (C) levels. For most patients, these levels are easily obtained using clinical techniques that utilize behavioral, objective, or a combination of both types of measures. However, certain patients are simply unable to provide subjective feedback to assist in the determination of stimulation levels. Furthermore, objective measures such as electrically-evoked stapedial reflexes (eSRT) may not be present necessitating the need for an alternative means of determining appropriate stimulation levels. Neural Response Telemetry (NRT) has been proposed as a possible solution; however, all methods proposed thus far require some degree of patient feedback during the programming session.

We have demonstrated that NRT measures can be used to predict stimulation levels without subjective feedback in adult subjects by using regression to develop prediction formulas (King et al., 2004 ARO abstract #882, King et al., 2005 ARO abstract #231). We also demonstrated that speech perception performance with MAPs derived from predicted C levels was not significantly different when compared to clinical MAPs (King et al., CI 2004 abstract #137). While these results are encouraging, it is not yet known whether this technique can appropriately be applied to pediatric patients.

Preliminary data collected thus far demonstrate that children have considerably larger NRT growth function slopes as well as NRT response amplitudes when compared to adults. Also, children who were implanted at later ages tended to have smaller NRT slopes and amplitudes than those implanted earlier, which may affect their predictions. Of concern is the possibility that predicted C levels may be higher than C levels obtained clinically. This is also true for the adult population as our data showed that adult subjects with greater than 20 years of deafness prior to implantation were at risk for overestimation whereas the risk for the remaining subjects was less than 1 %. By taking these factors into account, we can reduce the potential risk of over-stimulation.

Overall, the data obtained from adults and preliminary data from children suggest that when using NRT measures to predict appropriate stimulation levels, one size does not fit all. That is, separate predictive equations may be necessary for different patient populations to optimize T and C levels. Due to the potential inaccuracy of predicted levels, behavioral or eSRT clinical measures should be used whenever possible, reserving prediction from NRT measures for difficult cases. Although we have had success predicting stimulation levels using NRT in adults, further research is needed to investigate applicability of this technique to the pediatric population.

WEDNESDAY, POSTER 17

LONGITUDINAL ANALYSIS OF T- AND C-LEVELS; OPTIMIZING THE REFITTING INTERVAL

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The growing number of implant recipients imposes a growing demand on audiological capacity. One way to meet this growing demand is optimization of the time interval between refittings of the CI sound processor. Accepting certain quality criteria concerning the maximum shift in T- and C-levels allowed between two successive fittings and the probability that this maximum shift is exceeded by some recipients in the population we have calculated the refitting intervals using the longitudinal data from about 200 recipients over a period extending to four years. The calculations are based on the assumption that the evolution of T- and C-levels towards stable values follows an exponential time course. A significant deviation from this assumption was found in only 5 cases. The results will be presented for shifts of 3, 6, 9, 12, and 15 current units within subsequent refitting intervals to be exceeded by not more than 5 or 10% of the population. The data pertain to the T- and C-levels of electrode 13 of the Nucleus CI24M implant. It is recognized that these results may depend on the audiologist's attitude toward the CI recipient. Therefore the data stem from four audiologists who worked without a common written protocol.

WEDNESDAY, POSTER 18

TNRT PROFILES WITH THE NUCLEUS RESEARCH PLATFORM 8 SYSTEM

Waikong Lai[1], Norbert Dillier[1], Benno Weber[1], Thomas Lenarz[2], Rolf Battmer[2], Bruce Gantz[3], Caroline Brown[3], Noel Cohen[4], Susan Waltzman [4], Margaret Skinner[5], Lisa Holden[5], Robert Cowan[6], William Gibson[7], Peter Busby[8], Sarah Ashburn Reed[8], Matthijs Killian[8] and Bas van Dijk[8]

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The Nucleus Research Platform 8 (RP8) system consists of the new CI24RE cochlear implant, a custom L34 processor and custom Nucleus Programming Environment software. Amongst the new features of the CI24RE implant is an improved measurement amplifier for making intracochlear recordings of the evoked compound action potential, which has less noise, greater linearity, higher sampling rates as well as larger sampling buffers compared to its predecessor in the CI24M/CI24R implant. The improved noise floor enables Neural Response Telemetry (NRT) recordings to be made much closer to the actual response threshold, resulting in lower and more accurate estimates of the NRT threshold (TNRT). With the increasingly widespread use of TNRT profiles as an aid for clinical fitting, it is of interest to examine if the TNRT profiles are significantly altered by the improved TNRT estimates.

Data from 31 subjects were analysed. For each Amplitude Growth Function, the TNRT was obtained, as well as the TNRT for the same data above 50uV ($TNRT_{50}$). The latter approximates NRT recordings made with the previous generation CI24M/CI24R implant, 50uV being the typical noise floor then. The resultant TNRT profiles from these two estimates of the response threshold were then compared with the behavioural map T & C levels, as well as against one another.

Correlations with the behavioural Map T & C levels were found to be very similar for both TNRT and $TNRT_{50}$. On average, TNRT was 6 Current Level units lower than $TNRT_{50}$. Comparisons of the corresponding TNRT and $TNRT_{50}$ profiles showed that the average variation in their differences ($TNRT_{50}$ – TNRT) along the array was practically zero, indicating that TNRT profiles and their corresponding $TNRT_{50}$ profiles were parallel to one another.

In conclusion, the TNRT profiles from the CI24RE implant are similar to those obtained using the previous generation implant. The correlations of the TNRT values to the behavioural Map T & C values are also similar to those from the previous generation implant, and the TNRT profiles from the CI24RE implant can thus be applied in the same manner as in current clinical fitting practice.

Supported by Cochlear AG, Basel, Switzerland

DELAYED ELECTRICAL STIMULATION AND NGF APPLICATION FOLLOWING INDUCED DEAFNESS IN GUINEA PIGS

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NGF application following ototoxic trauma can significantly reduce degeneration of spiral ganglion cells (SGC). The aim of the experiments presented was to investigate the protective effects of GDNF on SGC during delayed intervention.

