2007

Conference on Implantable Auditory Protheses

JULY 15 - JULY 20, 2007

Granlibbaken Conference Center

Lake Tahoe, California

2007 Conference On Implantable Auditory Prostheses

July 15 – July 20, 2007

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2007 Conference on Implantable Auditory Prostheses

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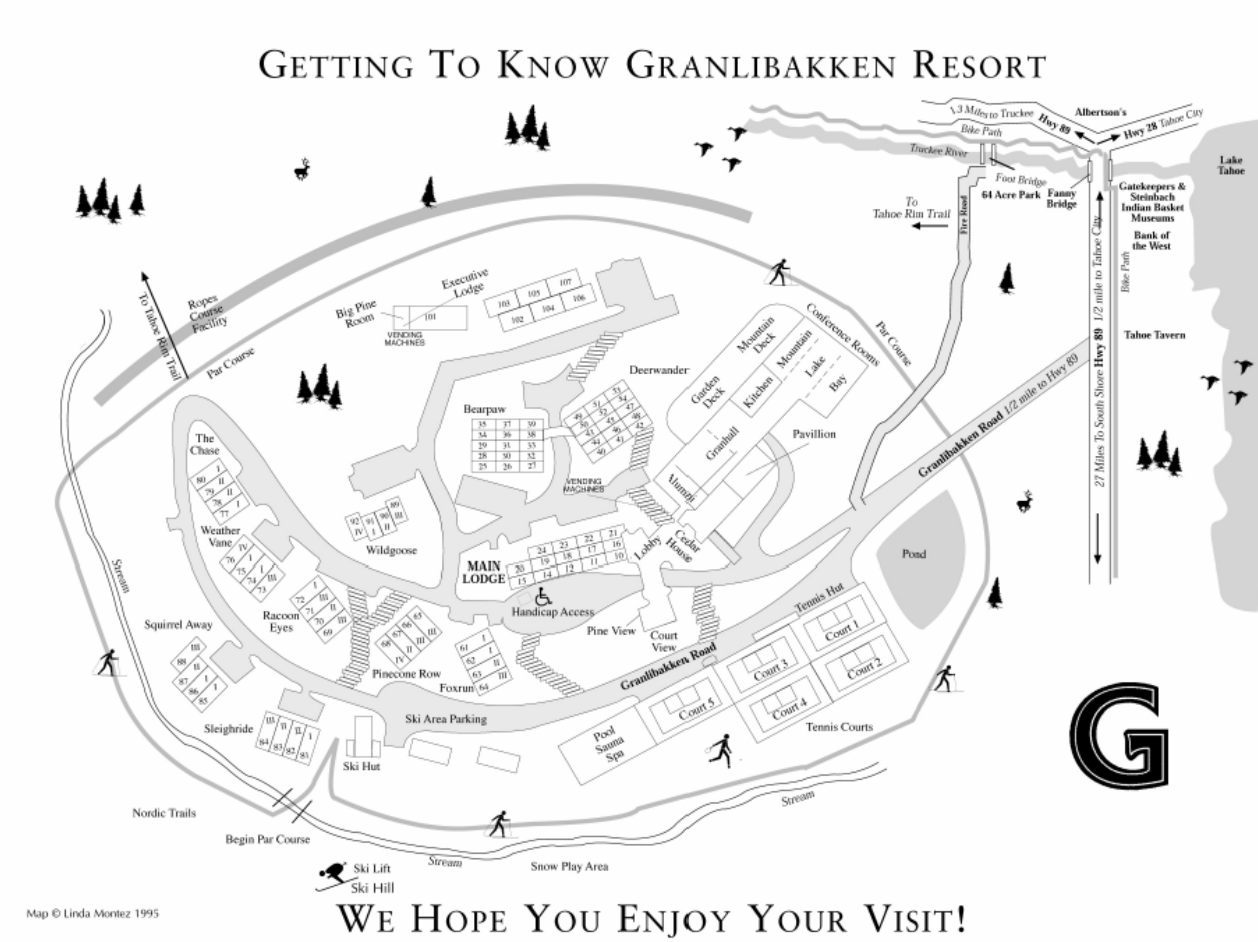
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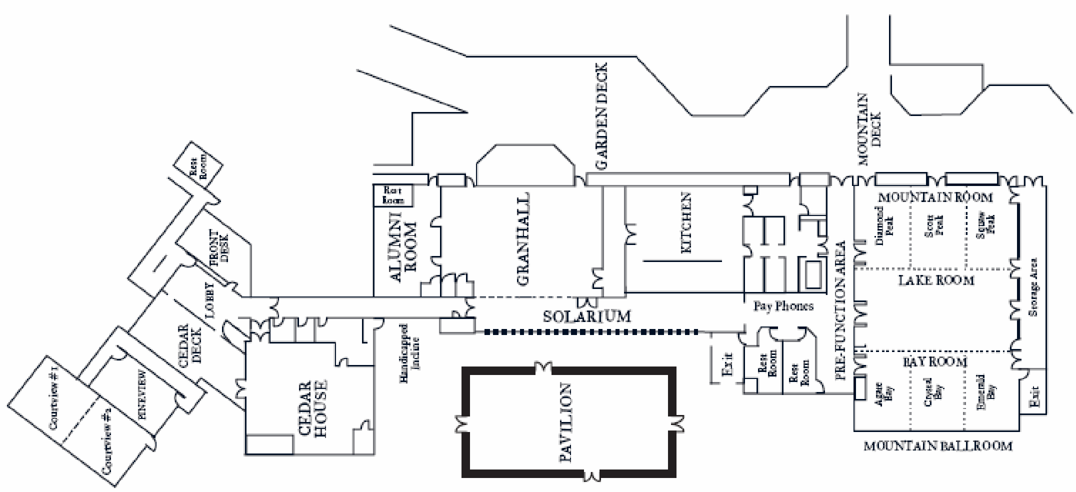
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MOUNTAIN DECK
Rest Room
FRONT DESK
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Courtview #1
Courtview #2
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Handicapped Incline
ALUMNI ROOM
GRANHALL
SOLARIUM
KITCHEN
Pay Phones
PAVILION
Exit
Rest Room
PRE-FUNCTION AREA
MOUNTAIN ROOM
Diamond Peak
Scott Peak
Squaw Peak
LAKE ROOM
BAY ROOM
Agate Bay
Crystal Bay
Emerald Bay
Storage Area
MOUNTAIN BALLROOM

2007 Conference on Implantable Auditory Prostheses
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7:00pm-midnight Welcoming Reception

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12:20 lunch
1:00-5:00pm Poster Viewing
7:00-9:05pm **Session 2: Trophic Factors and the Electrode/Neural Interface**
9:25pm-midnight Poster Viewing and Social

Tuesday July 17

8:30am-12:30pm **Session 3: Novel Stimulation and Signal Processing Strategies and Modeling**
12:30pm lunch
1:00-5:00pm Poster viewing
7-9:20 **Session 4: Thinking Outside the Scala**
9:20pm-midnight Poster viewing and Social

Wednesday July 18

8:30am-noon **Session 5: Infants and Children**
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8:30am-12:30pm **Session 5: Infants and Children**
12:30 Lunch
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7:00-9:00pm **Session 7: Manufacturers' Reports**
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Friday July 20

8:30am-10:35am **Session 8: Pitch Perception for Speech and Music**
10:50am-12:30pm **Session 9: Training**
12:30 Lunch and Conference End

2007 Conference on Implantable Auditory Prostheses
Granlibakken Conference Center, Lake Tahoe, California

Monday Morning, July 16

Session 1: Temporal Fine Structure – Bob Shannon, Chair

8:30 1A: *The Role of Temporal Fine Structure in Normal Hearing, Hearing Impairment, and Cochlear Implants:* Brian C.J. Moore

9:15 1B: *The role of temporal fine structure in normal hearing for listening in complex environments: Implications for cochlear implants:* Andrew Oxenham

9:45 1C: *Perception of Music, Speech and Speech in Noise: Spectral and Temporal Contributions to Performance*: Jay Rubinstein

10:15 Break

10:30 1D: *Temporal Pattern Discrimination:* Tiffany Chua

10:50 1E: *Temporal fine structure coding in low frequency channels: speech and prosody understanding, pitch and music perception and subjective benefit evaluated in a prospective randomized study:* Stefan Brill

11:10 1F: *Effects of Interaural Time Difference in the Temporal Fine Structure:* Bernard Laback

11:40 1G: *ITD Sensitivity in Electrical Hearing: Effect of Channel Interactions:* Gary Jones

12:00 General Discussion

Monday Evening

Session 2: Trophic Factors and the Electrode/Neural Interface – Stephen O'Leary, Chair

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7:45 2B: *Effects of transgenic BDNF-producing Fibroblasts on spiral ganglion Neurons: a model for cell coating of the cochlear implant electrode:* Timo Stoever

8:05 2C: *Unilateral Acoustic or Electric Hearing Maintains the Contralateral Deaf Ear for Successful Cochlear Implantation:* Jill Firszt

8:25 2D: *Degraded Topographic Specificity of Spiral Ganglion Projections to Cochlear Nucleus in Cats after Neonatal Deafness and Electrical Stimulation:* Patricia Leake

8:45 Discussion

Tuesday Morning, July 17

Session 3: Novel Stimulation and Signal Processing Strategies and Modeling– Blake Wilson, Chair

8:30 3A: *Encoding Fine Structure in Cochlear Implants*: Fan-Gang Zeng

9:15 3B: *Response Properties of Electrically Stimulated Auditory Nerve Fibers:* Leon Heffer

9:35 3C: *Loudness, Current Summation or Stochastic Resonance? The Effect of Concurrent High-Rate Pulse Trains on Signal Detection and Loudness:* Collette McKay

9:55 3D: *Stochastic Beamforming for Cochlear Implant Coding*: Nigel Stocks

10:15 Break

10:30 3E: *Inferior Colliculus Responses to CI Current Steering and Field Focusing:* Ben Bonham

11:00 3F: *Novel Simultaneous Stimulation Paradigms for Cochlear Implant Sound Processors*: Leo Litvak

11:30 3G: *Validating Patient-Specific Electro-Anatomical Models: Empirically-Measured and Model-Predicted Evoked Potentials from the Same Individual:* Darren Whiten

11:50 3H: *Effects of Amplitude Ramps on Phonemic Restoration of Speech:* Deniz Baskent

12:10 Discussion

Tuesday Evening

Session 4: Thinking Outside the Scala – John Middlebrooks, Chair

7:00 4A: *Stimulation of the auditory nerve using optical radiation:* Claus-Peter Richter

7:30 4B: *Intra-Neural Stimulation using Penetrating Auditory Nerve Arrays as a Basis for an Auditory Prosthesis:* Russ Snyder

8:00 4C: *The Auditory Midbrain Implant: Effects of Stimulation Location*: Hugh Lim

8:30 4D: *Psychophysics of Electrical Stimulation of the Human Cochlea, Cochlear Nucleus, and Inferior Colliculus:* Bob Shannon

9:00 Discussion

Wednesday Morning, July 18

Session 5: Infants and Children – Quentin Summerfield, Chair

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9:00 5B: *The Importance of Early Multimodal Experience on Spoken Language Development in Hearing-Impaired Infants with Cochlear Implants:* Tonya Bergeson

9:30 5C: *Measuring Psychometric Functions for Detection in Electric Hearing Infants and Toddlers using the Observer Based Psychoacoustic Procedure:* Vasant Dasika

9:50 5D: *Spatial Hearing Skills in Children and Adults Fitted with Bilateral Cochlear Implants:* Ruth Litovsky

10:20 Break

10:35 5E: *Binaural Hearing in Children with Bilateral Cochlear Implants:* Lieselot Van Deun

10:55 5F: *Critical Period for Bilateral Cochlear Implantation in Children:* Andrzej Zarowski

11:15 5G: *Tone Production in Mandarin Chinese Speaking Children with Cochlear Implants:* Li Xu

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9:15 6B: *Comparative Results in the Hearing Preservation for Patients with the Nucleus CI24RCA vs. Nucleus CI24RE Hybrid:* René Gifford

9:35 6C: *Integrating Acoustic and Electric Hearing: The Iowa/Nucleus Hybrid Project:* Lina Reiss

10:05 6D: *Contralateral Masking Between Electric and Acoustic Stimuli in a CI subject with Normal Acoustic Hearing:* Jeff Carroll

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10:40 6E: *Sensitivity to Interaural Level Difference and Loudness Growth with Contralateral Bimodal Stimulation:* Tom Francart

11:00 6F: *Inferior Colliculus Responses to Combined Electric and Acoustic Stimulation of the Acoustically Sensitive Cochlea*: Maike Vollmer

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11:50 6H: *Electrode Optimization of PZT Thin-Film Microactuators for Hybrid Cochlear Implants:* I.Y. (Steve) Shen

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7:30 7B: *Evolution of Coding Strategies in the Next Decade:* Peter Nopp

8:00 7C: *New Directions in Sound Coding: Customized Strategies to Improve Spectral Resolution:* Abhijit Kulkarni

8:30 Discussion

Friday Morning, July 20

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8:30 8A: *Pitch Perception and Sound Segregation by Cochlear Implant Users*: Robert Carlyon

9:15 8B: *Processing Fundamental Frequency with Cochlear Implants: Psychophysics and Speech Intonation:* Monita Chatterjee

9:45 8C: *Melodic Contour Identification by Cochlear Implant Listeners*: John Galvin

10:15 8D: *The Modified Melodies Test of Melody Perception*: Brett Swanson

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Session 9: Training – Stuart Rosen, Chair

10:50 9A: *A New Tool to Select Frequency-to-Electrode Maps for Auditory Prostheses:* Mario Svirsky

11:20 9B: *Maximizing the Benefits of Cochlear Implantation via Targeted Speech Training*: Qianjie Fu

11:50 9C: *Effectiveness of Computer-Based Auditory Training in Improving the Perception of Speech by Adult Users of Cochlear Implants:* Paula Stacey

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Poster Session A: Monday-Tuesday

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A2. RELATIONSHIPS AMONG MUSIC PERCEPTION, SPEECH PERCEPTION IN NOISE, SCHROEDER PHASE AND SPECTRAL DISCRIMINATION ABILITY IN COCHLEAR IMPLANT USERS: Jong Ho Won, Ward R. Drennan, Robby Kang, Jeff Longnion and Jay T. Rubinstein

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A7. INTERACTION BETWEEN NUMBER OF CHANNELS AND ACROSS-FREQUENCY INTEGRATION OF ENVELOPE CUES IN VOCODER PROCESSING: Michael A. Stone, Christian Füllgrabe and Brian C. J. Moore

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A9: PLASTIC CHANGES IN THE PRIMARY AUDITORY CORTEX OF THE DEAFENED CAT RESULTING FROM COCHLEAR IMPLANTATION James B. Fallon, Dexter R. F. Irvine, Lauren Donley and Robert K. Shepherd

A10. SPECIALIZED COCHLEAR IMPLANT COATING IMPROVES IMPLANT FUNCTION AND PROMOTES NEURITE REGROWTH: Jennifer A Chikar, Jeffrey L. Hendricks, David C. Martin, Yehoash Raphael, Bryan E. Pfingst

A11. STIMULATION EFFECT AND LONG-TERM IMPEDANCE DEVELOPMENT AFTER COCHLEAR IMPLANTATION: Gerrit Paasche, Anke Lesinski-Schiedat, Timo Stöver, Thomas Lenarz

A12. EFFECTS OF ERYTHROPOIETIN ON CULTURED SPIRAL GANGLION CELLS: Nurdanat Berkingali, Gerrit Paasche, Thomas Lenarz, Timo Stöver

A13. RAPID DEGENERATION OF SPIRAL GANGLION CELLS IN DEAFENED GUINEA PIGS AFTER CESSATION OF NEUROTROPHIC TREATMENT?: Martijn J.H. Agterberg, Huib Versnel, John C.M.J. de Groot, Lotte van Dijk, and Sjaak F.L. Klis

A14. COCHLEAR IMPLANT AND METHOD FOR PASSIVE DRUG DELIVERY: C. Jolly, C. Garnham, W.-D. Baumgartner

A15. ROUND-WINDOW DEXAMETHASONE FOR HEARING PROTECTION DURING COCHLEAR IMPLANTATION: David P. James, Hayden Eastwood, Rachael T. Richardson, Stephen J. O'Leary

A16. FINE-TUNING OF THE IMPLANT MATERIAL-CELL INTERACTIONS BY FEMTOSECOND LASER MICRO STRUCTURING: G. Reuter, U. Reich, P.P. Müller, T. Stöver, E. Fadeeva, B. Chichkov, T. Lenarz

A17. COCHLEAR NUCLEUS ALTERATIONS FOLLOWING ELECTRICAL STIMULATION IN CATS DEAFENED AT DIFFERENT AGES: Olga Stakhovskaya, Gary H. Hradek, Russell L. Snyder, Patricia A. Leake

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B35. EFFECTS OF HIGH RATE STIMULATION ON NEURAL RESPONSES: COMPUTATIONAL MODEL APPROACH: Jihwan Woo, Paul J. Abbas, Charles A. Miller

B36. POLARITY CONTRIBUTIONS TO NEURAL EXCITATION IN COCHLEAR IMPLANTS: Olivier Macherey, Robert P. Carlyon, Astrid van Wieringen, John M. Deeks and Jan Wouters

B37. SIMULTANEOUS STIMULATION BASED ON CHANNEL INTERACTION COMPENSATION: Clemens Zierhofer, Mathias Kals, Reinhold Schatzer, Andreas Krenmayr, Thomas Gründhammer

B38. THRESHOLDS FOR FACIAL NERVE STIMULATION VARY OVER TIME: Sharon L. Cushing, Blake C. Papsin, Karen A. Gordon

B39. FACIAL NERVE STIMULATION FROM COCHLEAR IMPLANTS OCCURS ALONG THE ENTIRE IMPLANT ARRAY: Sharon L. Cushing, Blake C. Papsin, Karen A. Gordon

Poster Session C: Wednesday-Thursday

C1. LASER STIMULATION OF THE AUDITORY SYSTEM: SELECTIVITY AND OPTICAL PARAMETERS Agnella D. Izzo, Heather Ralph, Jim Webb, Jonathon Wells, Mark Bendett, Joseph T. Walsh Jr., E. Duco Jansen, Claus-Peter Richter

C2. A NEW CONCEPT IMPLANTABLE HEARING AID Alan J. Lupin

C3. SPECTRAL SPECIFICITY OF SURFACE AND PENETRATING COCHLEAR NUCLEUS STIMULATING ELECTRODES Douglas McCreery

C4. AUDIOLOGICAL RESULTS WITH IMPLANTABLE HEARING DEVICE VIBRANT SOUNDBRIDGE IN MODERATE TO SEVERE MIXED HEARING LOSS Hamidreza Mojallal, Burkard Schwab, Timo Stoever, Thomas Lenarz

C5. NOVEL STIMULATION OF THE COCHLEA USING MECHANICAL EXCITATION VIA THE ROUND WINDOW Jane M. Opie, Peter Lampacher, Geoffrey R. Ball

C6. RESULTS OBTAINED WITH THE BONE ANCHORED HEARING AIDS (BAHA) IN FUNCTION OF THE BONE CONDUCTION THRESHOLDS Nadia Verstraeten, Andrzej Zarowski, Thomas Somers, Sofie Furniere, Daphna Riff, Erwin Offeciers

C7. SPEECH AND LANGUAGE DEVELOPMENT IN CHILDREN WITH BILATERAL COCHLEAR IMPLANTS Jane R. Madell, Richard G. Schwartz, Elizabeth Ying, Nicole Sislian, Megan Kuhlmey, Shelly Ozdamar

C8. DEVELOPING A SPEECH PERCEPTION TEST PROTOCOL FOR CHILDREN Jane R. Madell

C9. THE EFFECT OF INSTANTANEOUS INPUT DYNAMIC RANGE SETTING ON THE SPEECH PERCEPTION OF CHILDREN WITH THE NUCLEUS 24 IMPLANT Lisa S. Davidson, Margaret W. Skinner, Beth A. Holstad, Beverly T. Fears, Marie K. Richter, Margaret B. Matusofsky, Amy Birath, Jerrica L. Kettel

C10. LOCALIZATION ACUITY IN TODDLERS WHO USE BILATERAL COCHLEAR IMPLANTS Tina M. Grieco, Ruth Y. Litovsky, Lynne A. Werner

C11. IDENTIFICATION OF TONAL PATTERNS IN COMPETING BACKGROUNDS BY CHILDREN AND ADULTS WITH COCHLEAR IMPLANTS OR IMPLANT-PROCESSING SIMULATIONS Donna L. Neff and Michelle L. Hughes

C12. EARLY SEQUENTIAL BILINGUALISM FOLLOWING COCHLEAR IMPLANTATION Jan A. Moore

C13. NEURAL TONOTOPY IN CI: AN EVALUATION IN UNILATERAL CI PATIENTS WITH CONTRALATERAL NORMAL HEARING Katrien Vermeire, Andrea Nobbe, Peter Schleich, Ernst Aschbacher, Maurits Voormolen, Paul Van de Heyning

C14. COCHLEAR IMPLANTATION AS A TREATMENT FOR UNILATERAL DEAFNESS ASSOCIATED WITH IPSILATERAL TINNITUS: A CASE STUDY Andreas Buechner, Anke Lesinski-Schiedat, Rolf D. Battmer, Thomas Lenarz

C15. VISUAL SYSTEM CROSS-MODAL PLASTICITY AND SPEECH PERCEPTION WITH A COCHLEAR IMPLANT K. A. Buckley, E. A. Tobey

C16. A REAL-TIME HYBRID SOUND PROCESSING RESEARCH PLATFORM FOR THE NUCLEUS® SYSTEM Michael Goorevich, Tim J. Neal, Felicity R. Allen, Paul F. Holmberg

C17. MECHANICAL EFFECTS OF THE CI - ELECTRODE IN THE COCHLEA Kelly Lumiste, Frank Boehnke, Markus Pecher

C18. SPEECH RECOGNITION AS A FUNCTION OF THE NUMBER OF CHANNELS IN THE HYBRID COCHLEAR IMPLANT: QUIET AND BACKGROUND NOISE Sheryl R Erenberg, Lina AJ Reiss, Christopher W Turner, Bruce J Gantz

C19. PREOPERATIVE PURE TONE THRESHOLD AND PERFORMANCE AFTER COCHLEAR IMPLANTATION Wilma Harnisch, Stefan Brill, Alexander Möltner, Joachim Müller

C20. PRESERVATION OF RESIDUAL HEARING WITH A NEW STRAIGHT ELECTRODE Thomas Lenarz, Rolf-Dieter Battmer, Andreas Buechner, Melanie Boehm, Joerg Pesch

C21. FITTING PARADIGM IN THE COMBINED ELECTRIC-ACOUSTIC STIMULATION (EAS) Marek Polak, Marcus Schmidt, Artur Lorens, Silke Helbig, Sonelle McDonald , Katrien Vermeire, Peter Nopp

C22. A COMBINED ELECTRIC/ACOUSTIC SPEECH PROCESSOR FOR COCHLEAR IMPLANT PATIENTS WITH PRESERVED ACOUSTIC HEARING Aaron J. Parkinson, George Cire

C23. A COMBINED ELECTRIC/ACOUSTIC SPEECH PROCESSOR FOR COCHLEAR IMPLANT PATIENTS WITH PRESERVED ACOUSTIC HEARING Aaron J. Parkinson and George Cire

C24. COCHLEAR IMPLANT : A PRELIMINARY STUDY TO ASSESS THE EFFECT OF ASYNCHRONY BETWEEN ACOUSTIC AND ELECTRICAL STIMULATION Chin-Tuan Tan, Matthew B. Fitzgerald, Mario A. Svirsky

C25. ACOUSTICAL FREQUENCY DISCRIMINATION AND SPEECH PERCEPTION IN NOISE IN EAS IMPLANTED EARS Uwe Baumann, Silke Helbig, Wolfgang Gstöttner

C26. BIMODAL HEARING AFTER CI IN UNILATERAL SENSORINEURAL DEAFNESS AND TINNITUS Katrien Vermeire, Peter Schleich, Paul Van de Heyning

C27. ANALYSIS OF A LARGE OBJECTIVE MEASURES DATABASE Laure P. Arnold, Patrick J. Boyle

C28. THE NIC AND NMT RESEARCH TOOLS FORSPEECH CODING RESEARCH Colin Irwin, Herbert Mauch, Brett Swanson

C29. DESIGN FOR A SIMPLIFIED COCHLEAR IMPLANT SYSTEM Soon Kwan An, Se-Ik Park, Choong Jae Lee, Kyung Min Byun, Kyu Sik Min, Jung Min Lee, Blake S. Wilson, Dewey T. Lawson, Stephen J. Rebscher, Seung Ha Oh, Sung June Kim

C30. COMPARISON OF DUAL-TIME-CONSTANT AND FAST-ACTING AGC IN COCHLEAR IMPLANT USERS Patrick J Boyle, Michael A Stone, Brian C J Moore

C31. THE HR90K STREAMING INTERFACE Peter Bracke, S. Murtonen, F. Vanpoucke

C32. MICROPHONE CHOICE FOR COCHLEAR IMPLANT USERS IN WIND NOISE King Chung, Lance A. Nelson, Nicholas McKibben

C33. RESULTS OF 53 COCHLEAR IMPLANT SUBJECTS: PREFERENCE AND PERFORMANCE WITH RATE AND INPUT PROCESSING OPTIONS IN QUIET AND NOISE Linda A. Hazard

C34. DEVELOPMENT OF AN EFFECTIVE LOW-COST SPEECH PROCESSOR FOR COCHLEAR PROSTHESIS P. Seetha Ramaiah, K. Raja Kumar, Y.Damodar Rao

C35. A PORTABLE RESEARCH PLATFORM FOR COCHLEAR IMPLANTS Arthur P. Lobo, Philip C. Loizou, Nasser Kehtarnavaz, Murat Torlak, Hoi Lee, Anu Sharma, Phillip Gilley, Venkat Peddigari, Lakshmish Ramanna

C36. FORWARD MASKED THRESHOLDS FOR MONOPOLAR AND TRIPOLAR STIMULATION IN COCHLEAR IMPLANT LISTENERS Aniket Saoji, Leonid Litvak

C37. VALIDATION OF A COCHLEAR IMPLANT DEAD REGION MODEL USING MONOPOLAR AND TRIPOLAR THRESHOLD DATA Joshua H. Goldwyn, Steven M. Bierer, Julie A. Bierer

C38. EQUAL LOUDNESS CONTOURS FOR SIMULTANEOUS AND SEQUENTIAL DUAL ELECTRODE STIMULATION IN COCHLEAR IMPLANTS Aniket Saoji, Leonid Litvak

Poster Session D: Thursday-Friday

D1. PERCEPTUAL ADAPTATION TO A BINAURALLY MISMATCHED FREQUENCY-TO-PLACE MAP: IMPLICATIONS FOR BINAURAL REHABILITATION WITH COCHLEAR IMPLANTS: Catherine Siciliano, Andrew Faulkner, Stuart Rosen and Katharine Mair

D2. EFFECTS OF AGING ON THE RECOGNITION OF SPECTRALLY DEGRADED SPEECH: Kara Schvartz, Monita Chatterjee and Sandra Gordon-Salant

D3. SPEECH RECOGNITION AND PERCEPTUAL LEARNING IN SIMULATIONS WITH NOISE-VOCODED SPEECH: BEHAVIORAL AND NEUROIMAGING STUDIES: Carolyn McGettigan, Frank Eisner, Stuart Rosen, Andrew Faulkner and Sophie K. Scott

D4. CUSTOMIZED SELECTION OF FREQUENCY MAPS IN AN ACOUSTIC SIMULATION OF A COCHLEAR IMPLANT: Matthew B. Fitzgerald, Chin-Tuan Tan, and Mario A. Svirsky

D5. PERCEPTUAL ADAPTATION TO SPECTRALLY SHIFTED VOWELS WITHIN AN ACOUSTIC ANALYSIS FRAMEWORK: Tianhao Li and Qian-Jie Fu

D6. ADAPTATION TO COCHLEAR IMPLANT SIMULATED SPEECH: MULTIPLE ROUTES TO PERCEPTUAL LEARNING: Jeremy L. Loebach, Tessa Bent and David B. Pisoni

D7. A NEW “TOP DOWN” OR “COGNITIVE NEUROSCIENCE” APPROACH TO COCHLEAR IMPLANT DESIGN: Blake S. Wilson and Michael F. Dorman

D8. THE ROLE OF TEMPORAL AND SPECTRAL INFORMATION IN GENDER IDENTIFICATION AND DISCRIMINATION IN CHILDREN WITH COCHLEAR IMPLANTS: Damir Kovačić, Evan Balaban

D9. PITCH STEERING WITH THE NUCLEUS CONTOUR CI: Laura K. Holden, Timothy A. Holden, Bomjun Kwon, Jill B. Firszt, Ruth M., Reeder, and Margaret W. Skinner

D10. EFFECT OF FREQUENCY-PLACE MAPPING ON SPEECH INTELLIGIBILITY: IMPLICATIONS FOR A COCHLEAR IMPLANT LOCALIZATION STRATEGY: Matthew J. Goupell, Bernhard Laback, Piotr Majdak, and Wolf-Dieter Baumgartner

D11. EVALUATING THE PITCH STRUCTURE DUE TO MULTIPLE RATES AND PLACES FOR COCHLEAR IMPLANT USERS: Joshua S. Stohl, Chandra S. Throckmorton and Leslie M. Collins

D12. RATE DISCRIMINATION AS A FUNCTION OF BASELINE RATE IN MED-EL COMBI 40+ AND NUCLEUS CI 24 USERS: Ying-Yee Kong, John M. Deeks, Patrick R. Axon, Robert P. Carlyon

D13. HOW MUCH RESIDUAL HEARING IS “USEFUL” FOR MUSIC PERCEPTION WITH CI?: Fouad El Fata, Chris J James, Marie-Laurence Laborde, Bernard Fraysse

D14. VOCAL EMOTION RECOGNITION BY NORMAL-HEARING LISTENERS AND COCHLEAR IMPLANT USERS: Xin Luo, John J. Galvin III, and Qian-Jie Fu

D15. IMPROVING PITCH PERCEPTION WITH COCHLEAR IMPLANTS: Matthias Milczynski, Jan Wouters, Astrid van Wieringen

D16. AUDITORY STREAM SEGREGATION IN AMPLITUDE MODULATED BANDPASS NOISE: Yingjiu Nie and Peggy B. Nelson

D17. SPEECH INTONATION RECOGNITION WITH CONFLICTING AND COOPERATING CUES: ACOUSTIC VS. ELECTRIC HEARING: Shu-Chen Peng and Monita Chatterjee

D18. QUANTIFYING ELECTRIC PITCH: Qing Tang, Fan-Gang Zeng, Jannine Larky, and Nikolas H. Blevins

D19. CONTRIBUTION OF F0 TO COCHLEAR IMPLANT PERFORMANCE: Stephanie Tiaden, Jeff Carroll, and Fan-Gang Zeng

D20. THE PERCEPTION OF INDEXICAL PROPERTIES OF SPEECH BY ADULT COCHLEAR IMPLANT USERS: Rosalie M. Uchanski, Kristin P. Peters and Laura K. Holden

D21. PITCH AND TONAL LANGUAGE PERCEPTION IN COCHLEAR IMPLANT USERS: Andrew E. Vandali, Valter Ciocca, Lena L. N. Wong, Betty Luk, Vivian W.K. Ip, Brendan Murray, Hip C. Yu, Isabella Chung, Elaine Ng, Kevin Yuen

D22. THE EFFECTS OF SPECTRAL DISTRIBUTUION OF ENVELOPES ON LEXICAL TONE PERCEPTION: Ning Zhou and Li Xu

D23. THE RELEVANCE OF TEMPORAL AND PLACE PITCH FOR FREQUENCY DISCRIMINATION WITHIN A COCHLEAR IMPLANT SYSTEM: Andrea Nobbe, Peter Schleich, Peter Nopp, Clemens Zierhofer

D24. UPPER LIMIT OF RATE PITCH IN COCHLEAR IMPLANT USERS: John M. Deeks, Ying-Yee Kong, Christopher J. Long, Colette M. McKay, and Robert P. Carlyon

D25. INVESTIGATING THE IMPACT OF DURATION ON PITCH CUES IN COCHLEAR IMPLANTS: Joshua S. Stohl, Chandra S. Throckmorton and Leslie M. Collins

D26. BINAURAL UNMASKING WITH “TRANSPOSED” STIMULI IN BILATERAL COCHLEAR IMPLANT USERS: Christopher J. Long, Robert P. Carlyon, Ruth Y. Litovsky

D27. BREAKDOWN OF PRECEDENCE WITH COCHLEAR IMPLANTS - SIMULATIONS SHOW IMPORTANCE OF SPECTRAL CUES: Bernhard U. Seeber and Ervin Hafter

D28. MONAURAL AND BINAURAL CATEGORICAL LOUDNESS SCALING IN ELECTRIC HEARING: Florian Wippel, Piotr Majdak, and Bernhard Laback

D29. THE RELATIONSHIP BETWEEN SPATIAL TUNING CURVES AND SPEECH RECOGNITION IN COCHLEAR IMPLANT LISTENERS: Elizabeth S. Crump, Peggy B. Nelson, David A. Nelson, Heather A. Kreft, Mollie Carson, and Laura Jaeger

D30. SENSITIVITY TO SPECTRAL PEAKS AND NOTCHES IN COCHLEAR IMPLANT LISTENERS: Matthew J. Goupell, Bernhard Laback, Piotr Majdak, and Wolf-Dieter Baumgartner

D31. SPATIAL HEARING ABILITIES IN SUBJECTS USING A COMBINATION OF ELECTRIC AND ACOUSTIC STIMULATION: Melanie Böhm, Kerrie L Plant, Joerg Pesch, Andreas Büchner, Thomas Lenarz

D32. A MODEL FOR RESPONSES OF THE INFERIOR COLLICULUS NEURONS TO BILATERAL ELECTRICAL STIMULATIONS: Yoojin Chung and H. Steven Colburn

D33. EFFECT OF SPECTRAL HOLES ON SPEECH INTELLIGIBILITY AND SPATIAL RELEASE FROM MASKING: Soha N. Garadat, Ruth Y. Litovsky, Gongqiang Yu, Fan-Gang Zeng

D34. COMPARISON OF ELECTROPHYSIOLOGIC AND PSYCHOACOUSTIC MEASURES OF BILATERAL ELECTRICAL STIMULATION: Shuman He, Carolyn J. Brown and Paul J. Abbas

D35. INTEGRATING BEAMFORMING WITH BLIND SEPARATION FOR BETTER RECOGNITION WITH BILATERAL COCHLEAR IMPLANTS: Kostas Kokkinakis and Philipos C. Loizou

D36. BINAURAL LOCALIZATION ABILITY CAN BE PREDICTED FROM BASIC MEASURES OF ILD AND IS ROBUST TO EFFECTS OF AGC: Victor A. Noel and Donald K. Eddington

D37. RECOGNITION AND LOCALIZATION OF SPEECH BY ADULT COCHLEAR IMPLANT RECIPIENTS WEARING A DIGITAL HEARING AID IN THE NON-IMPLANTED EAR (BIMODAL HEARING): Lisa G. Potts, Margaret W. Skinner, and Ruth A. Litovsky

D38. BILATERAL ELECTRICAL STIMULATION RESEARCH TOOLS FOR NUCLEUS® COCHLEAR IMPLANTS: Colin Irwin, Shuman He

D39. INTERAURAL TIME SENSITIVITY TO COCHLEAR IMPLANT STIMULATION IN FIELD A1 OF HEARING AND CONGENITALLY DEAF CATS: J. Tillein, P. Hubka, S. Heid, D. Schiemann, R. Hartmann, A. Kral

D40. LOCALIZATION AND 3D SPEECH PERCEPTION WITH THE FSP STRATEGY: Peter Schleich, Peter Nopp, Clemens Zierhofer

1A: THE ROLE OF TEMPORAL FINE STRUCTURE IN NORMAL HEARING, HEARING IMPAIRMENT, AND COCHLEAR IMPLANTS

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Any complex sound that enters the normal ear is decomposed by the auditory filters into a series of relatively narrowband signals. Each of these signals can be considered as a slowly varying envelope (E) superimposed on a more rapid temporal fine structure (TFS). I consider the role played by TFS in a variety of psychoacoustic tasks. I argue that cues derived from TFS may play an important role in the ability to “listen in the dips” of a fluctuating background sound, and that TFS cues influence effects such as comodulation masking release and comodulation detection differences. TFS cues also play a role in pitch perception, the ability to hear out partials from complex tones, and sound localisation. Finally, and perhaps most importantly, TFS cues may be important for the ability to hear a target talker in the spectral and temporal dips of a background talker.

Evidence will be reviewed suggesting that cochlear hearing loss reduces the ability to use TFS cues. People with cochlear implants also appear to have a drastically reduced ability to process TFS. The perceptual consequences of this, and reasons why it may happen, will be discussed.

This work was supported by the Medical Research Council (UK).

1B: THE ROLE OF TEMPORAL FINE STRUCTURE IN NORMAL HEARING FOR LISTENING IN COMPLEX ENVIRONMENTS: IMPLICATIONS FOR COCHLEAR IMPLANTS

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Pitch perception in normal hearing relies primarily on low-numbered harmonics that are thought to be resolved in the auditory periphery. The temporal fine structure of these individual harmonics is believed to provide the information necessary to calculate the pitch of a sound, and it is widely believed that the failure of cochlear implants to represent temporal fine structure is one reason why implant users find understanding speech in complex acoustic backgrounds so challenging.

A common way of probing listeners' ability to deal with complex acoustic environments is to compare speech reception in a steady noise background with that in a more spectro-temporally complex background, such as a competing talker or a modulated noise. The improved performance shown by normal-hearing listeners in the more complex backgrounds, relative to that in the steady noise, is termed "masking release" and probably reflects their ability to make use of spectral and temporal "dips" in the complex masker. In contrast, cochlear-implant users typically show little or no masking release (or even an increase in masking) in the presence of complex maskers.

If low-frequency temporal fine-structure information is important for listening in complex backgrounds, and for obtaining masking release, it follows that the removal of low-frequency information should impair performance, even in normal-hearing listeners. We tested this prediction by comparing the recognition of sentences spoken by a male talker in steady speech-shaped noise with recognition in more complex backgrounds, including single male or female interferers and temporally modulated speech-shaped noise. We filtered both the target and the masker with either a high-pass (1500-Hz) or low-pass (1200-Hz) filter, with cut-off frequencies selected to produce equal performance in the presence of steady-state noise. After confirming that the high-pass-filtered stimuli elicited substantially weaker pitch percepts than the low-pass-filtered stimuli, we measured release from masking by comparing performance in steady noise with performance in the more complex maskers. Masking release in the filtered conditions was much less than in the unfiltered conditions but, surprisingly, was similar in both the low- and high-pass-filtered conditions. These results suggest that temporal fine structure (along with accurate pitch information) cannot alone account for the differences in performance between normal-hearing and cochlear-implant subjects in complex acoustic environments.

Support provided by the NIH-NIDCD (R01 DC 05216).

1C: PERCEPTION OF MUSIC, SPEECH AND SPEECH IN NOISE: SPECTRAL AND TEMPORAL CONTRIBUTIONS TO PERFORMANCE

Jay T Rubinstein,[1] Ward Drennan[1], Kaibao Nie[1], Jong Ho Won[1], Camille Dunn,[2] Shelley Witt[2]

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Over the past three years, we have been performing chronic trials of a version of CIS processing that applies a high-rate conditioning stimulus in Clarion users. A significant number of patients have shown substantial improvements in speech perception in quiet and/or noise using this conditioned CIS (CCIS) processor relative to their clinical processor. A number of them subjectively state that music sounds much better to them. In order to further investigate these findings we developed and validated a test of music perception in cochlear implant users, the UW Clinical Assessment of Music Perception (CAMP) test and correlated CAMP outcomes with speech perception measures in quiet and noise as well as with spectral ripple resolution and Schroeder phase perception. It is clear that speech perception in quiet and noise is highly correlated both with spectral ripple threshold, and with music perception measures. Pitch perception is jointly predicted by spectral ripple and by Schroeder phase.

At the same time, we have begun a systematic investigation comparing CCIS performance on a variety of music and speech measures and have also compared CCIS performance with performance on an identical version of CIS without a conditioner. While the results are highly variable across subjects, one of three subjects whose performance improved with CCIS clearly demonstrates that those improvements are attributable to the effects of the conditioner stimulus. In addition, two of five subjects show significant improvements in pitch and timbre perception using CCIS and one of these, whose pitch thresholds go from seven to one semitone shows a dramatic improvement in isochronous melody recognition. No change in spectral ripple thresholds were seen with CCIS suggesting that these improvements are indeed due to improved temporal coding as suggested by a variety of physiological studies.

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1D: TEMPORAL PATTERN DISCRIMINATION

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Current cochlear implant speech processing strategies typically present only the temporal envelope cue through 8 to 22 spectral channels. While these strategies allow cochlear implant (CI) users to achieve good speech recognition in quiet, the lack of encoding of the temporal fine structure cue is thought to be one factor contributing to poor CI performance in noisy speech recognition, music perception and speaker identification. The objective of this paper is to investigate temporal pattern discrimination abilities in cochlear implant users, compare their performance to normal hearing (NH) subjects and correlate temporal pattern discrimination performance with speech perception. Five CI and 5 NH subjects discriminated different temporal patterns over three different stimulus durations with the average rates corresponding to temporal envelope, periodicity, and fine structure. Experiment 1 measured temporal pattern discrimination based on gap correlation and experiment 2 measured that based on jitter difference. Subjects listened to two stimuli in one trial and had to judge whether the two were the same or different. The method of constant stimuli was used to estimate d' values as well as percent correct scores.

Results showed that, once the spectral cue is removed, CI users performed comparably to NH subjects in temporal pattern discrimination using the envelope cue, but were better than NH subjects in discriminating between stimuli differing in temporal periodicity or fine structure. For temporal envelope discrimination, performance was a function of both gap correlation and jitter difference. For periodicity and fine structure discrimination, performance was a function of jitter difference only. Spearman's rank order correlation was used to relate temporal pattern discrimination to speech recognition. In general, temporal pattern discrimination with long durations was more likely to be correlated with speech performance but that with short durations was not. These results can be interpreted as the limitation of current CI speech processing strategies, which incorporate the temporal envelope cue but not the fine structure cue. Further studies will investigate possible speech coding algorithms to incorporate fine structure.

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1E: TEMPORAL FINE STRUCTURE CODING IN LOW FREQUENCY CHANNELS: SPEECH AND PROSODY UNDERSTANDING, PITCH AND MUSIC PERCEPTION AND SUBJECTIVE BENEFIT EVALUATED IN A PROSPECTIVE RANDOMIZED STUDY

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In traditional stimulation strategies for cochlear implants only the envelope of the channel-specific band filtered signal is conveyed, while phase information is being discarded. However, the phase of the broad band speech signal alone contains enough information for normal hearing subjects to understand speech. In stage one (FS1 condition) of the first clinically available fine structure coding strategy, the phase information is presented on the low frequency channels, i.e. apical electrodes, by placing bursts of stimulation pulses at the zero-crossings of the respective channel's band-filtered signal. All other channels run CIS.

We tested 46 CI users in a prospective, multicentric, randomized ABA study. The Subjects participated in various listening tasks with both CIS and FS1, where at most two low frequency channels carried fine structure. Subjects had at least 6 months of listening experience with the CIS strategy before enrollment. In two visits (interval 1 and 3), resp. three intervals, including a postal survey (interval 2), subjects were tested with monosyllables in noise, vowels in noise, OLSA sentences and understanding of prosodic information in sentences. Additionally, they participated in music perception and pitch scaling tasks. Subjective benefit was assessed through a questionnaire in acute direct and blinded comparison of FS1 vs. CIS with prerecorded speech and music. Subjects had a three months phase of using FS1 before re-visiting for their second visit (interval 3) and conducting the test battery.

A statistically significant improvement in speech understanding was observed with the FS1 condition over CIS. The benefit appeared on the second visit only. In pitch scaling, the subjects' pitch range expanded significantly towards lower frequencies whithout compromising range and apparent resolution of the pitch range with CIS. In the music tests, performance with FS1 was either equal or better than with CIS.

The questionnaire exhibited substantial and statistically significant subjective benefit at all three intervals. Subjects were offered the choice of FS1 or CIS as an everyday map. 44 out of 46 subjects opted for FS1. Second visit re-testing of CIS yielded neither improvement nor deterioration with CIS as compared to the first visit. We can conclude that the additional three months of CI usage per se do not account for the gain in performance, but have to be attributed to additional information conveyed by temporal fine structure information in FS1. The fact that the gain is statistically significant at the second visit only, suggests, that the additional information has to be learned and interpreted by the subjects.

1F: EFFECTS OF INTERAURAL TIME DIFFERENCE IN THE TEMPORAL FINE STRUCTURE

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In normal hearing, interaural time differences (ITD) in the fine structure are important for the lateralization of sound sources and for speech understanding in noise. Here we present the results of three studies on the effects of ITD in the temporal fine structure and envelope in electric hearing. In all studies, the pulse rate was varied as an independent parameter. In the first study (Laback et al. 2007; J. Acoust. Soc. Am. 121, 2182-2191), unmodulated four-pulse-sequences were used and ITD was presented either in the ongoing pulses, or in the onset and offset pulses. Four bilateral CI listeners were tested. All of them were sensitive to ongoing ITD, one up to 800 pulses per second (pps), two up to 400 pps, and one at 100 pps only. This result reveals the importance of ITD in the fine structure. For three CI listeners, the sensitivity to onset ITD increased with the pulse rate.

In the second study (Majdak et al., 2006; J. Acoust. Soc. Am. 120, 2190-2201), amplitude modulated 300 ms pulse trains were used and ITD was independently presented in the fine structure and the envelope. For all four bilateral CI listeners tested, fine structure ITD had the strongest impact on lateralization at lower pulse rates, with significant effects up to 800 pps. At the higher pulse rates tested (up to 1600 pps), lateralization discrimination depended solely on envelope ITD.

The data from both studies suggest that bilateral CI listeners benefit from transmitting fine structure ITD at lower pulse rates. However, the rate limit in the perception of fine structure ITD in CI subjects (100-800 pps) is lower than the 1500 Hz fine structure rate limit in NH subjects listening to sinusoids (Zwislocki and Feldman, 1956; J. Acoust. Soc. Am. 28, 860-864).

In the third study, a new stimulation method has been evaluated with five CI listeners, showing large improvements of fine structure ITD sensitivity at higher pulse rates.

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1G: ITD SENSITIVITY IN ELECTRICAL HEARING: EFFECT OF CHANNEL INTERACTIONS

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Bilateral cochlear implant (BICI) users typically exhibit poor sensitivity to interaural timing differences (ITDs) when listening through their own speech processors. First, this may simply reflect temporal limitations of existing processors; data from experiments with a bilaterally coordinated research processor have shown that sensitivity to ITDs in the tens of microseconds can be achieved by adult bilateral cochlear implant users with postlingual onset of deafness when single electrode pairs are stimulated at low pulse rates. Second, poor ITD sensitivity could result from channel interaction effects. Specifically, ITD sensitivity when a single electrode pair is activated may not predict performance under more realistic listening conditions, in which there is activation of more than one electrode pair and where more than one ITD may be presented to the auditory system simultaneously.

In order to measure effects of channel interactions on binaural sensitivity, we examined ITD sensitivity in Nucleus-24 BICI users with bilateral pairs of pitch-matched electrodes on which unmodulated pulse trains were presented at 100 pps. A probe signal and an added signal were temporally interleaved so that the added signal led the probe. ITD JNDs for a probe in the middle of the electrode array presented at 90% of the dynamic range were measured using a 2-alternative forced choice (2AFC) procedure while varying the added signal's: a) place of stimulation relative to the probe from -8 to +8 electrodes, b) level from 20% to 90% of the dynamic range, c) temporal offset relative to the probe, and d) ITD (matched to probe or fixed at 0□s). Results of these experiments are as follows: 1) presence of the added signal influenced ITD sensitivity across added signal locations; 2) JND was higher when the added signal ITD was 0 than when it was matched to probe; 3) JND could either increase or decrease relative to single-electrode JNDs when the added signal's ITD was matched to probe; and 4) these effects disappeared as the level of the added signal was reduced. These results suggest that stimulation on multiple electrodes can result in a range of interaction effects that may make both positive and negative contributions to binaural sensitivity, and highlight potential difficulties in coding multiple ITDs using present stimulation methods.

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2A: NEUROTROPHINS AND ELECTRICAL STIMULATION FOR PROTECTION AND REPAIR FOLLOWING SENSORINEURAL HEARING LOSS.

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Loss of hair cells following sensorineural hearing loss (SNHL) sets in place degenerative and atrophic changes within the cochlea and central auditory pathway – in particular loss of spiral ganglion neurons (SGNs) - that has implications for the efficacy of auditory prostheses. Exogenous neurotrophins (NTs) have been shown to rescue SGNs from degeneration following a SNHL. However, NT administration must be continuous to ensure long-term SGN survival; this observation has important implications for the potential clinical delivery of these drugs. More recently, greater SGN rescue was observed when NT administration was combined with chronic electrical stimulation (ES). We review these studies and examine whether chronic ES can maintain SGN survival long after cessation of NT delivery. Profoundly deafened guinea pigs were unilaterally implanted with a scala tympani electrode array incorporating a drug delivery system. Brain derived neurotrophic factor (BDNF) was continuously delivered to the scala tympani over a 4 week period while the animal simultaneously received intracochlear ES. One cohort received ES for 6 weeks (i.e. including ES for 2 weeks after cessation of BDNF; ES_6); a second cohort received ES for 10 weeks (including a 6 week period following cessation of BDNF delivery; ES_{10}). The withdrawal of BDNF resulted in a rapid loss of SGNs in turns 2-4 of the deafened/BDNF-treated cochleae; this was significant as early as 2 weeks following removal of the NT when compared with normal controls ($p<0.05$). Importantly, while there was a reduction in SGNs in turn 1 (i.e. adjacent to the electrode array) after NT removal, this reduction was not significant compared with normal controls, suggesting that chronic ES can at least partially maintain SGNs after initial rescue using exogenous NTs. We discuss the implications of this work in relation to the clinical application of NTs within the deafened cochlea. We also describe a potentially safe and effective NT delivery technique using encapsulated neurotrophin producing cells implanted within the scala tympani.

