2009 CONFERENCE ON IMPLANTABLE AUDITORY PROSTHESES

July 12 -17, 2009

Conference Chair:	Bob Carlyon
Conference Co-chair:	Gail Donaldson
Administrative Co-chair:	Bob Shannon
Conference Coordinator:	Dana Rosario

Steering Committee

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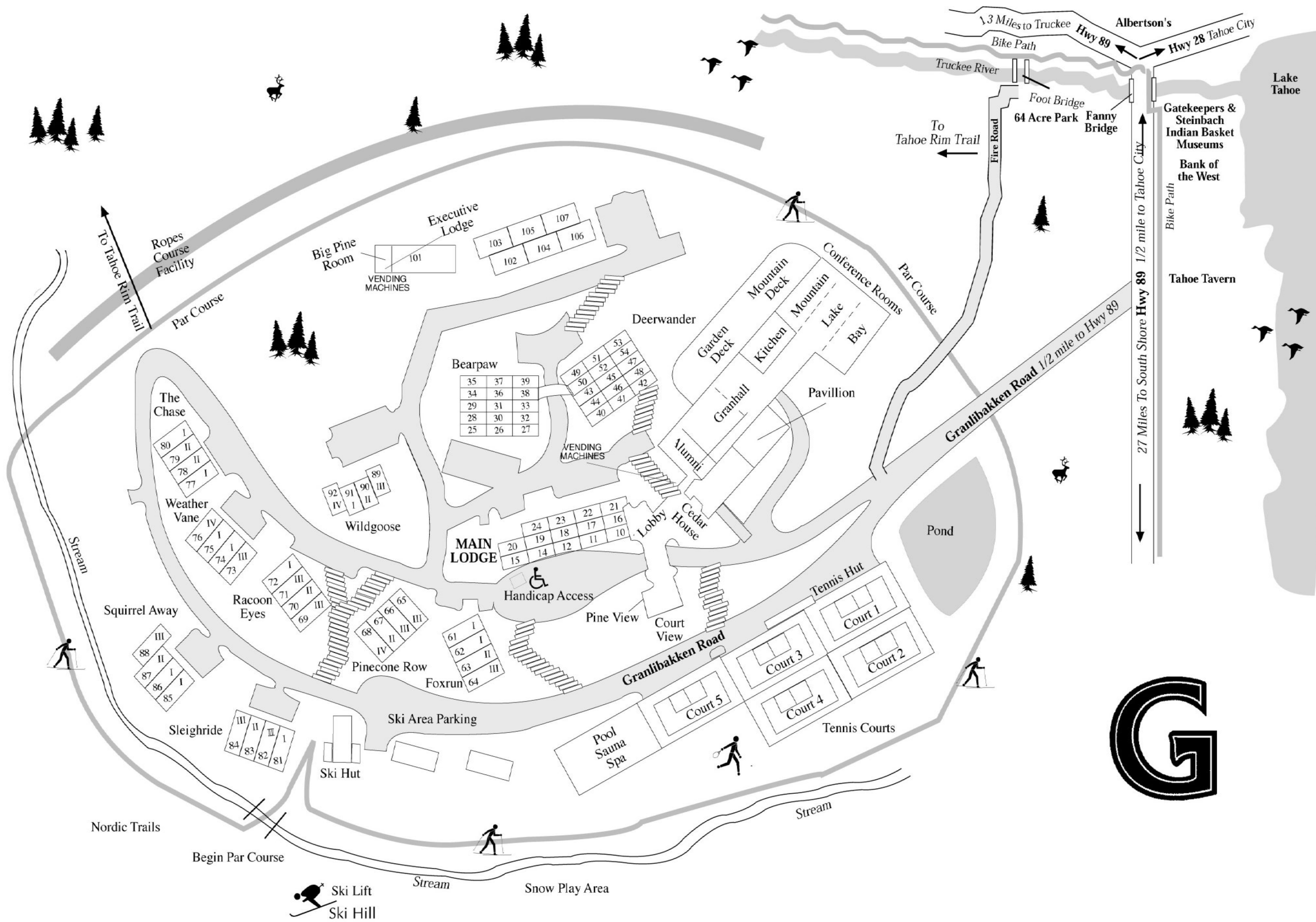

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WE HOPE YOU ENJOY YOUR VISIT!

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PROGRAM OVERVIEW

Sunday July 12	
3:00PM - 10:00PM	Registration
7:00PM – Midnight	Welcome Reception

Monday July 13	
7:00AM	Breakfast opens
8:50AM – 12:15PM	Session 1: Electrode-neural Interface
12:20PM	Lunch
1:00PM – 5:00PM	Poster Viewing
5:00PM – 7:00PM	Dinner
7:00PM – 9:15PM	Session 2: Plasticity and Development
9:20PM – 11:00PM	Poster Viewing and Social

Tuesday July 14	
7:00AM	Breakfast opens
9:00AM – 12:15PM	Session 3: Physiology
12:20PM	Lunch
1:00PM – 5:00PM	Poster Viewing
1:30PM – 3:00PM	Young Investigator Mentoring Session
5:00PM – 7:00PM	Dinner
7:00PM – 9:05PM	Session 4: Pitch and Electric-Acoustic Hearing
9:10PM – 11:00PM	Poster Viewing and Social

Wednesday July 15	
7:00AM	Breakfast opens
9:00AM – 12PM	Session 5: Electric-Acoustic Hearing
12:10PM	Lunch
1:00PM – 5:00PM	Poster Viewing
1:45PM – 4:50PM	Session 6: Spectro-temporal Processing; Tribute to Margo Skinner
5:00PM	Dinner
7:00PM	Social Event

Thursday July 16	
7:00AM	Breakfast opens
9:00AM – 12:30PM	Session 7: Bilateral Implants
12:40PM	Lunch
1:00PM – 5:00PM	Poster Viewing
5:00PM	Dinner
7:00PM – 9:35PM	Session 8: SGN Maintenance and Regeneration

Friday July 17	
7:00AM	Breakfast opens
9:00AM – 11:35AM	Session 9: Beyond the Cochlea
11:45AM	Lunch and Conference End

CIAP 2009 SESSION SCHEDULE

Monday, July 13, MORNING

<u>Electrode-neural Interface</u> *John Middlebrooks, Chair*

8:50 Carlyon - WELCOME TO CIAP 2009

9:00 Bierer (35) - IDENTIFYING IMPAIRED COCHLEAR IMPLANT CHANNELS BY USING THE PARTIAL-TRIPOLAR CONFIGURATION: IMPLICATIONS FOR COCHLEAR IMPLANT FITTINGS

9:35 Litvak (35) - "PHANTOM ELECTRODE" STIMULATION

10:10 Frijns (35) - THE FEASIBILITY OF DUAL ELECTRODE STIMULATION IN SPANNING LARGER INTER-ELECTRODE DISTANCES

10:45 BREAK (15)

11:00 Smith & Long (35) - ANALYSIS AND OPTIMIZATION OF FOCUSED INTRACOCHLEAR STIMULATION

11:35 Srinivasan (20) - CURRENT FOCUSING SHARPENS LOCAL PEAKS OF VIRTUAL CHANNELS

11:55 Schatzer (20) - SIMULTANEOUS STIMULATION WITH CHANNEL INTERACTION COMPENSATION

Monday July 13, EVENING

<u>Plasticity and Development</u> *Ruth Litovsky, Chair*

7:00 Summerfield (35) - CLINICAL EFFECTIVENESS AND COST EFFECTIVENESS OF BILATERAL COCHLEAR IMPLANTATION FOR DEAF CHILDREN

7:35 Fallon (35) - EFFECTS OF LONG-TERM DEAFNESS AND CHRONIC INTRACOCHLEAR ELECTRICAL STIMULATION ON THE PRIMARY AUDITORY CORTEX

8:10 BREAK (10)

8:20 Giraud (35) - PREDICTING COCHLEAR IMPLANT OUTCOME FROM BRAIN ORGANIZATION IN THE DEAF

8:55 Oba (20) - EFFECTS OF AUDITORY TRAINING IN NOISE FOR COCHLEAR IMPLANT USERS

Tuesday July 14, MORNING

<u>Physiology</u> *Paul Abbas, Chair*

9:00 Wang (35) **-** NEURAL CODING MECHANISMS IN AUDITORY CORTEX AND THEIR IMPLICATIONS FOR CORTICAL REPRESENTATIONS OF SOUNDS PROCESSED BY COCHLEAR IMPLANTS

9:35 Brown (35) - ELECTRICALLY EVOKED CORTICAL POTENTIALS

10:10 Wouters (35) - STEADY STATE RESPONSES IN COCHLEAR IMPLANTS

10:45 BREAK (15)

11:00 Miller (35) - AUDITORY NERVE RESPONSES TO PULSE TRAIN STIMULI

11:35 Richter (20) - TEMPORAL PROPERTIES OF INFERIOR COLLICULUS RECORDINGS DURING OPTICAL STIMULATION

11:55 Schoenecker (20) - MONOPOLAR INTRACOCHLEAR PULSE TRAINS CAN ELICIT FOCAL CENTRAL ACTIVATION

Tuesday July 14, AFTERNOON

1:30 – 3:00 PM YOUNG INVESTIGATOR MENTORING SESSION ***Ruth Litovsky, Chair***

Tuesday July 14, EVENING

Pitch and Electric-Acoustic Hearing *Brian Moore, Chair*

7:00 Rosen (20) - A QUANTITATIVE ESTIMATE OF THE CONTRIBUTION OF VOICE FUNDAMENTAL FREQUENCY VARIATIONS TO SENTENCE INTELLIGIBILITY IN TONE AND NON-TONE LANGUAGES