Guinea pigs were deafened by application of kanamycin and etacrynic acid. With a time delay of three weeks, the animals received a cochlear implant system in combination with local drug therapy with 100 µg/ml GDNF. A second experimental group received artificial perilymph instead of the neurotrophic factor. Electrical stimulation levels were at 100 and 200 µAmp.

The groups treated with GDNF showed a clear protection of the SGC in the implanted ear. Electrical stimulation at 100 µAmp resulted only in a slight increase in SGC survival compared to control, whereas stimulation at 200 µAmp together with GDNF treatment provided best spiral ganglion cell protection and survival.

The results indicate that, even with delayed intervention, GDNF is able to increase the number of surviving SGC. This protective effect can even be enhanced by simultaneous electrical stimulation of the cochlea. These findings could be a significant step towards a human application of NGF together with cochlear implantation.

PERISYNAPTIC AUDIOPATHY (AUDITORY NEUROPATHY) - MATCHED-PAIR COMPARISION IN COCHLEAR IMPLANT PATIENTS –

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Perisynaptic audiopathy is a well-discussed disorder, with its combination of symptoms (changing speech understanding up to profound loss of speech understanding, reproducible OAE, pathologic ABR) and the reports of effective cochlear implant (CI) use in these patients. The aim of this paper is to clarify whether clinical signs of a neural peripheral disorder in CI patients with perisynaptic audiopathy can be identified.

A group of 8 CI patients (4 children) with perisynaptic audiopathy were compared with matched-pair CI patients selected by the following criteria: etiology, duration of deafness und experience with conventional hearing aids, other neural deficits, age at time of deafness and implantation. In addition to the evaluation of speech understanding and development of speech in children, parameters of the CI maps and strategies used within the processing were compared.

The audiological results demonstrate that obtaining additional electrophysiological data (such as EcochG) allow more detailed differentiation of the group. All patients with perisynaptic audiopathy benefit from the CI. However, the level of electrical stimulation and the evaluation of the follow-up demonstrate that the pathophysiology includes cochlear, neural and synchronisation disorders. Only in one patient the CI does not lead to a benefit – which will be discussed under the focus of implantation in children.

AUTOMATIC ESTIMATE OF THRESHOLD FROM NEURAL RESPONSE IMAGING (NRI)

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Cochlear implants implanted in young children present a special challenge for accurate programming because, for the most part, these children can provide only limited verbal feedback. Modern cochlear implant systems support direct measurements of neural activity in response to stimulation by the implanted electrodes. While these measurements can supplement behavioral feedback and aid in programming, a difficulty in their interpretation arises from a stimulus artifact that can be much larger than the actual neural response.

We will describe a statistically-based method for determining whether a neural response is present. The method was automated and applied to 1076 traces of neural response imaging (NRI) data. These same datasets were also manually analyzed by 5 experienced observers, who classified each trace as a response or as a non-response.

The manual classification yielded full agreement amongst observers on approximately 60% of the traces. Of these agreed-upon traces, the statistically-based method correctly classified 100% of those labeled as responses by the observers and 98% of those labeled as non-responses by the observers.

The statistically-based classification method was incorporated into an algorithm for automatic determination of NRI thresholds. The NRI-based threshold estimates were significantly correlated with psychophysically-measured thresholds to equivalent stimuli (correlation coefficient of 0.9). The reliability and accuracy of this automation should enhance the interpretation of neural measurements and therefore assist in the programming of difficult cases.

CHANNEL SEPARATION AND INTERACTION IN A CHRONICALLY-IMPLANTED SILICON-SUBSTRATE ARRAY FOR A COCHLEAR NUCLEUS AUDITORY PROSTHESIS

Douglas McCreery

Neural Engineering Program, Huntington Medical Research Institutes, Pasadena CA, USA

The goal of this project is to develop central auditory prostheses based on an array of microelectrodes implanted into the ventral cochlear nucleus (vcn), in order to restore hearing to patients in whom the auditory nerve has been destroyed bilaterally. We are developing an array for implantation into the human cochlear nucleus which has 16 electrode sites distributed on 4 silicon shanks extending from an epoxy superstructure that floats on the surface of the nucleus.

Six cat have been implanted chronically with these array. We have made serial measurements of the neuronal responses (compound action potentials) evoked in the cochlear nucleus, and recorded via an electrode implanted in the contralateral inferior colliculus. In one cat implanted for 240 days, the thresholds of the response from most of the electrode sites in the cn were stable over this interval. Thresholds of the neuronal responses range from less than 5 µA to about 15 µA. Overall, there was a slight tendency towards increasing threshold, which is consistent with the thickening of the gliotic capsule around the silicon shanks of the microstimulating array.

To determine the range of stimulus amplitudes over which adjacent electrode sites in the vcn can activate separate neuronal populations that project to the contralateral inferior colliculus, we have used a version of the paired-pulse interaction experiment. The first stimulus pulse is applied to one stimulating site and the second pulse is applied to a second site, within the absolute refractory of the neurons that might also be excited by the first pulse. The technique allows for a very general definition of "information channel" in the lower auditory system, and is applicable to serial measurements in unanesthetized animals. Interaction between adjacent sites was measured over the stimulus range of 0 to 50 µA (0 to 4.5 nC/phase). Over this range, interactions between stimulating electrode sites 0.3 to 0.4 mm apart in various locations the cochlear nucleus ranged from virtually none to very strong, with the least interaction between stimulating sites in the caudal vcn.

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LONG-TERM STUDY OF IMPLANTABLE HEARING AIDS

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The implantable hearing aids are nowadays an inseparable part of modern Otology and Audiology clinics. In principle, an active prosthesis, which is driven through the appropriate signal processing, is implanted in the middle ear. In this way the patients could achieve a better acoustical recognition and speech perception with an open auditory ear canal at the same time.

In this study 11 patients out of 45 patients, who were implanted with an implanted hearing device (Vibrant® Sound bridge MED'EL) at the Otolaryngology Department of Medical University of Hanover, are revaluated with several audiological tests. The postoperative observation time averages 6.3 years.

Results indicate a hearing profit of 28 dB max. gain on average. At one-syllabic-speech tests the patients could achieve a 27% improvement of speech intelligibility with the VSB-system. The results of Multi frequency Tympanometry revealed that Vibrent Ossicular Prosthesis (VORP) hasn't any significant influences on normally resonance frequency of the middle ear, which is between 800 to 1200 Hz.