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2B: EFFECTS OF TRANSGENIC BDNF-PRODUCING FIBROBLASTS ON SPIRAL GANGLION NEURONS: A MODEL FOR CELL COATING OF THE COCHLEAR IMPLANT ELECTRODE

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Neurotrophic factors have a protective effect on spiral ganglion cells (SGC). Especially brain-derived neurotrophic factor (BDNF) has been demonstrated to protect SGC in vitro and after ototoxic trauma in vivo. Fibroblasts transfected to express BDNF can be used for the delivery of neurotrophic factors to the inner ear. They may serve for the coating of cochlear implant electrodes. To directly demonstrate the effects of BDNF producing fibroblasts on SGC, co-cultures of both cell types were performed and analysed.

Murine NIH-3T3 fibroblasts were transfected with a lentiviral vector to express BDNF and GFP. Transfected and not transfected (native) fibroblasts were seeded in 48-well plates at concentrations of 1.75×10^3 and 1.75×10^4 cells/ well. They were cultured for 24 hours in a humidified atmosphere of 5% CO_2 and 37°C. Spiral ganglion cells were dissected from neonatal rats (p3-5) and cultured on square (0.5 x 0.5 cm) laminin-coated glass plates for 4 hours. Then, glass plates were transferred into the 24 hour old culture of fibroblasts (transfected with BDNF or native). After co-cultivation for 48 hours under aforementioned conditions, survival and neurite outgrowth of spiral ganglion cells were evaluated.

Highest survival of spiral ganglion cells and most advanced neurites were observed in the co-culture of transgenic fibroblasts with SGC. The co-culture with native fibroblasts led to a significantly lower survival of SGC when compared to the one with BDNF-producing fibroblasts. ELISA of the supernatants of the co-cultures showed a significant amount of BDNF produced by transgenic fibroblasts. In comparison, supernatants from the co-culture of native fibroblasts with SGC did not contain any BDNF.

Fibroblasts transfected to produce BDNF secrete a significant amount of BDNF. In co-culture with SGC they have a significant positive effect on survival and neurite outgrowth. The results suggest that transfected fibroblasts can be applied via cell coating of the cochlear implant (CI) electrode to the inner ear to prevent progressive SGC degeneration after CI surgery.

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2C: UNILATERAL ACOUSTIC OR ELECTRIC HEARING MAINTAINS THE CONTRALATERAL DEAF EAR FOR SUCCESSFUL COCHLEAR IMPLANTATION

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The purpose of this research is to test the hypothesis that a) unilateral *acoustic* hearing or b) unilateral *electric* hearing reduces the negative effect of deafness in the other ear.

Individuals who have one ear with some *acoustic* hearing and one ear with severe-to-profound hearing loss have not previously been considered cochlear implant (CI) candidates. Preliminary findings were obtained in pediatric and adult patients with unilateral acoustic hearing who received a CI in the poor ear. Word and sentence recognition scores in quiet and in noise indicate that unilateral acoustic hearing maintains the contralateral ear (and associated central pathway) with profound hearing loss for successful cochlear implantation, defined as open-set speech recognition.

Individuals who have one ear with *electric* hearing (i.e. unilateral CI) are increasingly considering implantation of the second ear. Speech recognition scores from children with varied times between surgery suggest that early implantation in the first ear may preserve the contralateral deaf ear for later implantation. In some children and adults, rapid improvements in speech recognition scores in the later implanted ear were observed compared to rate of progress on identical measures in the first implanted ear.

In addition, recent data in animal models indicate that auditory nerve endbulb synapses in the contralateral ear are affected by unilateral cochlear implantation. In cats who received a 6-channel CI system in one ear, synapses in the contralateral ear were intermediate in size between those of normal and congenitally deaf animals. In summary, our studies are aimed at understanding the effects of unilateral *acoustic* or *electric* hearing on outcomes (e.g., speech recognition) in the contralateral deaf ear, and the implications for clinical decisions concerning cochlear implantation in children and adults.

Supported by NIH NIDCD.

2D: DEGRADED TOPOGRAPHIC SPECIFICITY OF SPIRAL GANGLION PROJECTIONS TO COCHLEAR NUCLEUS IN CATS AFTER NEONATAL DEAFNESS AND ELECTRICAL STIMULATION

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We have previously reported that the primary afferent projections from the cochlear spiral ganglion (SG) to the cochlear nucleus (CN) exhibit clear cochleotopic organization in adult cats deafened as neonates. However, the topographic specificity of the CN projections in deafened animals is proportionately broader than normal. This study examined the SG-to-CN projections in adult cats that were deafened as neonates and then received a unilateral cochlear implant (CI) at 6-8 weeks of age. After >6 months of intracochlear electrical stimulation, SG projections were studied by making focal injections of a neuronal tracer neurobiotinTM directly into Rosenthal's canal to label a small sector of the SG. Clear organization of the SG projections into frequency-band laminae was evident in these deafened animals despite severe auditory deprivation from birth. When normalized for the smaller CN size following deafness, however, AVCN, PVCN and DCN projections from the stimulated ears were broader by 32%, 34% and 53%, respectively, than projections in normal adults. Further, there was no difference between projections from the stimulated and contralateral cochleae. These findings suggest that early normal auditory experience is essential for the normal development (and/or subsequent maintenance) of the topographic precision of SG-to-CN projections. After early deafness, the CN is markedly smaller than normal and the spatial selectivity of SG projections that underlie frequency resolution in the central auditory system is reduced. Further, electrical stimulation from a CI introduced at 8 weeks of age failed to ameliorate, reverse or exacerbate these degenerative changes.

If similar principles pertain in the human auditory system, our results suggest that the selectivity of the neural connections underlying cochleotopic organization in the central auditory system is likely intact even in congenitally deaf individuals. However, the degraded spatial resolution observed in our studies suggests that there may be inherent limitations in the efficacy of CI stimulation in congenitally deaf subjects, and that spatial (spectral) selectivity of stimulation delivered on adjacent CI channels may be poorer due to the greater extent of overlap of SG central axons representing nearby frequencies within the CN. Such CI users may be more dependent upon temporal features of electrical stimuli, and it may be advantageous to enhance the salience of such cues, e.g., by removing some electrodes from the processor "map" to reduce channel interaction, or by using moderate rates of stimulation to enhance spectral contrasts.

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3A: ENCODING FINE STRUCTURE IN COCHLEAR IMPLANTS

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Mathematically, a signal can be transformed into different representations. The Hilbert transform decomposes a signal into the temporal envelope and fine structure. The Fourier transform decomposes a signal into magnitude and phase spectra; the magnitude spectrum can be further decomposed into the spectral envelope and fine structure, via linear predictive coding for example.

Traditional views in speech perception have focused on the envelope cues. Recently, we have realized that the fine structure cues are not merely redundant, but play an important role, particularly in speech recognition in noise, tonal language understanding, and music perception. However, how to encode these fine structure cues remain unresolved. In this talk I will review recent development in encoding fine structure, including explicit encoding of F0 and frequency modulation, high-rate stimulation, utilization of residual acoustic hearing and virtual channels. I shall also discuss roadblocks that we have to overcome if we want to improve cochlear-implant performance. These roadblocks include loosely defined concepts and terminology, a lack of understanding in basic processing of the envelope and fine structure cues at the mathematical, physiological, and perceptual levels, and technical limitation in current cochlear implants.

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3B: RESPONSE PROPERTIES OF ELECTRICALLY STIMULATED AUDITORY NERVE FIBERS

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The stimulation rate used in cochlear implants is dependant upon patient preference and speech recognition performance. However the physiological basis for selecting this rate is not well understood. Therefore, this study investigated auditory nerve fibre (ANF) response properties to electrical stimulation across stimulus rate and current. Recordings from ANF were made in acutely deafened guinea-pigs. Electrical pulse trains of 100ms duration were delivered via an acutely implanted scala tympani electrode, using a monopolar electrode configuration. Stimuli were presented at rates of 200, 1000, 2000 and 5000 pulses per second (pps). Stimulus current was varied from subthreshold to a current that evoked a spike discharge rate up to 400 spikes/second.
ANF spike discharge rate increased monotonically with current for each stimulus rate. ANF threshold, defined as the current required to evoke a spike discharge rate of 10 spikes/second, was maximal for a stimulation rate of 1000 pps. Threshold decreased monotonically for stimulus rates above 1000 pps and at 200 pps. Dynamic range, defined as the current range required to increase spike discharge rate from 10 to 100 spikes/second, increased with stimulus rate. Accommodation, defined here as a decrease in ANF spike discharge rate over the duration of an electrical pulse train, was greatest at threshold for each stimulus rate. This observed decrease at threshold was not a refractory effect, as most inter-spike intervals were much longer than the time-course of refraction. The magnitude of accommodation increased with stimulus rate and decreased with stimulus current. These results demonstrate that stimulus rate and current interact in a complex manner to affect ANF responses. At threshold, accommodation plays a far more important role in ANF responses than refraction. This has important implications for the development of cochlear implant speech processing strategies, particularly in the selection of stimulation rate.

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3C: LOUDNESS, CURRENT SUMMATION OR STOCHASTIC RESONANCE? THE EFFECT OF CONCURRENT HIGH-RATE PULSE TRAINS ON SIGNAL DETECTION AND LOUDNESS

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The possible beneficial use of sub-threshold ‘conditioners’ has received recent attention. It has been hypothesised that such stimuli can induce stochastic behaviour in nerve cells, leading to better signal detection or discrimination. Experiments have reported a decreased signal threshold when a subthreshold high-rate pulse train is present. The experiments reported here investigated the effect on signal detection and comfortable loudness of concurrent sub- and supra-threshold conditioning pulses. Parameters which would be assumed to impact upon such an effect (conditioner rate, and spatial separation from the signal) were manipulated. Signals were pulse trains between 200 and 500 pps, and conditioners were pulse trains between 500 and 10,000 pps. The first experiment, using interleaved conditioners, showed little effect on threshold or loudness of the signal until the conditioner was above threshold, and no effect of conditioner or signal rate, nor of spatial separation of signal and conditioner elecrode. The second and third experiments, using simultaneous signal and conditioner pulses, showed a reduction in signal threshold with increasing conditioner level, but this effect could be explained by the direct summation of signal and conditioner currents. All of the results were consistent with known effects of current and loudness summation, and there was no evidence of any additional ‘stochastic resonance’ effect.

The experiments were supported by the Australian National Health and Medical Research Council (authors 1 and 3)

3D: STOCHASTIC BEAMFORMING FOR COCHLEAR IMPLANT CODING

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We have previously advocated the deliberate introduction of random fluctuations (noise) into cochlear implants. The purpose of the noise is to more closely replicate the stochastic neural response that is known to occur in normal hearing but is largely absent in a deafened ear. However, if noise is added in an uncontrolled manner with a limited number of electrodes then it will almost certainly lead to worse performance. The reason for this is that the noise will be highly spatially correlated and hence will not induce sufficient independent neural activity. Only if partially independent stochastic activity can be achieved in a significant subpopulation of nerve fibres can mechanisms like suprathreshold stochastic resonance (e.g. Stocks et al. *Noise Fluct. Lett.*, **2**: L169-L181, 2002) come into play. Our aim is to develop ways in which noise can be introduced to achieve statistical independence across nerve populations.

True independence is impossible to achieve with electrical stimulation given that the deafened ear typically contains about 10,000 nerve fibres and a typical cochlear implant contains up to about 22 electrodes: it is therefore not possible to stimulate each remaining cochlear nerve fibre with a separate electrode. Even partial independence, however, may lead to a great increase in the amount of information transmitted by an array of nerve fibres.

We are investigating a method we term stochastic beamforming to achieve greater independence. The basic strategy is to present each electrode with a linear combination of independent Gaussian noise sources. The noise currents from the electrodes interact and the effective stimulus for each nerve fibre will be a different weighted sum of the noise sources. By an appropriate choice of weights it is possible to induce a stochastic noise field that is spatially decorrelated at specified spatial locations; hence different subpopulations of fibres experience independent stochastic noise currents. We show that it is possible to get one independent point of excitation (one null) for each electrode. The solution, however, is not unique and any set of orthogonal vectors can be used in its construction. This enables further constraints to be placed on the strategy, such as power consumption by the speech processor or the predicted spontaneous rate of the nerve fibres. The terminology is motivated by the use of similar strategies termed beamforming where a spatial filter operates on the output of an array of microphones to enhance directional selectivity.

In this study we use a computational model of a cochlear implant to demonstrate two key findings; first, that the stochastic beamforming strategy can be used to significantly decrease the level of spatial correlation and, second, that this reduced correlation leads to an enhancement in the amount of signal information that the cochlear implant can, in principle, transmit along the auditory nerve. Consequently, we demonstrate for the first time that, in principle, the addition of noise to cochlear implant electrodes can enhance the coding of speech information.

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3E: INFERIOR COLLICULUS RESPONSES TO CI CURRENT STEERING AND FIELD FOCUSING

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Shaping of electric fields by co-stimulation of two or more cochlear implant (CI) electrodes has the potential to improve sound reception or quality of perception in implant users without requiring re-engineering of intracochlear electrode devices. Several clinical studies have reported on the perceptual effects of field shaping – either field focusing by tripolar or partial-tripolar stimulation, or creation of perceptually intermediate virtual channels by simultaneous activation of two adjacent CI electrodes. Other studies have reported on physiological responses of the auditory nerve and auditory cortex to tripolar stimulation.

We have examined neuronal responses in the central nucleus of the inferior colliculus (ICC) in the guinea pig auditory midbrain to virtual-channel and partial-tripolar stimulation. In these studies, we stimulated the cochlea using an electrode specially-designed for the guinea pig as a model of contemporary peri-modiolar clinical electrodes. We examined neuronal activity using multi-channel recording probes along the tonotopically-organized dorso-lateral to ventro-medial axis of the ICC, allowing us to infer the location and extent along the frequency axis of spiral ganglion (SG) neurons activated by CI stimulation.

Our studies provide physiological confirmation that these field shaping paradigms can be effective in focusing intracochlear electrical stimulation and in creating virtual channels. However in some cases, field shaping may fail to create the predicted patterns of SG activation. Comparison of results from these physiological studies with a simple model of neuronal activation suggests mechanisms that may contribute to this variability.

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3F: NOVEL SIMULTANEOUS STIMULATION PARADIGMS FOR COCHLEAR IMPLANT SOUND PROCESSORS

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Simultaneous stimulation can produce unwanted channel interactions in monopolar analog sound coding strategies. However, if used in a controlled way, simultaneous stimulation can be used to shape the electric fields generated whthin the cochlea. This presentation will provide an overview of the psychophysical and modeling findings associated with two field-shaping techniques.

The first technique, current steering, involves simultaneous in-phase stimulation of nearby electrodes. Theoretically, current steering creates activation patterns which may have maxima at locations that are intermediate to the locations of the stimulated electrodes. Psychophysically, such “virtual channels” give rise to intermediate pitch sensations. Although intermediate pitches also can be generated with non-simultaneous stimulation of adjacent electrodes, the mechanism for the latter appears to be more central in origin. Consequently, the percepts would be harder to control in a real-time sound processing strategy that uses a non-simultaneous approach.

The second technique, current focusing, consists of simultaneous out-of-phase stimulation of two flanking electrodes in addition to the center electrode. Theoretically, the ratio of the current on the flanking electrodes relative to the center electrode controls the width of excitation near the center electrode. However, for larger proportions of the current, the flanking electrodes can generate side lobes which potentially can be audible. In addition, stimulation that is more focused requires larger overall stimulation currents. The degree of current focusing can be controlled precisely to achieve optimal tradeoff between the width of the main lobe, while controlling for amplitude of the side-lobes. Preliminary estimates of spatial tuning curves measured using a forward masking paradigm indicate that current focusing can lead to a better-defined peak in the neural activation pattern. In some cases, current focusing also could lead to sensations that are more tonal relative to monopolar stimulation.

Finally, this presentation will address how both techniques can be used to better represent the within-channel fine structure in a wearable sound processing strategy. Specifically, HiRes with Fidelity 120 ®, the first commercial speech processing strategy that utilizes current steering, will be described.

3G: VALIDATING PATIENT-SPECIFIC ELECTRO-ANATOMICAL MODELS: EMPIRICALLY-MEASURED AND MODEL-PREDICTED EVOKED POTENTIALS AND EFI DATA FROM THE SAME INDIVIDUAL

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As the collection of implanted temporal bones available for histological study has grown, attention has turned toward identifying how various pathological features may impact performance. To study this, we have developed a detailed, three-dimensional (3D) electro-anatomical model (EAM) of the implanted ear based on hundreds of registered histological images taken from the processed temporal bone of a single patient. In response to electric stimulation, this model predicts an estimate of (1) the 3D electric field, (2) the cochleotopic pattern of neural activation, and (3) the electrically-evoked compound action potential (ECAP) recorded from intracochlear electrodes. Incorporating patient-specific attributes into the model allows for its predictions to be tested against analogous measures collected earlier from the same individual upon which the model is based.

We first focus on the key tissue properties that impact the EAM-predicted spatial spread of activation, and their relation to estimates made by previous volume conduction models. The ratio of perilymph to bone conductivity associated with these various models is shown to account for the wide range of spatial spread they predict. By comparing measured and EAM-predicted intracochlear potential recordings (also known as electric field imaging or EFI), the ratio which best predicts the empirically-measured data is identified.

Predicted estimates of monopolar activation spread (up to 1.8 mm/dB) are nearly an order of magnitude larger than previous models, and the ratio of monopolar to bipolar spread (roughly 2.5) appears consistent with reported physiological results. Surprisingly, our data suggest that under many conditions the effect of moving an electrode from the lateral wall toward a medial position has relatively little effect.

Finally, we show that model-predicted ECAP waveforms accurately predict the waveform morphology, latency and growth functions of those measured empirically in the same individual. Both predicted and measured ECAPs show a waveform morphology that is relatively insensitive to the spatial relationship between the stimulating and recording electrodes, an attribute predicted by the model to result from similar N1-P1 contributions to the ECAP from neurons residing at various cochleotopic positions (i.e., the unitary response hypothesis).

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3H: EFFECTS OF AMPLITUDE RAMPS ON PHONEMIC RESTORATION OF SPEECH

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Speech recognition is poorer when segments of speech are removed. When these silent intervals are filled with sufficiently loud noise bursts, speech can be perceived as continuous (continuity illusion). Intelligibility may also increase even though the added noise bursts do not bring useful speech information (phonemic restoration). As a result, speech recognition may be enhanced in noisy listening situations where parts of speech are masked by loud background sounds.

Front-end processing of hearing aids and cochlear implants, especially compression, may produce amplitude fluctuations on speech when background noise is present. For example, during a loud noise, the signal and the noise would be compressed fully. If the noise level is decreased, compression would become less active, and such recovery from compression would produce a ramp on speech envelope following the offset of the loud noise burst. Similar amplitude fluctuations, specifically ramps or damps on the stimulus envelope, have been shown to reduce the continuity illusion, but only with simple stimuli such as pure tones. The present study explores if such amplitude manipulations that might be caused by auditory device compression would also affect the perceived continuity and the phonemic restoration of speech.

Phonemic restoration was measured by the difference in speech recognition performance between two conditions: 1) with sentences with silent intervals, 2) with sentences where the silent intervals were filled with loud noise bursts. In the second condition, subjects were also asked to provide a subjective rating for the perceived continuity of the presented sentences. Damps/ramps of varying durations were added on the envelope of the speech segments at locations preceding and/or following the noise bursts and phonemic restoration and continuity ratings were measured. The effects observed with the ramps that were placed after the noise bursts would be most similar to the amplitude fluctuations that might occur in hearing aids and cochlear implants. The effects observed with ramps placed at both sides of the noise bursts would be related to previous studies with simpler stimuli. A reduction in phonemic restoration and/or perceived continuity was observed for a number of damp/ramp conditions, however, the degree of the reduction depended on whether these damps/ramps were placed before, after, or on both sides of the noise bursts.

4A: STIMULATION OF THE AUDITORY NERVE USING OPTICAL RADIATION

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Cochlear implants bypass damaged hair cells in the auditory system and directly electrically stimulate the auditory nerve. Stimulating discrete spiral ganglion cell populations in cochlear implant users' ears is similar to the encoding of small acoustic frequency bands in a normal-hearing person's ear. In contemporary cochlear implants, however, the injected electric current is spread widely along the scala tympani and across turns. We have shown that extreme spatially selective stimulation of the cochlea is possible using light (Izzo et al. JBO, Vol. **12**, 021008), Here, we review the basic optical parameters required to stimulate the auditory nerve and present the correlation between surviving spiral ganglion cells after acute and longterm deafening and neural stimulation with optical radiation.

In vivo experiments were conducted in gerbils with each gerbil serving as its own control. Pre-deafening acoustic thresholds were obtained and stimulation with optical radiation was made with various pulse durations, energy levels and repetition rates. For acute deafening, 100 mM neomycin was applied to the round window membrane. For longterm deafening the animals received 25, 50, 75, and 100 mM Neomycin transtympanically and were allowed to survived for several weeks during which neural degeneration occurred. Deafness was confirmed by measuring acoustically evoked compound action potentials. Optically evoked compound action potentials were determined for different radiation conditions. After completion of the experiment, each animal was euthanized and cochleae harvested for histology.

For acute deafening procedures, thresholds for acoustic compound action potentials were significantly elevated after neomycin application. Thresholds for optical radiation were affected minimally. For chronic deafening experiments, for which neural degeneration occurred, the thresholds and amplitudes of the compound action potential depended on the number of surviving spiral ganglion cells.

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4B: INTRA-NEURAL STIMULATION USING PENETRATING AUDITORY NERVE ARRAYS AS A BASIS FOR AN AUDITORY PROSTHESIS

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Contemporary intracochlear auditory prostheses provide good speech reception in the absence of ambient noise, but most implant users experience poor pitch perception, poor speech reception in noisy environments, and poor spatial hearing, even in conditions of bilateral implantation. These limitations likely are due in large part to poor stimulation selectivity, which in turn is due in part to the remote intrascalar position of the stimulating electrodes relative to excitable cochlear elements. Contemporary electrodes lie within the scala tympani immersed in electrically conductive perilymph and separated from any neural elements by scala's bony wall. This remote position elevates thresholds and promotes channel interactions. Therefore, we have tested in anesthetized cats a more direct approach, intraneural stimulation. Using a penetrating 16-electrode stimulating array that traverses the modiolar trunk of the auditory nerve and a conventional intracochlear electrode, we compared responses evoked by a penetrating intra-neural array with those evoked using an intrascalar electrode. We monitored the spread of activation across the nerve by recording simultaneously at 32 sites along the tonotopic axis of the inferior colliculus. In each animal, we characterized responses to acoustic tonal stimulation and intraneural stimulation in normal-hearing conditions and to intrascalar stimulation after deafening. Our results indicate that intra-neural stimulation permitted frequency specific activation of nerve-fiber populations representing the full range of audible frequencies at very low current levels. In addition, intraneural stimulation nearly eliminated interactions between channels during simultaneous stimulation using two electrodes. All this can be accomplished while preserving substantial acoustic hearing in the stimulated ear. These results suggest that intra-neural stimulation implemented in a human auditory prosthesis could provide improvements in speech reception, reception in noise, low-frequency hearing, and improved spatial hearing.

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4C: THE AUDITORY MIDBRAIN IMPLANT: EFFECTS OF STIMULATION LOCATION

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The auditory midbrain implant, which is a new auditory prosthesis for neural deafness, is now in clinical trials. Three patients have been implanted with a single shank array (20 electrodes, 200 µm spacing; Cochlear Ltd., Australia) and they all obtain various loudness, pitch, temporal, and sound localization percepts in response to midbrain stimulation. They also obtain enhancements in lip reading capabilities and environmental awareness with some improvements in speech perception performance. Although the intended target was the central nucleus of the inferior colliculus (ICC), the array was implanted into different locations within each patient. The first patient was implanted into the dorsal nucleus of the inferior colliculus, the second was implanted near the ventral surface of the lateral lemniscus, and the third was implanted within the ICC. Stimulation of these different regions elicits different psychophysical and electrophysiological properties that provide some insight into the functional organization of the human central auditory system. We will present human and animal results suggesting that certain regions within the midbrain, especially along the isofrequency dimension of the ICC, may be more appropriate for transmitting specific features of sound using electrical stimulation. Stimulation of the dorsal nucleus of the IC exhibits strong adaptive effects and may be more appropriate for modulating activity in other regions. Within the ICC, stimulation of more caudal and dorsomedial regions have higher thresholds and do not elicit strong, synchronized cortical activity even though a loud sound can be perceived. Furthermore, frequency-specific cortical activation is severely degraded for stimulation of the caudal ICC. Therefore, a single shank array aligned along the tonotopic gradient of the ICC yet in a more rostral and lateral region along the isofrequency dimension may achieve more precise and effective activation of higher auditory pathways and potentially improve hearing performance. The question remains if a single shank array will be sufficient or if a three-dimensional array designed for simultaneous stimulation throughout the inferior colliculus will be necessary for restoring intelligible speech perception and more complex sound processing (e.g. speech in noise and music appreciation).

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4D: PSYCHOPHYSICS OF ELECTRICAL STIMULATION OF THE HUMAN COCHLEA, COCHLEAR NUCLEUS, AND INFERIOR COLLICULUS

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Cochlear implants are not useful for patients with no remaining auditory nerve, so prosthetic devices have been designed to stimulate the cochlear nucleus in the brainstem and the inferior colliculus in the midbrain, using both surface and penetrating electrodes. We will present psychophysical results and speech recognition results from surface and penetrating electrodes at the level of the cochlear nucleus and inferior colliculus. Surprisingly, psychophysical measures of temporal, spectral and intensity resolution are similar across stimulation sites and electrode types. Speech recognition and modulation detection are excellent in some patients with stimulation of the cochlear nucleus, but not in patients who lost their auditory nerve from vestibular schwannomas. Quantitative comparison of results from electrical stimulation of the auditory system at different stages of neural processing, and across patients with different etiologies can provide insights into auditory processing mechanisms.

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5A: PRELIMINARY OBSERVATIONS IN THE CHILDHOOD DEVELOPMENT AFTER COCHLEAR IMPLANTATION (CDACI) STUDY

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Objectives: The CDaCI study is an ongoing, prospective multisite investigation of US children with cochlear implants. The study is designed to expand our understanding of child, family, school and peer factors that influence children's progress in developing spoken language after cochlear implantation. Of particular interest is the potential effect that early-established trajectories in oral language have on children's psychological, social and scholastic adjustment as they progress through school. Because the emergence of spoken language is seen to flow from success across developmental domains, the CDaCI study attempts to relate variability in post-implant outcome to environmental, social, interventional, and biological influences.

The reliable elicitation of communication and linguistic data poses a challenge in early childhood research. We address this challenge with prospective, hierarchical measures of speech recognition and language, video-analytic techniques that track communication skills, and parental surveys of quality of life. CDaCI participants are (CI) children implanted prior to the age of 5y (n=188; mean age=2.2$\pm$1.2y) and normal hearing (NH) age-mates serving as controls (n=97; mean age=2.3$\pm$1.1y). Here we report baseline and observations from year 2 of evaluative follow-up.

Despite wide recognition of the benefits of early cochlear implantation, there remains uncertainty with respect to approaches that enable children to use cochlear implants to their fullest potential in supporting oral language acquisition. Early CDaCI results suggest that linguistic outcomes are modified not only by temporal variables related to intervention with an implant, but also by environmental and surgical factors and the quality of caregiver-child interactions.

5B: THE IMPORTANCE OF EARLY MULTIMODAL EXPERIENCE ON SPOKEN LANGUAGE DEVELOPMENT IN HEARING-IMPAIRED INFANTS WITH COCHLEAR IMPLANTS

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Infants are typically inundated with a variety of rich sensory experiences such as brightly colored toys and highly exaggerated speech. Recent research has shown that multimodal experiences such as listening to and watching a caregiver speak, as well as the nature of such infant-directed speech, are extremely important for normal language and cognitive development in infancy. In fact, early identification of hearing loss and subsequent intervention have a large impact on infants' language development. The effects of early experience in hearing-impaired children who receive cochlear implants (CIs) are also quite substantial.

Recent studies in our lab have shown that children's pre-implantation audiovisual (AV) speech comprehension performance is strongly correlated with performance 3 years post-implantation on a variety of measures of speech and language abilities. Because measures of AV speech perception may be used to predict speech and language benefit in CI users, we have begun to explore the development of AV integration skills of normal-hearing (NH) infants and CI infants. In one experiment we found that NH infants were able to integrate auditory and visual spoken words, whereas CI infants did not demonstrate AV integration. In a second experiment, we found that NH infants prefer to look at faces when accompanied by auditory speech, particularly when the faces are dynamic rather than static; CI infants show similar preferences only after several months of device use.

To understand better the development of speech perception in infants after receiving a CI, it is important to explore the nature of the speech input these infants receive everyday from their caregivers. Moreover, because language environment and infant-directed speech quality have been shown to have enormous effects on language and cognitive development, investigation of caregivers' interactions with their CI infants is needed to determine the optimal input for the development of speech and language skills. We have recently shown that mothers of CI infants tailor the prosodic characteristics of their speech according to their infants' "hearing age" rather than their chronological age (Bergeson et al., 2006). Preliminary longitudinal results have also demonstrated effects of hearing experience on prosodic and linguistic characteristics of mothers' speech to CI infants from pre-implantation to 1 year post-implantation.

Taken together, these studies highlight the importance of understanding the multimodal nature of CI infants' early experiences with spoken language.

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5C: MEASURING PSYCHOMETRIC FUNCTIONS FOR DETECTION IN ELECTRIC HEARING INFANTS AND TODDLERS USING THE OBSERVER BASED PSYCHOACOUSTIC PROCEDURE

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Psychophysical data on infant and toddler cochlear implant (CI) recipients are scarce. Greater psychophysical information could contribute to CI technology and interventions, which in turn could improve speech and music perception outcomes. A greater range of behavioral methods would facilitate the acquisition of psychophysical data in this population.

Here, the Observer based Psychoacoustic Procedure (OPP) is applied to study detection in electric hearing infants and toddlers. OPP is more objective and arguably more sensitive than standard visual reinforcement audiometry for two reasons. First, the observer is blinded to the stimulus on each single-interval trial, and second, any response the child may produce, in addition to a typical head-turn, is used to make a judgment about whether the child perceived the stimulus.

Data from 6 subjects ranging in age from 14 to 46 months have been collected to date. Psychometric functions for detection were measured using OPP or play audiometry. Freefield or direct-audio stimuli were delivered using a child's clinical map or a customized single-electrode map with partial clinical parameters. When testing the single-electrode map, acoustic processing was applied to the other electrodes. This allowed the child to "hear" the environmental sounds in a manner similar to their clinical map, which may have increased motivation.

In 4 out of 6 subjects, percent-correct detection generally increased with either sound pressure level or stimulation current level. Maximal (asymptotic) percent correct scores suggest that subjects with as few as 2 months of electric hearing experience attend to suprathreshold stimulation as well as their normal hearing counterparts.

These data suggest that OPP is a valid method to conduct psychophysics with preverbal infant and toddler recipients. It is possible that OPP could be used in future studies to measure more complex psychophysical tasks. For example, spectral ripple detection could be measured, which has been shown to correlate with speech and music reception in adult recipients.

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5D: SPATIAL HEARING SKILLS IN CHILDREN AND ADULTS FITTED WITH BILATERAL COCHLEAR IMPLANTS

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In recent years there has been a marked increase in the number of patients receiving bilateral cochlear implants. Our research group is concerned with understanding what benefits, if any, can be measured in young bilateral implant users, as well as in adults.

In children, we are concerned with whether the age at which bilateral hearing is activated is an important factor to consider and how post-implantation experience affects performance. To date, over 60 children ages 2.5 to 14 have participated in our studies. Measures include speech perception in quiet and in the presence of competing sounds, left-right discrimination of sound location (minimum audible angle; MAA) and sound localization in a multi-loudspeaker array. In children under age 3 we are also investigating the emergence of word learning skills. Results to date suggest that spatial left-right discrimination of sounds in free field emerges over a 12 to 24 month period; MAA thresholds decrease from ~50° to ~15° during this period. Children with post-lingual deafness show an especially early emergence of this skill, with MAA thresholds reaching 5-15° within 2-3 months of bilateral hearing, suggesting that early acoustic input facilitates localization acuity with bilateral cochlear implants. Sound localization in a multi-loudspeaker situation emerges more slowly than the right-left discrimination. This is unlike our findings in post-lingually deafened adults whose localization abilities emerge within 3 months of bilateral hearing, suggesting that development of a spatial map may depend on exposure to acoustic cues earlier in life, and is otherwise slow to emerge. Studies on speech understanding in noise show that the extent to which children can experience benefits from listening with 2 cochlear implants compared with a single implant is similar to the effects measured in adult populations. The benefit appears within 3 months following activation of bilateral hearing, and does not change significantly with additional experience.

Studies in adults were conducted using the Spear3 research processor. Pitch-matched electrodes in the right and left cochleae were directly stimulated with biphasic pulse trains. The age of onset of deafness in adults has a significant impact on sensitivity to interaural timing cues but not on sensitivity to interaural level cues. This work impacts our thinking about auditory plasticity and the types of cues that children might most benefit from with early exposure.

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5E: BINAURAL HEARING IN CHILDREN WITH BILATERAL COCHLEAR IMPLANTS

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It is well known that listening with two ears offers several advantages for normal-hearing people, with regard to sound localization and speech recognition in noise. The extent to which bilateral implants restore binaural hearing, however, is less clear. In Belgium 42 children, who received a second cochlear implant at an age between 1;6 and 12 years, participate in a multi-center research project. In this project not only bilateral benefits (summation, head shadow effect) are investigated, but also true binaural benefits (binaural squelch). Several test setups for measuring binaural hearing were modified to the interest and attention span of young children. A sound localization task in free field, a sound lateralization task based on interaural time differences and a binaural masking level difference task were evaluated with large groups of normal-hearing children between 4 and 9 years of age. Most children from the age of 4 and all children from the age of 5 were able to execute the tasks. Furthermore, results show that at least some binaural hearing capacities are fairly well acquired at this young age. Subsequently, the same tasks were administered to the bilaterally implanted children. The localization study indicated that reliable localization of a broadband signal in the frontal horizontal plane is possible, with best scores close to normal-hearing results. Sound lateralization and binaural masking level differences will be tested using direct electrical stimulation. First results will be presented at the conference.

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5F: CRITICAL PERIOD FOR BILATERAL COCHLEAR IMPLANTATION IN CHILDREN

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Introduction: 53 patients (including 37 children) have received bilateral cochlear implants (CIBIL) at our department since 1997. Sequential bilateral implantation of congenitally deaf children allows to study the influences of the rehabilitation time and the patient's age on the results obtained with CIBIL. Recent reports [1,2] show a possibility for existence of a critical period for CIBIL in children.

Objectives: 1.) To document the time course of development of the auditory and language skills of children bilaterally implanted at our clinic. 2.) To evaluate the influence of the age at implantation and the time interval between the implantations on the magnitude of improvement in auditory performance.

Material and Methods: 10 children have been chosen for this longitudinal study and followed for at least 2 years. All children have been implanted non-simultaneously with the Nucleus-Nucleus or the Laura-Nucleus CI combinations. Children included in the study were implanted at different ages (ranging from 15 to 129 months for the first implant, and from 51 to 157 months for the 2nd implant) and with different intervals between the first and the second implantations (range: from 28 to 106 months). At pre-defined time intervals extensive audiological evaluation was performed.

Results: 1.) The maximum speech discrimination with the first implant remains stable after implantation of the 2nd CI. 2.) The average maximal speech understanding results with the 2nd implant only, obtained at 3 months post-operatively, was 57% (monosyllabic CVC open-set identification task in quiet). 3.) The 2nd CI achieves performance at a level comparable to the first one after approximately 18 months. 4.) During the observation period there is a continuous improvement of the speech understanding results measured in the CIBIL condition owing to the improvement of the results with the second CI. A ceiling effect is expected to occur. 5.) Multiple regression analysis shows that with only 2 independent parameters - the age at the first CI and the age at the second CI – we are able to predict 72% of the variability of the results after bilateral implantation. 6.) Additional benefit in speech discrimination evaluated in the second year after bilateral (2nd) implantation (measured as the improvement in the maximal phonemic score with both implants relative to the best mono-aural condition, CVC monosyllabic words, NVA-list in quiet and at +10dB S/N speech noise) disappears in children who received the 2nd implant after the age of 10 to 12 years.

Conclusions: 1.) Contrary to what had been reported before, the results of speech understanding obtained with the 2nd CI do not differ significantly from the results obtained with the first one. The time needed for the 2nd CI to approach the results of the first one is approximately 18 months. 2.) The average maximal speech understanding results at 3 month post-operatively obtained in the mono-aural condition with the 2nd CI only were much better than the matched results obtained with the first CI. This indicates that the first CI primes the central auditory system in such a way that the subsequent input from the 2nd CI is integrated in a faster and a more efficient way. 3.) In our group there seems to exist a critical period for obtaining additional benefits in speech understanding with bilateral implantations as compared to unilateral implantations. Children implanted with the 2nd CI after the age of 10 to 12 years tend to show no additional benefits in speech understanding. Therefore bilateral cochlear implantation should be performed at the earliest possible age and with the shortest possible time interval.

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5G: TONE PRODUCTION IN MANDARIN CHINESE SPEAKING CHILDREN WITH COCHLEAR IMPLANTS

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Tone production is of great importance for communication using tone languages such as Mandarin Chinese. In Experiment 1 of the present study, speech samples from 14 prelingually-deafened, Mandarin-speaking children (2.91–8.33 years old) who had received cochlear implants and 14 age-matched, normal-hearing Mandarin-speaking children were recorded and then presented to 7 native Mandarin-speaking adults for tone perception tests. Results showed that there was a remarkable deficit in tone production in a majority of Mandarin-speaking children with cochlear implants and that tone production performance was negatively correlated with the age at implantation and positively correlated with the duration of implant use. In Experiment 2, the sample size of the normal-hearing children was increased to 61. The F0 contours of all speech tokens were extracted using an autocorrelation method. Acoustical analyses were performed to examine the distributions of the onset and offset values of the F0 contours represented by tonal ellipses. The size and relative distances of the tonal ellipses that reflect the degree of differentiation among tones were quantified using three indices. Next, a feed-forward back-propagation neural network was used for automatic tone recognition. The neural network was trained with the F0 data from the normal-hearing children and used to recognize the tones produced by the cochlear implant children. The acoustical, neural-network and perceptual measures were highly correlated with each other in evaluating tone production of children. All measures showed that Mandarin-speaking children with cochlear implants had various degrees of impairment in tone production. The acoustical and neural-network analyses of speech samples provide an objective and effective means of evaluating tone production of children.

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6A: PSYCHOPHYSICAL AND SPEECH PERCEPTION RESULTS FROM EAS PATIENTS WITH FULL, 20 AND 10 MM ELECTRODE INSERTIONS

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We have conducted tests of auditory function and speech perception in four groups who hear with the aid of combined acoustic and electric stimulation: 1) patients with a full insertion of a standard, long electrode array and who have acoustic hearing in both the ipsilateral and contralateral ears; 2) patients with full insertions of a long electrode array who have hearing only in the contralateral ear; 3) patients with a short 20-mm array who have hearing in both the ipsilateral and contralateral ears, 4) patients with a 10-mm array who have hearing in both the ipsilateral and contralateral ears.

For patients with preserved hearing in the implanted ear, tests of auditory function in the region of low-frequency acoustic hearing revealed the following: Most generally, thresholds were elevated, frequency resolution was poorer than normal but was still present; amplitude resolution was normal, temporal resolution was poorer than normal (patients were unable to use temporal gaps in noise in the aid of speech understanding) and the cochlear nonlinearity was reduced or absent. However, for a few patients in the 20 and 10 mm groups psychophysical tests were the same as before surgery.

Residual auditory function is not significantly correlated with either pre-implant speech understanding or post-implant benefit from auditory stimulation. Residual auditory function is correlated with melody recognition.

The addition of low-frequency acoustic stimulation to electric stimulation adds significantly to the intelligibility of CNC words and sentences in quiet and in noise. A better representation of pitch could account for the improvement in noise -- by helping segregate the speaker's voice from the background. The same explanation can not account for the improvement in performance in quiet.

When signals are presented from a single loudspeaker, EAS patients do not outperform the very best patients fit with unilateral cochlear implants. However, the proportion of patients achieving very high scores is much higher for EAS patients than for conventional patients. Some EAS patients perform as well in noise as patients fit with conventional hearing aids who have sloping mild-to-severe hearing losses.

When patients from different EAS groups (see first paragraph) are matched on measures of pre-implant speech understanding and audiometric configurations then, following surgery, marked differences in post implant speech understanding can be observed.

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6B: COMPARATIVE RESULTS IN THE HEARING PRESERVATION FOR PATIENTS WITH THE NUCLEUS CI24RCA VS. NUCLEUS CI24RE HYBRID

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An area of increasing interest in cochlear implant research and clinical practice involves the combination of electric and acoustic stimulation (EAS). Individuals with residual, low-frequency hearing are implanted with a relatively short electrode array into the basal portion of the cochlea. This allows for the integration of low-frequency acoustic hearing and higher frequency electric stimulation. Preservation of low-frequency hearing is typically associated with the surgical insertion of a short-electrode array such as that associated with the Nucleus Hybrid and Med-El EAS clinical trials. Four patients from Mayo Clinic implanted with Nucleus 24 perimodiolar arrays have demonstrated significant preservation of low-frequency hearing. These individuals have exhibited significant benefit of low-frequency acoustic hearing (< 750 Hz) in both the implant and non-implant ears. Comparisons of electric and electric plus acoustic hearing show significant benefit of acoustic hearing below 750 Hz on measures of speech recognition in both in quiet and in noise.

Speech understanding in quiet and in noise was evaluated for cochlear implant recipients with similar pre-implant audiograms. Subjects were either participants in Cochlear Americas' clinical trial of the 10 mm Hybrid device (n = 7) or were recipients of a standard, long perimodiolar electrode array (n = 4). Speech understanding was assessed with monosyllabic word recognition (CNC), sentence recognition in quiet, and sentence recognition in noise (BKB-SIN). All speech stimuli were presented at 60 dB SPL in the soundfield. Post-implant high resolution CT was performed to verify placement of the electrode array in scala tympani vs. scala vestibule as well as angular insertion depth.

A comparison of the two groups of listeners revealed i) both short- and long-electrode patients had similar degrees of preserved low-frequency hearing, and ii) long-electrode patients tended to outperform short-electrode patients on measures of speech perception. It is important to note, however, that the Hybrid results include just 12-month postoperative data. Recent studies have shown that EAS users may require up to 4 years to achieve maximum performance (Gantz et al., 2007). The results reported here suggest that individuals with a standard long electrode and preserved low-frequency hearing are able to achieve higher levels of speech recognition than patients implanted with a short-electrode array.

6C: INTEGRATING ACOUSTIC AND ELECTRIC HEARING: THE IOWA/NUCLEUS HYBRID PROJECT

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For some individuals with severe high-frequency hearing loss, hearing aids cannot provide a satisfactory improvement in speech recognition. However, these same patients often have too much low-frequency residual hearing to qualify as a candidate for a traditional cochlear implant. Here we provide an update on results from subjects using the Iowa/Nucleus Hybrid cochlear implant, which is designed to preserve the patient's residual low-frequency hearing while at the same time supplementing their high-frequency hearing by electric stimulation (Gantz and Turner, 2003).

The update will include the success rates in preserving residual hearing following surgical implantation of the Hybrid device, as well as an evaluation of speech recognition performance in quiet and in backgrounds. The data presented will also address the degree to which performance depends upon the quality of preserved residual hearing, in addition to some other factors that appear to be predictive of success, such as patient age, and pitch matches obtained soon after device activation. We will also address the issue of what frequency allocations can be used for the speech processor driving the electric stimulation, with implications for the ability of patients to adapt over time to distorted and/or shifted cochlear mapping functions.

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6D: CONTRALATERAL MASKING BETWEEN ELECTRIC AND ACOUSTIC STIMULI IN A CI SUBJECT WITH NORMAL ACOUSTIC HEARING

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The recent implantation of cochlear implants (CI) into patients with significant residual hearing has shown that the benefit from low frequency hearing is significant for difficult listening situations such as speech in noise. Little, however, is known about how acoustic and electric sounds interact on a psychophysical level. Previous work relating acoustic narrow-band noise to electric stimulation showed a place-pitch relationship between the center frequency of the noise bands and the place of the electrode [James, et al. Audiol Neurootol 2001].

The present work measured contralateral masking in a unique subject who had a CI on one side and normal acoustic hearing on the other side. The subject received a HiRes 90K device (Advanced Bionics) to treat a disabling tinnitus as a result of sudden hearing loss. Electric thresholds were measured on electrode, 1, 5, 9, 12 and 15 with monopolar stimulation with and without an acoustic masker. The masker was a pure tone delivered at a comfortable level with a frequency of 250, 1000 or 4000 Hz and with a random starting phase. The electrodes were stimulated at the same rate as the acoustic frequency. Data showed a peak of 2-4 dB masking with the peak position correlating to the characteristic frequency estimated from the insertion angle of the electrode in the organ of Corti. The size of the 2-4 dB masking corresponded to 7-12% of the electric dynamic range (16.7 +/- 3.2 dB), equivalent to the size of contralateral masking in acoustic stimulation. The place-pitch map obtained from contralateral masking will be compared to the place-pitch map obtained from direct pitch matches. Theoretical and clinical significance of contralateral masking between acoustic and electric stimulation will be discussed.

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6E: SENSITIVITY TO INTERAURAL LEVEL DIFFERENCE AND LOUDNESS GROWTH WITH CONTRALATERAL BIMODAL STIMULATION

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The interaural level difference (ILD) is an important cue for localization of sound sources. While the sensitivity to ILD is well known in normal hearing subjects and even in bilateral cochlear implant (CI) users, in this study, it is quantified in users of contralateral bimodal hearing systems (a combination of a CI in the one ear and a hearing aid in the other). Loudness growth functions (LGF) and just noticeable differences (JND) in ILD were measured in 10 subjects who use a cochlear implant and a hearing aid on a daily basis. The most apical and another usable electrode were selected and pitch matching with acoustical sinusoids was performed to find a stimulus that sounded as similar as possible in both ears. The subject's dynamic ranges were sampled and a constant stimuli loudness balancing procedure between electric and acoustic stimuli was performed for each sample. The point of equal loudness was determined by fitting a psychometric curve to the results. Linear regression was then performed on the obtained equal-loudness points to assess linearity. A straight line proved to be a good fit for all loudness growth functions on a dB (acoustical) versus μA (electrical) scale. The slope of the line depended on both the electrical and acoustical dynamic range. Therefore, to achieve maximal localization performance, the loudness transfer functions of the CI and HA must be matched on a dB/μA scale and fitted to the subject's dynamic ranges. From the psychometric curves, JNDs in ILD were determined. JNDs ranged from 1.0dB to 3.0dB with a mean of 1.7dB for the most apical electrode and from 1.0dB to 7.5dB with a mean of 3.0dB for the most basal electrode. The found JNDs for the most apical electrode were in the same order of magnitude as in normal hearing subjects. The JNDs for the most basal electrode were slightly worse. This might enable users of a contralateral bimodal system to do localization based on ILD alone with performance close to that of normal hearing subjects if the stimulus is well perceived at both ears. As a clear increase in JND with increasing mismatch in place of stimulation between the cochleas is observed, it is important for localization to match the frequency mapping in the cochlear implant and the contralateral acoustic signal.

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6F: INFERIOR COLLICULUS RESPONSES TO COMBINED ELECTRIC AND ACOUSTIC STIMULATION OF THE ACOUSTICALLY SENSITIVE COCHLEA

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The present study investigated neuronal responses in the auditory midbrain to combined electric and acoustic stimulation (EAS). Of particular interest was to investigate further the existence and influence of (presumably) hair cell-mediated *electrophonic* responses on acoustic and electroneural responses to EAS in cochleae with different degrees of hair cell survival.

Normal hearing cats were implanted with scala tympani electrodes, and an earphone was sealed to the ipsilateral auditory meatus for acoustic stimulation. Unmodulated and sinusoidally amplitude modulated (SAM) acoustic tones and electric pulse trains and sinusoids were presented to the implanted ear using either a simultaneous- or forward-masking paradigm. Midbrain responses to cochlear stimulation were recorded along the tonotopic axis of the contralateral inferior colliculus (IC) using a 16-channel silicon electrode array. The electric and acoustic stimuli were systematically varied in intensity, frequency and temporal delay, which allowed us to determine the spectro-temporal response patterns to combined EAS.

Changes in the relative modulation phase of simultaneously presented electric and acoustic SAM signals strongly affected neuronal discharge rates and the degree of synchrony (phase-locking) to the stimuli. These phase effects were dependent on the relative intensity of the electric and acoustic signals and included both facilitation and inhibition of neuronal responses.

In cochleae with intact hair cells, responses evoked by electrophonic stimulation were observed at locations along the IC tonotopic axis corresponding to the carrier frequency of the electric signal. Electrophonic responses had much lower thresholds (up to 34 dB difference) and longer latencies at threshold (up to 10 ms) than direct electroneural responses. Further, electrophonic responses demonstrated rate-level functions and dynamic ranges that were similar to those evoked by acoustic stimulation and unlike those of electroneural responses.

The results demonstrate that the spectral and temporal stimulus characteristics of electric stimulation and combined EAS of the hearing cochlea lead to complex interactions in the central auditory system. It is not yet clear to what extent such interactions are beneficial to speech coding in EAS users with residual hearing.

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6G: COMBINED ELECTRIC AND ACOUSTIC STIMULATION IN THE COCHLEA OF THE GUINEA PIG

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Patients with severe to profound high-and mid-frequency hearing loss, but residual low-frequency hearing are nowadays considered as potential candidates for cochlear implantation (Kiefer et al., *Audiol Neurotol* 2005). Preservation of residual hearing can improve speech intelligibility and esthetic value of sounds after implantation. However, the improvement by the addition of a hearing aid to a cochlear implant is variable (Gantz et al., *Laryngoscope* 2005). This raises the issue of how electric and acoustic cochlear stimulation interact.