7:20 Macherey (20) - EFFECT OF INTRACOCHLEAR STIMULATION SITE ON THE UPPER LIMIT OF TEMPORAL PITCH

7:40 Luo (20) - ENCODING PITCH CONTOURS USING CURRENT STEERING

8:00 BREAK (10)

8:10 Carlyon (20) - PITCH MATCHING BETWEEN ELECTRIC AND ACOUSTIC STIMULI BY PATIENTS WITH NORMAL HEARING IN THE UNIMPLANTED EAR

8:30 Nopp (35) - COCHLEAR IMPLANTATION IN UNILATERAL DEAFNESS

Wednesday July 15, MORNING

Electric-Acoustic Hearing *Bob Carlyon, Chair*

9:00 McDermott (35) - ESTIMATING AND CONTROLLING THE LOUDNESS OF ELECTRIC AND ACOUSTIC STIMULI

9:35 Turner (35) - ACOUSTIC AND ELECTRIC HEARING – RESULTS FROM SHORT-ELECTRODE STUDIES

10:10 Dorman (35) - PSYCHOPHYSICAL AND SPEECH PERCEPTION RESULTS FROM EAS PATIENTS WITH FULL, 20 AND 10 MM ELECTRODE INSERTIONS

10:45 BREAK (15)

11:00 Francart (20) - BIMODAL LISTENERS ARE SENSITIVE TO INTERAURAL TIME DIFFFERENCES IN MULTICHANNEL STIMULI

11:20 Sheffield (20) - RELATIVE CONTRIBUTIONS OF PITCH AND INTELLIGIBILITY TO ELECTRO-ACOUSTIC SPEECH PERCEPTION IN NOISE

11:40 Brown (20) - THE EFFECTS OF MANIPULATING F0 ON THE BENEFITS OF ELECTRIC-ACOUSTIC STIMULATION

Wednesday July 15, AFTERNOON

(i) Spectro-temporal Processing *Gail Donaldson, Chair*

1:45 McKay (35) - IN SEARCH OF FREQUENCY RESOLUTION

2:20 Rubinstein (35) - SPECTRAL AND TEMPORAL CONTRIBUTIONS TO CLINICAL PERFORMANCE

2:55 Hu (20) - TOWARD RESTORING SPEECH INTELLIGIBILITY IN NOISE

3:15 BREAK (15)

(ii) Tribute to Margo Skinner *Gail Donaldson, Chair*

3:30 Donaldson - INTRODUCTION

3:35 Firszt (25) - MARGARET SKINNER'S CONTRIBUTIONS TO OPTIMIZATION OF SPEECH RECOGNITION IN INDIVIDUAL CI RECIPIENTS

4:00 Finley (25) - MARGARET SKINNER'S CONTRIBUTIONS TO UNDERSTANDING THE BASIS OF SPEECH RECOGNITION VARIABILITY ACROSS CI RECIPIENTS

4:25 Seligman (25) - THIRTY YEARS OF COCHLEAR IMPLANT DEVELOPMENT

Thursday July 16, MORNING

Bilateral Implants *Christopher Long, Chair*

9:00 Litovsky (35) - CONTRIBUTING AND LIMITING FACTORS TO BINAURAL SENSITIVITY IN BILATERAL COCHLEAR IMPLANT USERS

9:35 Van Hoesel (35) - OBSERVER WEIGHTING OF LEVEL AND TIMING CUES IN BILATERAL COCHLEAR IMPLANT USERS

10:10 Hartley (20) - SPATIAL HEARING IN FERRETS WITH COCHLEAR IMPLANTS

10:30 BREAK (15)

10:45 Vollmer (35) - ENCODING OF ACOUSTIC AND ELECTRIC INTERAURAL TIME DIFFERENCES IN THE MONGOLIAN GERBIL

11:20 Delgutte (35) - NEURAL CODING OF ITD WITH BILATERAL COCHLEAR IMPLANTS: EFFECTS OF AUDITORY EXPERIENCE AND TEMPORAL FINE STRUCTURE

11:55 Kral (35) - CORTICAL RESPONSES TO BILATERAL COCHLEAR IMPLANTS IN DEAF CATS

Thursday July 16, EVENING

SGN Maintenance and Regeneration ***Rob Shepherd, Chair***

7:00 Leake (35) - BRAIN-DERIVED NEUROTROPHIC FACTOR (BDNF) AND ELECTRICAL STIMULATION PROMOTE IMPROVED SURVIVAL OF SPIRAL GANGLION NEURONS IN CATS DEAFENED AS NEONATES

7:35 Edge (35) - REPLACEMENT OF AUDITORY NEURONS BY STEM CELLS IN THE DE-AFFERENTED ORGAN OF CORTI: FORMATION OF GLUTAMATERGIC SYNAPSES WITH HAIR CELLS

8:10 BREAK (10)

8:20 Nayagam (35) - THE POTENTIAL OF STEM CELLS FOR AUDITORY NEURON GENERATION AND REPLACEMENT IN THE DEAF COCHLEA

8:55 Lenarz (20) - NANOPARTICLES AS NOVEL DRUG DELIVERY SYSTEMS FOR COCHLEAR IMPLANTS: CELL-UPTAKE AND –TOXICITY IN VITRO AND IN VIVO

9:15 Wise (20) - PROTECTION OF SPIRAL GANGLION NEURONS WITH NEUROTROPHINS AND CHRONIC ELECTRICAL STIMULATION

Friday July 17, MORNING

Beyond the Cochlea ***Bob Shannon, Chair***

9:00 Middlebrooks (35) - INTRANEURAL STIMULATION FOR AUDITORY PROSTHESIS

9:35 Phillips (35) - BEHAVIORAL AND NEURAL RECORDING TO EVALUATE A MINIMALLY INVASIVE VESTIBULAR PROSTHESIS BASED UPON COCHLEAR IMPLANT TECHNOLOGY

10:10 BREAK (15)

10:25 Colletti (35) - DEVELOPMENTAL TRAJECTORY OF CHILDREN WITH ABI: PERFORMANCE vs ETIOLOGY

11:00 Lim (35) - AUDITORY MIDBRAIN IMPLANT: CURRENT PROGRESS AND FUTURE DIRECTIONS

POSTER SESSION A: MONDAY - TUESDAY

A1: INTRACOCHLEAR MONITORING OF ACOUSTICALLY-GENERATED POTENTIALS DURING COCHLEAR IMPLANTATION: IMPLICATIONS FOR ATRAUMATIC ELECTRODE INSERTION
Douglas C. Fitzpatrick, Stefan J. Mlot, Joshua B. Surowitz, Craig A. Buchman, and Oliver F. Adunka

A2: INFERRING THE ELECTRODE TRAJECTORY FROM ELECTRICAL SPREAD MEASURES
Filiep J. Vanpoucke and Johan H.M. Frijns

A3: FOCUSED-STIMULATION THRESHOLDS AND MEDIAL-LATERAL ELECTRODE POSITION
Christopher J. Long, Timothy A. Holden, Wendy S. Parkinson, Zachary M. Smith and Chris van den Honert

A4: TWO CHANNEL OPTICAL STIMULATION OF THE COCHLEA
Agnella Izzo Matic, Suhrud M. Rajguru and Claus-Peter Richter

A5: SURVIVAL OF SPIRAL GANGLION CELLS AFTER CESSATION OF BDNF-TREATMENT; COCHLEAR IMPLANTS IN DEAFENED GUINEA PIGS
Martijn J.H. Agterberg, Huib Versnel, John C.M.J. de Groot and Sjaak F.L. Klis

A6: NEURAL REPRESENTATION OF PULSE TRAIN ENVELOPE MODULATION DEPTH IN THE INFERIOR COLLICULUS OF CATS TREATED WITH INTRACOCHLEAR INFUSION OF BDNF
Ben H. Bonham, Matthew C. Schoenecker, Olga A. Stakhovskaya, Alexander M. Hetherington, Stephen J. Rebscher and Patricia A. Leake

A7: PROTECTION OF SPIRAL GANGLION NEURONS WITH NEUROTROPHINS AND CHRONIC ELECTRICAL STIMULATION
Andrew K. Wise, James B. Fallon, Alison J. Evans, Jacqueline Andrew, Lisa N. Pettingill, Marilyn Geaney and Robert K. Shepherd

A8: FUNCTIONAL ASSESSMENT OF A NEW DOUBLE-SHANK AUDITORY MIDBRAIN IMPLANT IN A GUINEA PIG MODEL
Roger Calixto, Minoo Lenarz, Anke Neuheiser, Thomas Lenarz and Hubert H. Lim

A9: MODELING THE TEMPORAL RESPONSE PROPERTIES OF AUDITORY NERVE FIBERS TO PULSATILE ELECTRICAL STIMULATION
Leon F. Heffer, Mark W. White, James B. Fallon, David J. Sly and Stephen J. O'Leary

A10: USE OF LOW LEVEL STIMULI TO ASSESS CHANNEL INTERACTION
Paul J. Abbas, Christine P. Etler, Sara N. O’Brien and Carolyn J. Brown

A11: A COMPARISON OF ARTIFACT REMOVAL TECHNIQUES FOR INTRACOCHLEAR EVOKED POTENTIAL RECORDINGS
Philip R. Brown, Chandra S. Throckmorton, Joshua S. Stohl,
Lianne A. Cartee and Leslie M. Collins