In the case of a correct patient's recruitment the implantable hearing devices present a good hearing profit, a high qualified speech perception with more comfort.

GUIDING SPIRAL GANGLION NEURITES TOWARD A COCHLEAR IMPLANT

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Increased cochlear implant (CI) electrode resolution may be possible, if spiral ganglion (SG) dendrites could be attracted to the electrodes of a CI in a controlled manner. With this end in mind, we explored signals that mediate the extension and guidance of SG neurites in culture.

A variety of soluble factors were found to increase the extension of SG neurites, including neurotrophin-3 (NT-3) and acidic fibroblast growth factor (FGF-1). In the case of NT-3, this effect was restricted to basal and middle turn SG neurons. Neurites presented with point sources or gradients of growth factors sometimes exhibited spatial or directional responses. For example, SG neurites exposed to FGF-1 bound to the surface of beads showed a strong tendency to branch. Neurites exposed to cells engineered to secrete FGF-1 tended to brach and terminate upon the cells, a response also seen to isolated hair cells. In contrast, neurites exposed to cells producing NT-3 or brain-derived neurotrophic factor (BDNF) neither branched nor terminate. Microfluidic methods were used to expose SG neurites to gradients of NT-3, and to a choice between media with or without NT-3. The neurites showed a strong tendency to chose growth in neurotrophin-containing media.

Uniform surfaces of extracellular matrix proteins including laminin (LN), fibronectin (FN) and collagen (CL) were also found to stimulate neurite extension, as were collagen gels in which 3-D growth was observed. However, neurites growing toward a FN stripe tended to stop or change direction at the FN border. Neurites growing on a pattern of FN, LN or CL stripes showed a strong tendency to grow off of the stripes. When presented with alternating FN and LN stripes, however, neurites chose to grow upon LN. Interestingly, neurites showed a strong positive growth response to certain metals that might be incorporated into a CI, especially titanium.

Eph/ephrin signaling was found to provide negative guidance. SG neurites encountering an EphA4 stripe exhibited growth cone collapse and strong repulsion. This response was abolished by antibodies against ephrin B2 and B3, indicating reverse signaling via these membrane-bound ligands.

The results suggest a strategy for attracting SG dendrites to a CI in a controlled manner. Matrix gels could be used to bridge the fluid gap between the modiolus and an implant array. Permissive factors and substances could promote growth, with repulsive signals channeling neurites to the preferred direction. Termination signals could stop and maintain neurites at the desired location.

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THE NUCLEUS® FREEDOM™ QUAD-DSP SIGNAL PROCESSING PLATFORM

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The Nucleus® Freedom™ speech processor platform is based on a custom designed ASIC with 4 identical digital signal processing (DSP) cores running simultaneously. Designed in partnership with Philips Electronics N.V., the platform offers up to 180 million operations per second (MOPS) of parallel processing capability, in a low-power behind-the-ear (BTE) system.

Each DSP is fully programmable, and the allocation of tasks across all DSPs is also programmable as required by the signal processing strategy. When multiple DSPs are used in parallel, each individual DSP can be run at a lower supply voltage and clock speed than otherwise would be the case, resulting in significantly lower power consumption for the system than for the same algorithm running on a single DSP.

Signal processing in the Freedom system is spread across all 4 DSPs. Any combination of SmartSound™ and Nucleus coding strategies is possible. The capability of the system is such that the Freedom processor is able to run all of the SmartSound algorithms (Whisper™, ADRO™, Beam™) simultaneously. The Freedom DSPs are able to calculate common DSP functions such as FFT, IIR and FIR filters using fewer execution cycles than commercially available DSPs. For example, a 128 pt FFT executes in Freedom in less than 500 cycles, compared to nearly 4000 on a Texas Instruments C54' DSP. For most configurations of the processor, less than half of the available signal processing capacity is being used, providing significant future potential for new algorithms.

Audio input to the DSP is via three (3) on-chip analog-to-digital converters which are connected to a directional microphone, omni-directional microphone, and auxiliary/accessory input within the Freedom BTE housing. The Beam algorithm is processed first, followed by Whisper, Automatic Sensitivity Control and Automatic Gain Control. Speech coding for SPEAK, ACE or CIS follows, and ADRO may also be applied to any coding strategy. Instantaneous Input Dynamic Range (IIDR) is configurable in steps of 1 dB from 15 to 75 dB.

Output from the DSP platform to the implant is via a high efficiency active coil, and the Freedom platform is compatible with all Nucleus implants. Support for the Nucleus 24 and Nucleus 22 systems will be released as approval is obtained from the relevant regulatory authorities.

A NEW REAL-TIME RESEARCH PLATFORM FOR THE NUCLEUS® 24 AND NUCLEUS® FREEDOM™ COCHLEAR IMPLANTS

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A new real-time research platform for sound processing and speech coding research has been developed for the Nucleus® 24 and Freedom™ Implants. This combined hardware-software platform makes use of a real-time PC-based signal processing tool, xPC, from the Mathworks. xPC runs on a separate, standalone Intel-based PC using models developed in Simulink. A custom Simulink framework has been designed to allow existing and new speech coding algorithms for cochlear implants to be implemented in a similar time frame as in Matlab and much more quickly than in DSP assembler. A Simulink DSP library called the *Nucleus Matlab Blockset* (NMB) has been built on this framework and implements the commercially available algorithms for the Nucleus system including SPEAK, ACE, CIS, Whisper™, ADRO™ and Beam™.

Commands to the implant are streamed via a real-time communications protocol to a custom FPGA-based hardware platform called *StimGen,* designed and built for the project. StimGen interfaces to the implant and controls all aspects of stimulation parameters and timing with 200 ns resolution. StimGen is configured by the Simulink NMB model to one or more of a number of modes, which allows flexibility in how groups of stimuli are output.