In this study the effects of ipsilateral electric stimuli on acoustically evoked cochlear potentials were examined using a forward masking paradigm. In anesthetized guinea pigs, extracochlear stimulation electrodes were placed on the round window and on, or near, the basal turn. Recording electrodes were placed on the apex of the cochlea and on the bulla wall. Acoustically evoked compound action potentials (CAPs) were recorded in response to 0.5-16 kHz tone bursts. The masker was presented as a train of 10 biphasic, alternating pulses at 1 kHz preceding the tone burst.

Electric masking reversibly reduced the amplitude of acoustically evoked CAPs. Masking increased with higher electric current levels and shorter masker-to-probe intervals. Masking was more pronounced at higher acoustic stimulus frequencies (8 and 16 kHz), and became relatively stronger at lower acoustic stimulus levels. At high acoustic frequency and low acoustic level, the observed amount of masking could be as high as 90%, while CAP latency increased by no more than 0.2 ms. CAPs elicited by lower acoustic stimulus frequencies were hardly affected by electric stimulation, probably due to the fact that the electric masker was presented basally on the cochlea. These results support the idea that high frequency regions can be stimulated electrically without affecting low frequency hearing, by limiting the use of apical electrodes in conventional implants, or by using short implants (Gantz and Turner, *Acta Otolaryngol* 2004).

This work was funded by the Heinsius-Houbolt Foundation, The Netherlands.

6H: ELECTRODE OPTIMZATION OF PZT THIN-FILM MICROACTUATORS FOR HYBRID COCHLEAR IMPLANTS

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An ideal hybrid cochlear implant would integrate electric and acoustic auditory stimulation into a single device to rehabilitate patients with sensori-neural hearing loss. We propose a hybrid cochlear implant consisting of an electrode array coupled with an acoustic microactuator inside the cochlea. The electrode array transmits electrical signals to rehabilitate high-frequency hearing as in traditional cochlear implants. An integrated intracochlear piezoelectric microactuator would deliver 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. We describe microactuators consisting of a silicon diaphragm and a Lead-Zirconate-Titanate Oxide (PZT) thin film driven by a bottom and a top electrode designed to fit within the basal turn of the cochlea. We have limited the size of the PZT microactuator to less than 0.8mm x 1.2mm x 0.5mm with a diaphragm size of 0.8mm x 0.8mm x 2□m (Figure 1). The actuator must generate at least 200-nm displacement to achieve 120 dBA. Through experimental analysis and finite element simulations, we find that the dimensions of the top electrode can substantially affect the displacement generated by the microactuator (Figure 2). For a given diaphragm size, the top electrode dimensions can be optimized to generate the required displacement. We believe that a device with these specifications may have applications as an intracochlear acoustic microactuator and/or microphone.

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7A: PERCEPTUAL EVIDENCE OF SPATIALLY-RESTRICTED EXCITATION WITH FOCUSED STIMULATION

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It is possible to produce optimally focused electric stimulation within scala tympani using so-called phased array (PA) channels by inverting intrascalar potential spread functions (van den Honert and Kelsall, 2007). We have previously shown that simultaneous channel interactions as measured by spatial ripple detection are substantially reduced with PA channels in comparison to those of monopolar (MP) channels (van den Honert and Kelsall, 2005).

Perceptual thresholds for PA channels vary substantially with cochlear place. The ratio of PA threshold to MP threshold at the same place can range from 0 dB to more than 20 dB. The profile of PA-to-MP threshold ratio across place is idiosyncratic to each subject. This may be attributable to variations in modiolar proximity of electrode contacts and/or variability in surviving neural density across place.

Differences in loudness summation were studied by loudness balancing multichannel simultaneous MP or PA stimuli composed of equally-loud component channels. Mixtures employed either fixed phase or alternating phase across adjacent channels. Summation was consistently greater with MP than with PA channels. The difference in summation varied across subjects from modest to dramatic.

Spread-of-excitation was explored using a forward masking paradigm. A PA or MP masker was adaptively adjusted to mask a soft PA probe at the same place. MP maskers were consistently louder than equally effective PA maskers, suggesting they excited neurons more broadly than the PA masker.

Masking level varied as the masker was moved away from the probe place. MP masking levels were generally flat or rose gradually with distance from the probe. PA masking levels generally rose steeply with distance when the probe was delivered at a place where neuronal survival was ostensibly high, as indicated by low PA-to-MP threshold ratios. For probe locations where the neuronal survival was ostensibly low, the profiles of PA masker level vs. distance were sometimes nonmonotonic in a manner consistent with the primary neural response to the probe occurring at a place other than the probe location.

While the clinical utility of PA stimulation remains unproven, these data suggest that under certain circumstances PA stimulation can deliver punctate excitation.

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7B: EVOLUTION OF CODING STRATEGIES IN THE NEXT DECADE

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The coding strategy provides the crucial algorithm in a cochlear implant, by mans of which the stimulation data are derived from the sound signal. Basically, all CIS and n-of-m based coding strategies which have been in use in cochlear implants for the last 15-20 years rely on the signal envelope and largely disregard the fine structure. These strategies thus mainly provide place coding by presenting envelope information across all channels. Temporal coding is largely restricted to envelope modulations which mainly provide a code for pitch across all channels, similar to unresolved harmonics at higher frequencies in normal hearing. Recently, research in normal hearing subject has shown that the fine structure of a sound signal is the main information carrier for music and tonal languages, whereas for speech it is the envelope. These results correlate well with the general pattern of performance of users of CIS and n-of-m based cochlear implants today, who on average show good to very good speech perception (at least in quiet) and poor to moderate music appreciation.

Users of electric-acoustic stimulation (EAS) can serve as a model for how to further improve cochlear implant performance. Similar to regular cochlear implant users, EAS users receive envelope based stimulation *via* a cochlear implant in the mid to high frequencies. However, in contrast to regular cochlear implant users, EAS users receive acoustic stimulation in the low frequencies. Thus, similar to normal hearing subjects, EAS users are provided with fine structure information here. As a result, EAS users show better speech perception in noise and music appreciation when compared to regular cochlear implant users.

In an attempt to extrapolate these results to regular cochlear implants, coding strategy research at MED-EL currently concentrates on the concept of improving temporal coding in the low to mid frequencies using a stimulation paradigm which defines the timing of stimulation on a certain channel from the fine structure in the respective frequency band. As a first implementation of this concept, the FSP strategy was recently released. Users of the FSP strategy show equal or improved speech perception and improved sound quality and music appreciation. Psycho-acoustical tests revealed that improved temporal coding can lead to improved frequency discrimination, and that place coding is equally efficient with parallel and sequential stimulation. In addition, test results suggest that both the temporal code and the place code complement each other so that the user can make use of the code he is more sensitive to.

7C: NEW DIRECTIONS IN SOUND CODING: CUSTOMIZED STRATEGIES TO IMPROVE SPECTRAL RESOLUTION

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HiRes with Fidelity 120 ® is the first commercial speech processing strategy that uses current steering to provide spectral detail within individual stimulation channels. The signal processing approach utilized in current steering potentially can increase the pitch information available to cochlear implant (CI) users and has ushered in a new era of expectations. Many users now have the opportunity to hear better in real-world listening environments and to appreciate music.

A key challenge that still confronts CI researchers is the wide variation in benefit experienced by CI users. One hypothesis is that the differences across individual patients can be attributed to differences in spectral resolution achieved with today's stimulation paradigms. For example, previous studies have shown that the perception of correct musical intervals is correlated strongly with the spectral resolution available to CI listeners (Litvak et al. 2005). In this talk, we present two efforts aimed at enhancing the spectral contrasts for individual CI users.

The first effort uses signal processing to overcome spectral processing deficits in individual listeners. We have shown previously that spectral modulation detection thresholds (SMDT) are highly correlated with vowel and consonant recognition scores (Saoji et al. 2005). More recent studies with CI listeners have revealed strong correlations between SMDTs at low modulation frequencies ($\leq$ 1 cycle/octave) and speech understanding scores. Preliminary results using these spectral enhancement techniques have yielded a significant improvement in speech perception scores for the majority of patients tested.

The second effort uses current focusing to enhance spectral contrasts in the electrical stimulation pattern. Preliminary estimates of spatial tuning curves measured using a forward-masking paradigm indicate that current focusing can result in a better-defined peak in the neural activation pattern. In most cases, current focusing also leads to perceptions that are more tonal relative to those achieved with monopolar stimulation. Applied together, current focusing and current steering have the potential to provide frequency resolution and frequency tuning that are customized for individual CI listeners.

8A: PITCH PERCEPTION AND SOUND SEGREGATION BY COCHLEAR IMPLANT USERS

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Pitch perception by cochlear implant (CI) listeners is degraded relative to that experienced by their normal-hearing (NH) counterparts. I will discuss how this degradation may be influenced by the different ways in which pitch is encoded in CIs compared to NH, and the possible consequences for the perceptual separation of competing voices presented to the same ear.

When several harmonics interact within each channel of a modern CI processor, a pulse train presented to the corresponding electrode is modulated at a rate equal to the fundamental frequency ("F0" - the physical correlate of pitch). Pitch perception is poor, although a modest improvement can be obtained experimentally by presenting a low-rate, unmodulated pulse train to one electrode. When this is done, most CI users can discriminate pulse rates up to about 300 pps, and some can identify musical intervals between two pulse trains of different rates. However, rate discrimination at higher rates usually breaks down, a finding likely to hamper attempts to encode temporal fine structure in CIs. Furthermore, evidence from CI users and from simulations with NH listeners suggests that, even when two rates can be discriminated when presented *sequentially*, they are unlikely to provide a cue to the separation of *simultaneous* sounds.

The way the F0 of a periodic sound is encoded in CIs differs from that in NH, which depends on the lower-numbered harmonics, that are resolved by the peripheral auditory system. Psychoacoustic experiments have shown that the temporal response ("phase locking") of auditory nerve (AN) fibers to the stimulus is necessary for good pitch perception. However, there is evidence that some stimuli, such as bandpass filtered pulse trains presented to NH listeners and electric pulse trains presented to CI users, elicit good phase locking at the level of the AN but result in relatively poor pitch perception. Hence some other aspect of the neural response, produced by resolved harmonics but not by other stimuli, may be required. This additional factor may be a match between the frequency of phase locking and a particular place along the AN array, and/or the presence of across-fiber timing differences that have been observed in the response of the AN array to resolved harmonics. Neither of these factors are encoded in CIs.

My presentation will include a discussion of what conditions will need to be achieved to produce good pitch perception and sound segregation by CI users. An important question for discussion is whether it is worthwhile to try to reproduce "normal" pitch processing, or whether effort should be concentrated on other issues, such as improved channel selectivity.

8B: PROCESSING FUNDAMENTAL FREQUENCY WITH COCHLEAR IMPLANTS: PSYCHOPHYSICS AND SPEECH INTONATION

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In speech perception, fundamental frequency (F0) information is not only important for tasks such as speaker identification, but also serves as a critical cue for the processing of prosodic information. Speech intonation, in which F0 is a dominant component, conveys linguistic cues, particularly in tonal languages, as well as important information about the emotional context of the speaker's utterance. Present-day cochlear implants (CIs) are not designed to explicitly deliver fundamental frequency (F0) information to the listener. Although multi-channel cochlear implants provide sufficient information about the gross features of the spectral envelope for speech to be intelligible in quiet listening conditions, they are unable to transmit the finely-resolved spectral information that is required for the recognition of subtle changes in voice pitch. The majority of F0 information is transmitted to CI listeners through the periodicity cues present in the time pattern of the acoustic signal, which is conveyed to the electrodes via the temporal envelope.

Here, we report on a series of experiments designed to measure CI listeners' sensitivity to changes in F0. Ten CI users participated in parallel psychophysical and speech intonation detection experiments. In the psychophysical task, a three-alternative forced-choice adaptive procedure was used to measure discrimination thresholds for changes in the frequency of sinusoidal amplitude modulation (20% depth) of 2000 pps pulse train stimuli (monopolar for N-24/Freedom users, bipolar for N-22 users) applied to an apical electrode. The reference modulation frequency was varied from 50 to 300 Hz, and the modulation frequency discrimination threshold was measured at each reference modulation frequency. Effects of modulation depth (salience) and intensity changes (roving) were also measured. In a second experiment, listeners' ability to label changes in the F0 contour of a bisyllabic word "popcorn" was measured as a function of the degree of F0-change within the word (intensity and duration cues were roved). In the task, the listener was presented with a single sample of the word, and asked to judge whether it sounded more like a question or a statement. Results (plotted as a psychometric function, and analyzed as percent correct and as cumulative d') showed that CI listeners are able to follow and use the F0 cue, but to varying degrees. A statistically significant correlation was observed between the psychophysical thresholds and the speech intonation detection results. Effects of modulation depth (salience) and intensity roving were found to be small. Some effects of place of stimulation were observed in a subset of the subjects. These, and other related results, will be discussed.

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8C: MELODIC CONTOUR IDENTIFICATION BY COCHLEAR IMPLANT LISTENERS

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Despite great gains in speech understanding, music perception and appreciation remain difficult for cochlear implant (CI) users. The limited spectro-temporal resolution of current CI devices does not provide the fine-structure cues needed to support complex pitch perception, which is important for melody recognition. As researchers strive to restore these fine-structure cues, it is important to quantify the capacity of the implant device to convey melodic information. To address this issue, we developed a closed-set melodic contour identification (MCI) test. In the MCI test, performance was assessed using nine 5-note melodic contours (i.e., rising, falling, rising-falling, falling-rising, flat, flat-rising, flat-falling, rising-flat, falling-flat); rhythm cues were held constant, musical notes were generated using 3-tone complexes, the overall frequency range was varied (220-698 Hz, 440-1397 Hz, 880-2794 Hz), and the interval between successive notes in the contours ranged from 1 to 5 semitones. Results showed that MCI recognition performance was highly variable among CI subjects, ranging from 14% to 91% correct. The low frequency range produced slightly lower performance than the mid and upper ranges. The best performers identified more than 90% of contours given a 9-semitone range, while the poorest performers identified less than 35% of contours given a 21-semitone range. The results suggest that even good performers lacked the spectro-temporal resolution needed to identify the most challenging contours (i.e., 1 semitone between notes).

In the previous experiment, MCI performance was evaluated using relatively simple 3-tone complexes. However, the harmonic structure can vary greatly among different musical instruments and even within an instrument for different frequency ranges (i.e., instrument “timbre”); transients associated with the “attack” of a note may change the harmonic structure over time. Because CI speech processing strategies primarily encode spectral envelope cues, instrument timbre may interact with CI patients’ frequency allocation and influence musical pitch percepts. We recently tested CI patients’ MCI performance for a variety of musical instruments. Results showed that different instruments significantly affected performance. For many subjects, performance was poorer for instruments with a strong attack (piano), while performance was better for instruments with a more orderly harmonic structure (organ). Musically experienced CI subjects were less susceptible to timbre differences, suggesting that music training may help CI patients to better extract pitch information from a variety of spectral envelopes.

8D: THE MODIFIED MELODIES TEST OF MELODY PERCEPTION

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Cochlear implant recipients suffer from poor pitch perception, affecting their enjoyment of music and causing difficulties with tonal languages. Our goal is to evaluate new sound processing and stimulation strategies that are intended to improve cochlear implant pitch perception. Two commonly used tests are pitch ranking and melody recognition, but both have drawbacks. In a pitch-ranking test, implant recipients may be using the electrode “place-pitch” cue, but this percept may be more akin to the brightness attribute of timbre than pitch. A direct test of melody perception is preferable. Drawbacks of a closed-set melody recognition test are that it can be difficult to find an adequate set of familiar melodies, and many cochlear implant recipients score near chance. Furthermore, normal hearing subjects can obtain high scores even with distorted melodies, so a high score does not necessarily imply good pitch perception.

To address these drawbacks, we developed the “Modified Melodies” test. In each trial, a familiar melody is presented twice. In one presentation, randomly selected, the pitch is deliberately modified. The subject’s task is to select the un-modified melody. The difficulty of the test can be controlled by adjusting the type and amount of pitch change.

Evaluation with normal hearing subjects showed that shrinking musical intervals by 5% was a more noticeable distortion than stretching intervals by 5%. Harmonic tones yielded better performance than pure tones.

Evaluation with cochlear implant recipients showed much poorer performance than normal hearing subjects, but most subjects could obtain scores significantly better than chance. There was no significant difference in performance between ACE (using quadrature envelope detection), and an experimental strategy implemented on the Freedom processor that used half-wave rectification. The performance of cochlear implant recipients was significantly improved by a contralateral hearing aid.

An ongoing study uses the Modified Melodies test to investigate the relative contributions of place and temporal cues to pitch, and seeks to answer the question: is "place-pitch" really pitch?

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9A: A NEW TOOL TO SELECT FREQUENCY-TO-ELECTRODE MAPS FOR AUDITORY PROSTHESES

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Cochlear implants (CI´s) can restore hearing to deaf individuals by electrically stimulating the auditory nerve. They do so by assigning different frequency bands to different stimulating electrodes via a frequency map. The closer an electrode is to the base of the cochlea, the higher the frequency of the corresponding band. This is done to mimic what happens in a normal hearing cochlea. Almost all postlingually deaf CI users (those who lost their hearing after learning speech and language) can hold a fluent face-to- face conversation in a quiet environment, and a majority of patients can even understand speech without the help of lipreading. However, this result is not always obtained immediately after implantation. Instead, months of experience listening with the CI are required for most patients to reach asymptotic levels of speech perception. This extensive perceptual learning may be required due to the ways in which CI´s distort auditory input, which include spectral degradation and frequency shift. The former happens due to the limited number of stimulation channels; the latter is due to physical limitations in electrode insertion depth, which may cause a mismatch between the speech processor´s analysis filters and the characteristic frequency of the stimulated neurons. A possible way to address We have developed a PC-based speech processing platform that enables us to change the frequency map in real time, and used this platform to study normal-hearing adults listening to an acoustic simulation of a cochlear implant. In this study we investigated what frequency maps were initially preferred, and how the ability to understand speech with that preferred map compared with two other maps. We show that naïve listeners prefer a map that balances the need for low-frequency information with the desire for a naturally-sounding stimulus, and that initial performance with this listener-selected map is better than that with a map that distorts the signal to provide low-frequency information. Finally, we present results from a mathematical model of vowel perception by CI users that may help explain the speech perception data.

This work was supported by NIH-NIDCD grant R01-DC03937.

9B: MAXIMIZING THE BENEFITS OF COCHLEAR IMPLANTATION VIA TARGETED SPEECH TRAINING

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Advanced cochlear implant technology and speech processing strategies have provided great benefit to many cochlear implant patients. However, some patients receive little benefit from the latest implant technology, even after many years' experience with the device. Moreover, even top cochlear implant performers have great difficulty understanding speech in the presence of background noise; music perception and appreciation also remain major challenges.

Recent studies have shown that targeted auditory training can significantly improve cochlear implant patients' speech recognition performance. Such benefits are not only observed in poor-performing patients, but also in good performers listening to difficult conditions (e.g., speech in noise, telephone speech, music, etc.). Targeted auditory training has also been shown to enhance performance gains provided by new implant devices and/or speech processing strategies. These studies suggest that cochlear implantation alone may not fully meet the needs of many cochlear implant patients, and that additional auditory rehabilitation may be necessary to maximize the benefits of the implant device. More research efforts are needed to develop efficient and effective training protocols and materials to minimize the time commitment required for auditory rehabilitation, while maximizing the benefit of cochlear implantation for all cochlear implant recipients.

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9C: EFFECTIVENESS OF COMPUTER-BASED AUDITORY TRAINING IN IMPROVING THE PERCEPTION OF SPEECH BY ADULT USERS OF COCHLEAR IMPLANTS

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We investigated whether unsupervised computer-based auditory training leads to improvements in speech perception among post-lingually deafened adult users of cochlear implants. Evidence from Fu et al. (2005) suggests that computer-based training is a promising intervention for implantees with limited speech-perception skills. The present study extends that work in two ways: (i) by administering two tests of sentence perception as well as tests of vowel and consonant discrimination, and (ii) by exploring whether training leads to improvements in quality of life.

To date, six subjects have participated. Before training, they displayed sentence-perception scores ranging from 55% to 81% correct. Subjects were instructed to complete an hour of training a day, five days a week, for three weeks, dividing their time equally between two training tasks. In the first task, they recognised isolated words; in the second task, they recognised words in sentences. Both tasks have previously been shown to help normally-hearing subjects perceive noise-vocoded speech processed to simulate the consequences of tonotopic misalignment. To evaluate the effectiveness of training, tests of speech perception were administered repeatedly until subjects reached a stable baseline, and then following every week of training. In addition, subjects completed the Glasgow Benefit Inventory (GBI) following every week of training. The GBI is self-report measure of change in otologically-relevant quality of life.

Improvements in speech perception were variable across subjects and tests. There was a trend across all tests for subjects who performed more poorly before training to benefit more from training. Significant improvements in quality of life were reported by the two subjects who also displayed a significant improvement in consonant discrimination.

The results suggest that unsupervised computer-based auditory training might be an effective intervention for implantees who achieve lower levels of speech perception.

Acknowledgements
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Reference

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A1: SPEECH RECOGNITION WITH COHERENT ENVELOPES

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Most modern cochlear implants deliver envelope modulated pulse trains to electrodes. Traditionally, speech envelopes are extracted through the full-wave rectification, half-wave rectification, Hilbert envelope or magnitude of a short-time Fourier transform. These approaches generate a positive and slowly-varying low frequency signal to modulate a pulse train at a constant rate. As demonstrated by previous studies, this process eliminates the temporal fine structure originally embedded in sound waves, resulting in overwhelming difficulties in perceiving music and noise-contaminated speech among cochlear implant recipients.

In this study, we propose alternative ways of extracting envelopes using fixed or dynamically varying coherent demodulation techniques. For fixed coherent demodulation, a band-limited signal is assumed to reside at a specific high-frequency carrier, e.g. the lower boundary, center, or upper boundary of that sub-band. The band-limited signal is downward shifted to the base band or low-frequency band in a manner similar to the Single Side Band (SSB) or Double Side Band (DSB) demodulation in wireless communication. The resultant envelope is real but slowly-varying over time. In the dynamically varying coherent demodulation, the downward frequency shift is the same as in the fixed case except that the carrier frequency is estimated based on the spectral center of gravity (COG) of a one-sided sub-band. This dynamic coherent envelope is a complex signal with slowing-varying amplitude and phase.

Unlike the traditional envelope extraction methods, the above coherent approaches have minimal information loss, preserving spectral and temporal cues. The dynamically varying coherent envelope might provide additional advantages by tracking the most prominent frequency components in speech.

As a preliminary experiment, we evaluated speech recognition on normal hearing subjects listening to noise-vocoded sounds using coherent envelopes. Initial experimental results suggested that the two approaches can achieve higher consonant recognition scores compared to traditional envelope extraction algorithms.

The coherent envelope extractions are promising in providing perceivable cues to implant listeners as a result of spectral shifting. They could be potentially implemented in real time and effectively encoded in the pulse train stimulation for better speech and music perception.

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A2: RELATIONSHIPS AMONG MUSIC PERCEPTION, SPEECH PERCEPTION IN NOISE, SCHROEDER PHASE AND SPECTRAL DISCRIMINATION ABILITY IN COCHLEAR IMPLANT USERS

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Cochlear implant users often show remarkable speech perception abilities in quiet. However, it is still challenging for cochlear implant users to understand speech in noise and to listen to music. This study examined the relationship among spectral resolution, Schroeder phase discrimination, speech perception in noise, and music perception in cochlear implant users.

A 3-alternative forced-choice (AFC), 2-up, 1-down adaptive procedure was used to determine the spectral-ripple threshold. A 4-interval, 2-AFC paradigm at four fundamental frequencies was used to measure the Schroeder-phase discrimination ability. A 12-AFC, 1-up, 1-down adaptive procedure was used to determine speech reception thresholds (SRTs) for spondees in two-talker babble and in steady-state noise (SSN). Melody identification, timbre identification, and pitch direction discrimination ability were measured with the University of Washington Clinical Assessment of Music Perception (UW-CAMP) test.

For 30 subjects, spectral-ripple thresholds were significantly correlated with melody (r = 0.52, $p = 0.0032$), timbre (r = 0.64, $p = 0.0001$), pitch (r = -0.46, $p = 0.011$), and SRTs (r = -0.56, $p = 0.0012$ in babble; r = -0.63, $p = 0.0002$ in steady-state noise). For 25 subjects, Schroeder-phase discrimination was significantly correlated with SRTs in SSN (r = -0.44, $p = 0.031$) and pitch direction discrimination (r = -0.4, $p = 0.047$). Significant correlations were also found between SRTs and melody (r = -0.50, $p = 0.0063$ in babble; r = -0.52, $p = 0.0047$ in SSN), timbre (r = -0.47, $p = 0.011$ in babble; r = -0.58, $p = 0.0013$ in SSN) and pitch direction discrimination (r = 0.64, $p = 0.0002$ in babble; r = 0.57, $p = 0.0017$ in SSN) for 28 subjects. Independent of the effect of spectral-ripple, the correlations between SRTs in SSN and melody and timbre identification were -0.34 and -0.39, respectively. The results suggest that spectral-ripple discrimination ability underlies numerous clinically relevant capabilities in cochlear implant users.

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A3: REVERBERATION, DISTANCE, MASKING & CI PROCESSED SPEECH

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Cochlear implant (CI) users often report difficulty hearing in real-world environments despite performing well in clinical or laboratory settings. These difficulties may in part be related to the effects of reverberation and other competing talkers. The present study extends previous work [Poissant et al (2006). JASA 119, 1606-1615] concerned with such effects. Specifically, it examines the effects of the direct-to-reverberant energy ratio (DRR), a parameter influencing speech intelligibility and source location perception, on CI processed speech. The DRR was controlled by varying the distance between the sound source and the listener as well as the uniform absorption coefficient in a simulated room.

Two experiments are presented. In Experiment 1, 13 young adults with normal hearing listened to both processed and unprocessed lists of topic-based sentences. Processing included simulated reverberation (estimated RT60 = 0.425 s) in both quiet and in the presence of steady-state speech spectrum noise (SSN) at target-to-masker (TMR) ratios ranging from -8 dB to +18 dB and source-listener distances of 1, 3, or 4 meters. Vocoding employed amplitude modulated sine wave carriers and varied only in the number of spectral channels (6, 12, 24). Results showed that factors of distance, number of channels, and TMR all had significant effects on intelligibility scores. Post-hoc analyses indicated that processed speech scores had decreased significantly at the 4 meter distance.

For fixed room geometry, nearly identical DRRs can be produced by various combinations of source-listener distances and room absorption. Since room absorption also affects reverberation time, we cannot assume that matched DRR values in different rooms are associated with matched reverberation patterns or matched perceptual effects. Experiment 2 examines the interaction between distance and absorption for speech produced by the 6-channel CI simulator. Normally hearing subjects were tested in simulated reverberant environments (RT60 = 0.152-0.425 sec) both in quiet and in the presence of SSN or two-talker babble at source-listener distances of 1, 2, 3, and 4 meters. Both our experimental data and our analysis of envelope modulations (Houtgast, Steeneken & Plomp, 1980) should help resolve the practical question of the extent to which poor speech recognition in reverberant rooms can be compensated for by decreasing the distance between the sound source and the listener.

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A4: VISUALIZING FINE STRUCTURE SPEECH CODING STRATEGIES

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A new algorithm for displaying stimulation pulse patterns, as generated by speech coding strategies which apply fine structure information, is presented. Common cochlear implant speech coding strategies convey the envelope information within the band pass filtered input signal but discard fine structure information. The fine structure stimulation paradigm considered here is called Channel Specific Sampling Sequences (CSSS), which triggers an amplitude weighted sequence of stimulation pulses at each zero crossing of the filter output signal.

Within the simulation the behavior of the filter bank and functional parameters of the coding strategy can be set deliberately within the specifications of the MED-EL OPUS1 speech processor. This includes methods to increase the information content per stimulation pulse (Selected Groups algorithm and parallel stimulation with Channel Interaction Compensation), setting parameters governing stimulation rate, and choosing CSSS sequence shapes for CSSS channels. For a given set of parameters, the algorithm calculates the stimulation pulse pattern for an arbitrary input signal as would an actual implementation of the speech coding strategy within the OPUS1. In order to get a more realistic picture of the resulting potential distribution within a human cochlea, an approximation of channel interaction is performed by applying a spatial exponential distribution to the pulse amplitudes of the single channels.

The visualizations enable a simple comparison of different implementations of speech coding strategies. They show that CSSS-type strategies much better convey the temporal fine time structure of an input signal than CIS-type strategies do.

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A5: THE EFFECT OF CHANNEL-SPECIFIC HILBERT PHASE RANDOMIZATION ON SPEECH PERCEPTION IN NOISE AND COMPLEX-TONE FREQUENCY DISCRIMINATION FOR COCHLEAR IMPLANT USERS

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To test the role of acoustic phase in perception by cochlear implant users, speech perception ability in noise was evaluated with and without randomized Hilbert phase. The stimuli were processed with a 12-channel vocoder from which the Hilbert envelope of a bandpass filter was used to modulate the original Hilbert phase or 100% randomized phase. If cochlear implant users are not sensitive to acoustic phase, equal performance on psychoacoustic tasks would be expected whether they were tested with 0 or 100% randomization of the Hilbert phase. Our tasks included a complex tone frequency discrimination task and measurement of the speech reception threshold (SRT) for spondees presented in two-speaker babble. For 9 of 14 CI listeners, complex-tone frequency discrimination was better with no phase randomization; the difference between 0 and 100% phase randomization increased for each frequency tested: difference limen (DL) 130Hz = 0.9 semitone ($p=0.08$), DL 164Hz = 1.5 semitones ($p=0.03$), DL 233Hz = 2.1 semitones ($p<0.001$). Individual SRTs were better for 15 of 20 listeners with no phase randomization. The SRT averaged 3.6 dB higher ($p < 0.001$) with 100% phase randomization. The differences in performance for original phase and randomized phase stimuli were correlated with other tasks that might benefit from phase sensitivity, e.g. SRT in babble noise, complex-tone pitch direction discrimination, and melody identification. The results suggest that temporal information beyond the temporal envelope is accessible to implantees with envelope-modulated strategies.

A6: RESULTS FROM A STRATEGY ENCODING TEMPORAL FINE STRUCTURE

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Current cochlear implant stimulation strategies are widely based on the continuous interleaved sampling (CIS) paradigm. With CIS, temporal fine structure is only crudely represented in the stimulation pattern, and pitch is encoded primarily in the place of stimulation and to a limited extent in the temporal fluctuations of the channel envelopes. However, fine structure information is a crucial ingredient for the perception of music and of tonal languages, as demonstrated in studies with normal hearing subjects.

In the fine structure strategy presented, “channel specific sampling sequences” (CSSS) or pulse-packages are applied to the apical electrodes, while the remaining basal electrodes carry CIS-like stimuli. The pulse sequences are triggered by the zero-crossings of the corresponding filter channel outputs and scaled with the channel envelopes. Thus, both fine time structure and envelope information are represented on CSSS channels.

The new strategy has been evaluated in two experiments: In a first experiment, pitch discrimination and scaling abilities were compared for the fine structure strategy and CIS in four MED-EL implant recipients. For pure tone stimuli below 300 Hz, pitch discrimination with CIS was limited. Conversely, CSSS seems to add robust temporal cues to pitch at low frequencies, supporting better discrimination.

In a second experiment, speech reception measures were taken for MED-EL implant recipients and native speakers of Cantonese Chinese in Hong Kong. Preliminary results from a pilot study showed substantial improvements in the perception of lexical tones with the fine structure strategy over CIS and triggered a more extensive survey. Data from this ongoing study will be presented.

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A7: INTERACTION BETWEEN NUMBER OF CHANNELS AND ACROSS-FREQUENCY INTEGRATION OF ENVELOPE CUES IN VOCODER PROCESSING

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Both noise- and tone-carrier vocoders have been widely used to simulate the effects of cochlear implant (CI) processing using normal-hearing listeners, [e.g. Shannon et al., Science 270:303-304 (1995)]. Speech intelligibility, especially in difficult listening conditions, generally increases with increasing number of vocoder channels. This pattern is demonstrated to a lesser extent in hearing-impaired [Baskent, J. Acoust Soc. Am. 120:2908-2925 (2006)], and CI listeners [Friesen et al., J. Acoust Soc. Am. 110:1150-1163 (2001)]. Performance appears to plateau at much lower numbers of channels with the impaired than with the normal-hearing listeners: there is a mismatch between presented and functional spectral resolution. Hearing-impaired and CI listeners have also been shown to have poorer access than normal listeners to temporal fine structure cues. Therefore they rely more on the temporal-envelope cues. However, there is another problem with the use of the vocoder as a simulation tool: as the number of channels increases, the channel bandwidths decrease, restricting access to high-frequency temporal envelope cues. Potentially a mismatch arises between the temporal resolution capable of being presented to the acoustic-hearing compared to that possible with the CI listeners.

The experiments reported here investigate the effect of varying the cut-off frequency of the envelope extractor in vocoder processing for a wide range of numbers of channels. The extractor used one of two low-pass filters: one, the ‘E’ filter, preserved only low-frequency modulations, i.e., below 100 Hz, while the other, the ‘P’ filter, preserved modulation frequencies up to 400 Hz. The same filter was used on each channel in a block of channels above and below 1500 Hz. All four combinations of E or P and their use across the low-or high-frequency blocks were tested. Using a competing-talker task, experiment 1 shows that envelope modulations carrying cues to fundamental frequency are a strong aid to intelligibility provided that they are available in all channels. Experiment 2 investigates further the finding of experiment 1 that above 11 channels, the band-pass filters may compromise the ability to use high-frequency temporal envelope cues, especially if the listener is unable to integrate cues across channels. Overall, these results with normal-hearing listeners and preliminary results with hearing-impaired listeners show that vocoder simulations of CI processing should be interpreted more guardedly, especially when high channel numbers are used.

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A8: DIFFERENTIAL EFFECTS OF COCHLEAR IMPLANT ELECTRIC PULSE RATE ON GAP-DETECTION AND FORWARD MASKING

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Forward masking in electric hearing provides evidence that a component of this temporal process occurs central to cochlear hair cells. We measured forward masking and gap detection in the guinea pig primary auditory cortex. Masking stimuli were 200 ms in duration and consisted of either acoustic broadband noise bursts or electric pulse trains presented through a cochlear implant at a range of pulse rates (254, 1017, 4069 pps); animals were deafened in the electric stimulus conditions. Cortical gap detection thresholds shortened with increasing electric pulse rate and increasing stimulus level. The time constant for recovery from forward masking was consistent with human psychophysical recovery from masking and did not vary significantly over pulse rate or masker level. Therefore, the dependence of gap detection thresholds on pulse rate must be accounted for by the effectiveness of the masker and the probe in each condition.

Rate-level functions measured at stimulus onset were consistent with higher pulse rates stimulating more effectively than lower pulse rates. This dependence of onset response strength on pulse rate is likely due to temporal integration at the site of spike generation in auditory neurons. Tonic cortical responses, however, were more difficult to characterize due to potentiation of inhibition by anesthesia. A decrease in temporal integration after onset at higher pulse rates due to the refractory period at the level of the auditory nerve could cause more adaptation to the masker at higher pulse rates. More effective probes in high pulse rate stimulation with the possible contribution of less effective maskers would be consistent with shorter gap thresholds at higher pulse rates.

In acoustic forward masking, the time constant obtained for recovery was significantly shorter than that for recovery from electric pulse train forward masking and did not vary across stimulus level. Acoustic gap detection thresholds were roughly equivalent to those in electric stimulation. The shorter recovery constant indicates a difference in the recovery process in acoustic and electric stimulation, likely involving adaptation at the hair-cell synapse in the acoustic condition and synchrony of excitation in the electric conditions.

These findings have implications for understanding perception of cochlear implant stimulation at varying pulse rates and for design of processors to take advantage of these properties.

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A9: PLASTIC CHANGES IN THE PRIMARY AUDITORY CORTEX OF THE DEAFENED CAT RESULTING FROM COCHLEAR IMPLANTATION.

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Chronic intra-cochlear electrical stimulation (ES) is known to alter the cochleotopic organization and increase the temporal responsiveness of parts of the auditory system. However, the effect of long-term deafness and chronic ES on the cochleotopic organization and temporal responsiveness of neurons in the primary auditory cortex (AI) is less clear. In addition, the issue of trophic effects of ES - in the absence of neurotrophins - on spiral ganglion neurons (SGN) requires further investigation. Therefore, two months after neonatal deafening via daily neomycin injections, fourteen profoundly deaf cats were implanted with a multi-channel scala tympani electrode array. The animals received unilateral monopolar or common-ground ES for periods of up to 11 months to restricted sections of the basal turn via a Nucleus® CI24 cochlear implant and Nucleus® ESPrit 3G speech processor. An additional nine animals served as age-matched unstimulated deaf controls. Recordings from a total of 1275 multi-unit clusters in AI were made using a combination of single tungsten and multi-channel silicon electrode arrays. Significant cochleotopic organization of AI was observed in all but one of the chronically stimulated animals (Pearson correlation; all $p < 0.01$), while none of the unstimulated control animals exhibited cochleotopic organization. The maximum rate at which units could be driven from chronically stimulated cochlear regions was significantly higher than that at which units could be driven by stimulation of the corresponding regions in unstimulated deaf control animals (Mann-Whitney; $p < 0.05$). Finally, SGN density showed no evidence of a significant difference between ES cochleae and their unstimulated controls across all cochlear turns. In summary, behaviorally relevant chronic ES delivered using a clinical stimulator results in i) a more defined cochleotopic organization of AI than is present in the long-term deaf; ii) an increase in the temporal responsiveness of units within AI; and iii) no survival advantage for SGNs. Maintenance or re-establishment of a cochleotopically organized AI by activation of a restricted sector of the cochlea may contribute to the improved clinical performance observed among subjects implanted at a young age and changes in the temporal responsiveness of AI have implications for the methods used to encode the fine temporal structure of stimuli used in modern cochlear implants.

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A10: SPECIALIZED COCHLEAR IMPLANT COATING IMPROVES IMPLANT FUNCTION AND PROMOTES NEURITE REGROWTH

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Cochlear implants stimulate auditory nerve processes that are susceptible to degeneration over time. It has been shown in animal models that promoting survival of the auditory nerve can improve cochlear implant function. The majority of this research has focused on promoting survival of spiral ganglion cell bodies. However, it is also possible to regenerate the peripheral processes that connect ganglion cells to the organ of Corti. Promoting survival and directing regrowth of peripheral processes to decrease the distance between the implant and the nerve could potentially provide numerous benefits to cochlear implant users, including lower thresholds and increased number of independent channels. However, neurons are unlikely to extend peripheral processes towards the cochlear implant when they have to traverse perilymph in the scala tympani where the implant is placed. The current study examined a novel cochlear implant coating designed to provide an extracellular matrix to fill this space in the scala tympani, providing a substrate for neuronal growth. This coating, labeled GelDOT, had three elements: An alginate hydrogel to coat the implant and provide the extracellular matrix; a conducting polymer to extend the surface area of each electrode and create scaffolds within the hydrogel; and the neurotrophin BDNF to act as a chemoattractant.

Guinea pigs were systemically deafened and then implanted with either a GelDOT coated cochlear implant or a bare implant. Impedances were measured on a daily basis and electrophysiological thresholds were measured on a weekly basis. One to four weeks after implantation, animals were sacrificed, temporal bones were removed and immunocytochemistry was performed on the entire cochlear specimen with the implant in place. We hypothesized that the GelDOT coating would attract peripheral processes regrowth towards the implant and decrease impedances and electrophysiological thresholds. Results from these morphological and functional assessments will be presented. These data show promise for improving cochlear implant function using this specialized prosthesis coating.

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A11: STIMULATION EFFECT AND LONG-TERM IMPEDANCE DEVELOPMENT AFTER COCHLEAR IMPLANTATION

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The increase of impedances of cochlear implant (CI) electrodes shortly after implantation is typically explained by the formation of a fibrous tissue sheath around the electrode carrier. Earlier studies have shown, that intra-operative and intra-cochlear application of steroids resulted in a reduction of the postoperative impedances of the stimulating electrodes in the cochlea whereas coating of the contacts with Iridium did not influence the short-term development of the impedances. We now present data on the influence of beginning electrical stimulation on the impedances during rehabilitation period after first fitting and long-term development of impedances and T- and C-levels in all study groups.

All patients received a Contour electrode array. The following groups of patients have been investigated: a) control (N=17), b) intraoperative application of steroids (N=8), c) Iridium-coated electrode contacts (N=10), and d) Iridium-coated contacts with intra-operative application of steroids (N=8). Impedances have been measured using standard fitting software and common ground mode during rehabilitation period in the morning before switch-on of the device and in the afternoon after at least 4 hours of stimulation. Furthermore, impedances and T- and C-Level were evaluated during regular test sessions from first fitting up to four years post implantation.

During evaluation of the stimulation effect, reductions of impedances by 0 to 5 kOhm or 0 to 50 % of its initial value were found. On average, the largest stimulation effect and also highest T-and C-Levels were found in the group with Iridium-coated electrodes. A correlation between initial impedances and the stimulation effect was only found in the steroid-treated groups. As the data for the stimulation effect showed some large variations between the patients, differences could not be allocated to the different treatments. Intra-operative application of steroids reduces the impedances on a long term but does not affect the development of the stimulation level.

A12: EFFECTS OF ERYTHROPOIETIN ON CULTURED SPIRAL GANGLION CELLS

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Hearing impairment is known to be related to the loss of inner and outer hair cells, followed by degeneration of spiral ganglion cells. The number of surviving spiral ganglion cells (SGC) is one of the factors determining the outcome of cochlear implantations. To enhance survival of SGC by pharmacological treatments, neurotrophic factors such as glial cell line-derived neurotrophic factor and brain-derived neurotrophic factor (BDNF) have been in the focus of research during the last years. As it is known that Erythropoietin (EPO) reduces apoptosis in retinal ganglion cells, we investigated the effects of different concentrations of EPO also in combination with BDNF on spiral ganglion cells in vitro.

SGC were explanted from P3-5 rats and cultivated in serum-free medium for 48 and 72 hours at 37°C. EPO was added in concentrations of 2.5, 5, 10, and 50 ng/ml and its effects compared to untreated controls and cells treated with 50 ng/ml BDNF. Furthermore, cells were treated with combinations of the EPO concentrations and 50 ng/ml BDNF. Numbers of surviving cells, diameter of the somata and lengths of the neurites were evaluated and compared between groups.

Treatment with EPO alone had no effect on the number of surviving cells but treated cells exhibited longer neurites than controls, approximately in the same range as for BDNF treatment alone. Application of EPO together with BDNF enhanced the BDNF-effect. Cultivation for 72 hours resulted in much longer neurites compared to 48 hours cultivation time for all treated cells.

The results indicate that EPO alone is not beneficial for increased survival of SGC but can be considered as co-treatment together with BDNF.

A13: RAPID DEGENERATION OF SPIRAL GANGLION CELLS IN DEAFENED GUINEA PIGS AFTER CESSATION OF NEUROTROPHIC TREATMENT?

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Several studies indicate that application of exogenous neurotrophins enhances spiral ganglion cell (SGC) survival in deafened animals. However, Gillespie et al. (*NeuroReport*, 2003) have reported that cessation of treatment with brain-derived neurotrophic factor (BDNF) leads to a more rapid degeneration than in deafened untreated cochleas. This observation raises fundamental questions: What are the morphological characteristics of BDNF-treated SGCs immediately before cessation, and what is the functional development of SGCs after cessation of treatment? In this study, we address these questions by electron microscopical analysis of SGCs in BDNF-treated cochleas and by recording electrically evoked auditory brainstem responses (eABR) during and after BDNF treatment.

Two weeks after deafening by treatment with kanamycin in combination with furosemide the right cochleas were implanted with a multiple-electrode array (Cochlear). BDNF (100 µg/ml) was infused into the cochlea over a period of four weeks at a rate of 0.25 µl/hr. Left cochleas were not treated with BDNF and served as controls. Electrical stimuli were monophasic pulses of 60-400 µA with a duration of 20 µs. The eABRs were recorded two times a week in awake animals. Animals were sacrificed either immediately after the BDNF treatment or two weeks after cessation of BDNF treatment, and both left and right cochleas were processed for quantitative analysis. Morphological parameters included SGC packing density, perikaryal size, and cell circularity.

Immediately after BDNF treatment, SGC perikaryal size was increased by 20% as compared to normal SGCs. The amplitude of eABRs did not significantly decrease after cessation of BDNF treatment, whereas a significant decrease was found after deafening in animals which did not receive BDNF. This implies that there is no functional degeneration of SGCs. Preliminary morphological data show a wide variability in SGC packing densities two weeks after cessation of BDNF treatment.

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A14: COCHLEAR IMPLANT AND METHOD FOR PASSIVE DRUG DELIVERY

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The objective of this research is to design and evaluate a cochlear implant (CI) electrode designed for passive diffusion of a substance into the inner ear. A previously proposed model for drug delivery to the cochlea incorporated a port and septum to access a channel through the electrode. This system was designed initially for the delivery of nerve growth factors, and required an implantable pump for delivery over a number of weeks. The port and septum of a prototype device have been rigorously tested for leakage for over 16 months and under accelerated aging conditions (100 degrees heat). Leak testing has been performed under 60, 300 and 2500 mili bars back pressure. The septum has also been successfully tested against biofilm formation and bacterial penetration.

The new concept for drug delivery involves the passive diffusion of a drug from a 10 µL reservoir built within the electrode itself. Loading of the drug into the reservoir takes place intra operatively through the same port and septum that has been designed and tested for long term drug delivery. The reservoir lets the drug diffuse through a slit or through micro-channels built in the silicone of the electrode carrier. Openings are limited to the intracochlear portion of the array. The reservoir, however, can extend several centimeters within the middle ear portion of the array to increase the therapeutic period. Preliminary experiments show that diffusion of small molecules takes place through four 50-µm holes in about 2 weeks. The procedure requires the surgeon to fill a small syringe with the substance under test and to fill the reservoir to capacity through the septum of the electrode. Electrode insertion can then proceed with the substance loaded in the core of the electrode. The advantages of this system are as follows:

- Loading of the electrode reservoir by the surgeon is easy and convenient through the self-sealing septum.
- A defined and controlled amount of drug can be loaded into the electrode.
- No increase of pressure is applied to the cochlea fluids (passive diffusion).
- An initial burst release would take place.
- The electrode size intra scala is not modified.
- The same electrode is usable for different types of drug (a generic drug reservoir).
- Passive diffusion takes place along the length of the electrode, giving uniformity of dosage.
- The reservoir can extend beyond the intra cochlear portion of the array.

The release rate out of the reservoir shall be controlled by the size and geometry of the openings on the electrode. The dosage can be controlled by drug concentration. Duration of release is a function of the reservoir size. The design is equivalent in many aspects to a drug eluting or coated electrode without the complexities of formulating a specific drug to a specific carrier. Device sterilization and shelf life are independent of the drug when loading takes place intra operatively, through the port and septum connected to the electrode and implant. Alternatively, a hydrogel could be loaded in the reservoir and polymerized in situ. Drug delivery to the inner ear during and after cochlear implantation has the potential to revolutionize the field and is likely to be the next major step forward for hearing preservation and regeneration.

A15: ROUND-WINDOW DEXAMETHASONE FOR HEARING PROTECTION DURING COCHLEAR IMPLANTATION

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Aims: Hearing preservation during cochlear implantation is essential for the success of electroacoustic hearing. Here we test whether dexamethasone, applied to the round window of the guinea pig can preserve hearing during cochlear implantation.

Methods: Seprapack™ (Genzyme, USA) beads were adsorbed with 5μl of either 2% (w/v) dexamethasone phosphate or Normal Saline. Normal hearing guinea pigs were implanted, by basal-turn cochleostomy, with a 3-band scala tympani electrode array 30 minutes following round window membrane placement of either a dexamethasone-loaded bead (n=15), a normal saline-loaded bead (n=15) or no bead (n=6). The main outcome measure was auditory function, estimated by pure-tone auditory brainstem response immediately before, immediately after, one week and one month following array insertion. Representational histological analysis was performed.

Results: In all treatment groups, there was an immediate loss of hearing across the frequency range (.5-32 kHz) after cochlear implantation, with a significant rebound by the end of the first postoperative week. Hearing returned to pre-operative levels below 2 kHz, but a permanent loss persisted above this frequency, which plateaued at ≈20 dB above 8 kHz. Dexamethasone treatment significantly protected residual hearing at 32 kHz, and this effect was greatest when resistance was met during electrode insertion. Histopathological examination revealed a foreign body reaction in saline controls, but not the dexamethasone treated animals.

Conclusion: The hearing loss in this model resembled that seen in human cochlear implantation, to the extent that there was a relative sparing of low frequencies after cochlear implantation, and that greater hearing loss occurred when electrode insertion was technically difficult. Dexamethasone applied to the round window protected hearing at the site of electrode insertion (32 kHz). These experiments demonstrate that in principle, better preservation of residual hearing may be achieved by pharmacological protection of the inner ear at the time of cochlear implantation, but further optimisation of the system would be desirable. In addition, it appears that dexamethasone may modulate the tissue reaction to implantation.

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A16: FINE-TUNING OF THE IMPLANT MATERIAL-CELL INTERACTIONS BY FEMTOSECOND LASER MICRO STRUCTURING

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Optimal electrical stimulation of neuronal cells requires a close position of the electrodes to the neuronal structure and low impedance of the electrode contacts. The aim of our research project is the physical modification of the electrode surface [1, 2, 3] to reduce tissue growing in different types of electrodes inserted in the cochlea, on the brain stem or in the midbrain to prevent increasing of impedance and unspecific electrical stimulation.

Different silicone (LSR 30, HCRP 50) which were used in CI electrodes by Cochlear Ltd, (Sydney) with rough and smooth surface and micro-structured platinum sputtered glass wafer were used. With the femtosecond laser technology geometric microstructures were produced on the surface of the materials with a width of 1-10 µm and a depth of about 1 µm. In case of the silicone sheets the micro structure was produced via laser ablation. To observe cell morphology and cell growth in correlation with the structure geometry also on the non-transparent materials over time we used GFP-marked fibroblasts and nerve cells [4].