A12: STIMULATION ARTEFACT IN COCHLEAR IMPLANT PERIPHERAL (eCAPS) AND CORTICAL ELECTROPHYSIOLOGICAL MEASUREMENTS: A PARAMETRIC STUDY
Idrick Akhoun, Mahan Azadpour, Deanne Jayewardene, Wael El-Deredy
and Colette McKay

A13: RECORDING OF ELECTRICALLY EVOKED AUDITORY BRAINSTEM RESPONSES AFTER ELECTRICAL STIMULATION WITH BIPHASIC, TRIPHASIC AND PRECISION TRIPHASIC PULSES
Andreas Bahmer, Marek Polak and Uwe Baumann

A14: DEVELOPING A NEW NON-HUMAN PRIMATE MODEL FOR COCHLEAR IMPLANT RESEARCH
Luke A. Johnson, Charles Della Santina and Xiaoqin Wang

A15: COMPARING SPATIAL TUNING CURVES WITH LOCAL AND GLOBAL MEASURES OF SPECTRAL RIPPLE RESOLUTION
Elizabeth S. Crump Anderson, Heather A. Kreft, Andrew J. Oxenham and David A. Nelson

A16: COMPLEX PITCH PERCEPTION IN THE ABSENCE OF A PLACE/RATE MATCH
John M. Deeks, Hedwig Gockel and Robert P. Carlyon

A17: STREAM SEGREGATION ON A SINGLE ELECTRODE AS A FUNCTION OF STIMULATION RATE
Sara I. Duran, Joshua S. Stohl, Chandra S. Throckmorton
and Leslie M. Collins

A18: TEMPORAL MODULATION DETECTION REVISITED: THE EFFECT OF CARRIER RATE
Matthew P. Fraser and Colette M. McKay

A19: RELATIONSHIP BETWEEN TEMPORAL ACUITY AND LOUDNESS GROWTH IN COCHLEAR IMPLANT USERS
Soha N. Garadat and Bryan E. Pfingst

A20: AN ACOUSTIC RECONSTRUCTION TECHNIQUE FOR PULSATILE STIMULATION WHICH MODELS THE RATE-DISCRIMINATION LIMIT IN COCHLEAR IMPLANTS
Ji-Jon Sit, Leonid M. Litvak, Anthony J. Spahr, Michael F. Dorman and Tyler C. Oakes

A21: EFFECT OF ACOUSTIC INPUT FREQUENCY RANGE ON COCHLEAR IMPLANT USERS' MUSIC PERCEPTION
John J. Galvin III, Qian-jie Fu, Sandy Oba

A22: EFFECT OF TRAINING ON NON-NATIVE ENGLISH LISTENERS' SPEECH RECOGNITION IN NOISE
Ying Zhang and Qian-jie Fu

A23: BENEFIT TO INTELLIGIBILITY FROM HIGH RATE ENVELOPE CUES ABOVE AND BELOW THE CHANNEL RMS
Michael A. Stone, Christian Füllgrabe and Brian C. J. Moore

A24: SPEECH FEATURE DISCRIMINATION IN FRENCH CHILDREN WITH COCHLEAR IMPLANTS
Sophie Bouton, Pascale Colé, Josiane Bertoncini and Willy Serniclaes

A25: MATHEMATICAL MODELING OF TALKER VARIABILITY EFFECTS IN COCHLEAR IMPLANTS
Yi-ping Chang and Qian-Jie Fu

A26: CONTRIBUTION OF INFORMATION CARRIED BY WEAK CONSONANTS IN SIMULATED ACOUSTIC-ELECTRIC HEARING
Fei Chen, Yi Hu and Philipos C. Loizou

A27: AUDITORY DEVELOPMENT IN THE ABSENCE OF HEARING IN INFANCY
Karen A. Gordon, Jerome Valero and Blake C. Papsin

A28: THE DEVELOPMENT OF LANGUAGE IN CHILDREN WHO USE BILATERAL COCHLEAR IMPLANTS
Cynthia M. Zettler, Shelly P. Godar, Susan Ellis Weismer and Ruth Y. Litovsky

A29: EFFECT OF MODIFIED TIME-FREQUENCY TRADE OFF USING DIFFERENT FFT WINDOW LENGTHS & COMPARISON WITH FILTER BANK ANALYSIS
Shibasis Chowdhury, Carl Verschuur

A30: AUTOMATIC INPUT SELECTION FOR A COCHLEAR IMPLANT SOUND PROCESSOR
Felicity Allen, Sasha Case, Paul Holmberg, Michael Goorevich

A31: EVALUATION OF LONG-TERM ADAPTATION IN THE STAR COCHLEAR IMPLANT SOUND PROCESSING STRATEGY
David B. Grayden, Jasmine S. Mar, William G. Kentler and Anthony N. Burkitt

A32: PERCEPTUAL DIFFERENCES BETWEEN MONOPOLAR AND BIPOLAR STIMULATION AND PRELIMINARY RESULTS OF MIXED-MODE SPEECH CODING
Bomjun J. Kwon

A33: BIMODAL SPEECH PERCEPTION: EFFECTS OF ELIMINATING OVERLAPPING MISMATCHED FREQUENCY COVERAGE
Tim Green, Andrew Faulkner and Stuart Rosen

A34: ACOUSTIC CUES FOR BIMODAL BENEFIT IN SPEECH PERCEPTION
Anisa S. Visram, Mahan Azadpour, Karolina Kluk and Colette M. McKay

A35: CONSONANT RECOGNITION AS A FUNCTION OF THE NUMBER OF SPECTRAL CHANNELS: COMPARISON OF LONG-ELECTRODE AND HYBRID COCHLEAR IMPLANTS
Lina A.J. Reiss, Sue A. Karsten, Christopher W. Turner and Bruce J. Gantz

A36: CO-ORDINATED BILATERAL STIMULATION FOR IMPROVED SPEECH RECOGNITION IN NOISE
Kostas Kokkinakis and Philipos C. Loizou

A37: LOUDNESS PERCEPTION OF BILATERAL CI USERS
Stefan M. Brill, Stefan Kaulitz, Therese Nägle and Alexander Möltner

A38: BILATERAL COCHLEAR IMPLANTS IN CATS: PRELIMINARY OBSERVATIONS ON SOUND LOCALIZATION ABILITIES
Seymanur Celik, Janet Ruhland, Sam Gubbels, Colin Irwin, James Fallon, Robert Shepherd, Ruth Litovsky and Tom Yin

A39: PERFORMANCE OVER TIME IN WORD RECOGNITION AND SOUND LOCALIZATION OF ADULT PATIENTS WITH SIMULTANEOUSLY IMPLANTED BILATERAL COCHLEAR IMPLANTS
Son-A Chang, Camille Dunn, Richard Tyler, Haihong Ji, Shelley Witt, Bruce Gantz and Marlan Hansen

A40: A MODEL FOR RESPONSE OF THE AUDITORY BRAINSTEM TO BILATERAL COCHLEAR IMPLANTS: STIMULATION OF THE LOW FREQUENCY PATHWAY MAY BE CRITICAL FOR ITD SENSITIVITY
Yoojin Chung and H. Steven Colburn

A41: DEVELOPMENT AND EVALUATION OF A PAEDIATRIC AUDIO-VISUAL SPEECH TEST IN NOISE
Laure P. Arnold, David Canning, Filiep J. Vanpoucke, Philippe Dykmans and Patrick J. Boyle

A42: RISKS AND BENEFIT OF DEEPLY INSERTED COCHLEAR IMPLANT ELECTRODE ARRAYS
Rolf Battmer

POSTER SESSION B: TUESDAY - WEDNESDAY

B1: OPTICAL COCHLEAR IMPLANTS: A STUDY OF EFFICACY AND SAFETY IN CATS
Suhrud M. Rajguru, Agnella Izzo Matic, Laura E. Moreno, Joe Breen, Allison Bradley, Andrew Fishman, Jonathon D. Wells Jr, Mark Bendett and Claus-Peter Richter

B2: LOUDNESS MEASURES USING VARYING PARTIAL-TRIPOLAR CONFIGURATIONS IN HIGH- AND LOW-THRESHOLD CHANNELS
Amberly D. Nye and Julie A. Bierer

B3: SURFACE PATTERNED COCHLEAR IMPLANT ELECTRODE ARRAY
Gerrit Paasche, Elena Fadeeva, Ronnie Oberbandscheid, Bart Volckaerts, Gerald Dumm, Uta Reich, Jürgen Koch, Boris Chichkov, Thomas Lenarz and Timo Stöver

B4: ADVANCED NEURAL INTERFACES
Satinderpall S. Pannu, Emil J. Geiger, Maxim Shusteff, Terri L. Delima, William J. Benett and Phillipe J. Tabada

B5: HOMEOSTATIC PROPERTIES OF HAIR CELLS, WHAT TO SEEK IN REGENERATED HAIR CELLS
Matthew R. Flax and W. Harvey Holmes

B6: SPIRAL GANGLION CELL SURVIVAL AFTER ROUND-WINDOW APPLICATION OF GELFOAM SOAKED WITH BRAIN-DERIVED-NEUROTROPHIC FACTOR IN DEAFENED GUINEA PIGS
Sarah Havenith, Huib Versnel, Martijn J.H. Agterberg, John C.M.J. de Groot, Robert-Jan Sedee, Wilko Grolman and Sjaak F.L. Klis

B7: EFFECTS OF PARTIAL DEAFNESS AND CHRONIC INTRACOCHLEAR ELECTRICAL STIMULATION ON AUDITORY AND ELECTRICAL RESPONSE CHARACTERISTICS IN PRIMARY AUDITORY CORTEX
James B. Fallon, Robert K. Shepherd and Dexter, R. F. Irvine