Up to 8 high quality audio inputs and outputs are simultaneously available as part of the system. Several dual-microphone behind-the-ear housings have been built, based on the Nucleus Freedom speech processor, and are used as the main audio input to the system. Alternate microphone housings can be easily added to experiment with new multi-microphone algorithms such as Beam. The measured latency from audio input to electrical stimuli output is less than 20 ms, making it suitable for use in real time speech perception and conversation tests, where lip reading and own-voice perception are important.

Preliminary test results with recipients, comparing performance with that of their existing commercial speech processor, will be presented.

THE NUCLEUS® FREEDOM™ BEAM™ MULTI-MICROPHONE ADAPTIVE BEAMFORMER SYSTEM

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Noise reduction strategies are important in hearing aids and cochlear implants in order to improve speech intelligibility in noisy environments. The 50 % speech reception threshold (SRT) in noise for cochlear implant recipients may be at a signal to noise ratio (SNR) level 10 to 15 dB higher than for normal hearing subjects. This problem has motivated the development and implementation of a multi-microphone adaptive noise reduction system called Beam™, as part of the SmartSound™ suite in the new Freedom™ system.

Beam is the result of a close collaboration between researchers at the Laboratory for Experimental ORL, K.U.Leuven and Cochlear during the development of the Freedom system. The Freedom processor is designed with two microphones in a behind-the-ear (BTE) housing, one directional and one omni-directional. Beam uses digital signal processing (DSP) of the two microphone signals to implement an adaptive beam-former, as a pre-processor to any of the commercially available Nucleus® speech coding strategies.

Beam is a two stage DSP algorithm. The first stage acts to provide a reliable noise reference by eliminating speech from the speech + noise signal. The second stage is an unconstrained adaptive noise canceller that uses the output of the first stage as a noise reference input, leaving just the speech. The second stage is only allowed to adapt during non-speech periods.

Preliminary results with Beam show that up to 16 dB improvement in the speech reception threshold is possible. Further details of the Beam implementation on the Freedom system will be presented.

WEDNESDAY, POSTER 26

FINDINGS OF AN IN VITRO MODEL OF THE ELECTRODE INTERFACE: IMPLICATIONS FOR COCHLEAR IMPLANTS

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The impedance of stimulating electrodes used in cochlear implants and other neural prostheses often increases post-implantation, and this increase is thought to be due primarily to fibrous tissue encapsulation of the electrode array. Increased impedance results in higher power requirements to stimulate target neurons at set charge densities. To enable investigation of the electrode-tissue interface in a highly-controlled environment, we have developed an *in vitro* model.

The model was tested using protein adsorption, cell growth and with and without charge balanced biphasic electrical stimulation. Under standard tissue culture conditions, a monolayer of cells was grown over the electrode surface. Electrode impedance increased in proportion to the extent of cell coverage of the electrode. The adsorption of radio-labelled proteins onto the electrode surface also resulted in an increase in impedance.

The application of electrical stimulus to cell-covered electrodes caused impedance fluctuations similar to that seen *in vivo*, with a lowering of impedance immediately following stimulation, and a recovery to pre-stimulation levels during inactive periods. Examination of these electrodes showed the stimulation-induced impedance changes were directly related to the percentage of cell cover over the electrodes. Changing the amplitude of stimulation resulted in different effects on cell cover and impedance.

This *in vitro* technique accurately models the changes in impedance observed with cochlear implants *in vivo*, and shows the close relationship between impedance and tissue coverage adjacent to the electrode surface. We believe this *in vitro* approach holds great promise to further our knowledge of the mechanisms contributing to electrode impedance.

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MINIMUM REQUIREMENTS FOR USEFUL ARTIFICIAL VISION:FULL-PAGE TEXT READING, VISUOMOTOR COORDINATION AND MOBILITY

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Within the framework of a large project aiming to develop a visual prosthesis, we use simulations of artificial vision on normal subjects to determine the minimum requirements for such a device to restore useful vision.

Retinal implants will be permanently implanted at a fixed (and eventually eccentric) position on the retina. We simulate this condition on normal subjects by projecting quantized (pixelized) stimuli on a defined and stabilized area of the visual field. We then assess subjects' performance on every-day tasks while systematically varying different parameters like resolution, viewing angle, and eccentricity. Three simple tasks were evaluated: full-page text reading, visuomotor coordination (pointing on targets and arranging chips according to a model), and full-body mobility in known environments (randomized 6-obstacle maze).

Our first results demonstrated that about 500 pixels, distributed over a 10°x7° viewing area (300 pixels/deg^2), are necessary for full-page reading. With central vision, almost perfect performance is rapidly obtained. At high eccentricities (15° in the lower visual field), although initial performance is poor, excellent performance is achieved after systematic training (1 hour/day for about 2 months).

Second, optimal visuomotor performance is achieved with image resolutions greater than 2 pixels/deg^2. Medium viewing angles (17°x12°) appear to favor performance. Subjects adapted to eccentric viewing after about 60 training sessions.

Our last series of experiments revealed that good mobility performance can be achieved with rather poor image resolutions ($\leq$ 0.1 pixels/deg^2). Larger viewing angles (33°x23°) were preferred. Subjects adapted to eccentric viewing quite quickly (about 40 sessions).

These data demonstrate that (1) reading is the most demanding task in terms of image resolution and, that (2) all these very different visual tasks can be successfully achieved with eccentric viewing. In conclusion, about 500 distinctly perceived points, retinotopically distributed onto a 10°x7° retinal area appear to be the minimum visual information required for these every-day tasks. Visual prostheses should aim to meet these criteria in order to restore useful visual abilities to blind patients.

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SURFACE MODIFICATION OF COCHLEAR IMPLANTS REDUCES POSTOPERATIVE IMPEDANCES AT HIGHER PULSE WIDTHS

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Reduction of power consumption is one of the main intentions in cochlear implant development. This can be achieved e.g. by decreasing the electrical impedance of the electrode. The objective of the study was to evaluate the effect of modified electrode contacts and steroid-induced reduced intra-cochlear tissue growth on postoperative impedance over time in a wider range of settings than it is possible with the standard fitting software.