The cell growth rate of fibroblasts on all kinds of silicone is significantly lower than on platinum. Polished silicone surface decreases cell growth on silicone. The laser structure further reduced the growth of fibroblasts. After 3 days of cell culture the number of cells on the micro structured platinum was significantly reduced. On all types of the silicones the effect of the micro structuring was visible. On LSR 30 with smooth surface the reduction during the microstructure tends to be larger than on the rough surface and also larger then on the moulded silicone.
On platinum we observed a maximal effect of the micro structuring procession to the cell growth on a structure width of 4-7 µm but not as strong on smaller (1-4 µm) and larger (7-10 µm) grooves. A comparable result was observed on silicone LSR 30 with a rough surface quality.

GFP-marked fibroblasts are a model for connective tissue cells. The microstructure affected fibroblast growth and guided neuronal cell growth. In further experiments structures of different sizes are to be tested on several electrode materials. The aim is to optimise the electrode interface, to reduce the connective tissue growth and to improve the electric contact to the neuronal target cells.

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A17: COCHLEAR NUCLEUS ALTERATIONS FOLLOWING ELECTRICAL STIMULATION IN CATS DEAFENED AT DIFFERENT AGES

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The goal of this study was to examine whether a brief initial period of normal auditory experience would affect either the vulnerability of the cochlear nucleus to auditory deprivation and/or influence the trophic effects of subsequent chronic electrical stimulation delivered by a cochlear implant. Morphological characteristics of the CN (CN area, and spherical cell size, number and density) were compared in neonatally deafened animals and animals deafened at 30 days of age and studied either at 8 weeks of age or after several months of electrical stimulation.

In animals deafened at 30 days and studied at 8 weeks of age, CN cross-sectional area was about 90-95% of age-matched normal animals. In the neonatally deafened group at this age, CN size was already significantly smaller, about 75-80% of normal. In older deafened animals studied at 36 weeks of age, a significant increase in CN size was observed in both neonatally- and 30 day-deafened groups, suggesting that the CN continued to grow during this 6 month period. However, CN size never reached that of normal hearing animals, remaining at about 75% of normal in the neonatally deafened animals and 85% in 30 day deafened animals. No significant difference was observed in CN size between the stimulated and non-stimulated sides in either deafened group.

In animals studied at both 8 weeks and 36 weeks of age, the mean cross-sectional area of AVCN spherical cells was significantly smaller in the neonatally deafened group than in the 30 day deafened group. Electrical stimulation in both older deafened groups resulted in an increase of about 6% in cell size in the stimulated CN, with the spherical cells reaching 90% of normal in 30 day deafened animals and 80% in neonatally deafened animals.

Numerical density of AVCN spherical cells was significantly higher in both neonatally and 30 day deafened animals as compared to normal animals. The total number of AVCN spherical cells did not significantly differ from normal values in the 30 day deafened group and was slightly smaller in the neonatally deafened group (90% of normal). No significant difference between stimulated and non-stimulated sides was observed.

The data suggest that most of the differences in CN morphology between the two deafened groups are due to the brief period of normal auditory experience early in life. Electrical stimulation did not alter the retarded growth of CN or the number of AVCN neurons but promoted an increase in spherical cell size in both deafened groups.

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A18: DIFFERENCES IN SPECTRAL SHAPE PERCEPTION ACROSS THE ELECTRODE ARRAY

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Recent studies have revealed strong correlations between spectral modulation detection thresholds (SMDT) at low modulation frequencies (≤ 1 cycle/octave) and speech understanding scores of cochlear implant (CI) listeners. SMDTs were measured by determining the minimum spectral contrast needed to discriminate a flat spectrum from a modulated spectrum. To date, these experiments have only measured thresholds using broadband stimuli (350-5600 Hz), which give no information about resolution within specific cochlear regions.

We hypothesized that sensitivity to spectral modulations would differ across the electrode array. Specifically, thresholds in the broadband condition could be influenced by the listener's ability to attend to regions of relatively good spectral resolution (best case) or by masking effects from regions of relatively poor spectral resolution (worst case). We tested this hypothesis by applying low frequency sinusoidal modulation to narrowband stimuli in a spectral modulation detection task. Test conditions included (i) broadband (350-5600 Hz) stimuli with modulation frequencies of 0.5 and 1.0 cycles per octave, (ii) narrowband (2-octave) stimuli (350-1400 Hz, 1400-2800 Hz, and 2800–5600 Hz) with a modulation frequency of 0.5 cycles/octave, and (iii) narrowband (1-octave) stimuli (350-700 Hz, 700-1400 Hz, 1400-2800 Hz, 2800-5600 Hz) with a modulation frequency of 1.0 cycles/octave.

Results from 10 CI listeners revealed a significant correlation between broadband SMDTs and speech understanding scores. Individual subjects demonstrated marked differences in sensitivity to spectral modulations across different frequency regions. In some cases, the broadband threshold was equal to the lowest narrowband threshold, suggesting the listener was able to attend to a region of good spectral resolution during the broadband task. In other cases, the broadband threshold was equal to the highest narrowband threshold, suggesting regions of poor spectral resolution exerted some masking effect over more sensitive regions. Possible translational benefits of identifying regions of poor spectral resolution are addressed.

This work was supported by the Advanced Bionics Corporation.

A19: JUST NOTICEABLE DIFFERENCES FOR BROADBAND FREQUENCY ALLOCATION CHANGES IN NORMAL HEARING INDIVIDUALS USING A COCHLEAR IMPLANT SIMULATION

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Speech perception outcomes in cochlear implant (CI) users are dependent on many factors. Research suggests that changing frequency allocation in CI speech processors may improve speech perception for some individuals. However, there is currently no systematic clinical method for adjusting frequency allocation. Decisions to change frequency allocation are typically based on clinical impressions and recipient feedback; changes are limited to a choice of manufacturer-defined frequency allocation tables. Allowing users to make active decisions about what they hear may result in greater satisfaction and reduced device rejection. This is the first of three experiments to identify a specific frequency allocation for cochlear implant recipients based on user preference.

The purpose of this study is to identify just noticeable differences (JND) in broadband allocation adjustments of three vowels: /a/, /i/ and /u/ in the context of /hVd/. The words were processed through an 8-channel cochlear implant simulation with a reference frequency bandwidth of 188 to 7938 Hz. Changes in frequency bandwidth were made at the analysis stage with the center frequencies of the noise bands held constant. A three interval forced choice adaptive procedure was used to identify the JND for % frequency changes in four conditions: (1) UP: frequency boundaries are adjusted upward, (2) DOWN: frequency boundaries are adjusted downward, (3) Expanded Bandwidth: lowest frequencies are adjusted lower and highest frequencies are adjusted higher, and (4) Compressed Bandwidth: lowest frequencies are adjusted higher and highest frequencies are adjusted lower.

The results for 8 NH participants suggest no difference in threshold on the basis of syllable. There was a main effect for frequency adjustment ($p < 0.05$), which appears to have been the result of increased thresholds for the bandwidth-narrow condition. The hearing participants were more sensitive to bandwidth narrowing than to the other three conditions. The results provide an estimate of the range of sensitivity of normal hearing subjects using a cochlear implant simulation.

As expected, there was wide inter-subject variability. The current study highlights the importance of measuring an individual's sensitivity before making changes to frequency allocation. These findings will be applied to later research with implanted subjects.

Support provided by OSERS-NIDDR

A20: PSYCHOACOUSTIC ESTIMATE OF THE RELATIVE LOUDNESS OF SELF-GENERATED SPEECH

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A novel approach to investigating self hearing has been developed. It is based on traditional psychophysical techniques and focuses on the individual's sensitivity to variations in different acoustic properties of his/her speech feedback (e.g., timing, intensity). In this project, the minimal perceptible difference in the loudness level between self- and other-produced speech is investigated in cochlear implant users and normally hearing individuals.

An adaptive two-track 2IFC procedure is used to compare the subject's perception of loudness of his/her speech feedback (listening while speaking condition) to the loudness of its audio recording (listening only condition). The subject is asked to produce a short utterance (papapa) and listen to his/her speech feedback, then to listen to the recorded utterance (replay) that follows immediately. The subject's task is to identify which of the two intervals ("first", with live speech or "second", with the replay) sounded louder. Based on the subject's choice, the gain for the replay on the subsequent trial is raised or lowered. The point of subjective equality is calculated from the final eight reversals on each track. Results from four normally hearing individuals and four CI users will be presented and discussed with reference to the available acoustic hearing of each subject.

The procedure is fully automated and can be applied to investigate the effect of different listening conditions (reverberation, speech-to-noise ratios) on the relative loudness of self- versus other-generated speech. One of the goals of the project is to provide efficient and objective means of assessing the self-hearing needs of individuals with hearing loss which could serve as a basis for alternative hearing aid/cochlear implant fittings.

Support provided by the Rehabilitation Engineering Research Center (RERC) on Hearing Enhancement and the Gallaudet Research Institute.

A21: ACOUSTIC ANALYSES OF TALKER VARIABILITY EFFECTS IN COCHLEAR IMPLANT SIMULATIONS

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For cochlear implant (CI) listeners, speech recognition has been shown to be significantly affected by talker variability (i.e., when consecutive speech stimuli are produced by multiple talkers rather than by a single talker). However, the underlying mechanism for this talker variability effect is still unclear. The present study investigated the correlation between the acoustic features of multi-talker vowel stimuli and talker variability effects observed in normal-hearing (NH) subjects listening to acoustic 4-channel sine-wave vocoder CI simulations.

Talker variability effects were assessed by measuring multi-talker vowel recognition performance in both “blocked” and “mixed” contexts. In the blocked context, a single talker produced each successive vowel token, and each talker was presented in sequence. In the mixed context, different talkers produced each successive vowel token. Four talker sets were tested for both context conditions; each talker set consisted of 2 male and 2 female talkers. All talker sets generated significant effects of talker variability. However, overall vowel recognition performance and the intensity of talker variability effects differed among the four talker sets.

Acoustic analyses were performed on the multi-talker vowel stimuli for each talker set, both in a blocked presentation model and a mixed presentation model. Acoustic features were analyzed in terms of the first and second formant frequencies and vowel duration. Scatter indices were derived for each talker set, and were calculated according to within-vowel acoustic distance divided by across-vowel distance; a larger scatter index indicates greater overlap between vowel features and, presumably, greater confusion and poorer performance. For talker sets that produced smaller scatter indices (i.e., less overlap), vowel recognition performance was better for the blocked context. For the mixed context, when all vowels were included in the analyses, there was no significant correlation between the scatter index and vowel recognition performance. However, when only the most easily confused vowel pairs were included in the analyses, the scatter index was significantly correlated with performance, suggesting that the observed talker variability effects were most likely restricted to this set of vowels.

Support provided by NIH-NIDCD.

A22: FACTORS PREDICTIVE OF OPEN-SET WORD RECOGNITION IN ADULTS WITH COCHLEAR IMPLANTS

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Adults, who had all Contour™ or HiFocus™ electrodes implanted inside the cochlea and who have post-operative open-set recognition of CNC words, participated in a study to determine what factors are predictive of their word scores. Lists of 100 words were presented in the sound-field at 60 dB SPL during 21 sessions between 2 wk and 2 yr after hookup. Data were fitted with a logistic curve to predict word score as a function of time (days). This logistic curve has three parameters: (a) an upper asymptote, representing the value to which performance converges (can be beyond 2 yr), (b) a "growth" parameter that captures the amount by which performance has increased from t=0 (hookup), and (c) a parameter that represents the "compression" of the growth or the speed of the transition from performance at t=0 to the estimated asymptote. To ensure clinical relevance, three dependent variables representative of three aspects of CNC word recognition were chosen for analysis: *Maximum Predicted Word Score* (≤2 yrs), *Minimum Predicted Word Score* (at 2 wk after hookup), and the *Rate of Growth from Min to Max Score*. Possible independent, predictor variables included *performance measures* (lipreading, speed of speaking, preoperative aided sentence recognition, and a battery of cognitive tests), *measures of the position of electrodes in the cochlea from CT scan analysis* (Skinner et al., Ann OLR 116 [Suppl129):1-12, 2007), and *biographical information* (duration of profound hearing loss, duration of hearing aid use, and educational level).

Preliminary multiple regression analyses (N=41) were conducted in which a series of *ad hoc* regression models were evaluated by sequentially introducing predictors to account for remaining variance for each dependent variable. The only significant predictor for *Minimum Predicted Word Score* was the CT measure of electrode insertion depth. That is, the CNC score at 2 wk would be higher if the electrode array is not inserted too deeply. The significant predictors for *Maximum Predicted Word Score* were duration of profound hearing loss, lipreading and a cognitive factor. The significant predictors for *Rate of Growth from Min to Max Score* were duration of hearing aid use, education level, lipreading, and array position (i.e., the more electrodes in scala tympani, the faster the growth). Analysis of a larger data set will be presented.

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A23: INPUT DYNAMIC RANGE TESTING

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In tests of speech perception the material is invariably delivered at a fixed presentation level. Even when determining psychometric functions, blocks of fixed level words or sentences are typically presented. As subjects may adjust their sensitivity control to optimize audibility they may score well on the test. However, this measure does not assess real-life listening ability and the Automatic Gain Control system is not exercised.

In a new approach to speech testing sentences were presented randomly at either, 55, 65 or 75 dB SPL. Competing speech shaped noise was used to estimate Speech Reception Threshold across a block of 30 sentences. SRT scores were compared to the commonly used HSM sentence test. Two groups of six subjects were tested: Advanced Bionics Auria or, Cochlear Corporation Freedom users. Both groups had equivalent demographics and scored well on the HSM test, being good or excellent performers.

SRT outcomes from the roving level test ranged from – 1 dB to over +20 dB speech to noise ratio (SNR). Testing on the fixed presentation level test found scores around 50% correct for SNRs between +5 and +10 dB, subjects showing relatively similar scores on this measure. While testing is still ongoing, it appears that the Freedom users struggled more with the roving level than did Auria users. Despite subjects scoring well in the conventional tests, subjective responses pointed to problems when listening in noise. Loudness was generally reported to be satisfactory in everyday life.

The roving level test was found to be much more difficult than a traditional fixed level test. The new test may better probe everyday listening experience and appears to support the usefulness of processing a larger acoustic dynamic range. Traditional tests may overestimate the ability of cochlear implant users to cope in noisy real life situations.

A24: ELECTRODE DISCRIMINATION AND MODULATION SENSITIVITY IN ELECTRIC HEARING

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It is known that both place-pitch discrimination and sensitivity to amplitude modulation are important for speech perception with a cochlear implant. Both kinds of sensitivity are highly variable across cochlear implant listeners. It is not known, however, whether CI users who are more sensitive in electrode discrimination are also more sensitive to amplitude modulation. Both kinds of sensitivity, for instance, may be linked to common underlying factors such as auditory nerve survival. On the other hand, hearing loss may result in changes in temporal sensitivity that are independent of changes in place-pitch sensitivity. The goal of this study is to examine i) the parameter-dependence of electrode discrimination and amplitude modulation sensitivity and ii) the relationship between the two kinds of measures in cochlear implant listeners. All stimuli are 300-ms long trains of biphasic current pulses presented at 1000 pulses/sec. Psychometric functions measuring electrode discrimination are obtained using a 3-interval, forced-choice procedure. The reference electrode is set at one of the following locations along the array: apical, basal, or medial. Measurements are made at different levels (% dynamic range). Sinusoidal amplitude modulation thresholds are measured at modulation frequencies of 100 and 10 Hz on the same electrodes, using a 3-interval, forced-choice, adaptive procedure. Effects of stimulation mode (monopolar vs bipolar) are also measured. Consistent with findings of previous studies, preliminary results indicate strong level-dependence of modulation sensitivity. Electrode discrimination shows weaker dependence on level. Both measures show dependence on the place and the mode of stimulation. The results will be analyzed to examine the relationship between the two kinds of measures. Implications for speech recognition will be discussed.

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A25: ELECTROPHYSIOLOGICAL SPREAD OF EXCITATION FOR MONOPOLAR AND BIPOLAR STIMULATION

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Monopolar stimulation has been thought to produce a broader spread of neural excitation along the cochlea than bipolar stimulation. However, a recent psychophysical forward masking study [Kwon and van den Honert (2006), JASA, 119, 2994-3002] in four adult Nucleus® subjects did not show a narrower spatial masking pattern for bipolar stimulation, and the bipolar masking patterns displayed more variation across the array than monopolar stimulation. These subjects were implanted with the Nucleus CI24M receiver-stimulator coupled to the straight electrode array. This array typically is positioned along the outer wall of the scala tympani.

The objective of this study was to compare the electrophysiological spread of neural excitation pattern for monopolar and bipolar stimulation in subjects implanted with the Nucleus Freedom™ system. This system uses the CI24RE receiver-stimulator which has improved Neural Response Telemetry capabilities which may make recording the electrically evoked compound action potential (ECAP) for bipolar stimulation easier than was the case with previous systems. The CI24RE is coupled to the Contour Advance™ half-banded electrode array which typically assumes a perimodiolar position in the scala tympani.

Spread of excitation (SOE) patterns were obtained using similar methods as used in previous studies [Hughes and Abbas (2006), JASA, 119, 1527-1537]. For monopolar stimulation, the monopolar probe electrode was fixed and ECAP measures were obtained for a series of monopolar masker electrodes which spanned the array. The subtraction (forward masking) paradigm was used to measure the ECAP. For bipolar stimulation, the probe and masker electrodes were bipolar pairs of electrodes, with a spacing of two electrodes between the two electrodes in the pair. SOE patterns were obtained for apical, mid and basal probe electrodes. In addition, ECAP amplitude growth functions were compared for monopolar and bipolar stimulation.

Early findings in three subjects revealed that the SOEs for bipolar stimulation were more irregular than for monopolar stimulation. As expected for monopolar stimulation, the peak of the SOE function was typically at the probe electrode and ECAP amplitude reduced with increased distance between masker and probe electrodes. For bipolar stimulation, peaks in the SOE function were at the probe electrode and also at other electrodes located apical and/or basal to the probe electrode. There were also some differences in the amplitude growth functions between monopolar and bipolar stimulation. Further data are being collected.

A26: COMPARISON OF PSYCHOPHYSICAL TUNING CURVES IN ACOUSTIC AND ELECTRIC HEARING

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It is well-known that cochlear implant (CI) listeners lack the sharp frequency tuning that exists in acoustic hearing; however, there are no direct comparisons of psychophysical tuning in the two systems. The purpose of the present study was to compare forward-masked spatial tuning curves (*fm*STCs) in CI users to previously-published forward-masked psychophysical tuning curves (*fm*PTCs) in normal-hearing and hearing-impaired acoustic listeners. As part of the study, the effect of probe level on *fm*STCs was evaluated. In acoustic listeners, *fm*PTCs are known to depend on stimulus level, with tuning being sharpest at low levels, reflecting the active process mediated by outer hair cells, and broadest at high levels, reflecting the passive mechanical properties of the basilar membrane. Such level dependencies were not expected in CI users, since the electrical stimulus bypasses cochlear processing.

*fm*STCs were obtained from a middle electrode in each of six Nucleus-22 users stimulated in bipolar mode and six Clarion C-I or C-II users stimulated in monopolar mode. *fm*STCs were measured at several probe levels using a fixed-level probe stimulus and variable-level maskers. Apical and basal sides of the *fm*STCs were fitted with logarithmic functions relating masker level (log μA) to spatial distance between the masker electrode and the probe electrode (mm). This yielded estimates of apical and basal slopes, as well as spatial bandwidths and tip locations. *fm*STCs were then re-plotted in terms of acoustic frequency using Greenwood's (1961) frequency-to-place equation. The transformed *fm*STCs were compared with *fm*PTCs obtained by Nelson (1991) from normal-hearing and hearing-impaired acoustic listeners.

Mean *fm*STC slopes obtained in Nucleus CI subjects with bipolar stimulation (3.7 dB/mm) were steeper than mean slopes obtained in Clarion subjects with monopolar stimulation (1.2 dB/mm). Consistent with this, mean spatial bandwidths were smaller for the Nucleus subjects (2.6 mm) than for the Clarion subjects (4.6 mm). However, there was considerable variability in slopes and bandwidths within each group. Neither the slopes nor the bandwidths of *fm*STCs varied significantly with probe level.

The *fm*STCs transformed to frequency coordinates in the CI users were similar to the broad *fm*PTCs observed in normal-hearing and hearing-impaired acoustic listeners at high stimulus levels. This similarity in tuning characteristics at high stimulus levels is largely coincidental, since the factors that govern spatial selectivity in cochlear implant users are different than those that govern frequency tuning in acoustic hearing.

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A27: PSYCHOPHYSICAL TUNING CURVES AND ELECTRICALLY-EVOKED AUDITORY BRAINSTEM RESPONSES WITH THE PARTIAL TRIPOLAR ELECTRODE CONFIGURATION

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We used three methods to identify electrodes with putatively poor neural interface in cochlear implant subjects: thresholds, psychophysical tuning curves (PTCs), and amplitude growth functions of the electrically-evoked auditory brainstem response (EABR), each employing narrow electrode configurations such as tripolar. The tripolar (TP) configuration consists of an active electrode flanked by two return electrodes that equally share the return current. Electrical field models and animal studies predict that the TP configuration should provide more detailed information than the MP mode about place-specific responsiveness of auditory neurons. Therefore, PTCs obtained using a TP probe should be narrower. The TP stimulus, however, is limited by the relatively high current requirements for most cochlear implant electrodes. Partial tripolar, a hybrid between MP and TP configurations was used such that a fraction of the return current normally delivered to the flanking electrodes in TP is directed to an extracochlear return electrode. A partial tripolar (pTP) fraction of 0 constitutes MP while a fraction of 1 is TP.

Thresholds and PTCs were measured using a 3-interval 3-alternative forced-choice method adaptive procedure. Thresholds obtained using the largest possible pTP fractions were compared across electrodes. The electrodes with the highest and lowest pTP thresholds served as the experimental electrodes. PTCs were measured with the experimental electrodes as the probe stimulus in either an MP or TP configuration using a forward masking paradigm. The probe was set at a fixed level of 3 dB above threshold. EABR responses were measured for the experimental electrodes described above for MP and pTP stimuli.

Perceptual thresholds were higher for pTP than MP as was the variability of threshold from channel-to-channel. These thresholds also predicted the sharpness of tuning of the PTC. That is, the high pTP threshold channel showed broad PTCs, consistent with poor neural survival, while the low pTP channel showed sharp PTCs consistent with good neural survival. In addition, the tuning curves were sharper when obtained with the TP probe versus the MP probe. Finally, the EABR results were consistent with the psychophysical results, and indicate that pTP stimulation is feasible with this experimental approach. Our findings suggest that once neural survival patterns are determined, more patient-specific maps may be made that could improve performance of cochlear implant listeners.

A28: LOUDNESS PERCEPTION OF PATIENTS WITH UNILATERAL CI IN COMPARISON TO NORMAL HEARING LISTENERS USING A MODIFIED SCALING METHOD

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To investigate the overall level of loudness perception of CI users in comparison to normal hearing listeners, 26 unilaterally implanted subjects (Med-El C40+ with Tempo+-processor) and 26 normal hearing listeners performed loudness scaling tasks. Four different types of stimuli, two narrow band and two broad band signals (1 kHz pure tone, warble tone, CCITT speech spectrum noise and a speech signal of 1 s duration each) were presented at 13 different SPLs in 5 db steps from 30 dB to 90 dB. The stimuli were presented in free field condition in an anechoic chamber. Each stimulus type was presented 169 times. This main sequence of SPLs was designed such, that each was offered 13 times and each SPL preceded each
possible other. An additional initial sequence of SPLs, unrecognized by the subject, preceded the main sequence to allow for possible adaptation. Loudness judgments were made on a 1 to 50 scale, which was subdivided into five main loudness categories. Responses had to be given within a time window of four seconds.

Depending on the individual normal hearing listener, loudness judgments varied in overall level and variance. In group statistics, judgments were strictly monotonic increasing with SPL, where each step of 5 dB was accompanied by a statistically significant increase in loudness judgment. Broad band stimuli were judged significantly louder than narrow band stimuli. A positive correlation of judgments both with the preceding SPL and the preceding judgment was found.

The 26 CI users tested in the same setup exhibited surprisingly similar results except for overall loudness level, especially in the lower SPL region. Judgments were strictly monotonic increasing with SPL, broad band stimuli were significantly louder than narrow band stimuli and a positive correlation between judgment and both preceding SPL and judgment could be observed. Generally, stimuli were judged significantly quieter than by normal hearing listeners. To produce the same loudness perception as in normal hearing listeners, approximatly 5 dB higher SPLs would be necessary.

The difference in loudness perception of the two groups can possibly be attributed to binaural loudness summation in normal hearing listeners as opposed to monaural hearing in the CI group. In the course of repeated mapping sessions and by adjusting their clinical processors, CI users have the option to decide about their CI system's loudness level. Assuming that binaural normal hearing establishes the optimal loudness perception, the question remains open, why CI users do not request loudness adjustment.

A29: LOUDNESS ADAPTATION: NOT JUST FOR FIXED-LEVEL STIMULI?

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It is well known that when a fixed-level stimulus is presented for several seconds either acoustically or electrically, the perceived loudness of the signal fades. It has been assumed that the fading only occurs when the stimulus is at a fixed-level and that the complicated stimuli of a speech processing strategy prevent the loudness fading. However, Shannon (unpublished) has data demonstrating loudness adaptation on a single electrode with AM stimuli in two ABI patients and one AMI patient. Therefore, it seems likely that patients with CIs may experience loudness adaptation with signals other than a fixed-level stimulus.

A procedure for measuring loudness adaptation was developed using the method of constant stimuli. In each trial, a bipolar stimulus was presented at the apical portion of an electrode array for 30 seconds. After 30 seconds, a 500 ms. fixed-level bipolar pulse train was presented in the medial portion of the electrode array. The subject's task was to report if the 500 ms. tone was louder or quieter than the end of the 30-second tone. The current of the 500 ms. stimulus varied from trial to trial. Using the psychometric function derived from the data, the amount of current required to make the medial stimulus equally loud as the end of the 30-second apical stimulus can be calculated. The 500 ms. medial stimulus with the calculated current was then loudness balanced to a 500 ms. version of the original 30-second stimulus using a double staircase method. If the measured current of the 500 ms. apical stimulus was lower than the current of the original 30-second apical stimulus, then loudness adaptation had occurred.

Preliminary data has shown that loudness adaptation is observed in CI patients with unmodulated, modulated, and uniform random deviated noise. Detailed results of loudness adaptation for these three types of stimuli will be presented.

Support provided by the NIH-NIDCD

A30: INDIVIDUAL DIFFERENCES IN DETECTION OF TONES IN REPRODUCIBLE NOISE

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A better understanding of mechanisms of signal detection and word recognition has sparked advancements in performance on difficult listening tasks with cochlear implants. Improved spectral resolution with the same number of electrodes has become a reality through benefits of channel interaction. Increased rates of stimulation and new processing strategies provide a more precise representation of temporal fine structure. Overall performance has increased, yet substantial variability between individual CI users remains, and responses are often much different than those from listeners with normal hearing.

We utilized a molecular psychophysical approach and mathematical models to evaluate individual differences in performance between listeners with normal hearing and listeners with cochlear implants. The task was to detect a 500-Hz sinusoid in a broadband noise. The noise consisted of 25 reproducible samples presented alone or with the signal. The S/N for each individual subject was fixed to maintain P(C) = 70% on a yes-no task (overall d' = 1.0).

For seven listeners with normal hearing, the S/N required for d'=1.0 spanned 4 dB. The variability in the responses to the individual noise samples when plotted in ROC space was small across listeners. A two-parameter, single-channel electrical analog model (EAM) [Jeffress, 1967, 1968; Gilkey & Robinson, 1986] consisting of a bandpass filter centered at the signal frequency, a half-wave rectifier, a leaky integrator, and a sampling strategy explained between 55-79% of the variance in the individual subject responses. A multiple-channel EAM explained an additional 10% of the variance, suggesting that listeners with normal hearing utilize information in bands away from the signal frequency.

For 5 listeners with cochlear implants, additional 5-18-dB increases in the signal level were required to achieve similar overall performance levels (d' = 1.0) as the listeners with normal hearing. When the responses to the 25 different noise samples were plotted in ROC space, the distributions for the CI users were compressed, but the inter-subject variability was significantly higher than for the listeners with normal hearing. A modified single-channel EAM explained approximately 60% of the variance in the CI subject's responses. However, model parameters were different for CI users than for listeners with normal hearing. Furthermore, a multiple-channel model did not improve predicted variance suggesting that across-channel listening for CI users is not occurring in this task.

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A31: CORTICAL AND PSYCHOPHYSICAL DETECTION OF TEMPORAL ENVELOPE MODULATION

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Temporal envelopes of trains of modulated electrical pulses are a key information-bearing component of most auditory prosthesis processing strategies. The objective of this study was to characterize key parameters that influence detection of charge modulation. Our approach was to compare results from parallel animal neurophysiological and human psychophysical experiments.

Results from psychophysical modulation-detection experiments in human cochlear implant users were compared with results from single- and multi-neuron recordings from guinea pig primary auditory cortex. In the humans, modulation detection thresholds (MDTs) were measured using a 2-alternative forced-choice procedure with flanking cues and adaptive tracking. In the guinea pigs, MDTs were determined using a signal-detection measure of cortical phase locking to modulation waveforms. In both cases, we tested three independent variables: Carrier pulse rate, electrode configuration, and stimulus level.

We found that carrier pulse rate had similar effects on psychophysical and cortical MDTs. In 71% of the cases tested, lower psychophysical MDTs (i.e., detection of shallower modulation depths) for a 40-Hz modulator were achieved with a low-rate carrier (250 pps) than with a high-rate carrier (4k pps). Similarly, phase locking was more sensitive with the lower rate carrier in 88% of the cortical neurons that showed phase locking. When examining configuration effects, the carrier rate was 250 pps and stimulus levels for the two electrode configurations were presented at equal loudness in humans or at equal levels relative to threshold for cortical activation in animals. Monopolar stimulation produced lower MDTs than did bipolar stimulation in approximately 89% of the cases tested psychophysically and in 80% of cortical neurons. These findings suggest that the effects of carrier pulse rate and electrode configuration on MDTs occur in regions peripheral to primary auditory cortex. In contrast, increases in stimulus level resulted in better psychophysical MDTs in almost all cases but had small and inconsistent effects on cortical encoding of modulation. This suggests that effects of level on MDTs depend on mechanisms distal to primary auditory cortex.

In conclusion, stimulus level, carrier pulse rate, and electrode configuration all have significant effects on MDTs, but the mechanisms responsible for these effects seem to originate from different levels in the auditory pathway.

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A32: INFORMATION TRANSFER ANALYSIS IN THE COCHLEAR IMPLANT LITERATURE: A FIRST LOOK AT ESTIMATION BIAS

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Information transfer (IT) analysis (Miller and Nicely, 1955) is frequently used to measure the extent to which speech features are transmitted to a listener, e.g. duration and formant cues for vowels; voicing, place and manner of articulation cues for consonants. Typically, data from a phoneme confusion matrix is partitioned into discrete categories for a feature, and a Maximum-Likelihood-Estimate (MLE) of the percent, or relative, IT is then applied to the partitioned matrix. An IT of 100% occurs when the partitioned matrix contains 100% correct responses. An IT of 0% occurs when all elements of the partitioned matrix are equal, i.e. a case where performance is purely random.

As asserted by Miller and Nicely, the MLE will be biased to overestimate IT for a small number of stimulus presentations. The purpose of this study is twofold: 1) to determine the size of the bias and the number of presentations required to overcome it, and 2) to assess the impact of the bias in the cochlear implant (CI) literature.

From preliminary analyses conducted thus far, the MLE bias depends partly on the size of the matrix, i.e. the number of cells. For larger matrices, the bias is larger and occurs over a larger number of stimulus presentations. The MLE bias also depends on the contents of the matrix. Matrices with higher percent correct will yield a smaller bias that can be overcome with fewer presentations. Conversely, purely random performance yields a larger overestimation which requires many presentations to overcome. For example a 10 x 10 matrix filled with 100 presentations, consisting of 10 arbitrary responses to each of the 10 matrix categories, will on average result in an IT estimate of about 20% even though it is known from the outset that IT is 0%. This is one example of how overestimation bias in IT measures could impact CI studies.

The bias can also be observed in cases where IT is first calculated for each CI listener, and then averaged across listeners as opposed to first pooling the data and then calculating IT. Typically, the averaged IT is larger than the pooled IT. In some of the CI studies analyzed thus far, the difference between these two measures can be as much as 10%.

A clearer analysis of the IT estimator could provide a correction for the bias as well as confidence intervals that would allow comparison of IT measures obtained with relatively fewer stimulus presentations. In the meantime, emphasis should be placed on Miller and Nicely's note of caution to ensure a large enough number of presentations in order to avoid unreliable IT estimates.

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A33: FORWARD MASKING WITH SYMMETRIC AND ASYMMETRIC PULSES IN COCHLEAR IMPLANTS

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Three psychophysical forward masking experiments were conducted with four cochlear implant subjects. The experiments were designed to investigate possible changes in spatial selectivity when using asymmetric pulses instead of symmetric ones. Three different pulse shapes were used as maskers of the same monopolar signal. The maskers were symmetric biphasic, pseudomonophasic (i.e. biphasic with a second phase longer and lower in amplitude than the first) and delayed pseudomonophasic (identical to pseudomonophasic but with an inter-phase gap). In monopolar configuration, two subjects showed a more spatially restricted excitation pattern for the pseudomonophasic masker compared to the symmetric masker whereas two subjects showed no difference. The introduction of an inter-phase gap between the two phases of the pseudomonophasic masker (i.e. using a delayed pseudomonophasic masker) reduced this benefit and even degraded spatial selectivity in the latter two subjects compared to the symmetric biphasic case. In bipolar configuration, the pseudomonophasic masker showed selective activation of fibers proximal to the electrode of the bipolar pair for which the short, high-amplitude phase was anodic. These results suggest that possible improvements in spatial selectivity might be achieved using pseudomonophasic pulses with no inter-phase gap and presented in bipolar configuration.

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A34: EQUAL LOUDNESS CONTOURS AND DISCRETE PITCH PERCEPTS FOR SIMULTANEOUS DUAL-ELECTRODE STIMULATION AS A FUNCTION OF SPATIAL ELECTRODE SEPARATION

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Equal loudness contours obtained for simultaneous dual-electrode stimulation (using adjacent electrodes) and the physical electrodes are consistent with the notion of peripheral summation of the electric fields. For the dual-electrode stimuli, the current is split between the two adjacent electrodes, with (1-α)*I delivered to the more apical electrode of the pair, and α*I delivered to the more basal electrode, where I is the total current and α ranges from 0 (all current on the apical electrode) to 1 (all current on the basal electrode). By systematically varying α, the simultaneous dual-electrode stimuli produce discrete pitch percepts in addition to those produced by the stimulation of physical electrodes.

In Experiment 1, equal loudness contours were measured as a function of electrode separation (maximum of 4 mm) to verify the theory of peripheral summation of electric fields across the cochlear space. Preliminary data indicates that the total current had to be adjusted by anywhere from -0.93 to 2.42 dB for the simultaneous dual-electrode stimuli (α = 0.5) across the following physical electrodes ([e, e+1], [e, e+2], [e, e+3], [e, e+4], e = apical electrode). The equal loudness contours obtained for the dual-electrode stimuli as a function of electrode separation are consistent with the notion of peripheral summation of electrical fields.

In Experiment 2, tonotopic nature of the pitch sensations evoked by varying the dual-electrode stimuli (α = 0 to 1, step size = 0.1) was examined. The pitch of the physical electrode e+1 in the electrode pair [e, e+2] and e+1, e+2, e+3 in the electrode pair [e, e+4] were compared with the different α values for the dual-electrode stimuli by determining psychometric functions. The current level on the physical electrode was roved between ± 10 percent of the presentation level to minimize the use of loudness cue for pitch comparison. A close match was obtained between the pitch sensation produced by the physical electrodes (between the electrode pairs) and the place pitch associated with various α values of the dual-electrode stimuli.

The results obtained in this study suggest that simultaneous dual-electrode stimulation between two electrodes separated by at least up to 4 mm can be used to generate intermediate pitch percepts in a real time strategy.

This work was supported by Advanced Bionics Corporation.

A35: SPEECH UNDERSTANDING WITH DIFFERENT STIMULATION RATES AND SPEECH CODING STRATEGIES USING THE NUCLEUS "FREEDOM" SYSTEM

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The Nucleus "Freedom" cochlear implant system allows using channel stimulation rates of up to 3500 pulses per second (pps) which is much faster than in the previous Nucleus CI systems.

Within an earlier clinical study, 17 adult subjects were implanted with the Freedom device and were evaluated in their speech performance with different stimulation rates in order to find the individual optimal rate. For the evaluation an ACE strategy and the rates 500pps (A), 1200pps (B) and 3500pps (C) were chosen. Test material consisted of a monosyllabic word test in quite and an adaptive sentence test in noise. To avoid learning effects the subjects started with the study after 3 months of experience and followed an ABC CBA investigational sequence with ~ 4 weeks of experience in between. Speech perception measures were taken after each sequence. At the end of the study the subjects were asked for their rate preference after a take home of all 3 programs for 4 weeks.

The subjects dominantly chose lower stimulation rates for preference: 7 subjects preferred 500pps, 8 1200pps and only 2 3500pps. The speech test results were in line with this finding showing significantly poorer speech scores in noise for 3500pps.

These results are contradictory to those found especially with the Clarion device where most of their subjects performed better with higher stimulation rates. They, however, used a CIS speech coding strategy.

To clarify this discrepancy 10 of the 17 subjects agreed to commence testing exactly in the same way as in the first study but using a CIS strategy. After the ABC CBA testing of the different CIS programs we added an additional sequence with their preferred ACE rate to evaluate the long term learning effect between the two parts of the study. At the end of the study the recipients again were asked for their preferred program after 4 weeks take home use of the 3 CIS programs and their preferred ACE program.

Again, the majority of subjects preferred more the low rates (3 500pps, 7 1200pps and none 3500pps) and did not show improved speech recognition with higher rates. Currently we are investigating other parameters (implementation of the strategies in both devices, pre emphasis, filter settings etc.) to find an explanation for the different outcomes compared to other rate studies.

A36: EFFECTS OF ELECTRODE CONFIGURATION ON MODULATION DETECTION AND FORWARD MASKING

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The effect of spread of neural activation on modulation detection was examined in 11 human cochlear implant users by comparing modulation detection thresholds (MDTs) obtained with monopolar (MP) and bipolar (BP) electrode configurations. The narrowest BP configuration (BP+0) was used to maximize the difference in spread of neural activation between the MP and BP configurations. Effects of pulse rate, stimulation site, and stimulus level on MDTs and the interaction of these variables with electrode configuration were also examined by testing three stimulation sites (4, 11, and 18) with pulse rates of 250 and 4000 pps at three stimulus levels (30%, 50%, and 70% of dynamic range (DR) where DR is dB of current). MDTs decreased as stimulus level increased and were lower at 250 pps than at 4000 pps. The effect of stimulation site only approached significance. The result of most interest in this study was that MP stimulation resulted in significantly lower MDTs than BP stimulation did. The effect of electrode configuration was more evident at the slower pulse rate, however, the interaction between pulse rate and configuration only approached significance. Finding lower MDTs with MP stimulation suggests that a greater spread of neural activation may facilitate modulation detection.

To verify that spread of neural activation actually differed in the conditions tested during the modulation detection task, forward masking was measured in six of the 11 listeners. Maskers were presented at sites 4, 11, and 18 and were followed by probes presented at nearby sites. Loudness matching was used to obtain the masker stimulus levels and the initial stimulus levels of the probes. Loudness matching was used to ensure that stimulus levels were comparable for the MP and BP configurations and roughly equivalent to 50% of the DR for MP stimulation. The difference between the detection threshold for the probe when it was masked and when it was presented in isolation defined the amount of forward masking.

MP stimulation caused significantly more forward masking than BP stimulation. This result suggests that MP stimulation also caused more spread of neural activation than BP stimulation. Coupled with the results of the first experiment, this result suggests that broader neural activation may facilitate modulation detection. Modulation detection abilities have been found to be related to speech perception in cochlear implant users. Thus, these results suggest that widespread activation with MP stimulation may be beneficial for speech recognition despite the fact that MP stimulation reduces spectral acuity through masking.

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A37: THE IMPACT OF WIDTH OF SPREAD OF EXCITATION ON SPEECH RECOGNITION IN COCHLEAR IMPLANT PATIENTS AND IMPLICATIONS ON FITTING PROCEDURES

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Measuring the peripheral spread of neural excitation (SOE) by means of Neural Response Telemetry (NRT) has been established over the last years and is now incorporated into the clinical software which works together with the Nucleus RE24 “Freedom” implant by Cochlear.

In our study we analyzed 40 subjects all implanted with the Nucleus RE24CA. SOE measurements have been performed at 8 electrodes distributed over the whole electrode array. We calculated the width of the bell-shaped SOE curves at 50% and 75% height. Some measurements have been repeated over time to judge the stability of the excitation pattern. Also speech recognition tests have been performed at every visit of the patient in our clinic.

Correlations between speech recognition test results and widths of SOE have been calculated and were compared over time where available. Further investigations will cover the influence of SOE width on fitting parameters. NRT measurements at each of the 22 electrode have been performed together with SOE measurements to calculate the threshold value TNRT. We will investigate if the deviation between behavioral fitting parameters, especially the comfort (C) and threshold (T) level and TNRT values could be explained by the width of the SOE curve. Current investigations consider the possibility of choosing the optimal speech coding strategy based on SOE measurements, especially the settings of the psychoacoustic model used in the new strategy called MP3^{000} (PACE).

A38: PHYSIOLOGICAL AND PSYCHOPHYSICAL CHANNEL INTERACTION WITH SIMULTANEOUS STIMULATION

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Partially-simultaneous speech-processing strategies yield faster overall stimulation rates by stimulating two relatively distant electrodes at the same time. However, in-phase current fields generated by simultaneous stimulation of two electrodes can have summative effects if the fields overlap. Although several studies have evaluated psychophysical spatial interaction patterns for simultaneous stimulation in cochlear implants, little data exist on physiological spatial interaction patterns in humans. Further, little is known about the relation between psychophysical and physiological interaction patterns for simultaneous stimulation. The purpose of this study was to: (1) Examine the relation between psychophysical and physiological spatial interaction patterns obtained with simultaneous stimulation of two electrodes and (2) Examine the effect of interaction stimulus level on channel interaction patterns.

Psychophysical thresholds were measured using a 2-alternative, 3-interval forced-choice adaptive procedure. Subthreshold and suprathreshold in-phase interaction stimuli were presented to 6-8 different electrodes for each of three fixed probe electrodes. Physiological interaction patterns were measured using electrically evoked compound action potential (ECAP) thresholds with the same interaction stimuli and electrode pairs used for the psychophysical procedure. All measures were made with monopolar stimulation. Threshold shifts were calculated as the difference in threshold with and without the interaction stimulus. The amount of threshold shift was compared for the two measures.

Preliminary results show good agreement between psychophysical and physiological measures of channel interaction with simultaneous stimulation. Some subjects demonstrated electrode interaction at the widest electrode separation tested (seven electrodes) for sub-threshold interaction stimuli. For the suprathreshold interaction stimuli, channel interaction patterns were typically broader. Listeners' comments suggest that decision criteria for the psychophysical task were based on spectral rather than loudness percepts for the suprathreshold interaction condition.

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A39: AMPLITUDE GROWTH AND SPATIAL SPREAD MEASURES OF HR90K USERS

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This study is an initial evaluation of the advanced neural response imaging (NRI) capabilities implemented in the research studies platform – objective measures (RSPOM) software.

Three methods are provided to capture amplitude growth functions, documenting how the auditory nerve responds to changes in stimulation intensity. The first two methods differ in the electrical artifact suppression method: alternating-polarity (AP) versus masker-probe (MP). The third intensity measure, SmartNRI, is a NRI threshold estimation algorithm, that automatically detects whether a trace contains a biological response.

Two methods are provided to study the spatial response of the auditory nerve: spread of excitation and selectivity. In the former the recording position is varied across the electrode array. In the latter the probe position is fixed, and the masker position is varied.

Finally recovery functions are provided to study the temporal aspect of the auditory nerve response.

In this study 10 adult HR90K users participated. All six NRI measurements were recorded. In addition accurate electrical field measurements were collected with the EFIM research software.

The comparison of the amplitude growth functions shows a good overall correspondence between the alternating polarity (AP) and masker probe (MP) measurements. MP responses exhibit a slightly lower noise floor. However for MP, as stimulation intensity increases, the electrical artifact changes size and shape, making it more difficult to separate the biological response from the electrical stimulus artifact.

The spatial profiles were modeled using a two-sided exponential decay curve. The comparison of the width of the NRI spread of excitation curves and the electrical fields learns that the two spread measures are broad and have very similar slopes. We hypothesize that these measurements reflect the electrical volume conduction of the tiny neural response, localized near the stimulation electrode. Therefore spread of excitation measurements provide limited added value. Spatial selectivity profiles are a purer way of assessing channel interaction. Their width is restricted to +/- 4 contacts, which is more in line with psychoacoustic forward masking patterns.

B1. ELECTRICALLY EVOKED AUDITORY STEADY-STATE RESPONSES IN A GUINEA PIG MODEL: LATENCY ESTIMATES AND EFFECTS OF STIMULUS PARAMETERS

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Cochlear-implant speech processors typically extract envelope information of speech signals for presentation to the auditory nerve as modulated trains of electric pulses. Recent studies showed the feasibility of recording, at the scalp, the electrically evoked auditory steady-state response using amplitude-modulated electric stimuli. Sinusoidally amplitude-modulated electric stimuli were used to elicit such responses from guinea pigs in order to characterize this response. Response latencies were derived to provide insight regarding neural generator sites. Two distinct sites, one cortical and another more peripheral, were indicated by latency estimates of 22 and 2 ms, respectively, with the former evoked by lower (13-49 Hz) and the latter by higher (55-320 Hz) modulation frequencies. Furthermore, response amplitudes declined with increasing carrier frequency, exhibited a compressive growth with increasing modulation depths, and were sensitive to modulation depths to as low as 5%.

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B2. DEVELOPMENT AND TESTING OF MP3000, A NEW CODING STRATEGY BASED ON PSYCHOACOUSTIC MASKING

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Cochlear has recently developed and tested a new promising coding strategy named the MP3000, which was formerly known as the Psychoacoustic Advanced Combination Encoder (PACE).

The structure of the MP3000 strategy is based on the ACE strategy. The concept implemented in MP3000 strategy is that the N bands are chosen utilizing a psychophysical masking model. Like the MP3 compression algorithm, the MP3000 strategy extracts the most meaningful components of any given audio signal and thereby reduces the stimuli that need to be transferred to the electrodes in the cochlea.

Feasibility studies with MP3000 were performed in Hannover using within-subject repeated measurement experiments with different parameter settings for MP3000 and ACE. For certain parameter settings the group results showed equivalence in scores between the MP3000 and ACE strategies for testing in both quiet and noise. More than 50% of the subjects preferred the MP3000 strategy. As expected battery life with the MP3000 strategy was significantly longer than with the ACE strategy.

In Europe, Cochlear recently started the multi center, “MP3000 Optimization Trial”, in which the MP3000 strategy will be tested against the conventional ACE/SPEAK strategies in established Nucleus Cochlear implant users. The main objectives of this investigation are to identify the optimal parameter settings for the MP3000 strategy, to compare the speech perception performance with MP3000 and ACE/SPEAK, to verify the preference for the MP3000 strategy, and to get an indication of battery life improvements with the MP3000 coding strategy.

The principles of the MP3000 coding strategy, results of the MP3000 feasibility studies and protocol of “The MP3000 Optimization Trial” will be presented.

Support provided by Cochlear AG

B3. VARIABILITY ACROSS SUBJECTS AS MEASURED BY INTRACOCHLEAR EVOKED POTENTIALS AND CT IMAGING

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Our objective is to identify in individual subjects the factors that limit speech reception outcome and which form the basis of variability in outcomes across subjects. To date we have examined 16 subjects implanted with the Advanced Bionics Corp. CII or 90K cochlear implant systems with the Hi-Focus electrode array, both with and without positioner. All subjects were examined using high-resolution CT imaging,, intracochlear evoked potential (IEP) recording, intracochlear electrical artifact (IEA) recording, pitch discrimination of electrodes, and measures of speech reception and sound field sensitivity using their best speech processor map preferred for daily use. On entry into the study all subjects had stable CNC performance which was used as baseline performance. Subjects were selected to provide a broad range of CNC word performance ranging from 2-90 % correct, with a mean of 46%.

In general, the test data reveal large variability in electrode placement, physiological response measures and psychophysical reports. The CT studies show significant variability in electrode placement including: depth of insertion, mediolateral position of the array within the scala, and contact location in either scala tympani (ST) or scala vestibuli (SV). IEP input/output measures vary widely in overall magnitude and growth rates both within and across patients suggesting variability in neural survival, synchronicity of firing, stimulation and recording electrode positions and/or electrical conductivity in the cochlear volume. There are several instances of unusually large IEP responses that may arise from cochlear damage as the electrode passed from ST to SV. IEP spatial distributions are also highly variable across subjects, but generally show spatial selectivity of neural recruitment in better performing subjects and poorer selectivity in lower performers. Variability in the N1 latencies of spatially measured responses to constant stimulation on a single fixed electrode is frequently observed and suggests the occurrence of multiple excitation sites within the cochlea. This latency variability occurs most commonly in the apical half of the cochlea and in lower performing subjects, but not exclusively.

The poster will present the results of a multiple regression analysis to determine how factors related to electrode position, IEP responses, psychophysical pitch perception and hearing history account for variability in speech reception outcome across all subjects.