B8: SPATIAL SELECTIVITY OF AUDITORY NERVE FIBERS TO MULTICHANNEL STIMULATION IN DIFFERENT STIMULUS CONDTIONS
Ning Hu, Charles A. Miller, Paul J. Abbas, JiHwan Woo and Barbara K. Robinson

B9: A PHYSIOLOGICAL CORRELATE OF PULSE TRAIN FORWARD MASKING SHOWS FASTER RECOVERY AT HIGH PULSE RATES
Alana E. Kirby and John C. Middlebrooks

B10: ECAP MEASUREMENTS PREDICT THE EFFICACY OF VESTIBULAR IMPLANT STIMULATION IN PRIMATES
Steven M. Bierer, Kaibao Nie, Leo Ling, Trey Oxford, Jay T. Rubinstein, and James O. Phillips

B11: DIFFERENT MEASURES OF AUDITORY NERVE REFRACTORINESS AFTER ELECTRICAL STIMULATION, USING PERIPHERAL ELECTROPHYSIOLOGICAL MEASUREMENTS (eCAPs)
Idrick Akhoun, Matthew Fraser, Mahan Azadpour and Colette McKay

B12: AUDITORY NERVE RESPONSES WITH INTERMEDIATE-ELECTRODE STIMULATION
Michelle L. Hughes and Adam M. Goulson

B13: A POSSIBLE METHOD FOR THE REMOVAL OF COCHLEAR IMPLANT ARTIFACT
Lendra M. Friesen and Terence W. Picton

B14: A BEHAVIORAL DETECTION TASK IN GUINEA PIGS USING AIR PUFFS AS AVERSIVE UNCONDITIONED STIMULUS
Martijn J.H. Agterberg, Huib Versnel, Marloes van den Broek, Ingrid H.C.H.M. Philippens and Sjaak F.L. Klis

B15: AMPLITUDE MODULATION DETECTION ANALYZED WITH A POINT PROCESS MODEL OF THE AUDITORY NERVE
Joshua H. Goldwyn, Eric T. Shea-Brown and Jay T. Rubinstein

B16: INFLUENCE OF INTENSITY ON PITCH PERCEPTION IN COCHLEAR IMPLANT USERS VS. NORMALLY HEARING LISTENERS
Lisette P. Harting-Oshovsky, J. Wiebe Horst, Jorien Loos, Kris Boyen and Pim van Dijk

B17: EFFECTS OF FINE STRUCTURE STIMULATION ON PITCH PERCEPTION
Andreas Krenmayr, Reinhold Schatzer, Mathias Kals, Daniel Visser, Katrien Vermeire, Christian Neustetter, Paul Bader, Matthias Zangerl and Clemens Zierhofer

B18: CURRENT FOCUSING IMPROVES VIRTUAL CHANNEL DISCRIMINATION
David M. Landsberger and Arthi G. Srinivasan

B19: TEMPORAL PITCH PERCEPTS ELICITED BY DUAL-CHANNEL STIMULATION OF A COCHLEAR IMPLANT
Olivier Macherey and Robert P. Carlyon

B20: THE INTEGRATION OF TOUCH AND AUDITION: THE DIFFERENCE BETWEEN MUSICIAN AND NON-MUSICIAN CI USERS
Juan Huang, Ben Sheffield and Fan-Gang Zeng

B21: INDEXICAL LEARNING IN SPECTRALLY DEGRADED SPEECH BY LISTENERS WITH NORMAL HEARING
Sangsook Choi, Karen Iler Kirk, and Vidya Krull

B22: IMPROVEMENTS IN SPEECH PERCEPTION IN NOISE FROM RATE AND PLACE PITCH CUES: COCHLEAR IMPLANT SIMULATIONS
Robert S. Hong and Christopher W. Turner

B23: DO COCHLEAR IMPLANTS PROVIDE SPECTRAL ENVELOPE CUES FOR VOICE GENDER IDENTIFICATION?
Damir Kovačić and Evan Balaban

B24: CONTRIBUTIONS OF TEMPORAL CUES AND TONOTOPIC INFORMATION TO VOICE GENDER DISCRIMINATION: A VIEW FROM A PERCEPTUAL LEARNING STUDY
Tianhao Li and Qian-Jie Fu

B25: EFFECT OF ENHANCED TEMPORAL PITCH CUES ON SPEECH PERCEPTION IN COCHLEAR IMPLANT LISTENERS
Matthias Milczynski, Jan Wouters and Astrid van Wieringen

B26: A SIGNAL ENHANCEMENT ALGORITHM FOR COCHLEAR IMPLANT USERS: FIRST RESULTS OF A PILOT STUDY WITH HIRES 120
Martina Brendel, Andreas Buechner, Hilke Saalfeld, Carolin Frohne-Buechner and Thomas Lenarz

B27: EVALUATION OF DIFFERENT SIGNAL PROCESSING OPTIONS IN UNILATERAL AND BILATERAL COCHLEAR FREEDOM IMPLANT RECIPIENTS USING R-SPACE BACKGROUND NOISE
Alison M. Brockmeyer and Lisa G. Potts

B28: CONVEYING LOW FREQUENCY INFORMATION TO COCHLEAR IMPLANT USERS THROUGH ELECTRICAL STIMULATION
Andreas Buechner, Martina Brendel, Waldo Nogueira and Thomas Lenarz

B29: SPARSE STIMULI FOR COCHLEAR IMPLANTS
Guoping Li and Mark E. Lutman

B30: SIMULATING HAIR-CELL ADAPTATION IN COCHLEAR IMPLANT PROCESSORS
Benjamin A. Milczarski, Robert L. Smith and Karen A. Doherty

B31: EXPERIMENTAL RESULTS WITH A SINGLE SIDEBAND ENCODING STRATEGY FOR COCHLEAR IMPLANTS
Kaibao Nie, Xing Li, Les Atlas and Jay T. Rubinstein

B32: A TONOTOPIC MAP OF THE ELECTRICALLY STIMULATED COCHLEA FROM CI USERS WITH CONTRALATERAL NORMAL HEARING
Reinhold Schatzer, Katrien Vermeire, Paul v.d. Heyning, Maurits Voormolen, Daniel Visser, Andreas Krenmayr, Mathias Kals and Clemens Zierhofer

B33: METHODS FOR TRACKING BEHAVIORAL AND PHYSIOLOGICAL CHANGES IN ACOUSTICELECTRIC PITCH MATCHING
Chin-Tuan Tan, Brett Martin and Mario Svirsky

B34: PITCH SCALING PSYCHOMETRICS IN ELECTRIC ACOUSTIC STIMULATION (EAS)
Uwe Baumann, Tobias Rader and Andreas Bahmer

B35: AMPLIFICATION OF INTERAURAL LEVEL DIFFERENCES IMPROVES SOUND LOCALIZATION IN ACOUSTIC SIMULATIONS OF BIMODAL HEARING
Tom Francart, Tim Van den Bogaert, Marc Moonen and Jan Wouters

B36: THE LOCALIZATION OF CHANNEL-VOCODED STIMULI IN THE MEDIAN PLANE
Matthew J. Goupell, Bernhard Laback and Piotr Majdak

B37: BINAURAL SUMMATION, HEAD SHADOW AND SQUELCH EFFECT IN CHILDREN USING BILATERAL COCHLEAR IMPLANTS
Wilma Harnisch, Wafaa E. Shehata-Dieler, Alexander Möltner, Stefan M. Brill and Joachim Müller

B38: ELECTRODE POSITION AND PERFORMANCE IN A BILATERALLY IMPLANTED NUCLEUS FREEDOM USER
Laura K. Holden, Timothy A. Holden, and Jill B. Firszt

B39: RELATIONSHIP OF MONAURAL AND BINAURAL CHANNEL INTERACTION EFFECTS IN BILATERAL COCHLEAR IMPLANT USERS
Gary L. Jones, Ruth Y. Litovsky and Richard van Hoesel

B40: AUDITORY MIDBRAIN IMPLANT: PRESENT CLINICAL RESULTS AND FUTURE DIRECTIONS
Minoo Lenarz, Hubert Lim, Gert Josef, Urte Rost, A. Samii and Thomas Lenarz

B41: MYMAPS - ENABLING RECIPIENTS TO MEASURE THEIR OWN STIMULATION LEVELS
Sean K. R. Lineaweaver, Ishan Ann Tsay and Sara L. Nulle

POSTER SESSION C: WEDNESDAY - THURSDAY

C1: OPTICAL BEAM PATH IN GUINEA PIG COCHLEA
Laura E Moreno, Suhurud M. Rajguru, Agnella Izzo Matic and Claus-Peter Richter

C2: OPTICAL COCHLEAR STIMULATION: EFFECT OF FIBER SIZE ON RESPONSES IN THE INFERIOR COLLICULUS
Suhrud M. Rajguru, Agnella Izzo Matic and Claus-Peter Richter

C3: OPTICAL RADIATION LIKELY TARGETS SPIRAL GANGLION CELLS
Claus-Peter Richter, Agnella I. Matic and Andrew J. Fishman

C4: REDUCED SIMULTANEOUS CHANNEL INTERACTIONS WITH OPTIMIZED FOCAL ELECTRODE CONFIGURATIONS
Zachary M. Smith, Chris van den Honert and Christopher J. Long

C5: INTRACOCHLEAR INFUSION OF BRAIN-DERIVED NEUROTROPHIC FACTOR (BDNF) AFFECTS FUNCTION AND MORPHOLOGY OF SPIRAL GANGLION NEURONS IN CATS DEAFENED AS NEONATES
Alexander Hetherington, Gary Hradek, Olga Stakhovskaya, Ben Bonham and Patricia Leake