For this purpose, three different groups of patients have been established: a) standard Nucleus 24 Contour (control), b) standard Nucleus 24 Contour with intra-operative application of steroids, and c) Nucleus 24 Iridium-Contour with intra-operative application of steroids. Electrode impedance was measured using Nucleus R116 fitting software and, additionally, timpani-software from day three after surgery to 2 years post fitting.

Impedance values measured with the fitting software show the same development over time as found earlier for larger patient groups. Intraoperative injection of steroids into scala tympani reduces the impedance significantly whereas iridium treatment has no effect. Using timpani-software for impedance measurements, the pulse width was modified between 26 µs (which is comparable to 25 µs in the fitting software) and 180 µs. During the first days after surgery, measurements are often unstable, which might be related to a swollen skin flap. Later, values become stable during the measurement series. Increasing the pulse width from 26 to 180 µs, impedance increases for controls by 6.5 kΩ, for steroid treated patients by 4.8 kΩ, and for the iridium plus steroid group by only 3.7 kΩ during one years measurements. The dependency of the impedance from the pulse widths is lowest for the iridium plus steroid group at all times.

Injection of steroids into scala tympani prior to insertion of the electrode array has a prominent and stable effect on the impedances whereas modified electrode contacts shows only an effect on postoperative impedance at large pulse widths.

HISTOLOGICAL ANALYSIS OF SHORT AND LONG TERM IMPLANTATION OF AUDITORY MIDBRAIN ELECTRODES IN THE COLLICULUS INFERIOR

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Introduction: Auditory brainstem implants with electrodes positioned in the Cochlear nucleus are used for the auditory rehabilitation of patients with neural deafness [1]. Alternative concepts for targeted tonotopic stimulation of the higher auditory areas, such as Colliculus inferior (IC), are currently under investigation. In acute experiments electrically in IC evoked potentials can be registered at the auditory cortex using surface and/or deep insertion electrodes and compared with acoustically induced cortical signals [2,3]. The running step is testing safety and functionality in chronic experiments with and without stimulation.

Material and Methods: In collaboration with Cochlear Ltd. (Sydney), a 4 mm 20-channel rod electrode was developed, electrode contacts being arranged in a circle on a rod at 200 µm intervals corresponding with frequency-band laminae in IC. In chronic experiments this type of electrode inserted in IC. Parallel to a non-stimulated control group daily stimulation with commonly used speech processor and impedance measurements are performed. After 3 months stimulation the brain was fixed for histological analyses.

Results and Discussion: Electrode insertion in IC proved to be easy and reproducible. The behavior of the implanted cats did not change in any way with or without electric stimulation. First experiments with electrical stimulation in IC with a during speech processor a little above hearing threshold evoked no avoidance reaction. There is no visible pain reaction. On short loud sounds neonatally and adult deafened animals react with attention and visual searching. Impedances stayed stable before and after electrical stimulation (0.008 – 0.04 C/m²) independent of current level and pulse width at about 10 kOhm. Histological analyses of IC showed a damage zone limited around the insertion channel. There was a thin endothelial cell layer and a few new capillaries around the electrode track. Tissue behind the damage-zone appears to be undamaged and healthy. There was no chronic inflammation.

Perspective: More long-term animal studies with and without stimulation are running. The implantation of this multi channel electrode in IC has to be considered safe. It is improbable that the speech processing strategies of the cochlea implant can also used in the IC. Therefore optimum stimulation parameters must be investigated in further acute and chronic experiments. The goal is auditory rehabilitation in patients suffering from neural deafness more efficiently than surface electrodes places on the Cochlear nucleus.

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SPATIAL COCHLEAR TUNING OBTAINED WITH OPTICAL STIMULI

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In individuals with severe to profound hearing loss, cochlear implants (CIs) bypass normal inner ear function by applying electrical current directly into the cochlea. Stimulating discrete populations of spiral ganglion cells in cochlear implant users' ears is similar to the encoding of small acoustic frequency bands in a normal-hearing person's ear. Thus, spiral ganglion cells stimulated by an electrode convey the information contained by a small acoustic frequency band. For normal listeners, speech recognition improves with an increasing number of frequency bands available for the listener. For cochlear implant users, however, speech recognition scores increase only to a maximum of about ten electrode contacts, a finding that might be explained in part by the overlap in stimulation of spiral ganglion cells by the electrodes. In contemporary cochlear implants, the injected electric current is spread widely along the scala tympani and across turns. Consequently, stimulation of spatially discrete spiral ganglion cell populations is difficult.

Recently we introduced a novel concept to stimulate small populations of spiral ganglion cells, optical stimulation. Light of 2.1µm is absorbed within 400µm from the stimulation source. Optically evoked compound action potentials (CAPs) are quantitatively similar (Richter et al., 2005 Assoc. Res. Otolaryngol. 28, 1012, Izzo et al., 2005, Assoc. Res. Otolaryngol. 28, 1013). An important difference between acoustically and optically evoked cochlear responses is the presence of cochlear microphonics (CMs). CMs are electrical potentials generated by the hair cells in response to an acoustic stimulus and are detectable in the acoustically evoked responses, but not in the optically evoked ones. While no auditory response could be acoustically evoked in longterm-deafened animals, it was possible to evoke CAPs using light.

The objective of the present study was to show that light evoked auditory responses are spatially selective. The spatial selectivity of optical stimulation was tested using a masking method. It is known that the response of a tone, a probe tone, can be masked by the simultaneous presentation of another tone, a masker tone. Spatial tuning of the cochlea can be measured using CAP tuning curves. In the present experiments, optical stimulation substituted for the constant-frequency probe, where the placement of the optical fiber along the cochlea determines the corresponding best frequency (BF), and the light energy corresponded to the probe level. An acoustic signal, variable in frequency and level, served as the customary masker. The resulting tuning curves are similar to tone-on-tone masking curves. For a BF of 8 kHz the Q_{10dB} value was 3.3. Müller (1996, Hear Res, 94, 148) has shown that tuning obtained from single fiber measurements for best frequencies between 4 and 8 kHz was 6.56±1.79 (average±standard deviation, n = 87). The results support our hypothesis that optical stimulation can provide spatially selective stimulation of the cochlea.