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B4. PSYCHOACOUSTIC COMPARISON OF SEQUENTIAL AND CURRENT-STEERED PULSE TRAINS

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Simultaneous stimulation of multiple electrodes causes their individual electrical fields to sum in the cochlea. So-called current steering causes the peak of the electrical field to continuously shift between two electrodes by varying the ratio of the current on adjacent electrodes. Therefore it may provide an improved site-of-excitation cue, potentially improving pitch perception and speech understanding. Alternatively, this intermediate pitch can be created by offering the pulses sequentially, thereby making use of charge integration on the neural membranes..

The two methods of generating intermediate pitches may differ in loudness, pitch percept and in timbre. Earlier psychoacoustic evaluations concentrated on pitch discrimination. This study focuses on loudness, the influence of roving on pitch discrimination and timbre differences.

Equal loudness contours were determined at most comfortable level in 20 adult CII/HR90K users. For simultaneous current-steering the loudness percept turned out to be approximately constant. For the sequential mode, major variations were found. The current increases approximately linearly, on average peaking at 50%,but varying between subjects and electrode locations.

The just noticeable difference of the current steering coefficient was measured using a 3AFC paradigm. To force using pitch rather than loudness cues amplitudes were roved by 0%, 6% and 12%. This level of roving did not significantly affect the current steering coefficient JND.

To study timbre effects, a multidimensional scaling experiment was performed. In this part of the study 10 adult CII/HR90K users participated. Subjects listened to pairs of stimuli (loudness balanced, 10% roving) only differing in their current steering coefficient or stimulation mode. The subjects indicated on a continuous scale how different the stimuli sounded to them. The resulting dissimilarity numbers were interpreted as distances in a 2D space. On average the clustered maps showed a clear pitch dimension, but a systematic timbre effect could not be demonstrated.

Better control measures will be needed to reduce the response variability, as not all subjects were able to complete this task successfully.

The absence of changes due to loudness roving suggests that the intermediate percepts are truly different in pitch rather than loudness. The loudness variations in the sequential mode are probably due to charge leakage from the neural membranes between the pulses.

B5. HIRESOLUTION WITH FIDELITY 120 SOUND PROCESSING: LISTENING BENEFITS IN CII AND HIRES 90K IMPLANT USERS

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In 2003, Advanced Bionics released HiResolution® (HiRes®) Sound, a sound-processing algorithm that implemented more channels and higher rates of stimulation than previous-generation methods. The goal of HiRes Fidelity 120 (HiRes 120), introduced in December 2006, is to build on the strengths of original HiRes by improving representation of the stimulus spectrum in the electrical stimulation pattern. HiRes 120 first analyzes the incoming sound signal using a 256-bin Fast Fourier Transform. The algorithm then processes the temporal and spectral information in parallel. Temporal detail is extracted using a Hilbert transform while a navigator determines the energy maximum for each electrode pair. The estimated frequencies of the spectral maxima are used to compute the rate of the pulse train and to continuously select the optimal locations for delivering stimulation. The 120 spectral bands are created by precisely varying the proportion of current delivered simultaneously to adjacent electrodes in each electrode pair using active current steering. For each electrode pair, eight real and "steered" bands are available, thereby creating at total of 120 separate spectral bands (15 electrode pairs x 8 spectral bands).

This multi-center clinical study documented the listening benefits of HiRes 120 sound processing in adult Bionic Ear users. Benefit with standard HiRes was assessed at a baseline visit and compared with HiRes 120 benefit after one and three months of use. Then subjects were refit with standard HiRes and tested again. Outcome measures included speech perception in quiet and noise, music and sound quality ratings, self-reported benefits, and a preference questionnaire.

Results from 34 subjects show that mean sentence perception scores in quiet and in fixed-level noise were significantly higher for HiRes 120 compared to baseline with HiRes and to scores after subjects were refit with HiRes. Clarity of voices and environmental sounds as well as mean ratings for pleasantness and distinctness of music were higher with HiRes 120 than with standard HiRes. Subjects reported greater frequency of and satisfaction when listening to music after using HiRes 120. Twenty eight of the 34 subjects (82%) reported a preference for the HiRes 120 over standard HiRes, with a mean strength of preference rating of 8.3 (range: 1-10, 10 = strong preference). Fourteen of the 28 subjects rated their preference as a 10.

The data indicate that HiRes with Fidelity 120 is a viable sound-processing option that can provide benefits that extend beyond speech perception, encompassing everyday sounds and music appreciation.

B6. MODELLING THE EFFECTS OF COCHLEAR-IMPLANT CURRENT SPREAD ON SENTENCE AND WORD RECOGNITION BY NORMAL-HEARING LISTENERS

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In bipolar stimulation (BS), the active and return electrodes are adjacent inside the cochlea and the electrical current decays at 4.0 dB/mm to either side of the active electrode. In monopolar stimulation (MS), the active electrode is inside and the return is outside the cochlea, and the current decays at 0.5 dB/mm [Bruce et al, IEEE Trans. Biomed. Eng., **46**, 617 (1999), and O'Leary, Black, & Clark, *Hear. Res.* **18**, 273 (1985)]. Because of the faster decay rate, the spatial (spectral) resolution is higher with BS than with MS, yet most cochlear-implant (CI) users prefer MS over BS. The effects of current decay or spread on speech recognition by normal-hearing listeners were modeled by varying the amount of spectral smear in the vocoder noise bands. HINT sentences and CNC words were processed through 4, 8, or 16 pass bands, rectified and low-pass filtered at 400 Hz. Each pass-band amplitude envelope was used to modulate the amplitude of noise bands centered at the same frequencies of the pass bands. The spectral envelope of each modulated noise band decayed to either side of the center frequency at a rate of 1, 4, or 8 dB/mm to approximate the MS or BS current decay (i.e., noise-band bandwidth was proportional to decay rate). With the summed signals, recognition was studied as a function of number of bands and decay rates. With 4, 8, and 16 channels, recognition improved when the decay rate increased from 1 to 4 dB/mm; increasing the decay rate to 8 dB/mm degraded speech recognition in the 4 but not in the 8 or 16 channel conditions.

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B7. CUSTOMIZATION OF ACUTE AND CHRONIC MULTICHANNEL COCHLEAR IMPLANTS FOR ANIMAL RESEARCH

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The efficacy of multichannel cochlear implants depends on the activation of perceptually distinct regions of the auditory nerve. Human and animal studies have demonstrated that specific design features of the intracochlear array directly affect various aspects of device performance. These features include the geometry, size, and orientation of the stimulating contacts, the proximity to spiral ganglion neurons, and the shape and position of the insulating carrier. Further, as studies continue to examine complex stimulation strategies (higher rate multichannel stimulation, virtual channel stimulation, modulated signals, bipolar and tripolar configurations) and channel interaction, the ability to manipulate the locations and size of the stimulating sites may become increasingly valuable. The direct measurement of neural responses to intracochlear electrical stimulation in animals provides a basic understanding of how the auditory system responds to electrical stimuli and a framework for the development of intracochlear arrays and signal processing strategies for use in human cochlear implant systems.

Here we describe a simple, cost-effective method for the design and fabrication of species-specific intracochlear electrode arrays for use in chronic and acute animal experiments. The techniques presented allow accurate modeling of current clinical devices and provide the flexibility to both create novel configurations and test new technologies (e.g. polyimide arrays). We describe modifications that enable chronic intracochlear delivery of therapeutic agents via single or multiple ports (basal and apical) in the electrode arrays. We have also taken advantage of high speed machining and smaller cutting tools, which are now widely available from independent contract vendors, to create smaller feature sizes and a smoother surface finish in our molds. The two-part molds are designed to permit the manipulation of various design features (e.g. shape and size of the carrier, the position, number, and spacing of stimulation sites, and insertion depth), thereby providing the versatility needed to customize devices to meet the requirements of individual experiments. We have successfully implanted various designs of these latest arrays acutely in guinea pigs and chronically in cats for periods of up to 6 months and have conducted acute electrophysiological experiments in these animals.

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B8. FAST RECOVERY AMPLIFIER FOR MULTICHANNEL NEURAL RECORDING USING HIGH RATE ELECTRICAL STIMULATION

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In neurophysiological studies of neural prostheses, it is often desirable to measure neural responses to amplitude-modulated, electrical pulse trains at relatively high carrier rates. However, long amplifier recovery times following electrical artifacts typically limit usable carrier frequencies to a few hundred pulses per second (pps), especially for monopolar stimulation. We have developed a fast-recovery recording system that can be used to record central responses to intracochlear stimuli at carrier rates above 1000 pps. The amplifier is relatively simple and is designed to be a component in an implantable multichannel recording device. Fast amplifier recovery is achieved by using a relatively wide recording bandwidth, 2 Hz to 40 kHz. The 2-Hz low-frequency cutoff prevents the baseline from shifting excessively after each biphasic stimulus and enables recording of low-frequency local field potentials. The 40-kHz high-frequency cutoff allows the amplifier to recover from each monopolar intracochlear stimulation artifact within 100 µs.

We successfully validated function of the system by recording data from the central nucleus of the inferior colliculus (ICC) in anesthetized guinea pigs while stimulating the cochlea with unmodulated and sinusoidally amplitude-modulated pulse trains. We recorded data from multiple locations in the guinea pig ICC while applying monopolar intracochlear electrical stimuli at 1000 pps. After artifact removal, regions of the ICC with appropriate tonotopic tuning showed evoked neural activity while other regions showed no evoked activity despite comparable or larger stimulus artifacts. Comparison of pre- and postmortem data confirm that the waveforms are of biological origin and not merely electrical artifacts.

To highlight one potential application for this system, we measured spatial tuning curves for sustained responses to 1000-pps pulse trains. We also measured the modulation index of responses to these same pulse trains amplitude-modulated at 100 Hz.

The system presented here will enable us to study interactions among multiple cochlear implant channels during interleaved stimulation at relatively high rates. Furthermore, the system is simple to implement and can find application in multichannel recording devices, both for neuroprosthesis and basic neuroscience applications.

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B9. CI COMPATIBILITY WITH DIGITAL WIRELESS PHONES

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Cochlear implant (CI) users, like hearing aid (HA) users, have reported hearing noise when using digital wireless telephones. The source of this interference noise between wireless phones and hearing devices is related to the radio frequency (RF) transmission that occurs between the wireless phone and its network. The resulting electromagnetic interference can have a range of adverse effects on the use of a wireless phone, varying from minor annoyance and/or reduced intelligibility to complete inability to use the phone. In 2003 the Federal Communications Commission (FCC) lifted the exemption for wireless phones from the Hearing Aid Compatibility (HAC) Act of 1988 requiring digital wireless phones to be capable of effective use with not only HAs, but CIs. Now, in addition to referring to a phone's inductive coupling capability, HAC also refers to a reduction of RF interference from the wireless handset. The FCC adopted ANSI C63.19 "Methods of Measurement of Compatibility between Wireless Communications Devices and Hearing Aids" as the applicable technical standard for establishing HAC requirements for wireless phones. Under ANSI C63.19, the performance requirement to achieve a particular level of telephone usability between a given wireless phone and HA during acoustic coupling is specified by a range of input-referenced, speech-to-interference ratios (SIRs). These performance requirements were developed based on subjective judgments of usability by HA wearers. Comparable data for CI wearers has not been obtained. The purpose of the current research was to begin examining whether the SIRs defined in the standard for given usability categories are adequate to provide the same levels of wireless phone usability for CI users. Postlingual, experienced CI users provided subjective ratings of usability for SIRs presented in a single-interval, forced-choice adaptive procedure. The subjective rating categories were developed to correspond to the usability categories in the standard. The interferer noises were generated from simulations of the RF signal envelope for three common digital wireless transmission technologies. These wide-band noises were paired with telephone voice-band speech samples coded to match the noise types, according to each technology's specification. The speech samples were presented in the soundfield at the subject's MCL. The level of the interferer was varied adaptively in order to find the SIRs corresponding to the boundaries between the ANSI C63.19 usability categories. Three adaptive searches were performed simultaneously with trials for the boundaries randomly interleaved. Testing continued until four reversals per boundary were obtained. The results will be discussed in terms of whether these CI users' SIR requirements for particular levels of digital wireless phone use are met by the performance requirements of ANSI C63.19.

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B10. ON ACOUSTIC SIMULATIONS OF COCHLEAR IMPLANTS

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Acoustic simulations of cochlear implants (CI) are used to explore perceptual performance with normal hearing listeners (NH) under a variety of listening conditions and speech coding strategies. However, performance discrepancies between simulated and actual CI users limit the extent to which the simulation can be substituted and the results interpreted. First, actual CI performance typically saturates with 4-7 electrodes whereas simulated performance continues to increase. Second, the temporal separation of electrical pulses between different electrodes as in a typical CIS strategy is unaccounted in current vocoderbased simulations. Third, the validity of acoustic simulation in terms of overall performance, error pattern, and sound quality has not been solidly established.

Here we developed a novel simulation and took advantage of access to a CI user who had normal acoustic hearing in the non-implanted ear to address these three critical limitations in current vocoder-based simulations. The novel simulation used discrete Gaussian-enveloped tones (GET) to control spectral and temporal overlap. In the GET simulation, three main features in cochlear implants can be independently manipulated: (1) place of stimulation can be manipulated by the carrier tone frequency, (2) rate of stimulation by the repetition rate of the GET train, and (3) electrical field spread by the duration of the Gaussian envelope, which is inversely related to the spectral bandwidth. Finally, the pitch map obtained by comparing acoustic and electric stimulation in the same subject allowed us to design overlapping frequency bands that simulated realistic channel interactions.

Six NH subjects and the CI subject with contralateral normal acoustic hearing participated in a range of psychophysical, speech recognition and sound quality experiments, including comparisons of the GET simulation to the traditional vocoder-based simulations. The overlapping filters, independent of the vocoder or the GET simulations, were able to account for the saturated performance in consonant and vowel recognition with 4-7 channels. The GET simulation produced more similar performance in temporal modulation detection error patterns and in sound quality than the vocoder-based simulations. The sound quality judgment in the same CI subject produced an 8/10 similarity rating between actual and simulated cochlear implants. These data suggest that by taking both temporal and spectral limitations in CIs into account, we can develop a highly accurate acoustic simulation of CI.

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B11. QUANTIFYING ENVELOPE CODING IN AUDITORY-NERVE RESPONSES TO CHIMAERIC STIMULI

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Smith *et al.* (2002) assessed the relative contributions of temporal envelope and fine structure to auditory perception using auditory chimaeras, which have the temporal envelope of one sound and the temporal fine structure of another sound. Based on perceptual tests, they concluded that the envelope is most important for speech reception, while the fine structure is most important for pitch perception and sound localization. However, their results only supported the envelope conclusion for conditions in which four or more frequency bands were used to create the chimaeras; for one- and two-band chimaeras, fine structure appeared to be most important for speech reception. Zeng *et al.* (2004) suggested that the apparent perceptual importance of fine structure for the fewband chimaeras may in fact result from the conversion of broad-band fine structure cues into envelope cues at the output of the relatively narrowband cochlear filters. Some support for this hypothesis was provided based on the envelope responses of a linear gammatone filter bank model. However, such an auditory model does not include many of the physiological factors that affect envelope and fine-time neural coding of sound. The goals of the present work are to extend these types of analyses by using a more physiologically accurate and detailed auditory-nerve (AN) model (e.g. Zhang *et al.*, 2001), and to develop robust metrics that quantify the amount of temporal envelope and fine-structure coding in neural responses to the types of complex stimuli often used in cochlear-implant (CI) simulation studies. The degree of speech envelope coding in responses of the auditory-nerve model to speech-noise chimaeras was evaluated based on envelope crosscorrelation and statistical metrics derived using 20 SPIN sentences. For oneband chimeras with speech fine structure and noise envelope, there was significant speech envelope coding for roughly 15 out of the 20 sentences for characteristic frequencies (CF's) up to 550 Hz. Speech envelope coding was present to a lesser degree at higher CFs. For 16-band chimaeras, none of the 20 sentences showed significant speech envelope coding. These results provide further quantitative support for Zeng *et al.*'s (2004) hypothesis, and suggest that Smith *et al.'s* (2002) original conclusion that envelope coding is important for speech does not need to be limited to multiple-band conditions. In the long-term, neural coding metrics will be most useful if they can beextended to experimental AN data (e.g., spikes), not just to the waveform outputs of an AN model. Towards this goal, we have begun to develop metrics based on shuffled auto- and cross-correlograms (Joris, 2003; Louage *et al.*, 2004) to quantify the extent of speech envelope and fine-structure coding in neural data. Metrics such as these would allow for the quantitative evaluation of the ability of CI simulators to provide amplitude- and frequency-modulation information at the level of the AN.

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B12. NEURAL-PERCEPTUAL MODEL FOR AUDITORY THRESHOLDS IN ELECTRICAL HEARING

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Electrical hearing thresholds were measured psychophysically in neonatally deafened cats using intra-cochlear trains of biphasic current pulses that varied in duration and intensity. Similar stimuli were used to evoke responses from sustained-response neurons in the central nucleus of the inferior colliculus. Histological analysis revealed complete bilateral degeneration of the organ of Corti; hair cells were not present in the deaf cats. Behavioral detection thresholds decreased when the stimulus duration was increased, and for each neuron studied, the total number of spikes increased directly with stimulus duration and stimulus intensity.

A model is presented that predicts behavioral detection when the neuronal response reaches or exceeds a threshold number of spikes. For short stimulus durations (≤ 100 ms), the accumulation of spikes is dependent on spatial-temporal integration (spatial summation across the activated population of neurons; temporal integration over the duration of the stimulus). For longer duration stimuli, spikes are accumulated during the duration of the stimulus at minimum neuronal threshold intensity by simple spatial summation. The model also predicts that behavioral detection of supra-threshold stimuli and perceptual loudness levels are dependent on accumulation of spikes.

Together, the results and model suggest that spatial-temporal integration and simple summation of neuronal responses are features of central auditory processes underlying detection of electrical signals by cochlear implant listeners.

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B13. ELECTRICAL FIELD MEASUREMENT AND LOUDNESS: ESTIMATING THE EFFECTIVE STIMULUS FOR COMPLEX ELECTRODE CONFIGURATIONS

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Complex electrode configurations, such as Quadrupoles, using multiple poles inside the cochlea have been investigated as a means to reduce channel interaction compared to monopolar stimulation. These complex configurations invariably require higher current levels to achieve sufficient loudness growth than a monopole. This study tests whether direct measures of the electrical field created by various stimulus configurations can predict loudness growth for these configurations in individual patients.

We have measured highly accurate intracochlear electrical fields using monopolar and multipolar electrode configurations. These fields are specific to each subject. We can show that the measured multipolar field corresponds accurately to the linear combination of the individual electrical fields generated by each electrode.

In terms of loudness perception, we hypothesize that the peak of the multipolar electrical field is the main determinant for the perceived loudness. Therefore we can make a subject-specific prediction of the quadrupolar loudness derived from the monopolar field measurement. This hypothesis was tested by establishing supra-threshold levels by loudness balancing in an adaptive psychophysical procedure.

We found that loudness growth predicted from the electrical fields almost perfectly matched the behavioural loudness growth in some subjects but deviated strongly in others. Per subject, this trend was constant per electrode number across all electrode configurations, suggesting a relation with the location of the electrode array in the cochlea. A possible explanation is the distance from the electrode to the neural tissue, influencing the contribution of the near-field component of the electrical field to the perceived loudness.

Additional data will be collected to validate these results. If successful, this will provide fundamental insight in the electrical stimulation of the auditory nerve. More practically, this method may provide a valuable predictor for fitting complex electrode configurations, enabling the adoption of these configurations in future clinical practice.

B14. EVALUATION OF ENVELOPE EXPANSION BASED NOISE SUPPRESSION TECHNIQUE IN COCHLEAR-IMPLANT USERS

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The performance of present day cochlear-implant users in noise is severely impeded, which adversely affects their quality of life. The goal of this study is to evaluate the effectiveness of temporal envelope expansion based noise suppression technique (Clarkson and Bahgat, Proc. IEEE Electr. Letts. 25, 1989) in speech recognition of cochlear-implant users. This approach has been already investigated in normal-hearing and hearing-impaired listeners with inconsistent results, but has not been studied in cochlear-implant users. Consecutive segments of 512 or 1024 samples were taken with 75% overlap. Fast Fourier Transform (FFT) was performed and the amplitude spectrum was raised to a power of 1.6. A pre-emphasis filter was employed to prevent unwanted suppression of the second and third formant peaks. The timedomain signal was created from the spectra using inverse FFT. The technique was implemented in Matlab 7 and was evaluated as a front-end noise suppression technique in cochlear implants. Six implant users performed phoneme and sentence recognition experiments in quiet and steady-state speech-shaped noise (0, 5, 10 dB SNR). Preliminary results showed that, on average, the technique improved vowel performance by 7-15 percentage points in both quiet and noise, and consonant (6-12 points) and sentence (3-10 point) recognition in noise only. However, consonant and sentence recognition in quiet was degraded by 11 and 10 percentage points, respectively. The data showed that while the temporal envelope expansion strategy has the potential to improve cochlear-implant speech performance in noise, it also has to address the degraded performance in quiet.

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B15. RESULTS OF THE NEW HARMONY SOUND PROCESSOR AND CURRENT STEERING SPEECH CODING STRATEGY HIRES120

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The clinical routine has shown that the majority of cochlear implant (CI) users are able to discriminate the pitches of two adjacent physical electrode contacts. To date, processing strategies have utilized a fixed number of stimulation sites, equivalent to the number of physical contacts. Because of its independent current sources, Advanced Bionics' system offers the possibility to create intermediate pitch percepts, so called "virtual channels". These are created by simultaneously stimulating two adjacent electrode contacts. The novel HiRes120 speech coding strategy is based on this technique and runs on the new Harmony ear level processor. The Harmony front end has been re-designed to process a larger 16 bit (96 dB) dynamic range.

Eleven adults participated in this five month study. The impact of the HiRes120 strategy and the Harmony processor were studied in terms of speech understanding. Prior to and after conversion to the Harmony subject performance was evaluated using a test battery: HSM sentence test (in quiet, in noise and for a single competing talker), questionnaires regarding general sound quality, music perception, battery life time and the handling of the processor. Later, perceptual channel and frequency difference limens tests were given. Subjects used HiRes90K or CII implants, had a mean age of 58.1 years (38.2 to 79.3) and a mean duration of deafness of 5.1 years (0 to 25.3).

In a second study group of 14 subjects we tested the Harmony processor in combination with the two coding strategies HiRes and HiRes120 for one month. These subjects already had experience with speech coding strategies based on current steering from former trials. The same test battery as for the first study group was used. The second group had a mean age of 55.1 years (25.1 to 79.3) and a mean duration of deafness of 5.0 years (0 to 26.0).

For the 25 subjects the results of the HSM sentence test with a +5dB SNR competing talker showed a 7.7% averaged increase for the Harmony compared to their previous processor. Analysis showed that 84% preferred the Harmony processor because of a better understanding, a more natural sound quality, or because of improved handling. Another important advantage was the extended battery life. The group can be separated into preference for HiRes120 (60%) and HiRes (24%) on the Harmony. The study revealed that standard testing material may not be sufficient to show differences between the HiRes and HiRes120 coding strategies. The most noticable difference between the strategies was seen using sentences with one competing talker of the same gender. Study results will be presented in detail.

B16. THE INFLUENCE OF PULSE WIDTH AND RATE ON SPEECH PERCEPTION AND T- AND M-LEVELS

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The availability of faster speech processors and electronics has led to an increase in stimulation rate, shortening of the pulses and the introduction of paired pulsatile strategies (PPS). These higher rates should provide for better temporal information and improved speech perception.

The present study systematically investigates the effect of stimulation rate (967 - 3868 pps/channel), pulse width (PW, 11 - 43 µs/phase) and paired pulsatile stimulation (PPS) versus continuous interleaved sampling (CIS) on speech perception, T-levels, M-levels and dynamic range. Although most strategy changes have been studied separately, no such grand parameter variation has yet been performed nor has the effect of using very short pulses been investigated. Previous studies have shown that with increasing pulse rate, the electrical threshold (T-level) decreases, and that the most comfortable loudness (M-) levels decrease relatively less, leading to an increased dynamic range.

During 3 non-consecutive days, 27 post-lingually deafened patients, implanted with either a CII or a HiRes90K with a HiFocus electrode, were fitted with nine 12-channel strategies following a Latin-square design. After one hour of customization, speech recognition was tested with CVC-words from CD in quiet and in speech-shaped noise (65 dB SPL, SNR = +10dB).

No strategy turned out to be significantly better for the group. Individual patients' best scores were obtained with a number of strategies, with no clear optimal pulse width or rate. However, the shortest pulse width of 11 µs/phase yielded insufficient loudness in 11 subjects. All PPS strategies yielded significantly worse scores than their CIS counterparts.

As expected, PW and rate influenced the T- and M-levels in a systematic way for all electrode positions. The T-levels decreased by 1.8 dB per doubling of the pulse rate, while the M-levels were considerably less influenced (slope 0.15 dB per doubling of the rate). The change in T-levels was -6.4 dB per doubling of pulse width, with an associated change in M-levels of -5.4 dB. Changing from CIS to PPS led to a reduction of T-levels by 1.3 dB and of M-levels by 1.9 dB. This reduction is superimposed on the changes caused by doubling the rate, inherent to the PPS paradigm.

It is concluded that PW, rate and paired stimulation have predictable and independent effects on both T- and M-levels for all strategies tested. Speech understanding with CIS is generally better than with PPS, but no CIS strategy outperforms the other ones.

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B17. REMOVING COCHLEAR IMPLANT ARTIFACT FROM THE EEG SIGNALS USING NOISE DISTRIBUTION PATTERNS

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Electroencephalography (EEG) is a physiological tool that has been used to examine the effects of electrical stimulation on the central auditory system. However, artifacts associated with the implant device have made eeg recordings more difficult to measure. Because the precise characteristics of the artifacts are poorly understood, investigators are left trying to remove the artifact from the EEG recording. As such, we attempted to characterize the implant artifact and use spatial distribution patterns of artifacts as part of a noise reduction method.

Four adult cochlear implant users (Hi-Res 90k device) participated in the study. The method was first tested on data collected from one subject using two simple auditory stimuli. The first stimulus was a 1000 Hz tone burst (tonepip stimulus), 5 ms in duration, with 1 ms on-off ramp time. The second stimulus was a 1000 Hz tone, 899 ms in duration, with a 4 ms on-off ramp time. The method was also tested on data recorded from four subjects using speech sounds *si* and *shi*, spoken by a female talker, from the nonsense syllable test.

Our results show that some of the implant noise was effectively eliminated by this method, enough to recover p1-n1-p2 responses. Moreover, consistent results were obtained across two measurement sessions with speech sound stimuli. This study demonstrates that spatial information of the implant noise can provide valuable information when attempting to remove implant artifact and therefore should be taken into consideration when developing new artifact removal algorithms.

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B18. MODEL-BASED INDIVIDUALIZED FREQUENCY MAPS: A FIRST CLINICAL APPLICATION

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The CI candidacy of patients with increasing amounts of residual hearing as well as bimodal and bilateral stimulation put a higher emphasis on an optimal frequency-to-place map, either within one cochlea or between cochleae. Several attempts to use psychophysical methods to determine this map on an individual basis failed in most (non-musically trained) patients. Therefore, the need is felt for an objective way to decide on the frequency-to-place map. Fortunately, modern CT scans show sufficient detail about the cochlear anatomy and the electrode position within the scala tympani or, mostly unintentionally, the scala vestibuli. In addition, a recent histological study quantified the difference between the tonotopical organization of the organ of Corti and that of the spiral ganglion.

The present study used a computational model to integrate histological with radiological data into a patient specific frequency map. For this purpose, patient specific models were created by matching the pre-operative CT scan with scaled versions of one of several basic cochlear shapes. These basic shapes were constructed from histological cross sections and micro-CT data and took into account the above mentioned histological information on the tonotopical organization and the course of the primary auditory nerve fibers. With this model, pre-operative planning of electrode insertion was performed. It turned out that the HiFocus1J electrode used was 1-2 mm too short and relatively thick to address the range of fibers physiologically tuned to frequencies between 250 Hz and 8.7 kHz. An important finding was that the excitation site along the fiber is not only dependent on the electrode position, but to a large extent also on each individual's anatomy. Moreover, the pitch, calculated on the basis of the center of excitation, shifts with stimulus intensity. The direction and magnitude of this shift depend on the location of the electrode contact. Although a downward shift is common in the apex, in a number of patients an upward shift was found. For basal contacts both upward and downward shifts were observed. Scala vestibuli insertions do not differ in pitch from their scala tympani counterparts, but do show elevated thresholds for apical contacts.

The actually achieved electrode location was modeled on the basis of the post-operative CT scan, allowing for prediction of threshold profiles, the induced pitch percept per electrode contact, and a detailed analysis of current spread and spread of excitation. These predictions will be compared with actual data for eight patients, implanted with a HiRes90k. They were fitted with a physiologically correct frequency-to-place map based on the model predictions. Their initial follow-up data will be presented.

This study was funded by the Heinsius-Houbolt Fund and Advanced Bionics.

B19. MODIFICATIONS IN INDIVIDUAL SUBJECT FITTING BASED ON VARIABILITY IN ELECTRODE PLACEMENT AND PLACE PITCH PERCEPTION

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Speech reception outcomes may vary broadly across patients implanted with the same cochlear implant (CI) device. It is also the case that average clinical outcomes are similar across different CI devices. These two observations suggest the following working hypotheses: (1) Patient-dependent factors play a significant role in determining outcome in individual CI patients; (2) Speech reception outcome may be improved by mapping revisions based on how such factors degrade the actual implementation of the speech processing strategy within an individual.

We have measured intracochlear electrode placement, evoked neural potentials, electric field spread, loudness growth, pitch discrimination, and CNC speech reception in 16 patients implanted with Advanced Bionics' electrode arrays and whose word recognition scores vary broadly. At the time of evaluations, all subjects had achieved stable performance using their "everyday" processor map obtained using conventional clinical fitting procedures. While the data indicate wide variability across subjects in all of these measures, we find that there are tendencies for the electrode array to be inserted overly deep, as well as being located within scala vestibuli as opposed to scala tympani. Both effects correlate with lower CNC word scores. A perceptual consequence of these electrode placements is increased difficulty for the subject to correctly discriminate stimulation electrodes on the basis of place pitch. In particular, very deep electrode insertions would often result in effective loss of apical stimulation sites because stimulation channels cannot be distinguished.

Based on the combined imaging, electrophysiological and psychophysical results, *ad hoc* changes were made in processor maps to minimize perceptual errors in information representation based on a vocoder model of speech processing. Simple mapping revisions of choosing a processing strategy employing sequential stimulation (if not already in use), removing electrodes from the map, readjusting stimulation rate per channel due to fewer overall channels, and adjusting individual channel gains for soft/loud speech audibility resulted in significant (and often immediate) improvement in lower- and mid-performing subjects. All but one subject found the new maps to be subjectively better and chose the new map as their "everyday" map.

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B20. INFERIOR COLLICULUS RESPONSES TO SAM TONES AND SAM ELECTRICAL PULSE TRAINS

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Contemporary cochlear implants (CIs) encode speech using several strategies. Most of these strategies employ amplitude modulation of fixed frequency pulse trains to encode the speech envelope. In these experiments we examined the neural encoding of unmodulated and sinusoidally amplitude modulated (SAM) tones and pulse trains in the central nucleus of the inferior colliculus (ICC) of normal hearing guinea pigs. Initially, we recorded the acoustic responses using a 16-site silicon probe inserted along the tonotopic axis of the ICC. In each animal we recorded responses to acoustic tones to estimate threshold, CF, and Q10 of neurons at each probe site; we fixed the recording probe in place and recorded the responses to one tone or two simultaneously presented SAM tones using various carrier frequencies, intensities, modulation frequencies (30 -200Hz) and modulation depths (0 -100%). We then deafened the cochlea, inserted a CI electrode custom-designed for guinea pigs, and recorded responses to single channel, monopolar and bipolar pulse trains (20 - 1000 pps) both unmodulated and SAM. We systematically varied stimulus channel, intensity, and modulation frequency and modulation depth. At stimulus onset, unmodulated acoustic and electric stimuli evoked relatively strong activity across a relatively broad region of the IC tonotopic axis. Subsequent activity diminished (“adapted”) rapidly but selectively. After 10 - 30ms, activity at locations remote from the best location (the site responding most strongly at the lowest threshold & for a given stimulus) decreased to near spontaneous levels. In contrast, neurons at the best location continued to respond throughout the stimulus. Decreased responses at remote locations enhanced selectivity of steady-state responses at best locations and strongly influenced responses to modulated signals. This effect was more pronounced for electric than for acoustic stimuli and decreased as modulation depth increased. Results suggest that 1) responses to CI processor transients are more broadly distributed across the auditory CNS than would be predicted by acoustic spectra; and 2) the amplitude compression of CI-processed speech favors activation selectivity.

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B21. CHANGES IN TEMPORAL REPONSES OF AUDITORY NERVE FIBERS TO LOW AND HIGH RATE ELECTRIC PULSE TRAINS

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While it has been shown that high-rate (e.g., 5000 pulse/s) trains of electric pulses can desynchronize auditory nerve fiber (ANF) responses, there has not been any systematic evaluation of the time course of such effects. The rate at which ANF responses are modified by ongoing stimulation may be highly relevant to implementations of speech processors. In this study, we investigated how ANF responses change over time using pulse rates of 250, 1000, and 5000 pulses/s. Eight chemically deafened cats were used in acute experiments that yielded data from 88 ANFs. Three measures, inter-spike interval (ISI), vector strength (VS), and Fano factor (FF), were assessed at several epochs over the 300 ms duration of our pulse-train stimuli. ISIs generally increased over time and decreased with onset spike rate (i.e., stimulus level). With 5000 pulse/s trains, ISIs were determined primarily by refractory and adaptation effects. Immediately after onset of this high-rate train, some ISIs demonstrated unique two-peaked interval histograms. VS was compared across pulse rates after correcting for effects of varying inter-pulse period. VS was found to decrease with the use of high-rate stimuli and decreased further over time after stimulus onset. FF was greater for 5000 pulse/s trains than for 250 pulse/s trains for wide range of response rates, again indicating the stochastic effects of high-rate stimuli. Our study advanced the state of research by charting VS and FF changes across time after train onset. With both measures, the largest changes occurred within the first 80 ms and generally reached asymptotic values before the end of the 300 ms pulse-train duration. In addition to detailing how ANFs response to the kind of stimuli used by cochlear prostheses, our results are relevant to needed improvements in computational models of ANFs and the interpretation of the electrically evoked compound action potential, which can be measured from cochlear-implant users.

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B22. A FULLY PROGRAMMABLE FILTER-BANK BASED ALGORITHM FOR MULTICHANNEL COCHLEAR IMPLANT

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Cochlear prosthesis apparatus is a recent biotechnological device permitting to restore partially hearing from profoundly to totally deaf patients. Such pathological cases were not curative and passed the rest of life in a silence world socially disintegrated. This apparatus could restore a great part of the hearing and would permit social reintegration if the considered pathology may have mechanically normal inner ear with sufficient sensory hair cells. It could then partially restore a sense of hearing through direct electrical stimulation of auditory residual nerve fibbers of the cochlea. Cochlear stimulation induced could initiate a nerve impulse (action potentials) that could be transmitted through synapses into auditory nerve center. Conceptual design of this recent cochlear prosthesis system includes three main parts: A sounds analyser which is an external digital signal processing 'DSP' unit, a radiofrequency 'RF' transmission unit which is a telemetry system for data transmission and an implanted micro stimulator coupled to an electrode array system (cochlear implant). The external signal processing unit detects sounds captured from a microphone and converts them to a specific electronic code that would be transmitted through the skin via a telemetry system to the implant.

Inside the implant, the micro stimulator circuit uses the demodulated code to generate electrical stimuli that drive the electrode array which is usually placed close to the residual cochlea nerve fibers. The objective of intracochlear stimulation was almost to replicate the neural activity produced in the normal ear during acoustic stimulation. In order to achieve maximum of flexibility, most stimulation strategies could be configured using various programmable parameters. The external digital speech processing operating according to an implemented stimulation algorithm could be accompanied by an aided software tool including the adjustment of these parameters. This clinical aided tool could be beneficial during clinical tests especially for adapting this biotechnological apparatus to each pathological case. A Fully programmable filter-bank based algorithm for multichannel cochlear implant would be presented in this paper. In fact, the strategy implementation on a digital signal processor 'TMS320 C6416 DSP' was our aim in this research, since this DSP type would be the pilot part for such cochlear prostheses apparatus (External part). DSP Implementation concerned on the other hand flexibility, performance as well as efficiency regarding filter order variation as well as coefficients' coding (bits format).

Our digital filter bench based speech processing dedicated to a fully programmable stimulation strategy for cochlear prostheses was validated by using different sounds. Simulation results obtained for pure and composite sounds, which are the base of speech processing test, confirmed strategy performance and efficiency. Using these implementation procedures, cochlear prosthesis's external part could be then driven by one fully programmable strategy. A graphical interface permits various stimulation possibilities with a great flexibility. This would certainly permit to explore total hearing capacities and satisfy different pathological cases' needs.

B23. A STIMULATION CONCEPT BASED ON "SELECTED GROUPS"

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In multi-channel cochlea implants (CIs), sequential stimulation across electrodes results in a current spread. This leads to masking of stimulation pulses, known as channel interaction. For example, if a sequence of high-rate sequential pulses is applied to adjacent electrodes, only pulses with higher amplitudes will consistently elicit action potentials, whereas those with lower amplitudes are masked to a great extent and thus are much less "effective".

For detecting and omitting these masked pulses we subdivide the channels into groups with presumed high channel interaction, denoted as "selected groups" (SG). Within each group, only the channels with the highest amplitude(s) are stimulated. Note that a N-of-M strategy represents a special case of SG, e.g., 6-of-12.

Our study investigated the effect of omitting presumably masked pulses with the SG algorithm. Speech processor variations with different group sizes were evaluated in eight subjects. Speech reception thresholds (SRTs) for German Oldenburg sentences in CCITT noise and subjective volume levels for comfortable loudness were assessed. Besides, the subjective quality of hearing was also recorded.

The results show that the cancellation of presumably masked pulses with the SG concept has only a minor influence on speech reception. As expected, an increase of group size needs just slightly more processor volume to reach comfortable loudness. According to anecdotal subject comments, sound quality starts to decreases outer group sizes larger than two or three compared to CIS. This suggests that the concept provides a robust and simple algorithm to omit masked pulses.

Support provided by the Christian Doppler Research Association

B24. PERFORMANCE AND PREFERENCE FOR THE EXPANDED STIMULATION RATES OF THE FREEDOM IMPLANT

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The Nucleus Freedom implant includes an expanded total stimulation rate up to 32 kHz. Three European multi-centre studies with different designs were performed to investigate the speech perception performance and the preference for the expanded stimulation rates. For all studies adult patients with post-linguistic onset of bilateral severe-to-profound sensorineural hearing loss were recruited.

The first study in 30 recipients investigated performance and preference of the ACE strategy at 500, 1200 and 3500 pps/channel using an ABC-CBA design. The results showed no differences in speech perception performance, and a preference for the lower stimulation rates.

The second study in 22 recipients investigated the subjective preference for the ACE and CIS strategy within the range of available stimulation rates. The preference of the recipients tended towards the ACE strategy and was scattered over the range of presented rates.

The third study in 20 recipients investigated the subjective preference for the ACE strategy at 1200 and 2400 pps/channel. The large majority of the recipients preferred ACE at 1200 pps/channel.

The three different studies clearly show that the majority of recipients have a preference for the lower stimulation rates. For the ACE strategy no performance benefit with increased stimulation rate was observed.

Support provided by Cochlear AG

B25. EFFECTS OF BANDWIDTH EXTENSION ON TELEPHONE SPEECH RECOGNITION BY COCHLEAR IMPLANT USERS

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Previous studies have shown that cochlear implant (CI) users' speech recognition was significantly worse for telephone speech than for face-to-face conversation. The deficit in telephone speech recognition may come from the limited bandwidth (i.e., 300-3400 Hz), elimination of visual cues and the reduced audibility of the telephone signal. The limited bandwidth may be particularly detrimental to those CI users who receive frequency information higher than this range. The present study investigated the effect of restoring the lost high frequency components to telephone speech signal on CI users' speech recognition performance. A bandwidth extension technique was used to restore the high frequency information. The spectral relation between narrowband speech and wideband speech was estimated by minimizing the mean square error of a training set of 300 sentences from IEEE database. The excitation was frequency extended by spectral translation. Then the source filter model was used to synthesize the wideband speech. CI users' performance with restored high-frequency information was evaluated using multi-talker IEEE sentence recognition tests. Preliminary results showed a significant improvement in the recognition of sentences with restored high-frequency information, relative to the performance with telephone speech. The present study indicates that cochlear implant users may benefit from the restored high-frequency speech information with the bandwidth extension approach.

Research is supported by NIH-NIDCD.

B26: THE EFFECT OF THE OUTER/MIDDLE EAR TRANSFER FUNCTIONS ON VOWEL IDENTIFICATION BY PERSONS FITTED WITH A COCHLEAR IMPLANT

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While the hearing aid industry has long recognized the importance of retaining the natural effects of ear canal resonance on the frequency response to natural sound and improved intelligibility, consideration of this and other natural frequency response effects associated with normal hearing has not been applied to cochlear implant sound processing. This study will address the possible effects of several frequency response variations that mimic natural resonance functions on vowel intelligibility. A set of 132 tokens of 11 American English vowels in an /h/-vowel-/d/ context (heed, hid, head, had, hod, hood, who'd, hud, heard, hayed, hoed) from recordings made by Hillenbrand et al. (1995) were used for this study. Three examples of each vowel that had been 100% correctly identified in Hillenbrand et al. (1995) were selected from a variety of speakers representing each of four voice groups: men (20 talkers), women (24), boys (20) and girls (14). Vowel tokens were processed in three ways using finite response digital filters. One was to remove the response of the Knowles EL7189 microphone packaged in the HS-8 headset used with the Sprint Nucleus cochlear implant (condition MICNEG). The second was to add the response of the outer and middle ear (based on Bentler and Pavlovic (1989) and Aibara et al (2001) respectively (condition OEME). The third was to remove the microphone response but add the outer/middle ear response (condition OEMEMN). Six persons with Nucleus implants (2 bilateral, 4 unilateral) and ten undergraduate students with self-reported normal hearing listened to the vowels starting with the original non-processed version (condition NOFILTER). Order of presentation of the conditions was: first NOFILTER for all subjects, then conditions were randomized for each subject. Within a condition, vowels were randomized separately for each subject. Subjects listened to one condition per week over four weeks and were asked to classify each stimulus as one of the 11 vowels. Persons with normal hearing identified vowels with 94% accuracy regardless of condition. Persons with CIs identified vowels with best accuracy in the OEMEMN condition (52%) and with worst accuracy in the MICNEG condition (41%). They identified vowels in the NOFILTER and OEME conditions with about 45% accuracy. These preliminary results (more CI listeners are being run) indicate that adding the outer/middle ear transfer functions can improve identification of vowels by CI patients. Results on specific voices (men's, women's, etc) will also be presented.

B27. THE POTENTIAL OF BINARY MASKING FOR NOISE REDUCTION IN COCHLEAR IMPLANTS

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Most cochlear implant (CI) users have acquired satisfactory speech understanding in quiet environments; however, speech recognition in noise is still problematic for CI listeners. Most noise reduction methods for CI have been based on preprocessing the noisy speech signal and presenting the enhanced signal to the input of the CI processor. In this project, we study a new noise reduction approach for cochlear implants based on binary masking, a technique originally developed for glimpsing models in computational auditory scene analysis.

In ideal binary masking models, stimuli are constructed using a time-frequency (T-F) masking technique that ensures that the target is stronger than the masker in certain T-F regions of the mixture, thereby rendering certain regions easier to glimpse than others. The ideal binary "mask" takes values of zero and one, and is constructed by comparing the local SNR in each T-F unit against a threshold (e.g., 0 dB). The ideal mask is commonly applied to the T-F representation of a mixture signal and eliminates portions of a signal (those assigned to a "zero" value) while allowing others (those assigned to a "one" value) to pass through intact.

To evaluate the potential of the binary masking approach to noise reduction in cochlear implants, we conducted a pilot study with two Clarion CII subjects. IEEE sentences, embedded in multi-talker babble and speech shaped noise (5 and 10 dB SNR), were time-frequency segregated using the binary masking model and presented to the CI users for identification. Results showed that the binary masking technique, when applied to the noisy envelopes, produced significant improvements in subjects' speech recognition in noise, and yielded performance close to that attained in quiet listening conditions. In realistic situations, the binary masking patterns need to be estimated from the noisy envelopes. Hence, to assess the impact of estimation errors, we randomly introduced errors in 2, 4, 8 and 12 channels in a separate experiment. Results indicated that errors can be introduced in the binary masking pattern in 2-4 channels without observing a significant decrement in performance.

Research supported by NIH/NIDCD

B28. EFFECTS OF MULTI-ELECTRODE STIMULATION ON TONE PERCEPTION: MODELING AND OUTCOMES

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Perceptual experiments were conducted with simultaneous stimulation of two adjacent electrodes, and simultaneous stimulation of four adjacent electrodes where the flanking electrodes presented reverse phase stimulation to control current spread from the ‘virtual channel’. In the four electrode condition three virtual channels were created by manipulating the amplitude relationship between the center electrodes (0.2, 0.6 and 0.9) and the sum of the current delivered to the flanking electrodes was between 0 and 100 % of the current delivered to the center electrodes.

Modeling data suggest that the use of flanking electrodes can potentially limit current spread and contain neural activation within a narrow region around the current sources.

Preliminary patient testing suggests that, for electrodes with low M-levels, tonal perception can be improved when applying relatively high amplitude, reverse phase pulses to flanking electrodes.

B29. USING EARLAB TO SIMULATE AUDITORY PROSTHESES

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Large-scale simulations of physiological systems hold great promise for integrating experimental data and for predicting the outcomes of experimental and therapeutic manipulations. We believe that, for simulation to become more widely used, simulation systems should be designed to mimic both the biological system and the diagnostic and therapeutic devices that may be used to study and/or treat the biological system.

We have developed a modular software system for use by auditory scientists and clinicians called EarLab <http://earlab.bu.edu>. The underlying software architecture is designed to be able to represent any physiological system or group of systems using interchangeable modules. Simulation parameters are loaded at runtime which facilitates species specific and patient-specific modeling.

To facilitate a wide range of simulation goals, EarLab modules have been developed that mimic the auditory periphery and brainstem nuclei. Additional modules have been developed to simulate data obtained through electrocochleography and to simulate cochlear prosthetics. The system allows the user to simulate impaired auditory systems as well as the normal auditory system.

Examples will be shown that demonstrate how the modular approach facilitates rapid modification and extension of existing models to simulate new experimental and clinical paradigms.

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B30. A NOVEL SIGNAL PROCESSING STRATEGY FOR CURRENT STEERING IN COCHLEAR IMPLANTS

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A new signal processing strategy for cochlear implants, based on the principle of parametric coding has been designed. Parametric representations of audio signals are based on model assumptions for the signal source and signal perception. Using sinusoidal modeling of the audio signal, a fine frequency resolution as well as a good temporal resolution can be reached. Furthermore, the novel strategy incorporates a parametric loudness-based selection of the sinusoidal components as only a limited number of components can be represented by the implant.

Speech processing strategies for cochlear implants decompose the audio signals into multiple frequency bands, where each of these bands is associated with one electrode. However, these bands are relatively wide to accurately encode tonal components of audio signals. The CII® and HiRes90K® implants of Advanced Bionics Corporation have the ability to share the stimulation current between two contacts (Current Steering). By stimulating two bounding electrodes with different weights, the perception of different pitches is possible (Virtual Channels). This feature of the implant allows to represent the audio signals with a more accurate frequency resolution. Therefore, a new signal processing strategy that analyzes the audio signal with higher frequency resolution is needed. The main constraint here is to increase the frequency resolution without reducing the temporal resolution as temporal resolution can be related to temporal pitch perception.

In a chronical trial study with 9 Clarion® recipients, the performance in frequency discrimination, speech intelligibility, and subjective quality for both, music and speech, was evaluated. The new strategy was compared with the commercial HiRes and a research version of the recent designed HiRes120 strategy. Results have shown an improvement of frequency discrimination for the new strategy against the HiRes. Speech intelligibility in quiet was similar with all strategies. Speech intelligibility performance in noise was better with the HiRes and the HiRes120 than with the new strategy. Subjective music and speech appreciation was better with the new processor than with HiRes. Besides, the new algorithm provides potential improvements in power saving and speech intelligibility by optimizing the way the sinusoids are selected.

B31. EVALUATION OF A PSYCHOACOUSTIC BASED SOUND CODING ALGORITHM ($MP3^{000}$) IN COCHLEAR IMPLANT RECIPIENTS

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A new sound coding strategy ($MP3^{000}$) has been developed and evaluated in adult cochlear implant recipients. This strategy applies psychoacoustic simultaneous masking principles, and the threshold in quiet curve, to selection of the N most-perceptually-significant channels from a total of M frequency channels. This new approach to maxima selection differs from that used previously in the ACE and SPEAK strategies, in which the selection of N stimulation channels from the M frequency channels is based on the filters with the highest spectral energy present. The development of the $MP3^{000}$ strategy is based on the MP3 algorithm, which is focussed on reducing the bit-rate of audio data without reduction in sound quality. The use of the $MP3^{000}$ strategy has potential for reducing the power requirements of the sound processor, by avoiding presentation of stimuli to masked channels. The strategy as currently implemented in the Freedom sound processor focuses on spectral masking. Future evaluations will expand the functionality of the $MP3^{000}$ platform to explore other dimensions such as temporal masking, electrical current spread and nerve activation/saturation effects.

Use of the $MP3^{000}$ strategy was evaluated in a group of twelve adult CI24M or CI24R subjects, all of whom were experienced users of the ACE coding strategy. In the study, the effect of adjusting the number of maxima and the masking slope function were explored and a clinical comparison was made between the ACE versus the $MP3^{000}$ strategy on tests of speech perception, musical sound quality, subjective preference and battery life. A balanced ABC, BCA or CAB experimental design was used, in which A represented the optimised MP^{3000} 4 maxima, B represented the optimised MP^{3000} 6 maxima, and C represented the standard ACE program. Speech perception was assessed with open-set monosyllabic CNC words presented in quiet at a level of 60 dB SPL RMS, and open-set CUNY sentences presented in multi-talker babble at a level of 65 dB SPL RMS. A paired-comparison sound quality rating technique was used to compare the quality of a range of musical tokens, consisting of single instruments, ensembles and male & female voices. Battery life was monitored for the duration of the study. A comparative questionnaire was administered to determine preference between strategies in a range of different real-world listening environments.