C6: DEXAMETHASONE ELUTING COCHLEAR ELECTRODE ARRAY: IN-VITRO AND IN-VIVO RESULTS
Claude Jolly, Hamid Mirzadeh, Jan Kiefer, Y Liu, Claudius Fauser, Alessandro Martini, Stavros Hastzopaulos, Laura Astolfi, Carolyn Garnham, Roland Hessler, Jochen Tillein and Susanne Braun

C7: A COMPUTATIONAL MODEL OF INCOMPLETE ADAPTATION TO A SEVERELY SHIFTED FREQUENCY-TO-ELECTRODE MAPPING BY COCHLEAR IMPLANT USERS
Elad Sagi, Qian-Jie Fu, John J. Galvin III and Mario A. Svirsky

C8: TEMPORAL PROPERTIES OF SINGLE AUDITORY NERVE FIBERS DURING STIMULATION WITH OPTICAL RADIATION
Philip Littlefield, Irena Vujanuvic, Agnella Izzo Matic and Claus-Peter Richter

C9: COMPARISON OF ELECTROPHYSIOLOGICAL RESPONSES EVOKED IN THE INFERIOR COLLICULUS OF THE CAT BY SURFACE MACROELECTRODES AND PENETRATING MICROELECTRODES IMPLANTED IN THE COCHLEAR NUCLEUS
Douglas McCreery, Martin Han and Victor Pikov

C10: NRT MEASUREMENTS IN SUBJECTS IMPLANTED WITH A NUCLEUS HYBRID-L COCHLEAR IMPLANT
Lutz Gärtner, Andreas Büchner, Timo Stöver and Thomas Lenarz

C11: AUDITORY STEADY STATE RESPONSES CAN BE RECORDED IN COCHLEAR IMPLANT USERS
Michael Hofmann and Jan Wouters

C12: IMPROVED MODELING OF REFRACTORY RECOVERY IN ECAP
Lawrence T. Cohen, David B. Grayden and Anthony N. Burkitt

C13: AUDITORY NERVE TEMPORAL RESPONSE VARIATION ACROSS ELECTRODES AND SUBJECTS
Michelle L. Hughes, Erin E. Castioni and Lisa J. Stille

C14: CORTICAL AUDITORY EVOKED POTENTIALS (CAEP) AND SPEECH PERCEPTION IN NOISE IN CHILDREN FITTED WITH COCHLEAR IMPLANTS
Catherine Morgan and Suzanne C. Purdy

C15: MISMATCH OF ENVELOPE AND TEMPORAL FINE STRUCTURE INFORMATION DESTROYS THE PRECEDENCE EFFECT
Bernhard U. Seeber

C16: ENVIRONMENTAL SOUND PERCEPTION IN COCHLEAR IMPLANT PATIENTS AND WHY IT MATTERS
Valeriy Shafiro, Brian Gygi, Minyu Cheng and Jay Vachhani

C17: CONTRIBUTIONS OF TEMPORAL AND PLACE CUES TO PITCH IN THE APICAL REGION
Katrien Vermeire, Reinhold Schatzer, Daniel Visser, Andreas Krenmayr, Mathias Kals, Christian Neustetter, Paul Bader, Matthias Zangerl, Paul Van de Heyning and Clemens Zierhofer

C18: ACOUSTIC TEMPORAL MODULATION TRANSFER FUNCTIONS IN COCHLEAR IMPLANT USERS
Jong Ho Won, Ward R. Drennan and Jay T. Rubinstein

C19: EFFECTS OF VARIATION IN SIGNAL POSITION AND FREQUENCY ON DETECTION OF SIGNALS IN REPRODUCIBLE NOISE
Ted A. Meyer and John E. King

C20: PITCH-RELATED SPEECH PERCEPTION ABILITIES AND LINKS TO MUSIC INVOLVEMENT IN EARLY-IMPLANTED CHILDREN
Ritva Torppa, Andrew Faulkner, Minna Huotilainen, Miika Järvenpää and Martti Vainio

C21: EFFECT OF REVERBERATION AND NOISE ON SPEECH RECOGNITION OF CHILDREN WITH COCHLEAR IMPLANTS
Arlene. C. Neuman, Marcin Wroblewski and Adrienne Rubinstein

C22: EFFECTS OF LINGUISTIC EXPERIENCE ON THE USE OF ACOUSTIC CUES IN QUESTION-STATEMENT IDENTIFICATION BY PEDIATRIC COCHLEAR IMPLANT RECIPIENTS
Shu-Chen Peng, Yung-Song Lin, Monita Chatterjee and Nelson Lu

C23: RECOGNITION OF SPEECH WITH A COMPETING TALKER USING FINE STRUCTURE IN COCHLEAR IMPLANTS
Reinhold Schatzer, Daniel Visser, Mathias Kals, Andreas Krenmayr, Katrien Vermeire, Paul Bader, Christian Neustetter, Matthias Zangerl and Clemens Zierhofer

C24: PROCESSING OF SPECTRALLY DEGRADED VOICE PITCH BY OLDER LISTENERS
Kara C. Schvartz and Monita Chatterjee

C25: SPECTRAL RESOLUTION AND INTELLIGIBILITY OF REVERBERANT SPEECH IN SIMULATED ELECTRIC-ACOUSTIC LISTENING
Kate Helms Tillery, Christopher A. Brown and Sid P. Bacon

C26: EVALUATION OF A NOVEL NOISE REDUCTION METHOD
Raymond L. Goldsworthy, Joseph G. Desloge and Patrick M. Zurek

C27: SOUND-DEPENDENT ENVELOPE COMPRESSION FOR IMPROVED SPEECH RECOGNITION IN NOISE
Ning Li and Philipos C. Loizou

C28: HRSTREAM: THE HIGH RESOLUTION STREAMING INTERFACE
Waldo Nogueira, Philippe Dykmans and Filiep Vanpoucke

C29: CLINICAL OUTCOMES OF THE MP3000™ SOUND CODING STRATEGY OPTIMIZATION STUDY IN FREEDOM™ RECIPIENTS
G. Rypkema, M. Killian, J. Pesch, A. Beynon, W. Szyfter, J. Allum, J. Brokx, S. Burdo, D. Cuda, I. Dhooge, N. Dillier, E. Estrada Leypón, J. Eyles, J. C. Falcón González, J. Festen, B. Frachet, D. Fürstenberg, A. Gentine, S. Gräbel, W. Grolman, M. Hey, U. Hoppe, A. Huarte Irujo, C. A. Leone, M. Mazzoli, B. Meyer, C. Morera Pérez, J. Müller-Deile, J. Müller-Mazzotta, K. Niemczyk, E. Offeciers, G. Paludetti, A. Quaranta, S. Roux-Vaillard, T. Steffens, J. Triglia, A. Uziel, P. Van de Heyning, T. Wesarg and A. Büchner

C30: INVESTIGATING THE ACUTE AND LONGITUDINAL BENEFITS TO SPEECH RECOGNITION OF A TUNED MULTI-RATE SPEECH PROCESSING ALGORITHM FOR COCHLEAR IMPLANTS
Joshua S. Stohl, Chandra S. Throckmorton and Leslie M. Collins

C31: TRAVELING WAVE DELAYS FOR COCHLEAR IMPLANTS: A STUDY OF ACROSS-FREQUENCY DELAYS
Daniel A. Taft, David B. Grayden and Anthony N. Burkitt

C32: VOICE IDENTIFICATION OF PATIENTS WITH THE HYBRID AND LONG-ELECTRODE COCHLEAR IMPLANT
Jessica E. Karnell and Christopher W. Turner

C33: EVALUATING PERFORMANCE IN TRADITIONAL AND HYBRID COCHLEAR IMPLANT PATIENTS
Sue A. Karsten and Christopher W. Turner

C34: ENHANCEMENT OF ACTUATOR DISPLACEMENT FOR INTRA-COCHLEAR APPLICATIONS
Cheng-Chun Lee, Sandrine Battesti, Clifford R. Hume, G. Z. Cao and I. Y. (Steve) Shen

C35: IMPROVED HORIZONTAL DIRECTIONAL HEARING IN UNILATERAL CONGENITAL CONDUCTIVE HEARING IMPAIRED PATIENTS FITTED WITH A BAHA
Martijn J.H. Agterberg, Thamar E.M. van Esch, Marc M. Van Wanrooij, Ad F.M. Snik and A. John Van Opstal

C36: BILATERAL COCHLEAR IMPLANTS: PSYCHOPHYSICS AND SPEECH UNDERSTANDING
Christopher J. Long, Wendy S. Parkinson, Zachary M. Smith and Chris van den Honert

C37: SPATIAL LISTENING WITH BILATERAL IMPLANTS OR BIMODAL DEVICES: A SIMULATION STUDY
Rosemary E.S. Lovett, Shan Huang and A. Quentin Summerfield

C38: CHANNEL INTERACTION EFFECTS ON BINAURAL UNMASKING SENSITIVITY IN BILATERAL COCHLEAR IMPLANT USERS
Thomas Lu, Ruth Litovsky and Fan-Gang Zeng

C39: 3-D SOUND LOCALIZATION IN COCHLEAR-IMPLANT LISTENERS
Piotr Majdak, Bernhard Laback and Matthew J. Goupell

C40: BINAURAL CUES AND ACOUSTIC-ELECTRIC SIMULATIONS
Ramesh Kumar Muralimanohar and Christopher J. Long