AUDITORY MIDBRAIN IMPLANTATION: STEREOTACTIC IMPLANTATION OF THE INFERIOR COLLICULUS WITH PENETRATING ELECTRODES IN CADAVERS

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Our aim is to test closed stereotactic approaches for implanting penetrating stimulatory electrodes into the inferior colliculus in cadaveric specimens. Even though a large majority of profoundly deaf individuals have benefited from advances such as cochlear implantation, there are those that due to a lack of an intact auditory nerve do not benefit from peripheral devices. The development of penetrating electrodes for auditory midbrain implantation has created a potential solution for these patients. The need is to define effective surgical maneuvers to implant these multipolar electrodes across tonotopic domains of the central auditory pathway. The inferior colliculus is a potential site. Even though there are extensive descriptions of both open and stereotactic approaches to the quadrigeminal area, a stereotactic approach to the inferior colliculus has not been fully described.

We believe that stereotactic implantation of stimulating penetrating electrodes within the central nucleus of the inferior colliculus can be performed with minimal compromise of important structures and placed into the central nucleus along a tonotopical orientation. We evaluated with cadaveric models three different stereotactic approaches for inferior colliculus implantation: A. Supratentorial (transfrontal trancortical) B. Infratentorial (transcerebellar) C. Transtentorial (posterior cerebral). We also evaluated the final placement of the electrodes within the central nucleus of the inferior colliculus and the electrode wires within the trajectory of the implantation probe.

In the pilot portion of this study halved heads were used to devise a set up that would best allow us to examine the trajectory of the probe and where the electrode wire would be placed. Various threads and injections using methyl blue were attempted. We discovered that using an implantation probe with a #5 size thread soaked in methyl blue allowed us to stain the pathway of the probe and the eventual placement of the electrode wire. This technique also allowed us to the test the final placement of the penetrating electrodes.

It is important to devise a surgical approach for auditory midbrain implantation that is minimally invasive. We believe that a stereotactic approach can offer this for midbrain implantation. In this pilot study we have devised a method to test this approach on cadaveric specimens to assess its applicability in human beings. A description of the techniques and anatomic pathways of the proposed approaches will be presented.

EVIDENCE FROM AUDITORY BRAINSTEM IMPLANTS OF A SEPARATE AUDITORY PATHWAY THAT IS CRITICAL FOR SPEECH RECOGNITION

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Excellent speech understanding has been observed in patients with prosthetic electrical stimulation of the cochlear nucleus. Psychophysical tests reveal that the difference between listeners with high and low speech understanding is not due to overall neuronal survival in the cochlear nucleus, the quality of electrode placement or the specificity of stimulation by individual electrodes, but is correlated to the ability to detect amplitude modulation. The difference in speech understanding was dramatic between patients whose deafness was caused by vestibular schwannomas on the VIII nerve or from other causes of VIII nerve loss. The relation between etiology, modulation detection and speech recognition suggests that tumor growth and resection has selectively damaged a physiological processing pathway specialized for modulation and speech. This suggests that modulation specialized cells represent a critical pathway for speech recognition and their loss impairs speech recognition even when other cell types survive.

INVESTIGATION OF BANDED NEURAL RESPONSE IMAGING (NRI) WITH PATIENTS USING HI-RESOLUTION SOUND PROCESSING

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The Hi-Resolution Bionic Ear is capable, through the SoundWave programming software, of measuring the electrical compound action potential (ECAP). Previous research, has documented that single channel NRI thresholds have fallen within the patient's electrical dynamic range. This information is useful as an adjunct for device programming for patients who cannot provide reliable behavioral responses. Additionally, the Hi-Resolution system can measure 'banded' stimuli (where 3-4 electrodes are stimulated simultaneously). Early research has demonstrated that banded- NRI responses have steeper growth functions, lower tNRI measures, can be collected faster, and are more robust than single channel measurements. Additionally, indications are that the slope of Banded- NRI are more similar to the loudness growth (perceptual) responses than to single channel NRI measures.

The major goal of this present study is to confirm previous research findings with a larger population, i.e. define the relationship between single channel and banded –NRI ECAP responses. Overall, the aim is to develop clinical guidelines for clinicians in programming the Hi-Res system through the use of NRI.

Ten adults implanted with the CII or 90K device were participants in this study. M levels were initially obtained and psychophysical loudness growth was measured using speech bursts delivered to bands of four electrodes along the array. Finally, ECAP input-output functions were measured using both single channel and banded NRI procedures.

Preliminary results confirm previously reported findings and demonstrate the usefulness of banded-NRI in device programming of the Advanced Bionics Hi-Res cochlear implant system.

DEVELOPMENT OF PZT THIN-FILM MICROACTUATORS FOR HYBRID COCHLEAR IMPLANTS

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Hybrid cochlear implants would integrate electric and acoustic auditory stimulation into a single unit to rehabilitate patients with sensori-neural hearing loss. Conceptually, hybrid cochlear implants consist of an electrode array and an acoustic microactuator inside the cochlea. The electrode array emits electrical signals to restore high-frequency hearing as in traditional cochlear implants. The intracochlear piezoelectric microactuator delivers a pressure wave directly to the perilymph fluid in the cochlea to augment the response of hair cells to auditory stimuli in the low-frequency range.

To enable hybrid cochlear implants, one must develop acoustic actuators small enough to be placed directly into the cochlea. In this study, the microactuators consist of a silicon diaphragm and a Lead-Zirconate-Titanate Oxide (PZT) thin film.

We first conduct a finite element analysis to design the diaphragm size and thickness. To be small enough for the cochlear, the diaphragm size is constrained to be less than 1.1 mm by 1.1 mm. The finite element analysis found that the thickness of the diaphragm must be small enough (e.g., less than 30 μm) in order for the diaphragm to present out-of-plane motion generating the pressure wave. When the diaphragm thickness is too large (e.g., 100 μm), the motion of the diaphragm becomes in-plane and cannot effectively generate the pressure wave.