The $MP3^{000}$ strategy was subjectively favoured by nine of the twelve subjects. There was no significant group mean difference in speech perception scores between the ACE and $MP3^{000}$ strategy with six maxima. A small but significant difference in scores was obtained between the ACE and $MP3^{000}$- for tests in quiet. Two of the twelve subjects obtained poorer scores in noise with one of the $MP3^{000}$ strategies as compared to ACE, however performance with their preferred $MP3^{000}$ strategy was not different to ACE. There was a significant saving of battery power with the use of the MP^{3000} strategy compared to the ACE strategy.

B32. DOES MORE APICAL STIMULATION PROVIDE INCREASED CI BENEFITS ?

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In normal hearing subjects the frequencies covered by the cochlea range from about 20 Hz to 20 kHz. With a Nucleus® Contour Cochlear Implant the frequency range directly covered by the electrodes is starting from about 500 Hz. In terms of a more natural sensation of hearing, an additional electrical stimulation of the low frequency range could be desirable. For this purpose the Nucleus® 24 Apical Cochlear Implant has been developed. This implant system has a second thin straight electrode array with 4 electrode contacts in addition to a modified Contour array with 18 active contacts spread over the same distance as for the standard Contour array. By inserting the second electrode array directly into the apical turn a stimulation of the more apical neural structures can be achieved.

In order to investigate the benefit of apical stimulation enabled by a deep insertion of the electrode array, a clinical trial has started at the Medizinische Hochschule Hannover (MHH). A total of 10 subjects will be implanted with the apical array and a comparison is made of each subject's performance with MAPs created with both arrays activated (condition A) compared to MAPs where only the basal array is activated (condition B). In both types of programs eighteen channels are used and the conditions A and B are randomised across subjects to be used as initial program. After 3 months of CI experience each subject follows an ABAB (or BABA) sequence with 4 weeks of take home use. Speech performance (words in quiet and sentences in noise) and pitch perception are tested at each visit.

Eight recipients have been implanted with the new device. None of the recipients showed significant pitch discrimination for the four apical electrodes. However, the pitch for the four apical electrodes was clearly perceived deeper compared to the most apical electrode of the more basally located array. All recipients showed poorer speech recognition scores, when the apical electrodes were activated compared to MAPs where only the basal array was used. All but one recipient preferred the activation of only the 18 basal electrodes. So far no benefit of the apical stimulation could be seen. Further investigations focus on the benefits of using one single apical electrode instead of the whole apical array.

B33. A FULLY IMPLANTABLE STIMULATOR FOR USE IN SMALL LABORATORY ANIMALS

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We describe a low cost, fully implantable, single channel stimulator that can be manufactured in a research laboratory. The stimulator generates charge-balanced biphasic current pulses which are delivered to a bipolar electrode array for chronic stimulation of neural tissue in free-running laboratory animals such as rats and mice. The system is magnetically coupled and contains no batteries or external leadwires. The subject is placed in a chamber surrounded by three orthogonal coils of wire which are driven to generate a magnetic field. Currents are induced in wire coils in the implanted stimulator then regulated to produce biphasic current pulses with fixed amplitude of up to 500 μA. Phase duration is adjustable from 25 - 250 μs per phase. Charge balance is maintained by capacitive coupling and shorting of the electrodes between pulses. Stimulus rate can be continuously varied, and the temporal precision of the stimulus means that the stimulator can be used in behavioural experiments or for generating electrically-evoked potentials such as EABRs. We have used this stimulator for chronic electrical stimulation of the auditory nerve; however it has application in other areas of neuroscience requiring controlled safe electrical stimulation of neural tissue over extended periods.

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B34. REALISTIC FIRING IRREGULARITY AND MODULATION SENSITIVITY WITHOUT PHYSIOLOGICAL NOISE

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Ongoing physiological noise is often presumed to produce the firing irregularity apparent in the discharge patterns of electrically stimulated auditory nerve fibers. This noise is likely generated primarily by the random opening and closing of voltage-gated sodium channels. Furthermore, it has been suggested that this physiological noise plays a critical role in enhancing the modulation sensitivity of the neural discharge pattern via “stochastic resonance.”

We note, however, that noise alone cannot account for changes in the firing irregularity with stimulus parameters, particularly the increase in the firing irregularity at high stimulation rates. At the very least, an additional mechanism is required to account for the irregularity over a broad range of stimulus conditions.

We have identified a mechanism that can account for the dependence of the firing irregularity on stimulus conditions. Specifically, we demonstrate using physiologically based models of neural excitation and refractoriness that the stability to small perturbations, such as ongoing noise and sinusoidal amplitude modulations, varies with stimulation parameters such as stimulus intensity and stimulus rate.

For a range of high stimulation rates, an instability emerges which produces a realistic range of firing irregularity even in the complete absence of ongoing physiological noise. Indeed, in the presence of this instability, physiological noise can actually regularize the discharge pattern, quantitatively reducing the firing irregularity below what would be present in the absence of noise. This instability also produces responses that are at least as sensitive as those of the electrically stimulated auditory nerve to sinusoidal amplitude modulations.

Based on these findings and on the strong, positive correlation between implantees’ speech perception ability and their sensitivity to small modulations, we hypothesize that, for a given electrode configuration, their speech perception would be optimized were the dynamical stability of their stimulated fiber population minimized. Our challenge for the future will be to devise stimulation strategies that minimize the stability. This will require elucidating how the dynamics of spike generation interacts with the stimulus to determine the stability/instability.

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B35: EFFECTS OF HIGH RATE STIMULATION ON NEURAL RESPONSES: COMPUTATIONAL MODEL APPROACH

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It has been shown that use of high-rate (i.e. 5000 pulse/s) stimulation can produce benefits to some cochlear implant users. Such stimuli produce unique temporal responses and increased desynchronization across active auditory nerve fibers (ANFs). In order to systematically evaluate these effects, we are developing a Hodgkin-Huxley type computational model that incorporates the kinetics of both sodium and potassium channels.

The rate constants of the Hodgkin-Huxley model were modified and the model was realized using the relatively efficient Fox algorithm. The lack of model data demonstrating adaptation-like ANF responses has been a significant drawback of contemporary modeling efforts. A novel feature of our work has been to dynamically modify potassium Nernst potentials in order to simulate adaptation-like phenomena. This will enable us to predict auditory-nerve responses to ongoing stimuli.

This presentation will present details of the implementation of our computational model as well as model results. Results will include (1) adaptation time constants, (2) effects of stimulus level manipulations, (3) effects of varying stimulus pulse rate, and (4) an evaluation of the recovery from adaptation from prior stimulation. The measures presented will, to the extent possible, parallel our recent efforts to characterize ANF adaptation to electric pulse trains using a feline animal model. Finally, we will present a summary of the sensitivities of model outcomes as a function of internal model parameters.

We believe that the addition of an adaptation component to a biophysically realistic model will prove to be highly valuable to understanding how the auditory nerve responds to a wide variety of the time-varying stimuli provided by speech processor algorithms implemented in current designs of auditory prostheses.

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B36. POLARITY CONTRIBUTIONS TO NEURAL EXCITATION IN COCHLEAR IMPLANTS

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Cochlear implants (CIs) have restored hearing to more than 100,000 deaf people. Electrical stimulation is provided via several electrodes implanted inside the cochlea which directly activate the auditory nerve fibers. Most existing devices use trains of amplitude-modulated, symmetric biphasic pulses. However, recent studies suggest that other pulse shapes may require less current to evoke a neural response, and may also increase the spatial selectivity of stimulation. Understanding the effects of pulse shape and particularly of pulse polarity will help to optimize the stimulation protocols and to deliver the most relevant information to the implant listeners. Animal experiments have shown that cathodic (negative) current flows are more effective than anodic (positive) ones in eliciting neural responses, and this finding has informed the development of novel speech-processing algorithms. Here we show electrophysiologically and psychophysically that human auditory nerve fibers exhibit the opposite pattern, being more sensitive to anodic stimulation. We measured electrically evoked compound action potentials in CI listeners for phase-separated pulses, allowing us to tease out the responses to each of the two opposite-polarity phases. At an equal stimulus level, the anodic phase yielded the larger response. Furthermore, a measure of psychophysical masking patterns revealed that this polarity difference was still present at higher levels of the auditory system and was therefore not solely due to antidromic propagation of the neural response. This finding suggests a human specificity which may relate to a substantial degeneration and/or demyelination of the peripheral processes and has potential applications to improve CI speech-processing strategies.

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B37. SIMULTANEOUS STIMULATION BASED ON CHANNEL INTERACTION COMPENSATION

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Channel Interaction Compensation (CIC) is an approach for the simultaneous application of pulsatile stimuli at the presence of spatial channel interaction. As a basic requirement for simultaneous stimulation, pulses are 100% synchronous in time and have equal phase polarities. CIC is based on an exponential model of spatial potential distribution within the scala tympani using two different decay constants α and β towards the apex and base, respectively. If a subset of electrodes is stimulated simultaneously, CIC takes the associated sequential amplitudes and computes reduced simultaneous amplitudes. Sequential and simultaneous amplitudes are related to each other via an "Interaction Matrix".

Simultaneous stimulation configurations include groups of simultaneous channels within each stimulation cycle, where the groups themselves are stimulated sequentially. E.g., for a 10-channel system, configuration P_5 = {[1 3 5 7 9], [2 4 6 8 10]} means that two groups of five simultaneous electrodes are stimulated alternatingly. Configuration P_{10} = {[1 2 3 4 5 6 7 8 9 10]} means that *all* electrodes are stimulated simultaneously.

Speech reception thresholds for German Oldenburg sentences in noise have been measured in several users of the $\text{PULSAR}_{\text{CI}}^{100}$ cochlear implant. To allow for a direct comparison, the same pulse rates per channel and phase durations as for CIS have been used for various simultaneous configurations. Test results demonstrate that simultaneous stimulation based on CIC can be employed without degradation of speech perception. In several subjects, this is true even for settings with fully simultaneous stimulation of all electrodes. Optimum speech perception requires proper setting of the spatial decay constants α and β.

Support provided by the Christian Doppler Research Association

B38. THRESHOLDS FOR FACIAL NERVE STIMULATION VARY OVER TIME

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BACKGROUND. Facial nerve stimulation is a known complication of cochlear implantation. Whereas clinicians have had to rely on self reports and visual inspection to detect facial nerve stimulation, we have shown that evoked surface electromyography (EMG) of the facial musculature is a useful and perhaps more accurate objective measure.[1] Moreover, this response can be measured in the same recording channel (CZ-ipsilateral earlobe) as the electrically evoked auditory brainstem response (EABR). Using this electrophysiologic technique, over 50% of paediatric implant users were shown to be at risk for non-auditory stimulation including facial nerve activation.[1] Given evidence of significant variability in the delay to onset across individuals[2], it is possible that thresholds of facial nerve activation may change over time.

OBJECTIVES. To determine whether the threshold for facial nerve stimulation varies over time using objective electrophysiologic methods.

METHODS. Activation of the facial musculature was evoked by single monopolar biphasic pulses delivered by individual implant electrodes (at basal, middle, and apical locations) in 15 children. The responses were measured at 3 facial locations and in the EABR recording channel and compared with previously recorded responses from the EABR channel in the same children.

RESULTS. The threshold for facial nerve stimulation for a given electrode varied over time. The pattern of threshold change was not consistent, with some thresholds increasing while others decreased. The mean threshold shift was 1.9 cU although variability was large (std 13.9 cU) and changes in threshold ranged from -20 cU to 15 cU.

CONCLUSIONS. Electromyographic measures provide sufficient sensitivity of facial nerve activation to reveal changes in facial nerve stimulation thresholds. Variations occur in an unpredictable fashion suggesting the need for monitoring in affected children.

1. Cushing, S.L., Papsin, B. and Gordon, K. A. Incidence & Characteristics Of Facial Nerve Stimulation In Children With Cochlear Implants. The Laryngoscope. 2006; 116(10):1787-1791.
2. Smullen JL, Polak M, Hodges AV, Payne SB, Telischi FF and Balkany TJ. Facial Nerve Stimulation after Cochlear Implantation. Laryngoscope. 2005; 115:977-982.

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B39. FACIAL NERVE STIMULATION FROM COCHLEAR IMPLANTS OCCURS ALONG THE ENTIRE IMPLANT ARRAY

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BACKGROUND. Facial nerve stimulation is a known complication of cochlear implantation. Using electrophysiologic methods, we have recently shown that nearly 50% of paediatric implant users are at risk for non-auditory stimulation including facial nerve activation.[1] It has been suggested but not confirmed that mid-array electrode contacts are most likely to elicit facial nerve stimulation given their proximity to the labyrinthine segment of the facial nerve.

OBJECTIVES. To determine which electrodes within the implant array were most likely to elicit stimulation of the facial nerve using objective measures.

METHODS. Evoked auditory brainstem responses (EABR) and surface facial electromyography (EMG) were prospectively performed post-operatively in children (n = 44). Responses were evoked by single biphasic monopolar pulses delivered by individual implant electrodes at 11 Hz. EABRs recorded in the same fashion in 121 children in a separate study were also reviewed for evidence of facial nerve signals. In all children a minimum of 3 implant electrodes were tested including a basal (3), mid-array (9 or 16) and apical (20) electrode. In several cases, additional electrodes were also tested.

RESULTS. EMG evidence of facial stimulation was present in 68 of165 (41%) children and multiple electrodes were tested in 53 patients. In 89% of children myogenic signals were evoked by all electrodes tested. The threshold for activation varied across the array but there were no statistically significant differences between the mean thresholds eliciting facial nerve stimulation for different electrode locations ($F(df_{model}= 3, df_{residual} = 106) = 0.54$, $p = 0.6529$).

CONCLUSIONS. Activation of the facial nerve by a cochlear implant is not limited to the mid portion of the array. Our evoked EMG recordings suggest that when facial nerve activation is present, all implant electrodes are likely to evoke a myogenic response. This finding may call into question current theories regarding the spread of current through low impedance pathways between the basal turn of the cochlea and the labyrinthine segment of the facial nerve.

Cushing, S.L., Papsin, B. and Gordon, K. A. Incidence & Characteristics Of Facial Nerve Stimulation In Children With Cochlear Implants. The Laryngoscope. Oct 2006; 116(10):1787-1791.

Support provided by CIHR, PSI Foundation, Alfred Bader Fellowship in Memory of Jean Royce and the Chapnik, Freeman, Friedberg Clinician Scientist Award

C1. LASER STIMULATION OF THE AUDITORY SYSTEM: SELECTIVITY AND OPTICAL PARAMETERS

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Light can artificially stimulate nerve activity in vivo. A significant advantage of optical neural stimulation is the potential for higher spatial selectivity when compared with electrical stimulation. An increased spatial selectivity of stimulation could improve significantly the function of neuroprosthetics, such as cochlear implants. Cochlear implants restore a sense of hearing and communication to deaf individuals by directly electrically stimulating the remaining neural cells in the cochlea. However, performance is limited by overlapping electric fields from neighboring electrodes.

Here, we report on experiments with a new laser, offering a previously unavailable wavelength, 1.94μm, and pulse durations down to 1μs, to stimulate cochlear neurons. Compound action potentials were evoked from the gerbil cochlea with pulse durations as short as 1μs. Results indicate that there is anoptimal pulse duration over which to deposit the laser energy.

In addition, we report on the spatial selectivity of optical stimulation in the cochlea with a novel method: tone-on-light masking. For the measurements, the probe response was evoked with light and was masked with a continuous acoustic tone. In a similar manner to tone-on-tone masking, the masker level was determined such that it reduced the laser evoked CAP by a constant fraction. From this method, we constructed tone-on-light masking curves to indicate the corresponding region of the cochlea that the laser is stimulating. Tone-on-light masking studies revealed tuning curves of optically stimulated cochleae that exhibit best frequencies between 6 – 11 kHz and Q_{10dB} ratios between 2 – 7. Tone-on-tone masking data and tone-on-electric masking data will be provided for comparison.

This project has been funded in whole or in part with federal funds from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health, Department of Health and Human Services, under Contract No. HHSN260-2006-00006-C / NIH No. N01-DC-6-0006, by NIH Grants R41 DC008515-01 and F31 DC008246-01, and the E.R. Capita Foundation. The authors from Northwestern University and Vanderbilt University have no financial interest in Aculight Corp.

C2. A NEW CONCEPT IMPLANTABLE HEARING AID

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The development of implantable hearing aids has been attempted for more than three decades. To date, there has been no long-term device successful enough to compare with the advances in cochlear implant technology. This may well be related to the fact that most of the attempts at producing an implantable hearing aid have involved placing mechanical devices in the middle ear and usually making some connection to the ossicles. This may disturb the functioning of the ossicles, or interfere with their blood supply which is largely on their surface. These considerations led to the writer's development in 2002 of a device which applies the sound to the dura and hence to the cerebrospinal fluid and brain. There is evidence in the literature that such an approach could be suitable and indeed we now have proof of its efficacy.

Since 2003, we have tested the concept of the new implant in humans under general anaesthesia during cochlea implant surgery*. The surgical dissection allowed of examination of the skull, an island of bone on the dura, and other structures, including the round window membrane. A laser Doppler vibrometer was used to measure movements of the individual structures while various elements were vibrated with a transducer from the BAHA device. The efficacy of stimulating via the dura and cerebrospinal fluid was shown in 2005 and subsequently. This indicates that a new method has been found for the delivery of sound to the cochlea in an implantable device. Recent tests, again in humans under general anaesthesia, confirmed these findings over the whole range of frequencies used by the human ear and the findings were reproducible. The concept of a “third window” for the cochlea is advanced.

This use of the information concerning the pathways of sound in the human head, allows for a safe, short surgical procedure, preservation of the ossicles and middle ear, avoidance of surgery near the facial nerve, and yet with total implantation and with adequate enhancement of hearing. It has the added advantage of transmitting bilaterally to the cochleae from a unilateral implant. It is also ideal for use with a cochlea implant in patients with some residual hearing.

This poster presents the new understanding of the pathway taken by “bone conduction” sound waves in the human head and the history of the development of this concept.

I wish to acknowledge Cochlear Limited for sponsoring this work and Professor Thomas Lenarz of Hannover Germany and his team for performing the tests.

C3. SPECTRAL SPECIFICITY OF SURFACE AND PENETRATING COCHLEAR NUCLEUS STIMULATING ELECTRODES

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A central auditory prosthesis based on a combination of macroelectrodes on the surface of the cochlear nucleus (CN) and penetrating microelectrodes within the nucleus can restore useful hearing to persons whose auditory nerve has been destroyed bilaterally and cannot benefit from cochlear implants. In adult cats, we compared the ability of penetrating microstimulating electrodes and surface macroelectrodes on the dorsolateral surface of the nucleus to selective access the tonotopic organization of the ventral cochlear nucleus. We used modified version of our microstimulating cochlear nucleus arrays, with 16 microstimulating sites on 4-shanks, and with 2 surface macroelectrodes (geometric area of approximately 0.4 $mm^{2)}$. Multiunit neuronal activity was recorded at 16 sites along the tonotopic gradient of the central nucleus of the contralateral inferior colliculus (ICC), while stimulating in the contralateral ventral cochlear nucleus with either the surface electrodes or the intranuclear microelectrodes. As determined from the spatial-temporal image of the neuronal activity in the ICC, the ensemble of penetrating microstimulating electrodes were able to access the tonotopic organization of the ventral cochlear nucleus in an orderly manner. For each electrode site and each stimulus amplitude, the spectral selectivity of the surface electrodes and penetrating microelectrodes was quantified as the ratio of the total recorded induced neuronal activity and the dispersion of the neuronal activity along the tonotopic gradient of the ICC. By this measure, the spatial selectivity of the surface and penetrating electrodes were similar near the response thresholds, but the selectivity of the penetrating microstimulating electrodes was greater when the total neuronal activity was greater. Therefore, the spectral selectivity of the penetrating microelectrodes was greater over the full dynamic range of the induced neuronal activity. The latencies of the centroids of the multiunit responses induced in the ICC were significantly different for the surface and microelectrodes, indicating that they were activating different neuronal pathways from the cochlear nucleus to the ICC.

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C4. AUDIOLOGICAL RESULTS WITH IMPLANTABLE HEARING DEVICE VIBRANT SOUNDBRIDGE IN MODERATE TO SEVERE MIXED HEARING LOSS

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Introduction: Hearing rehabilitation of moderate-to-severe mixed hearing loss with conventional hearing aids often presents insufficient improvement of hearing and speech discrimination. Application of implantable hearing devices to bypass the disordered middle ear may be a good possibility for such patients. An important advantage of these methods is preservation of residual cochlear hearing.

Methods and patients: In a new application of the implantable hearing device Vibrant Soundbridge (VSB) for treatment of mixed hearing loss, the stimulating transducer is implanted in the round window niche, on the round window membrane. In a clinical study, 5 patients with mixed hearing loss were implanted with this approach. Audiological tests consisting of pure tone audiometry (air and bone conduction), free-field audiometry, speech audiometry (SRT and SDS) and speech-in-noise test were performed with conventional hearing aids and VSB pre- and post- operatively.

Results: Post-operative results of the first 5 patients showed an average functional gain of 46 dB by VSB and 32 dB by conventional hearing aids. Particularly, there was a considerably higher functional gain for the frequencies above 1.5 kHz by VSB. In speech discrimination tests presented at 65 dB SPL, an average discrimination score of about 63 % was measured when using VSB whereas with conventional hearing aids a score of 33 % was achieved.

Conclusion: Implantation of a Vibrant Soundbridge middle ear implant on the round window membrane provides more effective amplification and better speech discrimination for patients with moderate-to-severe mixed hearing loss as compared to conventional hearing aids.

C5. NOVEL STIMULATION OF THE COCHLEA USING MECHANICAL EXCITATION VIA THE ROUND WINDOW

Jane M. Opie, Peter Lampacher, and Geoffrey R. Ball

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The Vibrant Soundbridge (VSB) is a middle ear hearing implant designed to augment hearing, using "direct-drive" stimulation of the auditory system via amplification of ossicular motion. The implant system is currently indicated for adults with sensorineural hearing loss of moderate-to-severe degree. Recently, however, the VSB has been applied to conductive and mixed hearing losses by placing the floating mass transducer (FMT) in the round window niche to deliver mechanical excitation to the cochlea. This novel stimulation of the cochlea may provide a level of hearing to persons with a variety of middle ear pathologies that may preclude the use of a traditional hearing aid, either due to medical reasons or because of very high acoustic hearing thresholds. Because residual cochlear hearing is often quite good in these cases, excitation of the cochlea may offer usable auditory information even to persons with poor air conduction thresholds.

Early pre-clinical and clinical evaluations of mechanical excitation of the cochlea via the round window have included laser-doppler-vibrometry, auditory brainstem response, and electrocochleographic measures. Data collected to date have suggested the practical equivalence of cochlear stimulation via ossicular and round window pathways. Those data will be reviewed here. In addition, alternative technical solutions to direct acoustic cochlear stimulation will be presented. The new techniques to stimulate the cochlea may also be suitable for providing fine structure information using combined electrical and mechanical stimulation, or electro-mechanical stimulation.

C6. RESULTS OBTAINED WITH THE BONE ANCHORED HEARING AIDS (BAHA) IN FUNCTION OF THE BONE CONDUCTION THRESHOLDS

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Objective: Evaluation of the results obtained with the BAHA in function of the average bone conduction (BC) thresholds in the to-be-stimulated ear performed in patients with the classical BAHA indications and in patients with single-sided deafness (SSD).

Study Design/Methods: Retrospective questionnaire-based evaluation performed in a tertiary otological care centre.

Outcome measures: Visual analogue scale of the general subjective satisfaction with the BAHA (score between 0-10) and the frequency of BAHA use in the week (5 categories).

Patients: Patients older than 10 years, wearing a BAHA Classic/Compact/Divino for more than 6 months. Of the participating patients 48 had the classical BAHA indications (bilateral aural atresia or bilateral chronical otitis with no possibility for wearing classical hearing aids) and 32 had a unilateral sensorineural hearing loss were the BAHA functioned as a transcranial cross.

Results: Responder rate was 94% for the classical indications and 97% for the SSD-population. For both indications there were no significant correlations found between the BC hearing thresholds and the outcome measures, the borderline patients were equally satisfied as the within-the-criteria patients.

Conclusions: 1.) In patients with the classical BAHA indications, the audiometrical 45 dB_{HL} average BC cut-off criterion may not be considered as an absolute, but rather as a relative indication criterion for the BAHA Compact/Classic/Divino. Patients with the average BC between 45 and 60 dB_{HL} show no statistically significant differences in the subjective satisfaction scores or the frequency of the BAHA use.

2.) In patients with SSD the cut-off criterion of 20 dB_{HL} at the ear with the better BC is too conservative and could be lowered to 40 dB_{HL}.

3.) Relatively large variability of the satisfaction scores and the frequency of the BAHA use in patients with SSD creates a necessity for setting up additional (e.g. socio-economic) indication criteria. Full “patient-profiling” comprising the multiple regression analysis of various otological and non-otological criteria would potentially improve the results of the BAHA application in the SSD group.

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C7. SPEECH AND LANGUAGE DEVELOPMENT IN CHILDREN WITH BILATERAL COCHLEAR IMPLANTS

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The efficacy of cochlear implants in providing the auditory input essential for language is now well established. A relatively new advance in the treatment of hearing impairments in children is the simultaneous or sequential implantation of a second CI. There are obvious advantages to having a second implant such as better localization of sound and some assumed advantages for auditory sensitivity, auditory perception, speech perception, as well as in the development of speech and language. The present study will focus on the latter potential benefits of bilateral implantation for young children.

In this preliminary study, we have selected six children (more will be added as subjects become available) with bilateral CIs who have been tested before and after their first implant and after the implantation of the second device. We have also selected six children with a single implant who are individually matched for age, gender, age of implant, implant experience, post implant auditory sensitivity in one ear. Thus, we examined the performance of children with bilateral CIs in relation to their own performance prior to receiving a second CI as well as to a peer with a single CI who is matched as closely as possible. We also compared their performance to children who have received simultaneous bilateral implants.

We examined the children's auditory sensitivity in the first implanted ear and bilaterally before and after their first implant and for the children with a second implant before and after that implant. Word recognition scores from age-appropriate standardized instruments were also compared under various listening conditions. Standardized speech and language scores along with measures derived from language samples were also compared.

Preliminary analyses suggest substantial advantages following the second implant for word recognition and auditory sensitivity. Smaller advantages we noted for language on standardized measures. We suspect that more detailed non-standardized testing of speech perception, language comprehension, and language production will reveal additional differences before and after the second implant as well as substantial differences over time as compared to the outcomes for a single implant despite potentially confounding factors such as pre-implant status of the second ear.

C8. DEVELOPING A SPEECH PERCEPTION TEST PROTOCOL FOR CHILDREN

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Speech perception testing is a critical part of candidacy determination and monitoring of cochlear implant progress. In the early years, cochlear implant candidates had very profound hearing losses and test protocols were designed for patients with limited hearing. With changes in technology and advances in auditory therapy, patients who have more hearing are being considered candidates. In addition, clinicians are trying to demonstrate benefit for patients with bilateral cochlear implants, bimodal patients with one cochlear implant and one hearing aid, and for patients with short electrodes.

While evaluation protocols are fairly well defined for adults, speech perception test protocols for evaluating performance infants and children are less clear. Clinicians frequently assume that children will not be able to perform on difficult tests and select easy tests which are administered at loud levels in quiet.

To demonstrate benefit for infants and children, a speech perception protocol needs to be developed which can assess performance in more difficult listening conditions than have been routinely used. Testing at normal and soft conversational levels in quiet and in competing noise can provide a great deal of important information for making candidacy decisions and for monitoring progress post implantation. Vocabulary levels as well as auditory skills contribute to the difficulty of selecting an appropriate test for an individual child. This presentation will discuss development of a speech perception test protocol for young children including a criteria tree for selecting which test to begin with, as well as for determining how to proceed during the evaluation process, determining when to move to more difficult or easier tests. Suggestions for determining test levels, for testing in quiet and with competing noise will be presented. A protocol will be suggested which can be used by clinicians in a variety of settings to assist in determining candidacy and in monitoring progress will be proposed.

C9. THE EFFECT OF INSTANTANEOUS INPUT DYNAMIC RANGE SETTING ON THE SPEECH PERCEPTION OF CHILDREN WITH THE NUCLEUS 24 IMPLANT

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This study examined the effects of two instantaneous dynamic range (iidr) settings (30 and 40 dB) of the Freedom Speech Processor™ on the performance of 30 children (7-17 yrs) implanted with the Nucleus 24. Prior to this study they used a 30-dB iidr with their 3G or SPRint processor. Performance was evaluated in the sound field with recorded Consonant Nucleus Consonant (CNC) words at 50 & 60 dB SPL in quiet; Bamford-Kowal-Bench Sentences presented at 65 dB SPL in 4-talker babble noise (BKB-SIN Test; Killion, 2004), and aided thresholds for Frequency Modulated (FM) tones. CNC words were scored in percent correct; BKB-SIN test was scored in signal-to-noise ratio (S/N) for 50% correct words. The same speech processor MAP, sensitivity and volume control settings were used by each child for both iidr settings.

Results revealed that mean group thresholds were significantly better with the 40 iidr ($F(1,58)=33.5$, $p<.001$). Group mean CNC word scores at 50 dB SPL were significantly better with the 40 iidr (59.2% vs. 47.8%, $p< .0001$). CNC word scores at 60 dB SPL and BKS SIN scores at 65 dB SPL were not significantly different for the two iidr settings.

It was concluded that an iidr of 40 provided significantly better sound-field thresholds and this enabled the children to achieve significantly better CNC word scores at 50 dB SPL by making more sounds audible and recognizable. Sentence and word recognition in quiet and noise (60 & 65 dB respectively) were not significantly different between the two iidr settings thus, improved aided thresholds and recognition of soft speech does not compromise recognition of higher level speech and speech in noise. All children continued to use the 40 iidr setting in their preferred MAP.

Research supported by NIDCD grant R01DC000581; Freedom speech processors provided by Cochlear Americas.

C10. LOCALIZATION ACUITY IN TODDLERS WHO USE BILATERAL COCHLEAR IMPLANTS

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There is a growing clinical trend in which children who are deaf are receiving bilateral cochlear implants at decreasingly younger ages. Although there is general agreement that better communicative and educational outcomes are achieved when the first implant is provided by 12 months of age, there are little behavioral data showing the functional benefits of providing these toddlers with two cochlear implants. One potential benefit of bilateral cochlear implants is improved spatial hearing, which develops within the first few years of life. Providing bilateral input to very young children who are deaf may allow spatial hearing to emerge more rapidly, and thus reach age-appropriate acuity sooner.

In the present study, we employed methods that are well established for use with typically-developing children to investigate the emergence of spatial hearing in toddlers who use unilateral or bilateral cochlear implants. The Bilateral group includes toddlers who received their second implant by 30 months of age and who have had bilateral input for at least 6 months (n=8). The Unilateral group includes age-matched toddlers who use a single implant alone (n=7). Spatial hearing was assessed with a 2-AFC, right/left discrimination task. The observer-based psychophysical method (Olsho et al., 1987, *Dev Psychol.*) was used to quantify performance in two ways: 1) calculating performance for a fixed angular separation between the right and left loudspeakers; and 2) estimating the minimum audible angle (MAA) with an adaptive procedure.

Preliminary results show that spatial hearing is emerging in the Bilateral group but not yet in the Unilateral group. Within the Bilateral group, performance appears to be better when toddlers use both of their implants versus one implant alone. In addition, performance appears to improve with longer durations of bilateral input. Although these data are preliminary, they are among the first to show spatial hearing abilities in very young children who use bilateral implants. As more data are collected, this work may contribute information about the development of auditory abilities in young children with cochlear implants.

This work was funded by NIDCD R21DC006642 (Litovsky), NIDCD F32DC008452 (Grieco), and in part by Cochlear Americas and Advanced Bionics (subject travel).

C11. IDENTIFICATION OF TONAL PATTERNS IN COMPETING BACKGROUNDS BY CHILDREN AND ADULTS WITH COCHLEAR IMPLANTS OR IMPLANT-PROCESSING SIMULATIONS

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Relatively little is known about the ability of cochlear-implant (CI) users to segregate sound sources based on pattern/background dissimilarity. For normal-hearing (NH) adult listeners, pitch cues are important for segregating auditory objects; however, CI users have much more limited spectral information available. Further, studies of NH children indicate that sound-segregation abilities change with development. This study used tonal patterns in quiet and embedded in various backgrounds to assess pitch-based sound segregation for children (age 6-12 years) and adults with CIs or with NH using CI simulations. Listeners with NH were tested with and without sine-wave vocoder-processed stimuli to simulate CI processing. CI listeners were tested using a common set of stimuli designed to stimulate the same frequency ranges and number of electrodes across devices in sound-field conditions. The task was to identify which of four 8-tone sequences (patterns) was presented, either in quiet or in competing backgrounds, using a 4-AFC procedure. Patterns differed in overall pitch contour: ascending, descending, flat, and alternating. Across conditions, endpoints of the pattern-frequency ranges were selected to correspond to separations of 0 (adjacent), 1, 2, or 3 electrodes, centered at the middle of the electrode array. Pattern identification (ID) in three types of backgrounds was tested: 1) wide-band noise (WBN); 2) two fixed-frequency tones (FF2), and 3) two random-frequency tones (RF2). Backgrounds were comprised of eight bursts (coinciding with each pattern tone). Stimulus design was motivated by previous work with NH adults showing performance differences across analogous conditions. The S/N ratio for 70% correct was achieved by increasing background levels until performance reached chance.

Data are being collected and will be reported in terms of differences between the NH and CI groups and separating effects of development and CI use for the performance of children. Based on preliminary results, it is expected that both NH children and CI users will have greater difficulty with WBN than NH adults, but listeners in all groups will show varying degrees of ability to use pattern/background spectral dissimilarity to aid performance for patterns in backgrounds. The generality of this approach for testing the development of sound-segregation abilities and improvements in pitch-perception for children and adults with CIs will be discussed.

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C12. EARLY SEQUENTIAL BILINGUALISM FOLLOWING COCHLEAR IMPLANTATION

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Objectives: The purpose of this single-case study was to document the lexical development in Spanish and English in a child following cochlear implant activation at 20 months-of-age and to compare those results to typical early sequential bilingual development and theoretical models of bilingualism.

Method: Language data were obtained from both parents and school personnel. During his first year post implant all speech, language and hearing services were provided in Spanish. At 1 year post-implant, he entered an oral program for the hearing impaired in an English environment. The participant is learning language via an auditory-oral approach. Although the child's parents are monolingual Spanish speakers, the participant's older sibling is a balanced late sequential Spanish-English bilingual. Vocabulary development in Spanish and English were measured by the MacAurthur Child Development Inventory through 3.5 years post-implant. The preschool teacher completed the MacAurther in English. The parent supplied the information regarding Spanish Acquisition. Specific questions addressed were how the lexical development in our Spanish-English emerging bilingual compares to other typically developing bilingual toddlers. How does this information inform our practice of aural habilitation with minority language families?

Results: Vocabulary development in both English and Spanish are proceeding at a steady pace with little overlap in vocabulary words. Some code mixing on specific words has been noted at 22 months post implant. Lexical development is similar to typically developing children acquiring early sequential bilingual skills. Lexical development showed little overlap in the lexicon which is normal. Assessment in L1 or L2 in isolation underestimates the language abilities of a bilingual child.

Conclusions: Language development data suggests children can develop simultaneous bilingual language skills. This development mirrors that of typical early sequential bilinguals in lexical development. Clinical application of these findings suggests the assessment of language skills in both L1 and L2 to obtain an accurate record of language development in these children.

C13. NEURAL TONOTOPY IN CI: AN EVALUATION IN UNILATERAL CI PATIENTS WITH CONTRALATERAL NORMAL HEARING

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Objectives: In actual cochlear implant systems the signal is filtered into different frequency bands and transmitted to electrodes along the cochlea which elicit different pitch perceptions. The study is investigating the frequency-place map for electric hearing in order to improve current speech coding strategies by delivering the spectral information of the incoming signal to the appropriate cochlear place.

Methods: Subjects with no or minor hearing loss at the contralateral ear have been provided with a MED-EL C40+ or Pulsar100 cochlear implant in order to reduce their tinnitus. These subjects are unique in a way that they can directly compare acoustic and electric hearing. First the acoustic and electric stimuli are compared regarding their perceptual dissimilarities in a multidimensional scaling task. The stimuli consist of 5 electric stimuli between E2 and E10 and five acoustic stimuli (sinusoids logarithmically spaced between 150 and 3790 Hz). Second a pitch scaling is performed with each of 12 electrodes and 12 acoustic stimuli (sinusoids logarithmically spaced between 100 and 8500 Hz).

Results: The frequency-place map is calculated according to the exact electrode position in the cochlea obtained by postoperative skull radiographs by means of a cochlear view and are compared to the Greenwood mapping.

Conclusions: Electrical stimulation with a constant stimulation rate elicits a low pitch perception in the apical region of the cochlea and shifting the stimulating electrode versus the basal region of the cochlea elicits an increasingly higher pitch perception. The frequency-place functions obtained with our subjects fall within 1 octave from the Greenwood function.

The results of the presented study are important for future speech coding strategies because they indicate a frequency-electrode allocation which delivers each frequency component of a signal to the place where its pitch is elicited by electrical stimulation of the cochlea.

C14. COCHLEAR IMPLANTATION AS A TREATMENT FOR UNILATERAL DEAFNESS ASSOCIATED WITH IPSILATERAL TINNITUS: A CASE STUDY

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Even though tinnitus is a widespread disease no universal cure is available today. Several treatments, such as retraining or masking, are based on acoustic input. Therefore, those treatments do not succeed in subjects who are deaf in the ear suffering from tinnitus. However, tinnitus suppression utilizing electrical stimulation of the auditory nerve has been reported to be successful by various research groups.

A study was initiated to investigate whether cochlear implantation is an appropriate treatment for unilaterally deafness associated with ipsilateral tinnitus. The HiRes 90K implant system offers a high stimulation rate combined with a high update rate allowing detailed transmission of the sound information in the time domain. This may help to increase the acceptance of the cochlear implant's sound quality for subjects with normal hearing on the contra-lateral side. Further increase in sound quality may be provided by a new technique called current steering. Current steering increases the number of stimulation sites above the number of contacts on the electrode array thereby increasing precision in the frequency domain.

To date two one-sided deafened subjects with completely normal hearing in the contralateral ear have been enrolled, one of them implanted in October 2006. The implanted subject reports reduced strain from his tinnitus and benefit in situations with competing noise; even though the benefit was not found consistently in objective tests. In everyday life he relies on his normal hearing ear which results in only little training of the implanted ear compared to regular cochlear implant subjects. While speech perception tests show a benefit from the cochlear implant the scores are lower than typical for regular users.

Detailed results of the effect of the electrical stimulation on tinnitus as well as data on the regained hearing with respect to speech perception in noise, directional hearing and pitch matching will be presented.

C15. VISUAL SYSTEM CROSS-MODAL PLASTICITY AND SPEECH PERCEPTION WITH A COCHLEAR IMPLANT

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Length of auditory deprivation has been shown to be negatively correlated with speech perception ability after cochlear implantation in severe to profoundly deaf individuals. We suggest the development of cross-modal plasticity during this period of auditory deprivation plays a role in limiting the brain's ability to process speech after prolonged periods of auditory deprivation. In deaf adults, auditory processing areas in the right temporal lobe have been shown to process peripheral visual motion. This remapping of cortical function may be limiting speech perception ability in cochlear implant recipients with prolonged periods of auditory deprivation. This investigation examined the relationship between speech perception with a cochlear implant and the presence of visual/auditory cross-modal plasticity. We measured the cortical evoked response to peripheral visual motion and speech perception ability in quiet and noise in individuals with cochlear implants. The amplitude of the evoked response to peripheral visual motion was recorded using a 64 channel electrode cap The amplitude of the N1 evoked response over the right temporal lobe (electrodes FT8, T8 and TP8) was averaged. The Hearing in Noise Test (HINT) was used to measure speech perception ability in quiet (HINT-Q) and with a +10 signal-to-noise ratio (HINT+10)

Preliminary results with nine adult cochlear implant participants revealed a significant negative correlation between the amplitude over the right temporal lobe of the evoked response to peripheral visual motion and speech perception ability in both quiet and noise. As the amplitude of the N1 response over the right temporal lobe increased, the HINT-Q score decreased. This negative correlation was significant R^2=0.4604, F(1,8), p<0.05. Likewise, as the amplitude of the N1 response over the right temporal lobe increased, the HINT+10 score decreased. This relationship was also significant R^2=0.5176, F(1,8), p<0.05. These results suggest that speech perception ability with a cochlear implant is negatively influenced by the development of cross-modal plasticity.

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C16. A REAL-TIME HYBRID SOUND PROCESSING RESEARCH PLATFORM FOR THE NUCLEUS® SYSTEM

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A hybrid cochlear implant system is one in which both acoustic (via a hearing aid receiver) and electric (via an electrode array in the cochlea) signals are delivered simultaneously to one or both ears. To aid in the development of hybrid signal processing schemes, a real-time research platform has been developed using the PC-based signal processing tool, xPC, from The Mathworks. xPC runs on a standalone Intel-based PC using signal processing models developed in Simulink. This system allows rapid development and real-time evaluation of new signal processing approaches. A combined hardware-software platform has been built supporting up to 12 high quality audio inputs and 8 high quality outputs, simultaneously with stimulation command streaming to one or more Nucleus implants. Any combination of audio input, output and Nucleus 22, 24 or Freedom implants is supported. By connecting an audio output to a suitable hearing aid receiver, hearing aid signal processing may be combined simultaneously with cochlear implant signal processing for hybrid studies. The commercially available algorithms for the Nucleus system including SPEAK, ACE, CIS, SmartSound™ (Whisper™, ADRO™, ASC and Beam™) are all supported.

Using several audio inputs simultaneously also allows studies into multi-microphone noise reduction algorithms such as SmartSound Beam™. Several dual-microphone behind-the-ear housings have been built, based on the Nucleus Freedom sound 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. To further evaluate multi-microphone algorithms, a separate 3-dimensional (3D) measurement system has been constructed (not based on xPC), which is capable of measuring the response of a hearing instrument from all directions. Directional microphones are traditionally measured in a horizontal plane producing the familiar 2D polar plot. However, due especially to head and torso effects a 3D measure is more informative.

Further details and capabilities of the platform will be presented, along with plots using the 3D microphone measurement system.

C17. MECHANICAL EFFECTS OF THE CI - ELECTRODE IN THE COCHLEA

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The implantation of a cochlear implant (CI) electrode in patients with residual hearing requires a better understanding of the electrode's mechanical effects on the basilar membrane (BM) displacement. Especially the combined electrical and acoustical stimulation (EAS) produced interest in the mechanical influence of the CI electrode.

Therefore we used slices of anatomical data from a µCT and reconstructed a 3D-model of the inner ear using one human temporal bone. Because the resolution of the µCT was not less than 50µm the BM could not be identified sufficiently. Thus the BM was inserted subsequent by a CAD Software (CATIA) starting from the Lamina spiralis ossea, which could be barely located from µCT data. Additionally the curved cochlea-implant (CI) electrode was included (C40+ M, Med-El).

The resulting data set was transferred to a finite-element software (ANSYS) and three different states were examined.

1. The BM displacements with sinusoidal stimulation and wave propagation (WP) in case of the mechanically undisturbed cochlea.
2. The BM displacements during WP with the CI present in the Scala tympani of the cochlea .
3. The BM displacements during WP with the CI present and in contact with the BM at preset sections.

To minimize the acoustic trauma the contact between the electrode and the BM is normally unwanted. But the results implement a hearing gain by fixation of the BM via the electrode in those regions where the inner hair cells are destroyed. In this case the external applied sound is mapped enlarged to those regions where the BM is yet able to vibrate (Kiefer J. et al., Hearing Research, 221, 2006). Indeed, the fixation of the BM increases the BM displacement aside by up to 40 dB dependent on the frequency and the section where the fixation is applied.

For future applications we recommend the localization of BM regions with destroyed inner hair cells and then fix the BM by the CI electrode in those identified sections. Support provided by Med-El (Innsbruck, Austria & Starnberg, Germany)

C18. SPEECH RECOGNITION AS A FUNCTION OF THE NUMBER OF CHANNELS IN THE HYBRID COCHLEAR IMPLANT: QUIET AND BACKGROUND NOISE

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The hybrid (short-electrode) cochlear implant is designed to provide high-frequency information while preserving residual low-frequency acoustic hearing. Long-term speech recognition scores in hybrid patients with the implant alone are comparable to those of traditional long-electrode patients, despite the use of fewer active electrodes (5 or 6) and a shorter insertion depth in the cochlea (10 mm). The purpose of our study is to investigate how many of these channels (active electrodes) are being used, with implications for whether increasing the number of channels along this 10 mm implant would improve performance.

We investigated discrimination of 16 consonants in quiet and background noise as a function of number of channels. Subjects were tested using the implant only (direct-electric stimulation, N=7) and in the acoustic+electric in the same ear condition (through a speaker, N=5) using a speech processor programmed with maps consisting of 6, 3, 2, and 1 channels. Three subjects were also tested with maps consisting of 5 and 4 channels. In quiet, subjects showed no significant improvements beyond 2-4 channels in both test conditions, with less variability in the electric-only mode. The 3 best subjects were also tested in steady background noise (0, +5 dB SNR), and showed slight improvements with 5 or 6 channels over 4. These results are similar to previous studies of channel use in long-electrode subjects who plateaued at 4 channels, spaced 2-3 times farther apart than the on the hybrid, in quiet (Shannon et al., 1995) but used more channels in noise (Fu et al., 1998; Friesen et al., 2001). This implies that electrode interactions may not be the limiting factor for channel benefit, at least in quiet.

Normal hearing subjects were also tested using electric-only simulations of the hybrid implant (N=11). In quiet and in noise, subjects performed similarly to the best hybrid subjects, suggesting that those patients maximize use of the channels available. Overall, these results suggest that increasing the number of electrodes in the hybrid implant will not improve speech recognition in quiet, but may improve recognition in noise.

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C19. PREOPERATIVE PURE TONE THRESHOLD AND PERFORMANCE AFTER COCHLEAR IMPLANTATION

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Previous studies have shown that auditory deprivation leads to cortical reorganization. Thus, we hypothesized that residual hearing prior to cochlear implantation might facilitate later performance with the device. A retrospective statistical analysis was conducted with inclusion criteria as follows: a) adults with post-lingual hearing loss, b) unilateral implantation, c) pure-tone audiogram measured within 2 years prior to operation, d) complete set of speech performance data at 3, 6 and 12 months after first activation of the device, e) full insertion of the electrode, f) no revision surgery. 66 patients (37 females, 29 males), implanted with the MEDEL Combi40+ or PulsarCI100 device, met all criteria and were included in the study.

Our speech test battery consisted of Freiburg numbers and monosyllables as well as HSM-sentences in quiet. Based on the last puretone audiogram, preoperative hearing on the implanted and the contralateral ear was categorized into 4 groups: 1) deafness, 2) pantonal sensorineural hearing loss above 60 dB HL, 3) residual low frequency hearing (in 2-3 frequencies below 1 kHz), and 4) fair low frequency hearing (20-60 dB HL) in at least 2 frequencies below 1kHz with additional residual hearing above 1kHz. Speech performance at each test interval and percentage gain between two intervals were analyzed depending on preoperative hearing.

Low frequency residual hearing (type 3+4) was evident in 17 out of 66 patients prior to implantation, pantonal sensorineural hearing loss and deafness was found in 20 and 29 cases respectively. One-way ANOVA did not reveal a statistically significant influence of preoperative pure tone threshold of the implanted as well as the contralateral ear. Group means of speech perception and gain over time did not differ significantly at any of the test intervals, although a trend to better scores in patients with some low frequency residual hearing on the contralateral ear (group 3 and 4) was seen.

As indicated by the slightly higher scores in patients with type 3 and 4 thresholds, residual hearing on the contralateral ear seems to have a supporting effect on performance after cochlear implantation. However, statistical power estimation revealed, that a much higher number of cases would be necessary in order to demonstrate statistical significance at the observed level of differences in the means of the groups.

C20. PRESERVATION OF RESIDUAL HEARING WITH A NEW STRAIGHT ELECTRODE

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Cochlear implants have proven to be successful for hearing restoration in deaf patients. Currently patients with well-preserved hearing in the low- and mid-frequency range are becoming candidates due to improved electrode technology and appropriate surgical insertion technique. A new “Hybrid-L” electrode has been designed for the Nucleus® Freedom™ CI. The Hybrid-L electrode is a custom straight electrode that is smaller in diameter compared to a standard Contour electrode resulting in an improved flexibility and reduced insertion trauma. It has 22 modiolus facing contacts spread over 15 mm with an overall insertion depth of 16 mm. The electrode is designed for a round window insertion.

After completion of a temporal bone trial and verification of the electrode design, a clinical trial has been started at the Medizinische Hochschule Hannover (MHH) and at the University of Melbourne in order to investigate the preservation of residual hearing after implantation of the Hybrid-L electrode. An additional goal is to determine whether speech understanding can be enhanced by combined electrical and acoustical stimulation while maintaining preoperative levels of acoustic hearing.

Twenty three patients with a mild to moderate hearing loss for frequencies $\leq$ 1500 Hz have been implanted with a Nucleus® Hybrid-L Implant. A single subject design with repeated measures of unaided pure tone thresholds and speech performance is used comparing different modes of electro-acoustic stimulation. Test material has been Freiburg Monosyllabic words in quiet and Oldenburg Sentences in noise.

Preservation of residual hearing has been observed in all cases. The difference for the average threshold (125-1000 Hz) after implantation is less than 30 dB in 94.1 % of the cases and less than 15 dB in 82.3 % of the cases. All patients show a benefit in speech recognition in quiet and in noise from combining CI and HA over the use of the CI alone and the HA alone. In combination with the full flexibility of a 22 channel array this results in a substantial functional benefit for the recipients.