C41: ASSESSMENT OF COCHLEAR IMPLANT PERFORMANCE WITH THE MANDARIN HEARING IN NOISE TEST (MHINT)
Sha Liu, Demin Han, Ning Zhang, Juanjuan Xu, Bo Liu, Xueqing Chen, Ying Kong, Liansheng Kuo and Yilin Yang

C42: PRE– AND POSTOPERATIVE ASSESSMENT OF COCHLEAR IMPLANTEES BY MEANS OF MULTI DETECTOR ROW COMPUTED TOMOGRAPHY (MD-CT)
Berit M Verbist, Jeroen J Briaire, Luca Ferrarini , Raoul Joemai, Jorien Snel-Bongers and Johan HM Frijns

POSTER SESSION D: THURSDAY - FRIDAY

D1: POLARITY SENSITIVITY OF THE ELECTRICALLY STIMULATED AUDITORY NERVE AT DIFFERENT COCHLEAR SITES
Jaime A. Undurraga, Astrid van Wieringen, Robert P. Carlyon, Olivier Macherey and Jan Wouters

D2: MAGNITUDE AND SHAPE OF TRIPOLAR FIELDS AS PREDICTORS OF LOUDNESS AND SPREAD OF EXCITATION
Carlo K. Berenstein, Lucas H.M.Mens, Jef J.S. Mulder and Filiep Vanpoucke

D3: A 3D FORCE MEASUREMENT SYSTEM APPLIED IN THE DEVELOPMENT OF A MINIMIALLY TRAUMATIC ELECTRODE ARRAY
Thomas Lenarz

D4: PERFORMANCE OF VIRTUAL CHANNELS IN COCHLEAR PROSTHESIS SYSTEMS
Charles T. M. Choi and Chien-Hua Hsu

D5: EFFECTS OF LOCALIZED NEUROTROPHIN GENE THERAPY ON AUDITORY NEURONS AFTER HEARING LOSS
Rachael Richardson, Andrew Wise, Clifford Hume, Brianna Flynn, Yogesh Jeelall, Courtney Suhr, Beatrice Sgro, Stephen O'Leary and Robert Shepherd

D6: EFFECTS OF BRAIN DERIVED NEUROTROPHIC FACTOR (BDNF) AND ELECTRICAL STIMULATION ON THE SURVIVAL OF SPIRAL GANGLION CELLS IN CATS DEAFENED AT 30 DAYS
Olga A. Stakhovskaya, Alexander Hetherington, Gary T. Hradek and Patricia A. Leake

D7: BEHAVIORALLY RELEVANT AUDITORY EXPERIENCE IMPROVES TEMPORAL PROCESSING IN DEAF JUVENILE CAT PRIMARY AUDITORY CORTEX (AI)
Ralph E. Beitel, Maike Vollmer, Marcia W. Raggio and Christoph E. Schreiner

D8: AUDITORY EXPERIENCE AFFECTS TEMPORAL PROCESSING IN THE LONG-DEAFENED CAT PRIMARY AUDITORY CORTEX
Maike Vollmer, Ralph E. Beitel, Marcia W. Raggio and Christoph E. Schreiner

D9: TEMPORAL PRECISION OF SPEECH CODED INTO NERVE-ACTION POTENTIALS
Huan Wang, Marcus Holmberg, Sonja Karg, Michele Nicoletti, Marek Rudnicki, Michael Isik and Werner Hemmert

D10: OPTIMIZATION OF COMPUTER MODEL PARAMETERS FOR THE SIMULATION OF AUDITORY NERVE RESPONSES TO PULSE TRAINS
Jihwan Woo, Charles A. Miller, Paul J. Abbas

D11: RESOLUTION OF RECORDING SYSTEMS FOR EVOKED COMPOUND ACTION POTENTIALS: IN-VITRO MEASUREMENTS WITH THE MED-EL PULSAR CI^{100} COCHLEAR IMPLANT
Christian Neustetter, Philipp Spitzer, Reinhold Schatzer and Clemens Zierhofer

D12: SPATIAL SPREAD MEASUREMENTS IN HR 90K USERS
Birgit Philips, Paul Corthals, Eddy De Vel and Ingeborg Dhooge

D13: ELECTRICALLY EVOKED COMPOUND ACTION POTENTIALS ARE REGION-DEPENDENT: MULTICENTER STUDY RESULTS AND MODELING INSIGHTS
Stefan Strahl and Philipp Spitzer

D14: ELECTROPHYSIOLOGICAL AND SPEECH OUTCOME MEASURES FOR THE EVALUATION OF COCHLEAR IMPLANTEES
Mohamed A. Talaat, Angela G. Shoup, Ossama A. Sobhy, Manal Elbanna, Peter S. Roland, Pamela T. Kruger, Christine E. Powell and Mona I. Mourad

D15: EFFECTS OF STIMULATION MODE AND PROBE LEVEL ON FORWARD-MASKED SPATIAL TUNING CURVES IN COCHLEAR IMPLANT USERS
Ziyan Zhu, Qing Tang and Fan-Gang Zeng

D16: TEMPORAL FINE STRUCTURE: NO SILVER BULLET
Brett A. Swanson

D17: MULTI-CHANNEL INTERACTIONS IN AMPLITUDE MODULATION DETECTION AND DISCRIMINATION BY COCHLEAR IMPLANT LISTENERS
Monita Chatterjee and Cherish Oberzut

D18: ESTIMATING PSYCHOPHYSICAL DISCRIMINATION PERFORMANCE FROM SIMULATED NEURAL RESPONSES: EVALUATING THE EFFECT OF SPIKE TRAIN METRICS
Nikita S. Imennov and Jay T. Rubinstein

D19: PLACE SPECIFICITY AND VARIABILITY IN SPEECH PERCEPTION PERFORMANCE IN COCHLEAR IMPLANTS
Mahan Azadpour, Idrick Akhoun, Wael El-deredy and Colette M. McKay

D20: EARLY EXPOSURE AND RESPONSES TO MUSIC IN YOUNG LISTENERS WITH AND WITHOUT COCHLEAR IMPLANTS
Rachel M. van Besouw, Mary L. Grasmeder, Mary E. Hamilton, Sarah E. Baumann and Kirsty V. Carey

D21: MUSICAL AND LEXICAL PITCH PERCEPTION BY COCHLEAR IMPLANT RECIPIENTS
Ning Zhou, Wuqing Wang and Li Xu

D22: THE ROLE OF EARLY REFLECTIONS IN THE PERCEPTION OF SPECTRALLY-DEGRADED SPEECH
Nathaniel A. Whitmal, III and Sarah F. Poissant

D23: EFFECTIVE TEMPORAL CUES FOR CHINESE TONE PERCEPTION
Meng Yuan, Tan Lee, Kevin C. P. Yuen, Sigfrid D. Soli, Michael C. F. Tong and Charles A. van Hasselt

D24: ACOUSTIC CHARACTERISTICS OF SIBILANT FRICATIVES IN CHILDREN WITH COCHLEAR IMPLANTS
Ann E. Todd, Jan R. Edwards, Ruth Y. Litovsky, Fangfang Li, Cynthia M. Zettler and Mary E. Beckman

D25: NONWORD REPETITION ACCURACY OF CHILDREN WITH BILATERAL COCHLEAR IMPLANTS: EFFECTS OF AGE AND VOCABULARY SIZE
Emilie A. Sweet, Jan R. Edwards, Ruth Y. Litovsky, Cindy M. Zettler, Mary E. Beckman and Timothy R. Arbisi-Kelm

D26: LEXICAL TONE DEVELOPMENT IN PRELINGUALLY-DEAFENED CHILDREN WITH COCHLEAR IMPLANTS
Li Xu, Ning Zhou, Juan Huang, Xiuwu Chen, Yongxin Li, Xiaoyan Zhao, and Demin Han

D27: AUDITORY MODEL BASED ACOUSTIC CI SIMULATIONS FOR PATIENTS WITH PROFOUND HEARING LOSS.
Jayanthan Ra.V, P. Vijayalakshmi and P. Mukesh Kumar

D28: MULTI-MICROPHONE NOISE REDUCTION STRATEGIES FOR COCHLEAR IMPLANTS
Tim Van den Bogaert, Sofie Jansen, Heleen Luts, Koen Eneman, Michael Hofmann, Jan Wouters and Marc Moonen

D29: SPEECH PROCESSING USING PSEUDOMONOPHASIC STIMULI IN BIPOLAR MODE
Astrid van Wieringen, Jaime A. Undurraga, Olivier Macherey, Robert P. Carlyon and Jan Wouters

D30: THE COHERENT FINE STRUCTURE APPROACH FOR BETTER REPRESENTATION OF PITCH FREQUENCY
Clemens Zierhofer, Reinhold Schatzer, Andreas Krenmayr, Mathias Kals, Daniel Visser, Paul Bader, Christian Neustetter, Matthias Zangerl, Katrien Vermeire

D31: WITHIN-SUBJECTS COMPARSION OF THE HIRES AND FIDELITY120 STRATEGIES: VOWEL AND CONSONANT PERCEPTION
Gail S. Donaldson and Patricia K. Dawson

D32: BENEFITS OF ELECTRICAL STIMULATION OVER TWO COCHLEAR TURNS IN POSTLINGUALLY DEAFENED CI USERS - A PROSPECTIVE LONG-TERM STUDY
Sabine Haumann, Andreas Büchner, Gert Joseph and Thomas Lenarz

D33: EFFECTS OF ELECTRICAL STIMULATION ON THE ACOUSTICALLY EVOKED COMPOUND ACTION POTENTIAL
H. Christiaan Stronks, Huib Versnel, Vera F. Prijs, Wilko Grolman and Sjaak F.L. Klis