Based on the results from the finite element analysis, two actuators are fabricated and tested. For the first actuator, the diaphragm size is 1.1 mm by 1.1 mm, the diaphragm thickness is about 12 μm, and the PZT film thickness is 1 μm. The microactuator is tested in an unloaded condition (in air) and a loaded condition (with water and glass sheets) equivalent to a loading of 17 Pa. The microactuator presents a constant displacement of 16 nm, when the driving voltage is sinusoidal with amplitude of 5 V and frequency ranging from 500 Hz to 10 kHz. For the second actuator, the diaphragm size is 800 μm by 800 μm, the diaphragm thickness is 1μm, and the PZT film thickness remains 1 μm. The second actuator presents a displacement of 6 nm, when the sinusoidal driving voltage is 7.5 V in amplitude. Given that the motion of the stapes in normal hearing is 10-30 nm when the incoming sound pressure is 1 Pa (i.e., 94 dBA), the PZT thin-film microactuators are a feasible design for hybrid cochlear implants.

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WEDNESDAY, POSTER 35

EXOGENOUS BDNF RESCUES RAT SPIRAL GANGLION NEURONS IN VIVO

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The effectiveness of cochlear implantation in patients with a profound sensorineural hearing loss relies, in part, on the survival of spiral ganglion neurons (SGNs). Previous research has shown that exogenous neurotrophins can rescue SGNs in deafened guinea pigs, however, it remains to be determined whether this effect is seen in other species. After documenting the rate of SGN degeneration following ototoxic deafening with gentamicin and furosemide, we investigated the trophic effects of exogenous brain-derived neurotrophic factor (BDNF) on rat SGNs. The left cochleae of profoundly deafened rats were implanted with a drug delivery system connected to a 200 µl mini-osmotic pump. BDNF (5.4 µg/ml) or artificial perilymph (AP) was infused for 28 days and the cochleae were then prepared for histology. Treatment with BDNF led to a statistically significant increase in SGN density ($p < 0.001$; t-test) and a highly significant increase in SGN soma area ($p < 0.001$; t-test) compared to both AP-treated and untreated deafened cochleae. This work demonstrates, for the first time, that exogenous BDNF can rescue SGNs in the mature rat cochlea following deafness. Moreover, it provides confidence that such neurotrophin treatment may have potential clinical application among recipients of cochlear implants. Future studies are required to address safety issues associated with long-term neurotrophin delivery into the cochlea, including the development of therapies capable of delivering these proteins at physiological levels without the increased risk of infection associated with using an osmotic pump and delivery cannula.

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WEDNESDAY, POSTER 36

EFFECTS OF DEAFNESS AND ELECTRICAL STIMULATION IN ANIMALS WITH EARLY-ACQUIRED HEARING LOSS

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Previous studies reported by our group have shown that electrical stimulation delivered by a cochlear implant (over periods of several months) promotes improved survival of spiral ganglion cells (SGC) in cats deafened neonatally by administration of an ototoxic drug. In the present study we explored the possible role of developmental critical periods by studying a new deaf animal model. Cats were deafened at 30 days of age (rather than immediately after birth) in order to model early acquired hearing loss. The deafening procedure was identical to that used previously for neonatal deafening. One experimental group was studied immediately after deafening at 8-9 weeks of age. A second group received a cochlear implant at 8-9 weeks of age and underwent unilateral electrical stimulation with temporally challenging signals (325 pps/60Hz AM) for periods of 18-30 weeks. Data from the 2 groups were compared to 2 groups of neonatally deafened animals that were carefully matched to the 30-day deafened groups for age and duration of stimulation.

In the 30-day deafened group studied at 8-9 weeks of age, SGC survival was already significantly reduced, despite the fact that these subjects had adult-like hearing thresholds when ototoxic drug administration was initiated, and they were studied only about 1-2 weeks after profound hearing losses occurred. There was, however, an interesting difference in the distribution of surviving SGC within the cochlea. The neonatally deafened animals exhibited a consistent pattern of higher SGC survival in the base and apex, and more marked loss in the middle of the cochlea. In contrast, the 30-day deafened group showed more variable survival throughout the cochlea.

Electrical stimulation delivered over a mean of 6.3 months significantly enhanced SGC survival in the 30-day deafened group (n=4), with maintenance of about 17% higher cell density in the stimulated ears. However, the neonatally deafened group (n=5) showed a similar increase of about 19%. Thus, there was no significant difference in SGC survival between the 30-day deafened group (modeling early acquired deafness) and the neonatally deafened group (modeling congenital deafness), at least in the limited number of subjects studied to date.

Measurements of cochlear nucleus (CN) size, however, revealed significantly higher values in the 30-day group as compared to neonatally deafened cats at 8-9 weeks of age. There was also a trend toward larger CN size in the 30-day deafened group studied after chronic electrical stimulation, as compared to the neonatally deafened, stimulated group. These preliminary findings suggest that a short period of normal auditory experience may be significant in lessening degenerative changes in the central auditory system after early-acquired deafness (as compared to the effect of congenital deafening).

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AUTONRT™, FIRST CLINICAL RESULTS OF A COMPLETELY AUTOMATIC ECAP RECORDING SYSTEM

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NRT™, the ECAP measurement system in the Nucleus CI24R/M series implants has proven to be a useful tool for both research and clinical procedures. NRT however requires a reasonable level of technical skills to perform well.

The recently introduced Freedom™ system from Cochlear includes AutoNRT™, a completely automatic ECAP recording system that is aimed at facilitating both intra- and post-operative measurements of ECAP profiles. This study shows the results of a clinical validation trial where both the speed and the accuracy of the new algorithm were evaluated in a clinical setting.

AutoNRT is possible because of a combination of a few significant improvements in the Freedom implant (better signal-to-noise, inbuilt artifact reduction, and higher sampling rate) and a pattern-recognition based threshold finding algorithm in the software. The software increased the stimulation level until an ECAP response is identified and then steps down in smaller steps to find the equivalent of the 'visual' threshold. The advantage of this method over extrapolating AGF functions is twofold: first of all extrapolation gives doubtful results when the AGF shape significantly deviates from linearity, secondly to measure an AGF higher stimulation levels are needed.

Multicentre data on more than 45 recipients will be presented; the total dataset includes well over 200 electrodes. Initial analysis suggests that AutoNRT (without manual intervention) is possible in more than 96% of the cases and the median difference between the automatically determined and the manually determined ECAP threshold is 3 CL. The measurements take on average 28 seconds per electrode intra-operatively and 57 seconds per electrode in post-operative mode.