Current research is focusing on additional benefits of acoustic hearing regarding spatial hearing abilities, listening in modulated noise and music perception.

C21. FITTING PARADIGM IN THE COMBINED ELECTRIC-ACOUSTIC STIMULATION (EAS)

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Previous experiments showed that both electric and acoustic parameters in EAS differ from electric or acoustic stimulation only. The goal was to develop a fitting paradigm for EAS with the new DUET Hearing System (Combined EAS device).

Twenty five EAS users with at least 12 months of experiences with their cochlear implants (CI) and 1 month with their hearing aids (HA) participated. Speech tests and subject's opinions were investigated and evaluated for each parameter change.

Several programming parameters such as low frequency slope, compression, AGC threshold and electric and acoustic frequency ranges play an important role in the fitting of EAS. The parameters are dependent on the amount of residual hearing. The optimized fitting rules for both the electric and the acoustic stimulation will be proposed.

Optimized programming has an effect on speech test performance and quality of hearing in EAS. The CI and HA parts may be programmed separately, but several aspects have to be taken into account.

C22. ADAPTATION TO CONFLICTING FREQUENCY-TO-PLACE MAPS IN SIMULATIONS OF BIMODAL LISTENING

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Many CI users have a degree of usable hearing in the unimplanted ear and recent studies have demonstrated better speech perception when a contralateral hearing aid (HA) is used with a CI. However, the processes involved in providing bimodal benefits are not well understood and there is considerable variability across studies, with some users gaining no significant benefit from the hearing aid and a few performing worse in the bimodal condition than with the CI alone.

One factor that may be important is the relationship between the frequency-to-place mapping provided by the implant and the HA. In the context of monaural CIs, it has been argued that speech recognition is hampered by a frequency mismatch between the filters in the speech processor and the characteristic frequencies of nerves at electrode locations. Although monaural CI users and normal listeners can adapt to mismatched frequency-to-place maps, it may be that mismatches of mapping between the two ears are problematic.

This study simulated in normal listeners an overlap of frequency coverage between the ear with a HA and a shifted map in the 'implanted' ear. Subjects were given 2½ hours of training, using Connected Discourse Tracking, in each of three noise-band vocoder 'bimodal/binaural' conditions. All three conditions provided information up to 800 Hz in the 'unimplanted' ear. The 'implanted' ear in Condition 1 provided information up to 3000 Hz but shifted up by the equivalent of 6mm along the basilar membrane. This produced a region of conflict where the same frequencies were encoded at mismatched places in the two ears. This conflict was eliminated in Condition 2 by presenting only information complementary to that received by the 'unimplanted' ear (from 800 Hz to 3000 Hz). In Condition 3, this same frequency range was presented to the 'implanted' ear but unshifted.

Subjects were tested before, during and after training using sentence, vowel and consonant materials in quiet. Binaural speech perception was significantly better than with either the 'implanted' or 'unimplanted' ear alone. Performance in Condition 3 was significantly better than in the other two conditions indicating that the shifted representations in the 'implanted' ear led to poorer binaural speech perception. Sentence scores for Condition 2 were significantly better than those for Condition 1 both pre- and post-training. Also, significant improvements across training were observed with Condition 2 but not with Condition 1. These results suggest that a region of conflict may have a detrimental effect on speech perception and on perceptual adaptation in bimodal hearing.

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C23. A COMBINED ELECTRIC/ACOUSTIC SPEECH PROCESSOR FOR COCHLEAR IMPLANT PATIENTS WITH PRESERVED ACOUSTIC HEARING

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Over 70 patients have received the Nucleus Hybrid cochlear implant system in the U.S. For patients with severe and profound high-frequency hearing loss, this device, with its 10 mm electrode array, allows electric stimulation of high-frequency hearing, while permitting low-frequency residual hearing to be stimulated acoustically. Results to date demonstrate that a short electrode array can be inserted into the cochlea without total loss of residual low-frequency hearing. Most patients show improved word understanding as well as improved speech perception in noise. Electric-acoustic hearing is currently delivered by the combined use of a cochlear implant and a conventional in-the-ear (ITE) hearing aid. This presentation describes clinical results for 12 subjects using a behind-the-ear processor that incorporates both electric and acoustic stimulation (Electroacoustic Speech Processor Investigational Device or EASPID), eliminating the need for patients to accommodate two independent hearing devices. The results of this study will be used to assess the viability of developing a commercially available speech processor that is capable of processing and stimulating patients electrically and acoustically. The study also examined hearing for speech in the presence of spatially separated competing noise (multitalker babble) to assess the potential benefits of preserved acoustic hearing in both ears.

Experienced Nucleus Hybrid patients were fitted with the EASPID and direct comparisons were made between the speech perception and subjective ratings of the EASPID relative to the subject’s own cochlear implant/hearing aid combination. Speech perception data indicated that the electroacoustic speech processor is capable of delivering equivalent levels of electric and acoustic stimulation to that provided by the patients’ own cochlear implant processors and hearing aids. Mean speech scores for speech perception in quiet and in noise were not significantly different nor were subjective ratings for various listening conditions. In addition, results for hearing in noise, where the target and competitor were spatially separated, illustrated the potential for improved hearing in noise when acoustic hearing is available in both ears, rather than in one ear contralateral to electrical stimulation via a cochlear implant.

C24. COCHLEAR IMPLANT : A PRELIMINARY STUDY TO ASSESS THE EFFECT OF ASYNCHRONY BETWEEN ACOUSTIC AND ELECTRICAL STIMULATION.

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Patients with usable amounts of residual hearing are starting to receive cochlear implants. In these cases, information provided electrically by the implant is combined with the acoustic information provided through the patient's residual hearing. Studies have shown that the combination of both modalities can lead to improvement in performance over electric stimulation alone (cf. Turner et al., 2004). However, different signal processing algorithms used in cochlear implant speech processors and hearing aids may introduce different processing delays and result in the loss of synchrony between electric and acoustic stimulation which may, in turn, affect speech perception by CI users who have residual hearing..

In our preliminary experiment, we tested CI users with residual hearing on a CNC word-recognition task. They were also required to rate the perceived speech quality during the task. Some listeners used their CI in combination with a contralateral hearing aid and others used a CI with short 10 mm electrode in combination with residual hearing from both ears. Four delay conditions between electric and acoustic stimulation were employed: 0ms, 50ms, 100ms, and 200ms. The conditions were presented to each listener in a pseudo-randomized order (Latin square design), with the acoustic stimulation delayed relative to the electric stimulation.

Results showed a trend for lower speech perception scores and lower signal quality ratings as delays in the acoustic signal with respect to the electrical signal increased. This suggests that optimization of speech perception by cochlear implant users with residual hearing may require at least a rough equalization of processing delay between the electric and acoustic stimulation.

This work was supported by grant R01-DC003937 from NIH/NIDCD.

C25. ACOUSTICAL FREQUENCY DISCRIMINATION AND SPEECH PERCEPTION IN NOISE IN EAS IMPLANTED EARS

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Objectives: The results of a recently published study with speech in noise stimuli delivered to a model with simulated cochlear implant speech processing and presented to normal hearing ears have shown, that the addition of low-frequency pitch cues can remarkably improve speech recognition in noise (Chang et al., 2006). A brainbased mechanism is assumed that uses the voice pitch cue in the lowfrequency sound to first segregate the target voice from the competing voice and then to group appropriate temporal envelope cues in the target voice for robust speech recognition under realistic listening situations. It is presumed, that this mechanism is responsible for the highly synergistic effects seen in combined electric and acoustic stimulation (EAS, Gstöttner et al., 2006). Therefore, a degradation of speech in noise performance of EAS implantees has to be expected if the mapping of small frequency deviations is damaged.

Methods: Frequency discrimination of implantees using combined electric and acoustic stimulation (EAS) was assessed by means of an adaptive procedure with a two-interval forced choice paradigm. The ears contra-lateral to the implanted side as well as ears of non-implanted patients with severe high frequency sloping hearing loss were tested additionally to collect reference data. EAS patients and candidates with sensori-neural hearing loss (SNHL) were recruited from the clinical program. EAS patients received either the MED-EL standard electrode or the recently introduced FLEX design with reduced diameter. Speech perception in noise was tested by means of the HSM sentence test (Schmidt et al., 1997).

Results: JNDF ranged from close to normal to grossly abnormal in either the EAS or the SNHL listeners. The median JNDF was 7.1% in the SNHL and 7.5% in the EAS group. There was no statistically significant difference in terms of JNDF between both groups of listeners. Currently, the so far obtained results show no correlation between speech perception in noise and JNDF.

Conclusion: Preliminary findings demonstrate that the insertion of an intra-cochlear electrode does not significantly hamper the average frequency discrimination ability in EAS patients.

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C26. BIMODAL HEARING AFTER CI IN UNILATERAL SENSORINEURAL DEAFNESAND TINNITUS

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Objectives: The aim of this clinical study was to assess speech understanding in noise and hearing-specific-quality-of-life effects of cochlear implantation in patients with a cochlear implant and contralateral functional acoustic hearing.

Methods: Eighteen subjects with a primary complaint of unilateral severe tinnitus that did not respond to conventional treatments received a cochlear implant. Nine of these subjects are normal hearing (NH-group) on the contralateral side, 9 use a hearing aid (HA-group). The subjects were tested in noise in 3 conditions: CI alone (using headphones), with their acoustic hearing alone, and with adding the CI to the acoustic hearing.

Results: All 18 patients use their cochlear implant every day, the whole day. They all reported benefit from bimodal stimulation. Results indicate that, when speech and noise are presented in front of the listeners, there is no significant difference between acoustic hearing alone and bimodal hearing, this difference being usually referred to as binaural summation. A significant squelch effect from adding the CI could be seen when noise was coming from the CI side for the HA-users, but not for the NH subjects.

Conclusions: Cochlear implantation can improve hearing capabilities in more difficult listening situations, although binaural effects were not always significantly present. There was no conflict between the hearing with CI and the hearing in the opposite ear. However, it has to be taken into account that the primary indication for cochlear implantation in these patients was the tinnitus reduction. The preliminary results of these eighteen subjects suggest that cochlear implantation is an adequate treatment providing improved hearing in unilateral profound sensorineural hearing loss combined with tinnitus.

C27. ANALYSIS OF A LARGE OBJECTIVE MEASURES DATABASE

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The objectives were to develop guidelines for using Compound Action Potential (eCAP) and Stapedius Reflex Threshold (eSRT) to optimise HiRes™ fittings by investigating the relationship between those objective measures and psychophysical data.

All subjects used a CII-Bionic Ear® or a HiRes®90K unilaterally. The eCAP was measured through Neural Response Imaging (NRI), with the SoundWave® software, on stimulating/recording pairs 3/1, 7/5, 11/9, 15/13. Measurements were taken intra-operatively, at first fitting, and after three, six and twelve months of use. Two NRI measures are defined: the threshold of NRI (tNRI), when the extrapolated NRI response would have a zero amplitude and the "1st NRI", when the NRI response typically has an amplitude between 20 and 50 μV and is the smallest response that may be identified visually. The eSRT was measured intra-operatively by visual detection of the stapes movement, using both single electrode stimulation and SoundWave® speech bursts where four electrodes were stimulated as a sequential group. Subjects were fitted using the SoundWave® default settings: speech bursts and automatic threshold calculation (10% of most comfortable levels (Ms)).

Data from 118 subjects across 14 clinics were evaluated. For the stapedius reflex, speech burst stimulation elicited a significantly higher success rate (sign test, $p<.05$ for electrodes 3, 7, 11, $p<.01$ for electrode 15) than single channel stimulation, 84% vs 64% respectively. The NRI success rate was 81% intra-operatively, increasing to 96% at six months of use. This difference was significant for all locations tested (sign test, $p<.05$ for electrodes 3 and 7, $p<.005$ for electrode 11 and $p<0.01$ for electrode 15). Each subject showed at least one NRI response. In spite of the measurement variability, correlations and Analysis of Variance could be conducted and showed that the electrodes could be split between apical (electrodes 3, 7) and basal (electrodes 11, 15). A multiple regression analysis generated a predictive model for the apical M levels in the congenitally deaf group of subjects, according to the following equation: $M = -43.37 + 0.14 \times IOeSRT + 1.39 \times FF1stNRI$, where IOeSRT is the intra-operative speech burst eSRT and FF1stNRI is the first fitting 1st NRI. The model was tested on the basal electrodes: the calculated basal Ms were correlated to the measured basal Ms (($R=0.638$, $p=0.014$). A paired sample t-test showed that there was no significant difference between calculated and measured basal Ms. This suggested that the model may be applied across the whole electrode array.

The above results produced useful insights into the behaviour of objective measures with respect to time, electrode, fitting parameters. The next steps will involve generalisation of the model to the entire population and investigation of a new NRI measurement method, likely to reduce the variability and to improve objectivity and quality.

C28. The NIC and NMT Research Tools forSpeech Coding Research

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The Nucleus Implant Communicator (NIC™) and Nucleus MATLAB® Toolbox (NMT) tools are two suites of software to be used for cochlear implant research. Research into sound processing algorithms for cochlear implants being broadly divided into two areas: modification of algorithm parameters, typically beyond that possible with clinical programming software, and the development of new processing algorithms. The tools were thus developed to allow researchers to quickly and easily create the necessary tools for both types of research. This much has been reported on previously – more recently these tools have been extended in a number of areas to better support the research. This poster aims to present on the additions to the both toolsets in the areas of latest generation implant support; support for new front end and pre-processing algorithms; and the provision of vocoder type models allowing implant processing simulations.

The NIC research tool provides for definition and delivery of stimulation patterns to the Nucleus range of cochlear implants. The second generation of this software now provides full support for the newer Freedom implant, with its higher stimulation rates, better current level resolution and improved evoked potential recording system. This support will allow research into signal processing algorithms that can better represent the fine time structures of the signal.

The NMT software suite is a toolbox for the MATLAB® software, now with additional models simulating the front end processing and pre-processing strategies included in the Freedom system. This allows research into the advanced features of the Nucleus signal processing strategies, in conjunction with the ability to select parameter values beyond what's possible with the clinical fitting software.

Also now included in the NMT are a set of vocoder type models allowing reconstruction, or resynthesis, of the processed audio signal. Using one of four types of resynthesis methods: sinusoid, noise, filtered impulses or filtered noise impulses, it is possible for a researcher to quickly gain an understanding of the signal processing algorithm being developed. The inclusion of these resynthesis models provide for a standard way to resynthesise stimulation patterns, either from a new/modified algorithm or from stimulation to be delivered.

C29. DESIGN FOR A SIMPLIFIED COCHLEAR IMPLANT SYSTEM

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A simplified cochlear implant system would be appropriate for widespread use in developing countries. Here, we describe a cochlear implant that we have designed to realize such a concept. The system implements 8 channels of processing and stimulation using the Continuous Interleaved Sampling (CIS) strategy. A generic Digital Signal Processing (DSP) chip is used for the processing, and the filtering functions are performed with a Fast Fourier Transform (FFT) of a microphone or other input. Data derived from the processing are transmitted through an inductive link using Pulse Width Modulation (PWM) encoding and Amplitude Shift Keying (ASK) modulation. The same link is used in the reverse direction for backward telemetry of electrode and system information. A custom receiver-stimulator chip has been developed that demodulates incoming data using pulse counting and produces charge balanced biphasic pulses at 1000 pulses/s/electrode. This chip is encased in a titanium package that is hermetically sealed using a simple but effective method. A low cost metal-silicon hybrid mold has been developed for fabricating an intra-cochlear electrode array with 16 ball-shaped stimulating contacts.

This work was supported in part by the Korea Science and Engineering Foundation (KOSEF) through the Nano Bioelectronics and Systems Research Center (NBS-ERC) of Seoul National University (#R11-2000-075-01001-0) and in part by the Nurobiosys Corporation.

Electrode development was conducted in collaboration with the Epstein Laboratory at the University of California, San Francisco with support from NIH contracts #NO1-DC-2-1006 and NO1-DC-3-1006.

C30. COMPARISON OF DUAL-TIME-CONSTANT AND FAST-ACTING AGC IN COCHLEAR IMPLANT USERS

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While cochlear implant sound processors need to apply more compression to the acoustic signal than do acoustic hearing aids, little work has been done to optimize the Automatic Gain Control (AGC) parameters of the former.

This work compared two different types of single-channel Automatic Gain Control: a fast-acting syllabic compressor and the dual-time-constant system developed in Cambridge, which is currently implemented in the Advanced Bionics implant system. Two sentence tests were used to assess benefit. One measured percent correct for a fixed signal-to-noise ratio (SNR). The SNR was selected for each subject during pilot trials such that their score was between 30% and 70% correct. The second test used an adaptive procedure to measure the speech reception threshold (SRT) as an SNR, while the overall level was varied over a 20-dB range.

Six adult subjects have completed long-term assessment with both AGC types. The results show a learning effect between first experience and the one month test points for the previously unfamiliar fast-acting system. Although subjective assessment in quiet revealed little difference between the systems, testing in noise revealed a highly significant advantage ($p<0.001$) for the dual-action system. On the fixed SNR test mean scores were 38.2% and 67.4% for the fast-acting and dual-time-constant systems, respectively. The adaptive test was difficult to perform, as some subjects had difficulty even at very high SNRs. SRT data were less consistent than for the fixed level test: SRTs ranged from +20 to – 1 dB.

The test in which the overall level was varied was intended to be representative of listening conditions in everyday life. This test proved to be very difficult for some of the implant users, suggesting worse performance than revealed in conventional fixed-level tests. More work is required to develop tests which accurately reflect everyday listening experience. However, overall the results suggest that the dual-time-constant system provides a substantial advantage for understanding speech in noise. This finding is consistent with earlier work based on a noise-vocoder simulation of a cochlear implant [Stone, M. A., and Moore, B. C. J. (2003). "Effect of the speed of a single-channel dynamic range compressor on intelligibility in a competing speech task," J. Acoust. Soc. Am. 114, 1023-1034].

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C31. THE HR90K STREAMING INTERFACE

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The electronic capabilities of the CII/HR90K implant extend beyond the typical clinical configuration of monopolar biphasic channels. They include flexible multipolar channel configurations (e.g. tripolar) and pulse shape definitions (e.g. asymmetric). These capabilities are attractive for researchers studying the electrical-neural interface.

To conduct psycho-acoustic evaluations or sound processing prototype evaluations, an environment is needed where the researcher can freely define stimuli on the PC, e.g. in matlab, and stream them in real-time, with small latency, to the implant. The clinical programming interface, based on a serial communication, cannot provide the required speed. Therefore we have developed a new USB-based hardware interface between the PC and the implant.

The associated software provides the possibility to freely define the stimuli. It consists of a strategy builder and a stream player. In the strategy builder the user specifies the temporal and spatial properties of the stimulation channels; i.e. their pulse shape and the electrode, and their relative timing. During strategy compilation the strategy builder generates the required binary objects, e.g. the pulse table, to be sent to the implant based on the user specification. The stream player provides a software interface to play arbitrary stimuli. The stimuli are stored in multi-channel wav files. Values represent stimulation strength in µA.

The software also includes a bidirectional status channel with events indicating the actual start and end of the stimulus. Other events indicate the status of the hardware. This flexible software has a .NET interface, a COM and a C++ interface. Therefore many interfacing possibilities exist to other applications, e.g. from Matlab.

C32. MICROPHONE CHOICE FOR COCHLEAR IMPLANT USERS IN WIND NOISE

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Wind noise has been reported to be a nuisance for hearing device users. The purpose of this study was to investigate the speech recognition performance and perceived sound quality of cochlear implant users in wind noise. The goal was to determine effective decision rules for automatic omni-directional – directional microphone switching algorithms so that the effects of wind noise can be minimized.

Local random aerodynamic pressure fluctuations over hearing aid microphones were recorded in an acoustically treated wind tunnel at two wind velocities when a digital hearing aid was worn on KEMAR. The flow incidence angle varied in 10° increments. The polar, spectral, and temporal characteristics of the wind noise signals recorded in the omni-directional and directional modes were analyzed offline. Recorded wind noise for flow incidence angles resulting in the lowest overall levels were then mixed with pre-recorded sentence materials. The speech recognition ability and overall sound quality preferences of sixteen cochlear implant users who had their cochlear implants turned on for at least 1 year, were assessed in the laboratory via direct audio input.

The spectral and temporal characteristics of wind noise changed drastically depending on the wind velocity and the angle of incidence. At 4.5 m/s, omnidirectional and directional microphones yielded similar speech recognition scores and preference ratings. At 13.5 m/s, the omni-directional microphone yielded better results in both measures due to lower high frequency masking from the wind noise after the pre-emphasis filtering in cochlear implants.

The implications to the decision rules for single- and multi-channel automatic microphone switching algorithms will be discussed.

C33. RESULTS OF 53 COCHLEAR IMPLANT SUBJECTS: PREFERENCE AND PERFORMANCE WITH RATE AND INPUT PROCESSING OPTIONS IN QUIET AND NOISE

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The performance results on a series of speech perception measures will be discussed on 53 subjects fit with the Nucleus Freedom Cochlear Implant System as it relates to their preference for rate and input processing option in quiet and in noise. The subjects were blinded for the first 6 months in regard to their preferences for rate as well as which input processing option was contained in each map. Subjects were also fit with one standard map that did not contain an input processing option.

The rates available for subjects were 500Hz, 900Hz, 1200Hz, 1800Hz, 2400Hz and 3500Hz. Input processing options available to the 53 subjects were Autosensitivity, ADRO and Whisper.

Autosensitivity is a noise suppression algorithm that dynamically adjusts the microphone sensitivity in response to the level of background noise. It is particularly useful in constantly noisy environments because it adjusts the sensitivity of the microphone. It is designed to ensure that the noise floor at which sound is present during breaks in speech remains 15dB below the sound level that triggers the main automatic gain control. ADRO (Adaptive Dynamic Range Optimization) is a digital pre-processing algorithm designed to make soft sounds more audible while making loud sounds comfortable. ADRO functions as a graphic equalizer by adjusting the gain of each channel independently according to its input level, the level of background noise, and the level of the loudest sounds. Channel gains are adaptively adjusted to maintain the signal in the upper 50% of the dynamic range of hearing. Whisper is a fast acting input processing algorithm that increases the instantaneous input dynamic range (IIDR) of the processor by compressing the input signal, improving the subject’s ability to hear soft sounds.

Results will be shown for preferred rate and preferred option for input processing at 3 months, 6 months and 12 months post activation for CNC words at 60dB SPL, Hint Sentences in Quiet at 60dB SPL and HINT Sentences in Noise at 60dB SPL with a + 10dB SPL signal to noise ratio.

C34. DEVELOPMENT OF AN EFFECTIVE LOW-COST SPEECH PROCESSOR FOR COCHLEAR PROSTHESIS

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The design, development and implementation aspects of a low-cost but effective body-worn Speech Processor for Auditory Prosthesis (SPAP) as a prototype laboratory model is addressed in a systematic approaches that is adaptable to fabrication. The most effective and successful parametric specifications based on practical speech processor devices used in cochlear prosthesis are considered for requirement phase of the design. After careful analysis of the requirements, the main hardware and software functional blocks are deduced and described the functional block diagram of the SPAP with the following main specifications: 8-Channel with 8 Filter-Banks for input audio band of 8 KHz, Continuous Interleaved Sampling (CIS) as Speech Processing Strategy, and Monopolar Stimulation at 1000PPS rate. The hardware design aspects for each of the hardware functional blocks of the SPAP based on 16-bit fixed-point digital signal processor as the main speech processor with high speed 8-bit microcontroller as speech data encoder and 4MHz Radio Frequency Amplitude Shift Key Transmitter for power and data are presented with practical details. The implementation features of the speech processing software – CIS and speech data encoder software are explained in detail. Finally, the experimental results of SPAP for sample speech input are presented.

C35. A PORTABLE RESEARCH PLATFORM FOR COCHLEAR IMPLANTS

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Currently commercial research processors for cochlear implants require the use of low-level assembly language programming for implementing speech and music signal processing strategies. We report ongoing work on a Pocket PC (PPC) based research platform for cochlear implants in which the software development is done in a high level language. We show that the processing for the Continuous Interleaved Sampling strategy can be done in real time on a PPC. We have implemented a 16-channel noise band vocoder on a 624 MHz PPC in C and Labview. We will present a demo of the noise band vocoder running on a PPC and a 802.11b WLAN implementation.

The research platform in addition has two more functions: 1) a data acquisition function to record auditory evoked potentials and 2) a controlled electrical stimulator for animal studies. We will present results of electroencephalogram (EEG) recordings on the PPC with a Compact Flash data acquisition card.

A Secure Digital IO (SDIO) card has been fabricated for interfacing the PPC with the Cochlear Nucleus CI24RE implant-in-a-box. We will present results showing the real-time stimulation of the Nucleus device with a PPC.

Research supported by NIH/NIDCD.

C36. FORWARD MASKED THRESHOLDS FOR MONOPOLAR AND TRIPOLAR STIMULATION IN COCHLEAR IMPLANT LISTENERS

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The broad spread of current produced by monopolar stimulation in cochlear implant (CI) listeners is suspected to adversely influence patient outcomes. One method of limiting current spread is to implement partially tripolar stimulation, where current is delivered to a primary electrode while compensating current of opposite polarity is delivered simultaneously to two flanking electrodes. The amount of tripolar compensation can be described by a coefficient σ, which ranges from 0 (monopolar) to 1 (full tripolar). More specifically, if current I is delivered to the primary electrode, current $-I*(\sigma/2)$ is delivered to each of the flanking electrodes.

In the present study, masked thresholds were obtained using a forward masking paradigm to estimate the spread of current for monopolar and partially tripolar stimulation. The monopolar and the tripolar maskers were 400 ms in duration, and were carefully balanced in loudness using a double-staircase adaptive procedure. Masked thresholds were obtained for 20 ms tripolar probes for a range of electrodes.

Preliminary data suggest that spectral peak enhancement occurs during partially tripolar stimulation when $\sigma \geq 0.8$, compared to the monopolar configuration. The masked thresholds did not show any significant differences between monopolar and partially tripolar stimulation when σ was less than 0.8. These results indicate that a tripolar strategy with σ ranging from 0.8 to 1 could yield a sharper representation of spectral maxima than monopolar stimulation, and therefore might improve perceptual outcomes in some CI listeners.

This work was supported by the Advanced Bionics Corporation.

C37. VALIDATION OF A COCHLEAR IMPLANT DEAD REGION MODEL USING MONOPOLAR AND TRIPOLAR THRESHOLD DATA

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The restricted electric field afforded by the tripolar (TP) electrode configuration should provide better resolution of tonotopic cochlear implant (CI) information than the more commonly used monopolar (MP). We previously developed a practical model of cochlear implant stimulation to explore whether the high channel-to-channel variability of TP thresholds may be due to the position of the electrodes in the scala tympani or to the presence of discrete spiral ganglion "dead regions." In this study, we validate the model by using subject data to fix certain biophysical parameters and compare model threshold curves to perceptual threshold data.

The model consists of three parts. The first part models the static electric potential produced by an array of point source electrodes surrounded by concentric cylindrical volumes of different conductivities. The second part models the activation of 20,000 spiral ganglion neurons evenly spaced in clusters using the activating function concept with probabilistic nerve firing. The third part computes perceptual threshold levels by summing active neurons across the cochlea.

Data from all subjects are used to fix biophysical model parameters, assuming complete neural viability. In initial model fittings, the radial position of each electrode is fit to the individual subjects' MP and TP thresholds. We observe that electrode-to-neuron distance can neither simultaneously fit MP and TP data, nor explain all threshold variations if the distance of adjacent electrodes is subject to physically reasonable constraints. This finding suggests the presence of neural dead regions.

In a second approach, the model is run iteratively to map the location and severity of putative dead regions. Electrode-to-neuron distance is now constrained to avoid unrealistic variations across the array. A single dead region, consisting of a span of cochlea with a reduced proportion of active neurons, is then introduced. Optimizing the center location, width of the dead region, and degree of neuron survival level led to improved model fits to the data. Future work will refine the optimization procedure in order to obtain a robust method for identifying neural dead regions based on perceptual threshold data.

C38. EQUAL LOUDNESS CONTOURS FOR SIMULTANEOUS AND SEQUENTIAL DUAL ELECTRODE STIMULATION IN COCHLEAR IMPLANTS

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Simultaneous and sequential stimulation of adjacent electrodes is known to generate pitch sensations that are intermediate to those of the physical electrodes in cochlear implant (CI) listeners. In the present study, equal loudness levels were determined for simultaneous and sequential dual-electrode stimulation at overall loudness levels corresponding to threshold, 40%, and 70% of a CI listener's dynamic range on the physical electrodes. Equal loudness levels as a function of the physical electrodes and the dual-electrode stimuli is known as an equal loudness contour. For the dual-electrode stimuli, the current was split between the two adjacent electrodes, with (1-α)*I delivered to the more apical electrode of the pair, and α*I delivered to the more basal electrode, where I is the total current and α ranges from 0 (all current on the apical electrode) to 1 (all current on the basal electrode). At the three different loudness levels, CI listeners balanced the loudness of the physical electrodes to that of the dual-electrode stimuli with α = 0.25, 0.5, and 0.75 by adjusting the total current for the dual-electrode conditions.

On an average the total current for simultaneous dual-electrode stimulation had to be adjusted by anywhere from -0.18 to 0.32 dB relative to the overall loudness of the current level on the physical electrodes. Equal loudness contours obtained for the physical electrodes and the non-simultaneous dual-electrode stimulation, shows a difference in total current from 2.43 to 5.42 dB, and was strongly dependent on α and the loudness level across subjects.

The equal loudness contours obtained for simultaneous stimulation are consistent with the notion of peripheral summation of the electric fields. For sequential stimulation, the loudness contours are suggestive of loudness summation that is more central in origin. In the context of a real-time strategy, non-simultaneous dual electrode stimulation may be more complicated to control as compared to simultaneous dual electrode stimulation.

This work was supported by the Advanced Bionics Corporation.

D1. PERCEPTUAL ADAPTATION TO A BINAURALLY MISMATCHED FREQUENCY-TO-PLACE MAP: IMPLICATIONS FOR BINAURAL REHABILITATION WITH COCHLEAR IMPLANTS

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Recent reports of success with bilateral cochlear implants and single implants used in conjunction with a hearing aid in the contralateral ear imply that listeners are able to adapt to frequency-place maps that differ between the two ears. The present investigation used simulations of cochlear implant processing to examine the process of perceptual adaptation to a binaurally mismatched frequency-toplace map in normal hearing listeners. A dichotic sine-carrier vocoder was used to simulate cochlear implant processing, with a spectral resolution of 6 adjacent bands (range: 200 – 5000 Hz). From apex to base, bands 1, 3 and 5 were presented to one ear with the equivalent of a 6 mm basalward shift, while bands 2, 4 and 6 were presented to the contralateral ear without a shift. Listeners were trained with Connected Discourse Tracking, and perceptual adaptation was monitored by testing sentence and vowel perception before, during and after training. In Experiment I, we trained listeners with the binaurally mismatched processor over eight 40-minute training sessions (5 h 20 m total). In Experiment 2, we looked at whether adaptation could be facilitated by training with just the shifted components (bands 1, 3 and 5). In Experiment 3, the effects of a longer term training period were examined; duration of training was doubled, and the trained condition alternated between those of the previous two studies. In all three experiments, intelligibility with the 6-channel binaurally mismatched processor never exceeded intelligibility with just the 3 unshifted components (bands 2, 4 and 6), suggesting that listeners learn to ignore the shifted bands rather than integrate the mismatched frequency maps from the two ears. Some learning of the mismatched frequency map appears possible over a longer time course of training, although the extent of this learning in the long term remains unclear since performance never reached asymptote. This resistance to adaptation is in contrast to earlier findings with adaptation to upward spectral shift in the monaural/monotic case, where relative frequency order is preserved. Adaptation for this type of processing has been demonstrated in as little as 3 hours training (cf. Rosen, Faulkner & Wilkinson (1999); Fu & Galvin III (2003)). It may thus be essential to keep frequency-to-place maps similar in the two ears in order to optimise the utility of bilateral hearing devices.

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D2. EFFECTS OF AGING ON THE RECOGNITION OF SPECTRALLY DEGRADED SPEECH

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The cochlear implant is now a common rehabilitative option for hearing impaired individuals of all ages, including the elderly. The existing literature supports cochlear implantation among older patients, as studies have indicated improved quality of life and communication abilities compared to pre-implant measures. The effects of channel interaction and spectral warping on speech recognition ability are well known in younger listeners, and it is apparent that individuals show considerable adaptation to the distorted signal over time. However, it is possible that the aging auditory system would respond differently to the spectrally degraded signals provided by a cochlear implant than a younger, more plastic system. The aim of this project is to explore the effects of aging on the perception of spectrally degraded speech. Normal hearing listeners (250-6000 Hz) of three age groups were recruited for participation in the current study: Younger (21-31), Middle-aged (41-51), and Older (61-71). Vowel and consonant recognition in quiet were measured using unprocessed and noise-band vocoded stimuli. Simulations were manipulated to vary the number of channels and degree of spectral shift. Preliminary results suggest that, compared to younger listeners, older listeners are more susceptible to spectral distortion, particularly when listening to the spectrally shifted conditions. Results on the speech recognition tasks will be compared to measures of working memory and speed of processing. Implications for rehabilitation of older cochlear implant recipients will be discussed.

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D3. SPEECH RECOGNITION AND PERCEPTUAL LEARNING IN SIMULATIONS WITH NOISE-VOCODED SPEECH: BEHAVIORAL AND NEUROIMAGING STUDIES

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Two sets of studies investigated speech perception in normal-hearing adults listening to cochlear implant simulations. In the first series of experiments we used noiseband-vocoded (NV) speech to examine variability in speech perception and adaptation. Speech recognition performance was quantified along an acoustic parameter (number of bands for criterion recognition), and these scores were used to explore cognitive correlates. NV sentence recognition scores were significantly correlated with verbal IQ, nonword repetition, and a measure of working memory and sustained attention. A study comparing recognition of NV sentences, words, consonants and vowels identified two listening 'modes' at work in perception of vocoded stimuli, namely higher-level linguistic listening and lower-level, acoustic-phonetic analysis. Information transfer analysis on NV segment perception scores revealed a significant relationship between vowel length discrimination and performance on word and sentence recognition tasks.

A second series of experiments investigated perceptual learning of NV sentences (6-band vocoding with a simulated 6.4 mm basalward shift) in a training paradigm. On each trial, listeners were asked to repeat back the sentence they heard, and then received written feedback with a simultaneous repetition of the auditory stimulus. In a behavioural study, listeners improved on average by 26% (across 100 trials) with this type of training. We also used functional magnetic resonance imaging to investigate which cortical areas may be recruited for learning these stimuli, compared with unlearnable control stimuli (the control stimuli were NV sounds in which the mapping from analysis bands to carrier bands had been inverted in the frequency domain). Results showed activation in the left inferior frontal gyrus during training for the learnable condition only, which suggests that this area plays an important role in integrating perceptual processing with externally provided feedback.

D4. CUSTOMIZED SELECTION OF FREQUENCY MAPS IN AN ACOUSTIC SIMULATION OF A COCHLEAR IMPLANT

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Cochlear implants (CIs) have proven to be a successful treatment for severe to profound hearing loss, enabling thousands of individuals to hear and understand speech. Despite this overall success, there remains considerable variability in individual outcomes. One factor that may influence this variability is that frequency-to-electrode maps are usually chosen based on a 'one-size-fits-all' approach, in which the same default frequency maps are applied to all users of a given device. We are interested in procedures that allow postlingually deaf patients to select customized frequency maps. Toward this goal, we have developed a real-time PC-based processor that allows the patient to continually adjust the frequency map while listening to running speech. Here, in two investigations employing different groups of listeners, we used this real-time processor in an acoustic simulation of a CI, and had listeners select a preferred frequency map. In this simulation, the output noise bands were fixed, and the input analysis filters were adjusted. After obtaining a *listener-selected* map, we assessed their word-recognition ability with this *listener-selected* map, and with additional frequency maps.

The first investigation employed speech signals presented diotically through loudspeakers. After obtaining the listener-selected map, their word-recognition ability with this map was compared with that on two other maps: a '*right-place*' map that matches the frequency range to the output noise bands, but eliminated low-frequency information below 851 Hz, and a '*right-information*' map that utilizes a frequency range of 250-6800 Hz, but must spectrally shift the signal to do so. Such basalward shifts are thought to be common in CI users. Results indicate that normal-hearing listeners listening to a CI simulation 1) prefer a map that is shifted somewhat basally relative to the *right-place* map, and 2) have better word recognition with the *listener-selected* map than the other two maps.

The second investigation used a dichotic presentation that simulated a mismatch in CI insertion depth for each ear. The degree of mismatch ranged from 0 to 6mm in four conditions. In each condition, word-recognition scores were first measured prior to any listener-selected adjustment of the frequency map. Then, the map in the left ear was fixed, and listeners adjusted the map of the right ear. At this time, word-recognition scores were retested for each condition. Results suggest a trend for improved speech understanding when listeners selected their own frequency map relative to their performance with the fixed maps.

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D5. PERCEPTUAL ADAPTATION TO SPECTRALLY SHIFTED VOWELS WITHIN AN ACOUSTIC ANALYSIS FRAMEWORK

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Both normal hearing (NH) and cochlear implant (CI) listeners are able to adapt to spectrally-shifted speech with or without supervision. However, the degree of spectral shifting may determine the ultimate performance and time course of adaptation. The present study analyzed and quantified the effects of spectral shifting on perceptual adaptation to spectrally shifted vowels, using a global spectra-based acoustic analysis framework; the acoustic analysis was compared to speech recognition results from NH subjects listening to spectrally-matched and shifted vowels. One underlying hypothesis is that within-vowel and across-vowel acoustic variability in the global spectra may be a limiting factor in perceptual adaptation to spectrally shifted vowels. Another underlying hypothesis is that low-level spectral integration range (i.e. 3.5 barks) may also affect perceptual adaptation to spectrally-shifted speech.

The acoustic analysis framework was a classic template matching scheme, with energy-normalized, Mel-scaled or Bark-scaled, short-term spectra as feature vectors. The effects of two hypotheses were unified into a weight function used in calculating the distances between spectrally-shifted vowels and unprocessed vowels. Frequency warping protocols were employed while matching global spectra. Three spectrally-shifted (their shift degrees linearly increased in terms of basilar membrane distance.) and two spectrally-matched conditions were analyzed within this framework. The acoustic analysis data was consistent with perceptual data for both hypotheses. These results suggest that both factors may affect perceptual adaptation to spectrally-shifted vowels, and indicate the limits of adaptation to severely shifted speech. While the absolute frequency-based and the global spectra-based analysis both predicted performance for spectrally-matched speech, the global spectra-based analysis better predicted perceptual adaptation to spectrally-shifted vowels. This suggests that the global spectra-based analysis may better reflect mechanisms used for speech pattern recognition, but at the cost of more computations in the neural system.

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D6. ADAPTATION TO COCHLEAR IMPLANT SIMULATED SPEECH: MULTIPLE ROUTES TO PERCEPTUAL LEARNING

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Adaptation to the acoustic world following cochlear implantation does not typically involve standardized rehabilitation protocols. Traditional training methods for cochlear implant users typically focus the listener's attention on the linguistic content of the signal. Linguistic training alone may not result in robust generalization, transfer to new tasks and new materials, or long-term retention. Therefore, we investigated whether focusing the listener's attention on the indexical properties of the speech signal (e.g. talker identity or gender) promote equivalent levels of performance as traditional linguistic training.

Normal hearing listeners (n=72) were trained over a two day period with 8-channel sinewave vocoded sentences in one of three conditions: sentence transcription (linguistic), talker identification (nonlinguistic, difficult) or gender identification (nonlinguistic easy). After training, subjects completed several speech perception tests, which included additional sentences from new talkers, old talkers and other materials that were more severely degraded. Three months after training, participants (n=43) returned for an assessment of the retention of perceptual learning.

In pre- to post-test comparisons, all three groups showed significant gains in sentence transcription accuracy. Post-test and generalization scores were highest for subjects trained on sentence transcription and talker identification where the task was sufficiently difficult to demand more attentional resources. Participants trained on gender identification performed more poorly than subjects in the other two groups due to decreased task demands. At retention, all three groups performed similarly (and significantly better than pre-test), suggesting that repeated exposure to the materials regardless of the information-processing task being performed results in equivalent levels of performance.

In sum, indexical training can provide equivalent gains to linguistic training. In the short term, tasks requiring increased controlled attention resulted in more robust transfer and generalization. However, long term effects show that all groups become equal as consolidation occurs over time. These results suggest that a novel rehabilitation method should include a wide variety of materials and tasks that will increase users' attention to both linguistic and indexical aspects of the speech signal and help keep users engaged and interested during the rehabilitation process.

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D7. A NEW “TOP DOWN” OR “COGNITIVE NEUROSCIENCE” APPROACH TO COCHLEAR IMPLANT DESIGN

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A new approach to the design of cochlear implants and other sensory prostheses is described, in which the brain is regarded as a key (and variable) part of the overall system. In particular, the approach asks what the usually-compromised brain needs as an input in order to perform optimally, as opposed to the traditional approach of replicating insofar as possible the normal patterns of neural activity at the periphery. The new approach may be especially helpful for patients who have suffered from long periods of sensory deprivation prior to receiving their implants and for patients with impaired “auditory brains” due to other causes.

D8. THE ROLE OF TEMPORAL AND SPECTRAL INFORMATION IN GENDER IDENTIFICATION AND DISCRIMINATION IN CHILDREN WITH COCHLEAR IMPLANTS

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This project examined gender identification of adult human voices in a population of forty-one children with cochlear implants (CI), and a control population of 15 age-matched hearing peers. An identification experiment tested whether children with CI were able to identify the gender of speakers from 2-sec speech excerpts (natural speech segments with fundamental frequencies between 80 Hz and 220 Hz), and a discrimination experiment quantified the participants ability to discriminate between genders as a function of the average fundamental frequency difference between pairs of natural speech segments. All control subjects had perfect or near-perfect performance in both tasks. CI subjects fell into three groups depending on their performance. One group (n=18) performed above chance in both experiments, and another group (n=18) performed at chance in both experiments. A third group of CI participants (n=5) could discriminate the gender of voices even at small fundamental frequency differences, but were unable to identify gender correctly. The spectral and temporal information provided by the CI device of each participant in response to
the specific stimuli used in the experiments were measured empirically, and the perceptual performance of all participants were analyzed according to this information and according to their hearing history (age of first deafness diagnosis, age of implantation, duration of CI use). The results of these analyses will be presented during the conference.

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D9. PITCH STEERING WITH THE NUCLEUS CONTOUR CI

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Cochlear implants (CI) are highly successful at improving speech recognition in quiet, even when speech is spoken at soft levels. However, understanding speech in noise and enjoying music continue to challenge most CI recipients. Recent research has shown that improving spectral resolution by eliciting intermediate pitch perception between adjacent electrode contacts can improve speech recognition in noise and music perception for some CI recipients. The objective of this study was to measure intermediate pitch perception between adjacent electrodes through the use of sequential, dual-electrode stimulation for Nucleus 24 and Freedom CI recipients and to determine the relationship between these measures and word recognition in quiet, sentence recognition in noise, and music perception.

Eleven postlinguistically deafened adults participated. Nine subjects were implanted with the Nucleus 24 and two were implanted with the Freedom device. Sequential dual-electrode stimulation was used to determine the number of intermediate pitch percepts between seven electrode pairs spaced along the electrode array (19/18, 16/15, 13/12, 11/10, 8/7, 6/5, 4/3). A process of subdivision between each electrode pair was initiated and subjects were asked to identify the higher pitched stimulus. Subdivision between electrode pairs yielded a percentage score (60%-95%) which was converted to a d' value (sensitivity index). The sum of the d' values obtained at each subdivision was used to determine the overall d' value (estimated number of intermediate pitch percepts) for each electrode pair. In addition, subjects were administered the following speech and music perception tests: CNC monosyllabic words, HINT sentences in noise, BKB-SIN Speech-in-Noise Test, and the UW-CAMP Music Perception Test.

Results revealed that all subjects could discriminate between adjacent electrodes except for one subject for one electrode pair. The average overall d' value across electrode pairs for each subject ranged from 1.48 to 11.29. Group overall d' values for each electrode pair was largest for the apical and smallest for the basal electrode pair. These findings agree with those of Kwon and van den Honert (2006). Intermediate pitch perception did not correlate with subjects' speech perception or music perception abilities. Future research involves determining if a processing strategy that takes advantage of intermediate pitch perception will provide Nucleus recipients with better perception of music and speech in noise.

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D10. EFFECT OF FREQUENCY-PLACE MAPPING ON SPEECH INTELLIGIBILITY: IMPLICATIONS FOR A COCHLEAR IMPLANT LOCALIZATION STRATEGY

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The current generation of cochlear implants (CI) is not optimized for sound localization. Nonetheless, developing a sound localization strategy should not hinder a cochlear implant's main function, to help the listener understand speech. The Oldenburger Sentence Test was used to test speech intelligibility in quiet and at several different signal-to-noise ratios with seven CI and six normal hearing (NH) listeners using a CI simulation. The experimental parameters that were varied were the upper frequency boundary (M) and the number of electrodes or channels (N). Both "matched" frequency-place conditions (M = N) and "unmatched" frequency-place (M ≠ N) conditions were tested. The lower frequency boundary of the speech was always fixed, different from previous studies on the number of channels for speech understanding.

It was found that for the matched conditions the number of channels can be decreased from 12 to 8 and speech intelligibility is not significantly affected, even for the lowest signal-to-noise ratios. It was also found that for the unmatched conditions speech intelligibility was insensitive to small spectral changes (±2 M or ±2 N) but not large ones. In the end, 5 of 17 different frequency-place mappings were found to provide the same speech understanding as the normal CI mapping.

The results have implications for new mapping strategies for CI listeners. A sound localization strategy would need to implement both interaural cues (for horizontal plane localization) and spectral cues (for vertical plane localization). If spectral cues are superimposed on the normal speech spectrum, this might be detrimental to speech understanding in CIs. These results show that it would be possible to separate the spectral cues from the speech information, which may help speech understanding in the localization strategy.

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D11. EVALUATING THE PITCH STRUCTURE DUE TO MULTIPLE RATES AND PLACES FOR COCHLEAR IMPLANT USERS

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It is well established that cochlear implant subjects have an ongoing difficulty understanding speech in noise, identifying familiar melodies, and in appreciating music in general. Recently, it has beenhypothesized that utilizing multiple stimulation rates on each channel may provide a means of transmitting additional fine structure information and act as a potential mechanism for addressing these issues (Fearn et al., 2001; Nobbe, 2004; Nie et al., 2005; Throckmorton et al., 2006). Although initial acoustic model studies have suggested that using multi-rate strategies may improve performance, data from cochlear implant studies has not consistently supported those findings.

One hypothesis which may explain the lack of success of the multirate strategies in cochlear implant subjects is that confounding cues may arise from unexpected pitch reversals due to a violation of the assumption that all rates applied to one electrode result in pitches that are higher than all pitches elicited by rates on the next more apical electrode. There is subjective evidence that contradicts this assumption (Eddington, 1978; Shannon, 1983; McDermott and McKay, 1997), indicating that multi-rate approaches may need to be tuned in order to accurately transmit relevant pitch-based information.

In this study, pitch ranking data were gathered as evidence for the hypothesis that multiple rates applied to multiple electrodes may result in pitch structures which invalidate this orderly assumption. Data was collected from five cochlear implant users with a SPEAR3-based psychophysical environment to assess the tonotopic structure for stimuli presented across the entire electrode array. Two paired-comparison pitch ranking tasks were performed. To determine the single-rate pitch structure for each subject, a single-rate task in which subjects ranked stimuli at 199 pps on all active electrodes was implemented. To asses the pitch structure due to multiple stimulation rates, a two-rate task that contained stimuli at both 199 pps and 398 pps on all active electrode was also implemented. The two-rate set of stimuli was separated into three subsets corresponding to the apical, middle and basal regions of the cochlea in order to avoid excessively long experiments (greater than ten minutes without a break). The resulting pitch ranking data indicated many cases where pitch percepts overlapped across electrodes and stimulation rates. Thus, the results from this study support the hypothesis that it tuning to avoid unwanted pitch anomalies be necessary in order to optimize performance in multi-rate sound processing strategies and that a pitch ranking task provides a relatively efficient and consistent mechanism to asses this structure.

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D12. RATE DISCRIMINATION AS A FUNCTION OF BASELINE RATE IN MED-EL COMBI 40+ AND NUCLEUS CI 24 USERS

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A common finding in the cochlear implant literature is that the upper limit of rate discrimination on a single channel is about 300 pps. It has implications not only for auditory theory but also for attempts to introduce fine timing differences into processing algorithms. Here, we study rate discrimination using a procedure in which, in each block of two-interval trials, the standard could have one of five rates (100, 200, 300, 400, 500 pps) and the signal rate was 35% higher than the standard. Advantages of this procedure over others are that (i) the use of multiple rates within a block encourages subjects to focus on pitch, (ii) unlike adaptive procedures, near-chance performance can be measured, and (iii) it does not assume that the underlying psychometric function is monotonic.

Eight subjects implanted with the Med-El Combi 40+ implants took part. Fifty trials were presented within each block, with 10 trials per standard rate. A total of 10 blocks were presented to each subject, resulting in 100 trials per data point. Electric pulses were delivered to the middle electrode for all subjects at their maximal comfortable level. The standard and signal stimuli were loudness balanced before the experiment. Percent correct discrimination was measured as a function of standard rate.

The pattern of results was different than those reported previously: six out of eight Med-El subjects performed better at the mid-frequency range (200-300 pps) compared to the lowest rate of 100 pps and the highest rates of 400-500 pps. Compared to an unmatched group of Nucleus CI 24 listeners tested using a similar paradigm and stimuli, Med-El subjects performed significantly better at 300, 400 and 500 pps but slightly worse at 100 pps. Two findings argue against the Med-El results being due to stimulus error or to the use of residual loudness cues. First, similar patterns of results were obtained with 5000-pps pulse trains that were sinusoidally amplitude modulated at 100, 200, 300, 400, and 500 Hz. Second, in addition to checking stimuli using a test device, we recorded the pulses presented by the implant in some subjects *in vivo* by means of surface EEG electrodes placed on the mastoid and forehead. In addition, the results are not specific to our new procedure: the pattern of performance across different rates was replicated when we measured psychometric functions at different baseline rates using the method of constant stimuli.