D34: MULTIDIMENSIONAL PITCH SCALING AND SPEECH UNDERSTANDING
Katrien Vermeire, Peter Schleich, Paul H. Van de Heyning

D35: COMPARISON OF SPEECH INTELLIGIBILITY BY EAS, BIMODAL, NI- AND BILATERAL COCHLEAR IMPLANT PATIENTS IN A MULTI-SOURCE NOISE FIELD' (MSNF)
Tobias Rader, Hugo Fastl and Uwe Baumann

D36: RESISTANCE TO INTEGRATION OF BINAURALLY MISMATCHED FREQUENCY-TO-PLACE MAPS: SPEECH IN NOISE
Catherine Siciliano and Andrew Faulkner

D37: BINAURAL PROCESSING IN THE AUDITORY CORTEX OF HEARING AND CONGENITALLY DEAF CATS
J. Tillein, P. Hubka, D. Schiemann, E. Syed, R. Hartmann and A. Kral

D38: SPATIAL SPEECH PERCEPTION IN NOISE IN BILATERALLY IMPLANTED CHILDREN
Lieselot Van Deun, Astrid van Wieringen and Jan Wouters

D39: SELF-SELECTION OF FREQUENCY MAPS IN USERS OF BILATERAL COCHLEAR IMPLANTS
Matthew B. Fitzgerald, Chin-Tuan Tan, and Mario A. Svirsky

D40: BENEFITS OF SHORT INTER-IMPLANT DELAYS IN CHILDREN RECEIVING BILATERAL COCHLEAR IMPLANTS
Karen A. Gordon, Jerome Valero, Neil Chadha and Blake C. Papsin

D41: VARIABLES AFFECTING FM PERFORMANCE WITH COCHLEAR IMPLANTS
Jace Wolfe and Christine M. Jones

D42: ACTIVE MIDDLE EAR IMPLANTS FOR HEARING AUGMENTATION IN CHILDREN WITH CONGENITAL AURAL ATRESIA
Mario D. Wolframm, Jane M. Opie, Pedro Clarós and Maria del Carmen Pujol

D43: PITCH MATCHING ACROSS SOUNDS AND EARS: IMPLICATIONS FOR PITCH COMPARISONS BETWEEN ACOUSTIC AND ELECTRIC STIMULI
Olivier Macherey and Robert P. Carlyon

PODIUM SESSION ABSTRACTS

1Ma: IDENTIFYING IMPAIRED COCHLEAR IMPLANT CHANNELS BY USING THE PARTIAL-TRIPOLAR ELECTRODE CONFIGURATION: IMPLICATIONS FOR COCHLEAR IMPLANT FITTINGS

Julie A. Bierer[1,2], Kathleen F. Faulkner[1], Kelly Tremblay[1,2], Amberly T. Nye[1], Steven M. Bierer[3], Joshua H. Goldwyn[4], John C. Middlebrooks[5]

[1]Department of Speech and Hearing Sciences
[2]V.M. Bloedel Hearing Research Center, [3]Department of Otolaryngology
[4]Department of Applied Mathematics, University of Washington, Seattle, WA, USA
[5]University of California, Irvine, CA, USA

The accurate identification of impaired cochlear implant channels during clinical fittings could greatly benefit patient performance. Here we present a series of experiments designed to characterize the functionality of individual channels based on the partial-tripolar (pTP) configuration, which allows a systematic variation of electrical current spread between monopolar (broad) and tripolar (narrow). 1) In each of five subjects implanted with the HiRes 90k device (Advanced Bionics) the channels with the highest, lowest and median thresholds using a focused pTP configuration were selected for further testing. 2) Psychophysical tuning curves using a masker-probe paradigm were measured to understand the perceptual consequences of high-threshold pTP channels. Broad tuning curve shapes and off-center tips were observed for the highest but not the lowest and median threshold pTP channels, suggesting that high pTP thresholds are predictive of poor spatial selectivity. 3) The psychophysical tuning curves of each subject were slightly wider when a monopolar probe stimulus was used. A similar effect of configuration was observed in the forward masked activation patterns of inferior colliculus neurons of anesthetized guinea pigs. 4) Electrically-evoked auditory brainstem response (EABR) thresholds were correlated with behavioral thresholds for monopolar and pTP configurations. Also, consistent with previous studies, growth functions were generally steeper with monopolar compared to pTP stimulation. A shallow growth function of the EABR was hypothesized for the highest threshold pTP channel, based on modeling and animal studies. However, such an effect was not consistently observed. 5) The effect of electrode configuration on perception was conceptualized with a two-stage computational model, consisting of volume conduction and subsequent neural activation along the cochlea. The model implicated a combined role of localized neuron loss and radial electrode position in producing high-threshold channels, but the relative contribution of these factors was highly dependent on configuration.

Overall, the results suggest that a relatively high threshold obtained with focused stimulation may be indicative of a poor electrode-neuron interface. As corroborated by the modeling, the monopolar configuration is much less sensitive to local irregularities. If the functionality of channels could be indentified clinically, then strategies for optimally stimulating the most effective channels could be developed and implemented.

Support provided by the NIH-NIDCD, R03 DC-008883 (JAB), VM Bloedel Mini-Grant (JAB) and Bloedel Travel Award (JCM).

2Ma: "PHANTOM ELECTRODE" STIMULATION

Leonid M. Litvak[1], Aniket A. Saoji[1], Abhijit Kulkarni[1], Ben H. Bonham[4], Russell L. Snyder[4], Anthony J. Spahr[2], Filiep Vanpoucke[1], Johan Frijns[3], Jeroen Briaire[3]

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[2]Arizona State University, Phoenix, AZ, USA
[3]Leiden University Medical Center, Leiden, The Netherlands
[4]Epstein Lab, Dept. of Otolaryngology - HNS, UCSF, San Francisco, CA, USA

Simultaneous stimulation of intra-cochlear electrode contacts can be used to shape the electric fields generated within the cochlea. One technique, "current-steering," has been used to generate virtual channels between two contacts through the simultaneous, in-phase, stimulation. Pitch ranking studies have shown that these virtual channels have associated pitches that are in between the perceived pitches when each contact is stimulated by itself.

In a new variation of the technique, which we refer to as "phantom electrode," one or more compensation electrodes are stimulated in opposite polarity with the primary electrode such that the electric field shifts in the direction opposite to that of the compensation electrodes. In theory, "phantom electrode" stimulation results in the creation of virtual channels that are outside the spatial bounds of the stimulated contacts. Using the phantom electrode technique, it is possible to generate a spatial pitch that is lower than the pitch associated with the most apical electrode (Wilson, B.S., Zerbi, M., and Lawson, D.T., NIH Contract NO1-DC-2-2401, 3rd Progress Report, 1993), or a pitch that is higher than the pitch associated with the most basal electrode in the electrode array.

In this talk, we will review the main modeling, psychophysics and physiology results with phantom electrode stimulation. This talk will also address speech and music perception with speech coding strategies that include phantom electrodes.

3Ma: THE FEASIBILITY OF DUAL ELECTRODE STIMULATION IN SPANNING LARGER INTER-ELECTRODE DISTANCES

Johan H. M. Frijns[1], Randy K. Kalkman[1], Jorien Snel-Bongers[1], Filiep Vanpoucke[2] and Jeroen J. Briaire[1]

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[2]Advanced Bionics, European Auditory Research, Niel, Belgium

In recent years dual electrode stimulation (DES) has been implemented in commercial speech coding strategies, as it allows for the generation of intermediate percepts between two physical contacts. If this concept also works when spanning larger inter-electrode distances, it would be an attractive work-around for CI users who have one or more defective contacts, and it would offer an opportunity to decrease the number of physical contacts in the electrode array. The present study focused on the effectiveness of such spanning and tried to identify the critical parameters involved. Special attention was paid to the occurrence of two rather than one separate excitation areas, as suggested by previous model studies, psychophysical experiments and objective measures (Frijns et al., 2009; Klop et al., 2009).

An elaborate 3-D model of the implanted human cochlea was used to study the effects of DES at a neural level. Several different cochlear shapes were used to allow the study the effect of anatomical variations. In three separate clinical trials the behavior of DES (and especially spanning) with respect to loudness, threshold, JND of DES coefficient α was studied in correlation with measurement of speech understanding, interaction index, objective spread of excitation (SOE) and electrical field modeling.

All patient data on the need for loudness correction when varying α were in good agreement with model data, both at threshold and at MCL. Sequential DES and simultaneous DES with spanning did require such a correction, as contrasted with non-spanning DES, although there was considerable inter-patient variability. The SOE measures for simultaneous DES were similar to that for a physical contact, and were in line with a linear shift with α of the region of excitation. However, in pitch matching experiments with spanned DES a significant deviation to the base of the cochlea was found in most conditions. Forward masking eCAP recordings with two sequentially stimulated spanned maskers confirmed the model prediction of an unstimulated zone between DES contacts. Parameters like pulse width and rate did not influence any of the results.

In conclusion, the data indicates that spanning one or more electrode contacts with DES is possible, but at the expense of a decreased resolution and with a higher risk of separate excitation areas. The model predicts that at least part of the large inter-patient variability observed, is due to anatomical differences.

Support provided by the Heinsius-Houbolt fund and Advanced Bionics.