The complete dataset will be analyzed and presented on this poster.

WEDNESDAY, POSTER 38

MICRO-CT EVALUATION OF THE HELIX ELECTRODE ARRAY

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Evaluation of the damage to the basilar membrane and to the lateral and medial cochlear walls due to the insertion of an electrode array is a challenging issue. Common techniques, such as histological slicing or grinding and polishing or micro-dissection have as major drawbacks that the sample preparation is time consuming and that there is a non-negligible risk for artefacts introduced e.g. by cutting the metallic wires. An ideal evaluation technique would require minimal sample preparation.

Radiological techniques are therefore attractive, but the current clinical CT equipment still lacks the resolution to visualize the anatomical details and to assess the position of the implanted electrode array with respect to the endocochlear tissues. Recently a highly accurate X-ray microtomography scanner (manufacturer Skyscan) has become available for in-vivo scanning of laboratory animals. Due to limitations in sample size, the technique is only applicable to temporal bone studies, but the resolution is excellent (up to 9 µm).

Without an inserted electrode array the scanner produces artefact-free images with nearly-histological quality. The membranes can be easily visualized. With an inserted electrode, the metallic parts produce image distortion. A protocol was developed that involves scanning the sample before and after the insertion of the electrode. Subtracting the 3-D reconstructions after alignment provides high-resolution images that allow to assess the position of the electrode array, not only with respect to the bony tissues and to the soft tissues along the full length of the cochlea.

In the poster results are presented for a temporal bone implanted with an Advanced Bionics' Helix electrode array. The array was designed for an atraumatic insertion, a perimodiolar positioning and a target insertion angle of 390 degrees. Micro-CT evaluation of the temporal bone shows that these objectives were met. As a consistency check a micro-dissection of the inserted bone was performed, exposing the basilar membrane. Direct inspection under the operating microscope confirmed these findings.

WEDNESDAY, POSTER 39

RESPONSES TO COMBINED ELECTRIC AND ACOUSTIC STIMULATION (EAS) IN CAT INFERIOR COLLICULUS

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Clinical studies have shown that combined electric and acoustic stimulation (EAS) of cochlear implanted subjects with residual low frequency hearing leads to improved comprehension of speech in noise when compared to either electrical or acoustical stimulation alone. Previous studies using EAS in implanted hearing cats showed complex mutual suppression and desynchronization of responses in the auditory nerve and inferior colliculus (ICC) (ARO 2004, 565; Asilomar 2003, 16). In the present study, the interactions of ICC responses to EAS were investigated using a forward masking paradigm.

Anesthetized normal hearing cats were implanted with a 5-channel scala tympani electrode array. Hearing was maintained close to normal thresholds (~20 dB SPL). An earphone was sealed to the auditory meatus for acoustic stimulation. Neural activity was simultaneously recorded at 16 sites along the tonotopic gradient of the ICC. In the forward masking experiments a 50-60 ms acoustic masker (1.5-32 kHz, 10-75 dB SPL) preceded a 20 ms electric probe (sinusoids and pulses). Intensity and frequency of probe and masker were varied systematically.

Response patterns along the tonotopic gradient varied dependent on the amplitude and frequency of the probe. At low intensities and frequencies above 1 kHz, responses occurred at ICC regions that corresponded to the frequency of the electrical stimulus and were considered 'electrophonic responses'. At much higher intensities, additional activation and masking occurred at ICC regions that corresponded to the cochlear site of the stimulating electrode pair ('electroneural responses'). The extent of masking decreased with increasing probe intensities (narrower inhibitory bandwidth, higher thresholds). This effect was markedly stronger for electroneural responses.

Our results demonstrate complex electrophonic and electroneural interactions to EAS along the tonotopic gradient of the central auditory system. These interactions are strongly dependent on the intensity and frequency of the electrical probe.

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FOCUSED STIMULATION WITH PHASED-ARRAY CHANNELS

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Sound encoding strategies that employ concurrent stimulation at multiple cochlear places have had limited clinical success due to the well known phenomenon of current spread and resulting channel interactions. The great majority of strategies in clinical use today circumvent this problem through sequential stimulation. Sequential stimulation avoids the loudness summation of channel interaction, but at the cost of imposing temporal constraints that preclude the use of asynchronous stimulus patterns that are needed to represent within-channel fine time structure.

To address this problem Van Compernolle[1,2] proposed a method, dubbed "current deconvolution," of inverting the current spread function. The method computes an instantaneous combination of currents through an array of electrodes that maximizes the stimulation at selected places, and minimizes it elsewhere. Van Compernolle's method was impractical because 1) the inversion was overspecified (thus inexact) because it determined stimulation intensity at more sites than the number of electrodes; 2) current spread from individual electrodes was assessed imprecisely using a psychophysical approximation; and 3) contemporary electrodes had broad spread functions, requiring impractically high compensating currents. Rodenhiser and Spelman[3] extended Van Compernolle's work, determining current spread functions from a lumped-element model of the cochlea in place of psychophysical measures. Although less time-consuming, this approach does not incorporate specific spread functions of an individual subject.

The 22-electrode Nucleus Contour Softip® perimodiolar array overcomes limitations (1) and (3) above. To address limitation (2) we developed a method of determining exact, subject-specific forward spread functions using potential measurements from unstimulated electrodes. Such functions were measured for three subjects with perctuaneous Contour cochlear implants, and used to compute "phased-array" channel sets. Like phased-array radar, such channels use constructive and destructive interference from multiple sources to produce a spatially punctate field. These channel sets provide precise simultaneous control of 22 potentials at 22 cochlear places. Suprathreshold simultaneous interaction was measured at various phased-array channel densities using a Spatial Ripple discrimination paradigm, and compared with monopolar channels.

Application of phased-array channels will be discussed in the context of several asynchronous stimulation strategies, including the Cochlear Resonance Modeling strategy that replicates place-appropriate spike timing patterns concurrently at 22 or more cochlear places.

[1] 1985, Ph.D. Dissertation, Stanford University

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