This presentation will consider the theoretical issues related to the limits of temporal pitch at low and at high rates, and consider possible reasons for the difference in results obtained with the two devices tested.

D13. HOW MUCH RESIDUAL HEARING IS "USEFUL" FOR MUSIC PERCEPTION WITH CI?

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We compared performance on a song recognition task of bilaterally combined electric and acoustic hearing (bimodal stimulation), with electric and acoustic hearing alone and evaluated self-reported subjective benefit for listening to music.

Subjects were 14 adult cochlear implanted (CI) patients, 12 Nucleus 22/24 and 2 MedEl Combi40+, who continued to use a hearing aid (HA) in the contra-lateral non-implanted ear. Subjects' residual hearing ranged from 20 to 100 dBHL at 250-500 Hz.

Subjects were asked to identify excerpts from 15 popular songs which were familiar to them, presented in a random order via a single loudspeaker. Presentation conditions were fixed in order: bimodal, CI alone and then HA alone. Musical excerpts were presented in each condition first with and then without lyrics. At the end of the test the subjects filled a questionnaire to report their preferred condition for listening to music and how they perceived it.

Taking the population as a whole (N=14); mean recognition scores for excerpts "with lyrics" were significantly greater for bimodal (76.5%) and CI alone (75.0%) versus HA alone (54.5%). For excerpts presented "without lyrics", there were no significant differences in mean scores between the different conditions.

However, taking a sub-group of subjects (N=8) with better residual hearing, where median pure tone thresholds (125-1000Hz) were ≤ 82.5dBHL, mean scores for bimodal stimulation, with (81.5%) or without lyrics (57.2%), were significantly greater than for cochlear implant alone (71.5%, 38.8%). In addition, "without lyrics" scores for HA alone (59.7%) were significantly greater than for CI alone (38.8%). The majority of these patients considered bimodal stimulation as the most enjoyable way to listen to music. Mean scores for the remaining subjects (N=6) showed no benefit from using bimodal stimulation over CI alone with or without lyrics, and the majority of these preferred to listen to music using CI alone.

Bimodal stimulation provided significantly better perception of popular music, particularly without words, compared to implant alone where low-frequency residual hearing was ≤ 80dBHL. Bimodal stimulation allows enjoyment of popular songs using speech recognition via the cochlear implant and improved melody recognition via residual hearing. For marginal candidates for cochlear implants these results suggest that a music test may be useful in determining which ear to implant, or whether or not to provide bilateral implants.

D14. VOCAL EMOTION RECOGNITION BY NORMAL-HEARING LISTENERS AND COCHLEAR IMPLANT USERS

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Besides conveying linguistic content, speech also transmits information regarding the emotional state of a talker. Acoustic cues that encode vocal emotion include voice pitch (F0), intensity, duration, the first three formant frequencies, and the distribution of energy in the frequency spectrum. The present study investigated the ability of normal-hearing (NH) listeners and cochlear implant (CI) users to recognize vocal emotions. A stimulus set of sentences were produced by one male and one female talker according to five target emotions: angry, anxious, happy, sad, and neutral. Overall amplitude differences between the stimuli were either preserved or normalized. In Experiment 1, vocal emotion recognition was measured in NH and CI listeners; CI subjects were tested using their clinically assigned processors. When overall amplitude cues were preserved, NH listeners achieved near-perfect performance, while CI listeners recognized less than half of the target emotions. Removing the overall amplitude cues significantly worsened mean NH and CI performance. In Experiment 2, vocal emotion recognition was measured in CI listeners as a function of the number of channels (from 1 to 8) and envelope filter cutoff frequency (50 vs. 400 Hz) in experimental speech processors. In Experiment 3, vocal emotion recognition was measured in NH listeners as a function of the number of channels (from 1 to 16) and envelope filter cutoff frequency (50 vs. 500 Hz) in acoustic CI simulations. Results from Experiments 2 and 3 showed that both CI and NH performance significantly improved as the number of channels or the envelope filter cutoff frequency was increased. In Experiment 4, vocal emotion recognition was measured in NH listeners as a function of the number of channels (from 1 to 16) and carrier type (noise bands vs. F0-controlled pulse trains) in acoustic CI simulations. Preliminary results showed that explicit coding of F0 information greatly enhanced vocal emotion recognition performance. Taken together, the results suggest that spectral, temporal, and overall amplitude cues each contribute to vocal emotion recognition. The poorer CI performance is most likely due to the lack of salient pitch cues and the limited functional spectral resolution.

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D15. IMPROVING PITCH PERCEPTION WITH COCHLEAR IMPLANTS

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Pitch, an essential perceptual property in hearing, facilitates recognition of melodies in music as well as extraction of prosodic (question/statement discrimination) and semantic cues (tonal languages) in speech. Cochlear implant (CI) users exhibit poor performance in pitch related tasks compared to normal hearing subjects, due to missing and inaccurately represented pitch cues. In particular listening to and enjoying music poses a difficult challenge for CI users.

The presented work concerns with further advancements of the F0mod strategy, a signal processing strategy that improves pitch coding. The concept behind F0mod is to enhance temporal pitch cues in CIs by encoding the fundamental frequency (F0) of an acoustical input signal in the electrical stimulation pattern. Thereby, the magnitudes of each filter bank channel are amplitude-modulated at the extracted F0 at full modulation depth and in-phase across channels. The F0 is estimated by a F0-extraction component that is embedded into the ACE-strategy-based processing chain.

In a first phase the F0-estimator has been optimized by incorporating robustness features such as voiced-unvoiced classification and subharmonic-error correction. In a second phase the F0mod algorithm was tested against the ACE strategy with several CI subjects. A real-time implementation of the F0mod algorithm on the Nucleus Freedom speech processor has been worked out in collaboration with Cochlear CTCE. Music-related tasks such as pitch ranking and tune identification as well as speech recognition have been addressed in the hope of improving pitch perception in music while maintaining the same speech perception performance.

First experiments with Nucleus Freedom users showed promising outcomes for both music and speech. Although significant inter-subject variability is apparent selected individual scores agree with our expectations.

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D16. AUDITORY STREAM SEGREGATION IN AMPLITUDE MODULATED BANDPASS NOISE

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The study used the approach proposed by Roberts, et al (2002) to investigate auditory stream segregation in normal hearing adults for amplitude modulated bandpass noises (vocoder band noise). Eight vocoder bands were applied and their cut-off frequencies were adopted from Fu and Nogaki (2005). The effects of both noise band separation and amplitude modulation rate separation on auditory stream segregation were investigated. Preliminary data showed: 1. stream segregation ability increased with the separation of vocoder bands, as expected; 2. stream segregation ability increased by the addition of amplitude modulation when modulation rates were distant and when noise bands were spectrally adjacent; 3. stream segregation ability was not affected significantly by the modulation rate separation in the conditions when the noise bands were wide separated. Results suggest that stream segregation can be improved by amplitude modulation cues when spectral cues are insufficient for full segregation. The interaction between the modulation rate separation and the overlapping spectra of the noise bands will be further investigated. Implications for stream segregation by cochlear implant users will be discussed.

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D17. SPEECH INTONATION RECOGNITION WITH CONFLICTING AND COOPERATING CUES: ACOUSTIC VS. ELECTRIC HEARING

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Multiple sources of acoustic cues often contribute to recognition of speech contrasts, although these cues may sometimes be in conflict. For intonation recognition, multiple acoustic dimensions may contribute; these include fundamental frequency (F0) variation, intensity, and duration, with F0 as the dominant cue. However, F0 is only weakly coded in cochlear implants (CIs), and hence CI users must rely strongly on other cues to recognize intonation contrasts. The purpose of this study was to assess how cooperation or conflict among these acoustic dimensions (F0, intensity and duration) in an intonation recognition task may affect listeners' sensitivity to F0 variation via acoustic vs. electric hearing, and how the effect may change under degraded listening conditions (e.g., in noise).

Ten CI and 4 NH listeners served as participants. Speech stimuli were resynthesized by orthogonally varying the F0, intensity, and duration properties of naturally-produced bisyllabic words. The bisyllabic tokens were designated as "cooperating" or "conflicting" based on the acoustic findings of the naturally-uttered speech of adult native speakers of English (3 per gender). The CI subjects were tested with unprocessed stimuli, using their own speech processors. The NH subjects were tested with unprocessed stimuli, as well as 8- and 4-channel acoustic CI simulations. Using a single-interval, 2 alternative forced-choice procedure, the listener was instructed to identify whether each token is question- or statementlike. Intonation recognition was measured in both quiet and noise (white noise and multi-talker babble). Each listener's sensitivity to F0 variation was assessed using estimated slopes of psychometric functions fit to the data (i.e., proportion of question judgments as a function of the amount of F0 variation), with the consideration of any potential subject response bias.

The data indicated that in quiet, NH subjects' sensitivity to F0 variation in intonation recognition did not differ when F0 cues were cooperating or conflicting with intensity and duration cues, with unprocessed stimuli. On the other hand, when the spectral resolution was reduced (i.e., CI listeners and NH listeners attending to CI simulations), listeners' sensitivity to F0 variation in intonation recognition was greatly reduced when acoustic cues were conflicting. Further, in noise, NH listeners' sensitivity to F0 variation with acoustic CI simulations was reduced to similar extents to that of CI listeners when F0 cues were in conflict with other acoustic dimensions.

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D18. QUANTIFYING ELECTRIC PITCH

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Understanding temporal and place contributions to electric pitch can potentially improve cochlear-implant (CI) performance in challenging environments. Previous studies of electric pitch by matching it to residual acoustic hearing were limited to: (1) subjects who usually had various degrees of hearing loss and might not have normal frequency discrimination; (2) only place pitch with a single stimulation rate and a fixed stimulation level; (3) a method that did not estimate the salience of electric pitch.

We identified a unique subject who received a cochlear implant (Clarion HiRes90K) to control his debilitating tinnitus and had essentially normal hearing as well as normal pitch discrimination in the non-implanted ear. We used a double-staircase as well as a 5-track adaptive procedure that had different starting points, step sizes, and decision rules to estimate not only the point of equality for the matched electric pitch but also its salience (standard deviation) and possible presence of multiple pitches. Electric pitch was measured as a function of stimulation rates from 100 to 5000 Hz, stimulation levels from barely above threshold to the most comfortable loudness, stimulation places from apex to base, and using either monopolar or bipolar stimulation.

Consistent with previous studies, we observed a systematic pitch change with the stimulation place that could be better modeled by the insertion angle rather than the insert depth. In addition, we observed that stimulation rate and stimulation mode, but not stimulation level, significantly altered this place-pitch map. In most cases, electric pitch salience was much poorer than acoustic pitch salience. In rare cases, electric pitch salience approached acoustic pitch salience as evidenced by both the small standard deviation of the matched pitches and the subject's subjective report. The general implications of this case study will be discussed in relation to (1) restoring simple and complex pitches in electric hearing, (2) recovering fine structure in cochlear implants, and (3) combing acoustic and electric stimulation.

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D19. CONTRIBUTION OF F0 TO COCHLEAR IMPLANT PERFORMANCE

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Recent studies have demonstrated that the presence of residual low frequency hearing in actual and simulated cochlear implant (CI) users can improve speech recognition in noise. It is presumed that the presence of the fundamental frequency (F0) of the target speaker, or possibly masker(s), is primarily responsible for this benefit. However, this point has not been explicitly examined. It is also not clear what physical characteristics of the F0, such as frequency and amplitude, are responsible for the observed benefit. We hypothesize that the presence of the target F0 is sufficient, and that frequency changes within the F0 are the dominant physical feature.

Nine normally hearing subjects were tested on their ability to detect speech in noise. The target was a male speaker and the masker was a female speaker. Subjects were asked to repeat the target sentence presented from the IEEE sentence set. A 1-up, 1-down adaptive procedure was used to determine the SNR at which the subject correctly identified 50% of the sentences. Subjects were presented with a 6-channel CI noise band simulation with and without the presence of low frequency components. The conditions tested were (1) lowpass below 500 Hz, (2) target F0 only, (3) masker F0 only, and (4) both target and masker F0s. All F0 contours contained both frequency and amplitude components. The presence of the lowpass information yielded a benefit of 5.5 dB in SNR. The presence of the target F0 produced comparable results. However, the masker F0 and both target and masker F0 conditions yielded no benefit over the CI alone condition.

The target F0 condition was used to investigate the contribution of frequency and amplitude modulation. Three additional conditions included the frequency only, amplitude only, or neither frequency nor amplitude (stationary). The amplitude only and stationary conditions had a sinusoid at the average F0 as the carrier. The stationary condition had constant amplitude when the F0 was present. The results show that both frequency and amplitude information are necessary to achieve a significant benefit in noise. The frequency only and amplitude only conditions showed no benefit over the CI simulation alone whereas the stationary F0 yielded significantly worse results.

Comparable data are being collected in actual CI users who have significant residual acoustic hearing. These data and the underlying mechanisms will be presented and discussed at the meeting.

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D20. THE PERCEPTION OF INDEXICAL PROPERTIES OF SPEECH BY ADULT COCHLEAR IMPLANT USERS

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In addition to the important linguistic content of a spoken message, indexical (or nonlinguistic) properties of speech are also present in a spoken message. Examples of indexical properties are a talker's identity, gender, age, dialect, level of sobriety and emotional state. In these experiments, the perception of two of these indexical properties, emotional state and talker individuality, is examined for adult cochlear implant users.

In the first set of experiments, participants were eleven adult cochlear implant (CI) users, with at least one year of experience with their device. Speech materials consisted of four short sentences with simple, emotionally-neutral language (e.g., "It's time to go.") spoken by two females, using each of four emotions ('angry,' 'happy,' 'scared,' 'sad'). Three recordings, or tokens, of each sentence spoken by each talker with each emotion were made. Emotion identification and emotion discrimination experiments were conducted. Identification scores ranged from 41 to 93% correct (chance: 25% correct) while discrimination scores ranged from 52 to 89% correct (chance: 50%) for these CI users. The identification and discrimination results were consistent. 'Angry' and 'sad' were relatively easy to identify and to discriminate from other emotions, while 'happy' and 'scared' were relatively difficult to identify and to discriminate from each other.

In the second set of experiments, adult CI users were tested for their emotion perception and talker discrimination abilities, using the standard HiRes (HiResStd) and HiRes120 speech processing strategies. As before, emotion perception was examined using identification and discrimination tasks. Talker discrimination was assessed using three conditions: a) across gender, b) within-gender female, and c) within-gender male. Sentences from 20 talkers (10 male; 10 female) were used, and sentences differed in each interval of each trial. Testing was conducted in four sessions (#1: HiResStd; #2: HiRes120 after 1-month experience; #3: HiResStd after 1 week; and #4: HiRes120 after 1 week). Results from the two strategies will be compared.

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D21. PITCH AND TONAL LANGUAGE PERCEPTION IN COCHLEAR IMPLANT USERS

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Pitch ranking and tonal language perception was investigated with nine native Cantonese-speaking postlingually deaf adults who were users of the Nucleus CI24 implant system. All subjects were experienced users of the Advanced Combinational Encoding (ACE) strategy.

The subject's use of three sound coding strategies was evaluated. Two of these were the ACE and the Continuous Interleaved Sampling (CIS) strategy which are widely used in current clinical practice. The third was a novel experimental strategy termed Multi-channel Envelope Modulation (MEM) that was specifically designed to enhance F0 periodicity cues in the stimulus envelope. All three strategies were implemented in an experimental body-worn research processor (SPEAR3). A repeated ABC-ABC experimental design was adopted, in which each strategy was taken home by subjects and used for a period of 4 weeks (for each strategy) in the first stage of evaluation and then subsequently for a further 2 weeks in the second stage (providing a total of 6 weeks use with each strategy over a period of 18 weeks in total, excluding follow-up tests). Tonal language perception was measured using the Cantonese HINT (CHINT) sentence test (presented in speech-spectrum shaped noise) and a Cantonese tone minimal-pair identification test. Pitch perception through the processor/strategy was measured using a 3-harmonic complex-tone pitch ranking test.

There were no significant differences in perception scores for use of the MEM strategy as compared to ACE for the Cantonese speech perception tests. However, scores using the CIS strategy were significantly lower than either ACE or MEM strategies for the CHINT sentence test in noise. Results for the pitch ranking tests provided lower F0 difference limens (DLs) for three of the subjects, comparable DLs for five of the subjects, and a poorer DL in one subject, when using the MEM strategy compared to the clinical strategies.

Previous studies had demonstrated that enhancement of F0 periodicity cues in the stimulus envelope can provide improvement to pitch perception, at least for pitch ranking of sung vowel stimuli. It may be that lack of experience and/or training in use of temporal periodicity cues exclusively for tone perception in tonal language may be important, and that this contributed to the findings of the current study. In addition, differences in central processing of pitch in music and language tasks may be partly responsible for these outcomes.

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D22. THE EFFECTS OF SPECTRAL DISTRIBUTUION OF ENVELOPES ON LEXICAL TONE PERCEPTION

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Shallow insertion of cochlear implant electrode array results in an upward shift of the frequency bands from their tonotopically mapped places. Previous studies have shown that such a spectral shift has dramatic detrimental effects on English phoneme recognition and the decrease of phoneme recognition depends on the degree of mismatch or the insertion depth.

The present study investigated the effects of mismatched spectral distribution of envelopes on lexical tone recognition using noise-excited vocoder speech samples. Eighty Mandarin Chinese words were recorded from a male and a female native Mandarin-speaking adult (10 syllables × 4 tones × 2 speakers). The speech signals were divided into analysis bands, the number of which varies from 4 to 16 in a step size of 4. The envelopes of each of the analysis bands were extracted using half-rectification and low-pass filtering and used to modulate a white noise. Two types of mismatch between the analysis bands and the carrier bands were created. One simulated an upward spectral shift, where the modulated white noises were band-limited to higher frequencies than the analysis bands. The simulation creates 0 mm (i.e., no-shift) to 7 mm basal shift in a step size of 1 mm (i.e., spectral upward shift). The other experiment simulated a randomized spectral distribution of the speech envelopes, where the modulated white noise were frequency limited to random bands. Five native Mandarin Chinese speaking subjects were trained using vocoder lexical tones stimuli with no spectral shift for about two hours before the experimental testing.

The group-mean tone recognition scores for the no-shift condition and the 7 upward-shift conditions across all numbers of channels (i.e., 4 to16) were 70.6% and 67.5% correct, respectively. These results indicated that tone perception was much more tolerant to the mismatched tonotopic mapping than English phoneme perception. Moreover, post-hoc analysis showed that tone recognition scores of the upward-shift conditions did not differ significantly from each other or from that of the no-shift condition except for the 7-mm upward-shift condition with 16 channels. The group-mean tone recognition score for the random-shift conditions was 58.1% correct across all channels, lower than the upward-shift condition. Therefore, although tone perception did not degrade as a result of spectral upward shift, disruption of the sequential frequency relationship of all bands caused a slight decrease in tone perception.

D23. THE RELEVANCE OF TEMPORAL AND PLACE PITCH FOR FREQUENCY DISCRIMINATION WITHIN A COCHLEAR IMPLANT SYSTEM

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The ability of cochlear implant users to detect low frequency changes is tested with a new strategy including temporal fine structure analysis in the low frequency bands in comparison to the CIS+ strategy in the MED-EL system.

Seven subjects implanted with a MED-EL cochlear implant participated in the study. The just noticeable frequency difference for sinusoids was measured with an adaptive 2 interval 2AFC procedure. Frequency discrimination was measured at 150, 180, 200 and 250 Hz. Stimuli were presented over headphones. First the CIS+ strategy was compared with a fine structure strategy (FSP) using the OPUS1. The fine structure strategy is analysing temporal fine structure using channel specific sampling sequences at the two most apical electrodes in a frequency range up to about 320 Hz. For both strategies the analysed frequency range was fixed between 100 and 8500 Hz. Additionally, the same procedure was used to test the relevance of place pitch information (virtual channels between two electrodes) and temporal pitch information (at single electrodes) alone.

The frequency discrimination for sinusoids is significantly better with FSP (10% of the base frequency) than with the CIS+ (15%) up to 200 Hz. Both temporal and place pitch alone lead to a frequency discrimination between 5 and 35%.

Within the FSP strategy both temporal and place pitch information are combined by implementing virtual channels and temporal fine structure. The FSP strategy improves the frequency discrimination when compared with the CIS+ strategy which is relevant for F0 discrimination and music.

D24. UPPER LIMIT OF RATE PITCH IN COCHLEAR IMPLANT USERS

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A number of researchers have reported that cochlear implant users can rarely discriminate rate changes once the base rate increases above 200 to 300 pps. We investigated possible reasons for this “upper limit” on rate encoding. Experiment 1 investigated the idea that the limitation is due to modulations in the pattern of electrically evoked compound action potentials that have been observed in response to high-rate pulse trains [1]. Rate discrimination by Nucleus CI24 listeners was measured with base rates of 100, 200, 300, 400 and 500 pps, all mixed within each block of trials. In each trial subjects had to indicate which of two sounds had the higher pitch. Feedback was provided. Most listeners showed a breakdown in performance above 200-300 pps. Manipulations predicted to reduce ECAP modulation, including the addition of 5000-pps “desynchronizing” pulse trains, the introduction of gradual onset/offset ramps, and the increase of duration from 200 to 800 ms, failed to affect this breakdown.

Experiment 2 obtained pitch rankings from CI24 users for stimuli over a wide range of rates (112.5-1800 pps) using the “MidPoint Comparison (MPC)” procedure [2] in order to investigate the recent suggestion that the upper limit may be increased when multiple electrodes are stimulated concurrently [3]. Contrary to the prediction, pitch ranks increased monotonically only up to about 300 pps, both for single- and multiple-electrode stimulation.

Experiment 3 investigated the upper limit in two “star” MedEl C40+ users, who showed monotonically increasing pitch ranks for rates up to at least 840 pps. Four rates between 500 and 840 pps were presented separately on three adjacent electrodes, leading to a total of 12 stimuli. A multi-dimensional scaling procedure revealed separate perceptual dimensions for electrode and rate.

Our results show that, when the upper limit is 200-300 pps, this limit is impervious to a wide range of manipulations expected to alter the pattern of auditory nerve activity. In contrast, for subjects showing a higher upper limit, it appears that pitch increases monotonically over a wide range, and that this increase is not due to incidental “place” cues.

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D25. INVESTIGATING THE IMPACT OF DURATION ON PITCH CUES IN COCHLEAR IMPLANTS

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It has been hypothesized that variable stimulation rate speech processing strategies may provide cochlear implant users with some of the missing fine-structure cues needed for successfully understanding speech in noise and performing various musical identification tasks (Fearn et al., 2001; Nobbe, 2004; Nie et al., 2005; Throckmorton et al., 2006). It has been established that changing the rate of stimulation causes a change in perceived pitch up to approximately 300 pulses per second (e.g. Zeng, 2002) and that such changes in the rate-pitch percept result in overlapping rate and place-based pitch percepts across multiple electrodes (Eddington, 1978; Stohl et al., 2007).

While the behavior of the rate-pitch percept has been established for stimuli of long durations (i.e., 300ms), this duration differs from the length of analysis windows in current sound processing algorithms (2-8 ms). It may therefore be important to understand how both place and ratebased pitch structures change as a function of the duration of stimulation. Furthermore, it may be important to know the stimulus duration at which an instantaneous change in rate becomes undetectable. In order to study these issues, the following psychophysical experiments were implemented in cochlear implants. First, subjects were asked to pitch rank 200 pps stimuli with durations ranging from 10 ms – 200 ms. These data provide information about how pitch structures may transform as a function of duration. Then, rate difference limens were calculated using traditional rate discrimination and compared to limens from an embedded rate discrimination task in which subjects were asked to select the interval containing a 200 ms rate change embedded in a 600 ms stimulus. This data set provides some insight into the impact of embedding a rate change in a pulse train in a manner that is reflective of current sound processing strategies. To determine the minimum detectable duration of an embedded change in rate, subjects were asked to perform a two-interval, forced-choice procedure in which one of the stimuli contained a rate higher than the subject's previously determined embedded rate difference limen, and the duration of the embedded stimulus was varied. This task was also performed using a rate that was below the subject's embedded rate difference limen to ensure that results were not affected by a secondary cue. These data provide some insight into the minimum duration that is required to elicit a perceptible change in pitch which may in turn influence the length of the analysis window in a variable stimulation rate strategy. Results from this battery of psychophysical experiments will be discussed, along with their impact on variable stimulation rate strategies.

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D26. BINAURAL UNMASKING WITH "TRANSPOSED" STIMULI IN BILATERAL COCHLEAR IMPLANT USERS

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Bilateral cochlear implants can potentially aid speech understanding in noise by two types of effects. "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. Recently, we showed that this fusion can aid signal detection, as seen with a significant Binaural Masking Level Difference (BMLD) for electric hearing (Long et al., 2006).

The present study extended our previous measurements (1) to include noise bandwidths more relevant to cochlear implant processors (125 and 250 Hz), and (2) to measure performance for stimuli presented to several different electrodes. Unless otherwise noted, the input noise was identical on the left and right sides while the signal was either identical across sides, or shifted by pi radians. 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, in a way analogous to the "transposed" acoustic stimuli used by van de Par and Kohlraush (1997).

First, we found that all CI subjects showed a substantial BMLD for all noise bandwidths tested. Second, additional tests of all related monaural conditions (N(left)S(left), N(right)S(right), N(right)S(shifted pi right)) in addition to NoSo showed that the NoSpi condition was truly indicative of binaural interactions. Third, we have seen indications that monaural signal detection in noise can vary significantly as a function of electrode and also that binaural detection varies as a function of interaural electrode offset.

These results indicate that the BMLD reported previously generalizes to more realistic stimuli and is clearly produced by binaural interactions. In addition, since the monaural signal detection in noise shows dramatic changes depending on electrode, this may indicate that some electrodes are not good carriers of information in noise. 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 continuing to investigate whether this advantage will generalize to supra-threshold tasks such as speech understanding in noise.

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D27. BREAKDOWN OF PRECEDENCE WITH COCHLEAR IMPLANTS - SIMULATIONS SHOW IMPORTANCE OF SPECTRAL CUES

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The precedence effect shows the suppression of a lagging copy of a sound, the echo, in the presence of the leading sound, the direct sound. It is considered a binaural phenomenon, but the results of the present studies suggest that it has to be seen in the larger context of auditory scene analysis, especially with cochlear implants (CIs).

Using current devices, CI-subjects have very limited access to interaural time differences (ITDs) and spectral information, while interaural level differences (ILDs) as well as representations of the temporal envelope are relatively available. This limited information is often sufficient to provide localization in quiet, but the presence of other sounds in the background might disturb it. In the first part we present results of a study on the precedence effect with bilateral CI-subjects. A 10ms noise-burst or a CVC-word were played from +30° or -30° accompanied by a delayed, identical sound copy from the opposite side loudspeaker. Subjects had to indicate with a light pointer the perceived sound direction or, in the event of two perceived sounds, to indicate in separate runs either the left- or rightmost sound location. Results show evidence for 3 different outcomes:

(1) Some subjects localized a single sound between lead and lag in the middle between both speakers, even for long delays.
(2) Two subjects showed precedence, with a single sound localized towards the lead at short delays.
(3) Two subjects showed a breakdown of precedence, with lead and lag sounds localized separately, beginning with relatively short delays.

Result (3) is interesting as it shows that CI-patients were able to separate and locate two sounds simultaneously in a situation where normal hearing subjects would hear only one sound. This is contrary to the belief that less information should produce less segregation ability. This breakdown of precedence was replicated with normal hearing subjects in a similar paradigm using a noise-band vocoder CI-simulation.

In hopes of explaining this breakdown of precedence, we varied the interaural match of the carrier frequencies of a sinusoidal vocoder and found that precedence broke down if carriers were not matched in frequency. However, for zero or small frequency offsets some subjects showed precedence and fusion into a single image. Interestingly, the interaural phase of the carrier played only a limited role which shows that precedence of ongoing sounds can be solely based on ILDs and envelope-ITDs. Together, these results suggest that proper place matching of CI-electrodes is important for the analysis of concurrent sounds.
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D28. MONAURAL AND BINAURAL CATEGORICAL LOUDNESS SCALING IN ELECTRIC HEARING

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In this study two types of an adaptive procedure for categorical loudness scaling in electric hearing were developed: monaural and binaural. For the monaural procedure, the aim is to measure the loudness growth as a function of the current level of the electric stimulus using a categorical scale. The binaural procedure takes additionally the binaural loudness summation into account. The procedures are based on the Oldenburg adaptive and constant stimuli procedures for normal hearing listeners (Brand and Hohmann, 2002; J. Acoust. Soc. Am. 112, 1597- 1604) and were adapted to the requirements for cochlear implant listeners. Seven binaural cochlear implant listeners were tested, five of whom were postlingually deafened and two prelingually deafened. In the monaural case the stimulus was presented at one electrode, in the binaural case the stimulus was presented at one interaural electrode pair. The monaural results were used to approximate the loudness growth functions, which were modeled as modified power functions. The results showed that the exponent of the loudness growth function differed across the subjects. It was greater than 1.5 for the postlingually deafened subjects and smaller than one for the prelingually deafened subjects.

The loudness growth functions obtained for the two ears were verified in a binaural loudness balancing test using an adjustment procedure. Additionally, the data were compared to the results obtained by the constant stimuli procedure. The analysis showed that the binaurally loudness-balanced current pairs were more consistent with the results of the adaptive procedure than with the results of the constant stimuli procedure. Compared to the constant stimuli procedure, the adaptive procedures showed a better adaptation to the dynamic range of the subjects, resulting in a better representation of the loudness functions.

This study was supported by the Austrian Academy of Sciences.

D29. THE RELATIONSHIP BETWEEN SPATIAL TUNING CURVES AND SPEECH RECOGNITION IN COCHLEAR IMPLANT LISTENERS

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There is considerable interest in the relation between spectral resolution in implant listeners and their ability to understand speech in noise. In particular, spectral resolution may be important for speech understanding in noise where envelope cues are unreliable. This work examines the relationship between parameters of forward-masked Spatial Tuning Curves (STCs) obtained from cochlear implant users, with their sentence and vowel recognition performance in quiet and in noise. Speech materials included IEEE sentences and closed-set vowel stimuli. Preliminary results suggest some significant relationships exist between STC bandwidths and performance on speech recognition tasks. Narrower STCs correlated with better abilities to understand speech, both in quiet and in noise. Concurrent work with normal-hearing simulation listeners shows a similar relationship between the slopes of the simulation filters and listeners' performance on the sentence materials in quiet and in noise. Relationships among variables will be described.

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D30. SENSITIVITY TO SPECTRAL PEAKS AND NOTCHES IN COCHLEAR IMPLANT LISTENERS

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This study determines the feasibility of cochlear implant (CI) listeners to localize sounds in vertical planes by determining their sensitivity to spectral peaks and notches from an equal-loudness background. Five listeners with a monopolar twelve-electrode implant participated in this study. Three places (low = electrodes 4-6, mid = 7-9, and high = 10-12) and three bandwidths (1, 2, and 3 electrodes) were tested. All conditions were tested without and with level roving.

It was found that the listeners were always sensitive to spectral peaks, without or with level roving, at any bandwidth and place. In most cases, increasing the bandwidth beyond two electrodes showed no significant increase in the threshold. Two and three electrode peaks without level roving required a change of less than 8% of the dynamic range of the electrodes (≅50 μA). Level roving significantly increased this threshold by 7% (≅40 μA). Listeners were much less sensitive to spectral notches, normally requiring changes of 17% of the dynamic range (≅80 μA) to be detected. Listeners could very rarely detect notches with level roving. The effect of place was highly variable between listeners. This variability was correlated with intensity discrimination thresholds without a background.

These results have comparable trends to those found in a similar study for normal hearing (NH) listeners; however, peak and notch detection seems worse in CI listeners compared to NH listeners (Moore *et al*., JASA, 1989). Nonetheless, listeners are sensitive to peaks (without and with level roving) and notches (without level roving) and it should be possible to develop a vertical plane sound localization strategy for CI listeners.

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D31. SPATIAL HEARING ABILITIES IN SUBJECTS USING A COMBINATION OF ELECTRIC AND ACOUSTIC STIMULATION

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Recent advances in electrode technology development and in surgical insertion techniques have resulted in an ability to preserve acoustic low to mid frequency hearing following cochlear implantation. Recipients with such hearing preservation are able to make use of two hearing aids and the cochlear implant in combination. The aim of this clinical study was to assess the benefit of using the residual hearing in the implanted ear.

Eleven adult subjects implanted with the Hybrid-L cochlear implant participated in this study. Clinical testing was conducted to assess the benefit of using the ipsilateral hearing aid, i.e to compare the ‘combined’ condition (using two hearing aids and the cochlear implant) to the ‘bimodal’ condition (using only the contralateral hearing aid and the cochlear implant). All testing was conducted at a minimum of three months after initial activation with the cochlear implant. Localisation ability was measured for four subjects using an 8-speaker array with a 180-degree span and for seven subjects using a 12-speaker array in a full circle. Speech perception was evaluated in a subset of subjects for a range of speaker configurations with spatially separated speech and noise sources to measure spatial hearing abilities. Test materials were open-set sentences presented in noise.

Significant benefits of using the ipsilateral hearing aid have been demonstrated on localisation tests and on speech perception measures for this group of subjects.

D32. A MODEL FOR RESPONSES OF THE INFERIOR COLLICULUS NEURONS TO BILATERAL ELECTRICAL STIMULATIONS

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Bilateral cochlear implant patients have poor sensitivity to ITD which is an important cue for sound localization. It has been reported that single neurons in binaural pathway can tune to the ITDs of electric stimulation in a narrow range of conditions. In this study, we hypothesize that central auditory processing is normal and that the abnormality in the response to the electric stimulation at the auditory nerve fibers (ANF) is the source of the limited binaural response in the ascending auditory pathway.

A descriptive model of ANF response to electric stimulation is developed as an input model to a model of binaural processing in the ascending auditory pathway. This model, an extension of Bruce et al. (IEEE Trans Biomed Eng. 1999) describes how the amplitude and stimulation rate of the electric stimulation affect the firing rate and temporal discharge patterns of the ANF response. Spikes from this ANF model are used as the input to a network of cochlea nucleus, medial superior olive, and inferior colliculus models for the normal auditory pathway. Inputs to the model are pulse trains of constant-amplitude and amplitude modulated pulse trains.

The IC model includes an adaptation mechanism which enhances the binaural response to modulated pulse trains when the stimulation rate is high. The narrow dynamic range of ANF response to electric stimulation makes the IC more sensitive to amplitude modulation, and leads to a strong dependence of the ITD tuning patterns on intensity. In addition, the effect of increasing stimulation rate on the ANF response is explored to understand the behavior of ITD tuning at high stimulation rates.

D33. EFFECT OF SPECTRAL HOLES ON SPEECH INTLLIGIBILITY AND SPATIAL RELEASE FROM MASKING

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Bilateral cochlear implants (CIs) are being provided clinically in order to improve the ability of patients to listen in noise and localize sounds. However, performance of bilateral CI users is still poorer than that of normal hearing listeners (NHLs) tested under comparable conditions. One factor responsible for this difference is the presence of “dead regions”, known psychoacoustically as “spectral holes”. When spectral holes are present, CI users must integrate spectral information from disjoint bands. The overall objective of this study is to investigate the effects of spectral holes on speech recognition in realistically simulated listening environments, including comparisons between binaural and monaural listening modes.

Using a CI speech vocoder, speech reception thresholds (SRTs) were measured adaptively, in quiet and in noise, by varying the level of the target. Prior to processing, stimuli were convolved through HRTFs to provide listeners with free-field directional cues. Targets were sentences from the Harvard IEEE corpus. Spatial release from masking (SRM) was computed by subtracting SRTs for noise on the side from SRTs with noise in front. The size of the holes (6mm and 10 mm) and location (base, middle, and apex) were varied. Target sentences were recorded with a male voice and convolved through the 0° HRTF. The interfering sentences were recorded with two-female talkers and presented from front (0°), right (90°) or left (-90°). Stimuli were presented over headphones under binaural or monaural (R ear) conditions.

Results show that spectral holes were the most disruptive to subjects' performance when they occurred in the middle of the simulated electrode array, in particular with the 10 mm hole size. No degradation in performance was caused by 6mm apical and basal holes. When the target speech and masker were spatially separated, performance improved significantly (SRM) in conditions with apical holes but not with middle or basal holes. This finding suggests that information delivered to the basal and middle portions of the simulated electrode array are most important for the benefits gained from spatial separation of target and masker in a simulated noisy environment.

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D34. COMPARISON OF ELECTROPHYSIOLOGIC AND PSYCHOACOUSTIC MEASURES OF BILATERAL ELECTRICAL STIMULATION

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Multichannel cochlear implants (CIs) have been widely accepted as the treatment of choice for profound sensorineural hearing loss for more than two decades. Many recipients are now electing to receive bilateral cochlear implants. Performance of these patients on tasks requiring integration of information from both ears has been mixed. To date, both electrophysiologic and psychoacoustic measures have been used to investigate the binaural processing in these patients, however, no study has explored the relationship between these two measures.

The binaural interaction component (BIC) of electrically evoked auditory brainstem response (EABR) is an electrophysiologic tool for evaluating binaural processing in bilateral CI users. It is defined as the difference between the algebraic sum of the two monaural evoked potentials and evoked potential recorded in response to binaural stimulation. It has been shown in cats that the largest BIC amplitude was obtained from stimulation of interaural electrode pairs with the same intracochlear insertion depths which in turn activated maximally overlapping neural populations (Smith and Delgutte, 2007). Binaural processing can also be investigated using some psychophysical methods, for example pitch ordering.

The goal of current study is determine if the electrically evoked binaural interaction component is related to psychophysical measures of pitch ordering. The long term goals of the study are to develop a new method for programming the speech processors of binaural CI users and to further evaluate the benefit from bilateral cochlear implantation in pediatric CI users.

BICs of the EABR were obtained from 11 electrode pairs of bilateral CI users. A pitch ordering test was also performed for these electrode pairs. Preliminary data will be presented and the correlation between these two measures will be described.

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D35. INTEGRATING BEAMFORMING WITH BLIND SEPARATION FOR BETTER RECOGNITION WITH BILATERAL COCHLEAR IMPLANTS

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Bilateral cochlear implants (CIs) partially restore the advantages of binaural hearing by improving access to binaural cues. However, when background noise or reverberation is present even at low levels, CIs are less effective. Until recently, the application of noise reduction in commercial CIs was limited to the use of a single microphone. To improve speech recognition amidst noise, a monaural two-microphone adaptive beamforming strategy, known as the BEAM™, is currently being marketed by Cochlear® as a pre-processor for the Nucleus Freedom™ system. This beamformer combines a directional with an omni-directional microphone to pick up and amplify sounds from one direction, while suppressing interferences arriving from all other directions. This has resulted in notable improvement within nearly anechoic settings. However, the effectiveness of the BEAM™ rapidly decreases, when reverberant energy increases. To ameliorate this shortcoming, we propose a novel processing approach based on merging adaptive beamforming (ABF) with blind signal separation (BSS) by utilizing two implants driven by a single processor. BSS uses multi-sensory observations of an inaccessible set of signals (sources) to reveal their individual form. More importantly, it does so without assuming any prior knowledge about the mixing structure or the source signals. Unlike existing strategies operating independently of one another, BSS presupposes the existence of a single processor driving two implants. As such, BSS capitalizes on ILD and ITD information present in the binaural mixtures to boost recognition by perceptually enhancing the waveform of the desired target from a set of composite signals. Based on this new strategy, the signals are first pre-processed binaurally by one processor per ear (two ABF blocks in total), while the recovered source estimates are then enhanced further through a BSS processing block. To evaluate the performance of the proposed ABF+BSS method, binaural open-set recognition experiments were carried out in both anechoic and reverberant settings using the SPEAR3® processor. Four different processing schemes were tested. The microphone stimuli were processed with BSS only, ABF only (similar to BEAM™ processing) and the new algorithm merging ABF with BSS. For the baseline condition we used signals processed through the ACE strategy. Word recognition tests showed that in anechoic scenarios, ABF, BSS and ABF+BSS all provide nearly the same benefit. In moderately reverberant settings, the BSS and ABF+BSS processing schemes significantly outperformed ABF and ACE.

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D36. BINAURAL LOCALIZATION ABILITY CAN BE PREDICTED FROM BASIC MEASURES OF ILD AND IS ROBUST TO EFFECTS OF AGC

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Binaural Cochlear Implantation has been shown to improve localization ability. Sensitivity to interaural level difference (ILD) is assumed to be an important basis for this improvement. In 4 bilaterally implanted subjects, we measured: (1) ILD threshold to pulse trains using direct electrode stimulation; (2), through-processor sensitivity to acoustic ILD, and (3), localization performance. Using software simulations of the speech processor signal path we quantitatively predicted the through-processor threshold. Using the predicted ILD threshold and a decision model for localization performance, we were then able to predict the localization error.

While these results do not preclude the use of interaural time difference as an aid to localization, they show that, in the frontal horizontal plane, localization performance can be predicted by measurement of a subject’s basic ILD sensitivity.

An important facet of our study was that both through-processor ILD threshold and localization were measured in two conditions: with the automatic gain control (AGC) activated and also with the AGC replaced by an appropriate linear gain. Because independent, binaural AGCs compress ILD, it has been assumed that they degrade sensitivity to the acoustic ILD naturally occurring at the ears, and therefore potentially degrade localization performance. However CI users, like normal-hearing listeners, give a strong preference to onset cues in lateralization. This fact, coupled with the time constants used for speech compression, minimize the effects of the AGC on ILD sensitivity for the sounds we tested. Surprisingly, neither acoustic ILD sensitivity nor localization differed significantly with the AGC engaged.

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D37. RECOGNITION AND LOCALIZATION OF SPEECH BY ADULT COCHLEAR IMPLANT RECIPIENTS WEARING A DIGITAL HEARING AID IN THE NON-IMPLANTED EAR (BIMODAL HEARING)

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The use of one cochlear implant without amplification in the non-implanted ear has been the standard fitting procedure for cochlear implant recipients. The possibility of successfully aiding the non-implanted ear has increased with less stringent implant candidacy criteria and improvements in digital power hearing aids. This study documented the effects of wearing a cochlear implant in one ear and a well-fit digital hearing aid in the opposite (non-implanted) ear (bimodal hearing).

Nineteen experienced adult Cochlear Nucleus implant recipients participated. All subjects were fit with a Widex Senso Vita 38 hearing aid to achieve maximum audibility and comfort within their dynamic range. Soundfield FM tone thresholds, aided loudness growth contours with broadband stimuli, localization of speech, roaming speech recognition, and subjective questionnaires were obtained. Subjects were tested and retested one month later for three conditions: hearing aid monaurally, cochlear implant monaurally, and cochlear implant plus hearing aid (CI+HA). The results were analyzed with a repeated measures ANOVA.

The CI+HA soundfield thresholds and loudness growth contours showed binaural summation. The localization of speech and roaming speech recognition tasks included presentation of CNC words at 60 dB SPL from a 15 loudspeaker 140^{o} array. All speech measures had high test-retest reliability (range: r=0.87 to r=0.98). Performance in the bimodal condition (CI+HA) was significantly better for localization of speech ($F[1.87, 33.60] = 59.42$, $p<.001$) and roaming speech recognition ($F[2, 36]=20.85$; $p<.001$) compared to the monaural conditions. The results were also analyzed by the side of the array that presented the word. This analysis showed a significant side effect for the monaural conditions. Performance was significantly better when the words were presented from the side of the array closest to the ear wearing amplification for both the localization of speech ($F[1.32, 23.66]=27.02$; $p<.001$) and roaming speech recognition ($F[2, 36]=3.24$, $p=.05$) tasks. Performance in the bimodal condition was equal regardless of which side of the array presented the word for both the localization of speech and roaming speech recognition tasks. Variables related to the audibility of sound in the non-implanted ear were significant predictors of performance including unaided hearing thresholds, aided soundfield thresholds, and Speech Intelligibility Index.

D38. BILATERAL ELECTRICAL STIMULATION RESEARCH TOOLS FOR NUCLEUS® COCHLEAR IMPLANTS

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The bilateral implantation of multi-channel cochlear implants (CI) is becoming increasingly common with the aim to restore binaural hearing to recipients. To maximise the effect of these bilaterally implanted CI's, research is required to understand how best to present the information from two 'ears'. In particular, the ability for a recipient to integrate the information from two sources is still not fully understood. This lack of understanding has an impact on the stimulation delivery from two sources, so as to best convey the effects of binaural hearing.

The second generation of the Nucleus Implant Communicator (NIC™) research tool has been specifically designed to allow this research to be performed. The research tool can be used to deliver stimulation which may be arbitrary in nature or derived from an audio test signal, in both a unilateral and bilateral fashion. Most importantly, the tool allows the delivery of synchronised bilateral stimulation which is required for the investigation of binaural effects. In addition, the NIC research tool can deliver stimulation which is synchronised to recording equipment thereby allowing electrophysiological measures, e.g., Evoked Auditory Brainstem Response (EABR) or similar.

This poster presents a case example of the use of the NIC research tools, being a study conducted at The University of Iowa. The study aims to compare electrophysiological and psychoacoustic measures, in particular binaural measures. It is hoped that investigation into these measures will provide both an understanding of binaural hearing and to better the bilateral signal processing algorithms used by the sound processors. The case example illustrates the features required from tools for such research, it details the set-up being used and presents the type of responses measured. Presenting such an example should show that research into binaural / bilateral effects is not difficult if a toolset with the right features is used.

D39. INTERAURAL TIME SENSITIVITY TO COCHLEAR IMPLANT STIMULATION IN FIELD A1 OF HEARING AND CONGENITALLY DEAF CATS

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Congenital auditory deprivation leads to deficits in cortical processing demonstrated in single-unit responses, gross synaptic currents and field potentials recorded from congenitally deaf cats (Kral et al., Cereb Cortex 2005; 552-62). These deficits are the consequence of an altered developmental sequence and additional degenerative processes.The present work focuses on the question to which extent the naive auditory cortex is able to process binaural cues - specifically, interaural time differences (ITD).

Four adult congenitally deaf cats were used, and four adult hearing cats served as controls. The controls were acutely deafened by intracochlear application of neomycin. All animals were stimulated with single charge-balanced biphasic pulses (200µs/phase, repetition rate 2/s) or a pulse train (3 pulses, 500 Hz, 6 ms) in wide bipolar configuration through a custom made cochlear implant inserted into the scala tympani on either side. Cortical thresholds were determined by recording local field potentials (LFPs) using Ag/AgCl macroelectrodes. The cortex was further mapped with glass microelectrodes using LFPs elicited at 10 dB above lowest cortical threshold. Within the most responsive cortical region (ROI region of interest area ~ 1mm^2) single and multi-unit activity was recorded by means of microelectrodes and 16 channel electrode arrays respectively (Michigan probes; 60-140 unit recording sites per animal). First of all the threshold of each unit (ie at each recording site) was determined after stimulation of ipsi- and contralateral ears. Sensitivity to interaural time difference in the range of 0-600 µs (ipsilateral ear leading and lagging) was then tested with single pulses and pulse trains (500 Hz, 3 pulses) at intensities of 0 – 10 dB above the unit's threshold.

Three different classes of unit responses were found. 1) More than 75% of the recording sites in hearing controls yielded unit responses selective (tuned) to a certain ITD – ie their firing rates peaked at a single ITD. Most units (~ 60%) responded best to ITDs with the ipsilateral stimulus lagging, corresponding to representation of the sound location in the contralateral hemifield. 2) Units with ITD sensitivity around the midline (near ITD=0 µs) were the second most common. 3) Tuning to ipsilateral-leading stimuli was less prevalent. In the naïve cortex, units tuned to the ITD stimuli were also found. However, their occurrence was much less frequent: less than 50% of all units showed clear ITD tuning in the congenitally deaf cats. Furthermore, units in deaf animals showed a significantly smaller maximum firing rate when compared to hearing controls. In both groups, tuning to time disparities below 200µs was most prevalent

The data demonstrate a residue of interaural time cue processing in the naïve cortex of congenitally deaf cats; nevertheless fewer units are tuned for ITD. Moreover, these units respond with smaller maximum firing rates. The data suggest that congenital absence of hearing experience may significantly affect the ability of the primary auditory cortex to respond to interaural time cues.

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D40. LOCALIZATION AND 3D SPEECH PERCEPTION WITH THE FSP STRATEGY

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A new generation of speech processors has been introduced by MED-EL, i.e. the OPUS 1 and OPUS 2 speech processor. Both implement a new type of signal processing, the Fine Structure Processing strategy (FSP). FSP performs temporal fine structure analysis of the 2-3 lowest frequency bands by starting channel specific sampling sequences (CSSS) synchronously with the zero-crossings of the corresponding band pass signals. Thus the fundamental frequency (F0) and low-frequency harmonics are coded in time and place.

The aim of the study was to investigate the effect of the current implementation of low-frequency temporal fine structure analysis on localization abilities and speech perception in 3D listening situations.

Bilateral users of the C40+ and PulsarCI^{100} have been tested. CIS+ as implemented in the TEMPO+ and FSP with the OPUS 1 were compared. To cover the whole range of F0s the input frequency range of the OPUS 1 was extended down to 100 Hz compared to 250 Hz in CIS+. Sound source localization of different noise and speech signals was tested in a setup consisting of 11 loudspeakers positioned in the frontal horizontal plane. SRTs were measured unilaterally and bilaterally using the adaptive Oldenburg sentence test in different spatial configurations: S0N0, S0N-90, S0N90, S-90N90, and S90N-90. Head shadow, summation, and squelch effect were calculated from the first three setups. In the last two setups the effect of FS analysis on spectral and informational masking was measured. Therefore two types of masker signals were used, i.e. a babble noise generated from the speech test material and a female talker.

First results will be presented and implications of coding fine structure on localization and the perception of spatially separated sound sources will be discussed.

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