4Ma: ANALYSIS AND OPTIMIZATION OF FOCUSED INTRACOCHLEAR STIMULATION

Zachary M. Smith[1], Christopher J. Long[1], Chris van den Honert[1], Donald K. Eddington[2], Tim A. Holden[3], Clough Shelton[4], David C. Kelsall[5]

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[2]Massachusetts Eye & Ear Infirmary, Boston, MA, USA
[3]Washington University School of Medicine, St. Louis, MO, USA
[4]Dept. of Otolaryngology, University of Utah, Salt Lake City, UT, USA
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At CIAP 2007 we argued that channel-specific temporal fine structure in the neural response to electric stimulation cannot be controlled with monopolar channels. Due to spatial spread of excitation, any given auditory neuron inevitably responds to stimuli from multiple channels. Thus the intended temporal patterning is smeared and corrupted in the activity of the target neurons. In order to address this problem we described a method for focusing intracochlear stimulation using multipolar phased array (PA) channels. We presented evidence that simultaneous interactions among PA channels are substantially weaker than those of monopolar channels. We also speculated that variations in PA threshold across cochlear place might reflect neuronal degeneration patterns.

Standard PA channel weights theoretically achieve optimal focusing of the potential field within scala tympani (ST). However analytic studies have shown that extrapolation errors in some of the transimpedance values that are used to compute the standard weights can compromise focusing in ST. Modeling of intracochlear current flow with PA stimulation further suggests that optimal focusing of the potential field in ST leads to suboptimal focusing of radial current within Rosenthal's canal. Parallel psychophysical studies have demonstrated that simultaneous channel interactions with PA stimulation can be further reduced by iteratively adjusting the channel weights in systematic ways. CT scan data have been used to estimate modiolar proximity of electrode contacts as a function of cochlear place. These studies show that a substantial part of the variance of PA thresholds across place is accounted for by modiolar proximity.

Results of these studies and their implications of these findings will be discussed.

5Ma: CURRENT FOCUSING SHARPENS LOCAL PEAKS OF VIRTUAL CHANNELS

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Recent research has investigated using simultaneous in-phase stimulation on adjacent electrodes to create current peaks between the two electrodes. The current peaks between electrodes are perceived as pitches between the two electrodes and are therefore called virtual channels (VCs) in the literature. Because these VCs are typically created by two Monopolar (MP) stimuli, we refer to these VCs as MPVCs. Tripolar stimulation (current focusing), in which the two flanking electrodes of a center electrode stimulate in opposite phase of the center electrode, has been shown to provide a narrower current spread than MP. Similarly to tripolar stimulation, we created a current-focused VC by stimulating simultaneously on four adjacent electrodes. The center two electrodes provide a current steered VC (similar to the MPVCs) while the flanking two electrodes provide stimulation out-of-phase (similar to the flanking electrodes in tripolar stimulation.) We refer to the current-focused VCs as Quadripolar VCs (QPVCs.) We hypothesized that by combining current steering with current focusing (using QPVCs), the localized current peaks would be sharper (and the current spread would be narrower) than the peaks produced by MPVCs.

Stimuli consisted of either focused (QPVC) or unfocused (MPVC) VCs. The current spread for MPVCs and QPVCs were compared using a forward masking experiment. The maskers were either an MPVC or a QPVC steered to the middle of the electrode pair. Probe stimuli consisted of QPVCs steered to multiple locations between the electrode pair used for steering. Masked thresholds were measured for probe stimuli for both masker conditions. Masker stimuli were loudness balanced to each other. The experiment was performed on Advanced Bionics Clarion II or HiRes 90K users.

The masking patterns of the MPVC and QPVC maskers were analyzed and measurements for spread of excitation were calculated. Results indicate that QPVC stimulation produces a narrower spread of excitation within the electrode pair compared with MPVC stimulation, thereby sharpening the peak of excitation for a virtual channel. The difference in spread of excitation of the masking patterns seems to correlate with difference in ability to discriminate virtual channels using MPVC or QPVC stimulation.

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6Ma: SIMULTANEOUS PULSATILE STIMULATION WITH CHANNEL INTERACTION COMPENSATION: CONCEPT AND RESULTS

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Recently, a method to compensate for the detrimental effects of electric field summation with simultaneous pulsatile stimulation has been presented (Zierhofer, 2008). The proposed Channel Interaction Compensation (CIC) concept is based on an exponential model of spatial potential distribution within the scala tympani. Two constants, α and β, model the field decay towards the apex and base at each electrode. A third constant, γ, models the decay of place-dependent field potentials from apex to base. If electrodes are activated simultaneously, CIC starts from the respective sequential pulse amplitudes and computes reduced simultaneous amplitudes by taking direct field summation into account.

CIC has been evaluated by measuring speech reception thresholds for sentences in noise in 7 subjects and vowel scores in 6 subjects for various CIC settings and CIS as a control condition. CIC decay constants and number of simultaneous channels were varied systematically. Identical channel pulse rates and phase durations were used across conditions.

Results demonstrate that simultaneous stimulation with CIC is feasible, supporting speech reception scores which do not differ significantly from sequential CIS stimulation. In some subjects, this is true even for settings with fully simultaneous stimulation on all electrodes. However, optimum speech reception requires proper settings of decay constants. Uncompensated simultaneous stimulation significantly degrades performance in most subjects.

Simultaneous stimulation with CIC may be applied to achieve substantially higher overall pulse rates for a precise temporal coding of fine structure information, or to increase pulse phase durations while at the same time reducing pulse amplitudes, lowering compliance voltage requirements.

Support provided by the C. Doppler Research Association.

1Mp: CLINICAL EFFECTIVENESS AND COST EFFECTIVENESS OF BILATERAL COCHLEAR IMPLANTATION FOR DEAF CHILDREN

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Policy makers in many countries have struggled to decide whether deaf children should receive two implants or one. Decision-making has been hampered by difficulties in estimating the additional number of quality-adjusted life years *(ΔQ)* gained from providing a child with bilateral implants and relating it to the additional costs *(ΔC)*. In England and Wales, the policy-making body is required to demonstrate that the *net benefit ($r\Delta Q$-ΔC)* of a health technology is positive for a maximum value of *r* of £30,000 before adopting the technology.

Difficulties in estimating ΔQ have arisen because: (1) Its value is small and is therefore hard to measure precisely; and (2) quality-of-life questionnaires may not have the resolution to detect the benefits of binaural hearing. We observed those difficulties when comparing 30 children using bilateral implants with 20 using unilateral implants. We found significant advantages for the bilaterally-implanted group on tests of localisation and spatial release from masking which were correlated with parental reports of the children's spatial hearing and speech perception in everyday life. However, parental valuations of the children's quality of life did not differ between the groups.

As an alternative, we constructed one-page vignettes describing a girl, born profoundly deaf and now aged 6 years, achieving typical outcomes with either a unilateral implant (One-CI), a unilateral implant with a contralateral hearing aid (CI+HA), or bilateral implants (CI+CI). One hundred and eighty adults who were not the parents of deaf children imagined that the child was their own. In each scenario, they estimated the number *(n)* of their remaining expected years of life *(e)* that they would give up in order for the child to hear normally, thereby valuing the child's quality of life as *(e-n)/(e)*.

We incorporated the distributions of gains in quality of life (from One-CI to CI+CI and from CI+HA to CI+CI) together with estimates of the additional costs of bilateral implantation in a probabilistic model which simulated the life-time management of cohorts of 1000 children. Life expectancy and probabilities of use of contralateral hearing aids, internal and external device failure, and elective non-use of implants were taken from published data. The model yielded paired estimates of ΔQ and ΔC for each simulated child. The average *net benefit* was positive for values of *r* greater than £21,000 and was robust over variation in uncertain parameters of the model.

We conclude that adults in the UK perceive sufficient additional value from giving children two implants rather than one to mean that bilateral implantation is likely to be a cost-effective use of health-service resources.

Supported by Deafness Research UK and Advanced Bionics SARL.

2Mp: EFFECTS OF LONG-TERM DEAFNESS AND CHRONIC INTRACOCHLEAR ELECTRICAL STIMULATION ON THE PRIMARY AUDITORY CORTEX

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Chronic intra-cochlear electrical stimulation (ES), like that produced by a cochlear implant, is known to alter spectral and temporal processing in parts of the auditory system. It is also generally accepted that monopolar (MP) stimulation results in broader activation in the cochlea and throughout the auditory pathway than bipolar or common ground (CG) stimulation. The effects of long-term deafness and different modes of chronic ES on the cochleotopic organization of the primary auditory cortex (AI) and on temporal resolution in AI, are less clear. We neonatally deafened seventeen cats, via daily neomycin injections, and a further three animals served as normal-hearing controls. Seven of the deafened animals were implanted at two months of age with a multi-channel scala tympani electrode array. These animals received environmentally derived unilateral MP or CG ES for periods of up to 11 months via a Nucleus® CI24 cochlear implant and Nucleus® ESPrit 3G speech processor. We recorded from single- and multi-unit clusters (n = 812) in AI of all cats as adults, using a combination of single tungsten and multi-channel silicon electrode arrays. We assessed spectral processing in AI by measuring the local tuning (i.e., selectivity for the site of cochlear stimulation) of neuronal clusters, the cochlea-to-cortex mapping, and the spread of cortical activation. We assessed temporal resolution in AI by measuring the jitter in response latency and the maximum rate at which clusters could be driven. In contrast to previous reports, MP stimulation did not resulted in significantly broader local tuning or spread of cortical activation compared to CG stimulation. Long-term deafness had little effect on the basic response properties of AI neurons, but resulted in complete loss of the normal cochlea-to-cortex mapping and an increase in the spread of cortical activation (Three-Way ANOVA; Bonferroni post-hoc; $p < 0.001$). Chronic ES did not affect the increase in the spread of cortical activation, but did reverse the disruption of the cochlea-to-cortex mapping, and resulted in a significant increase in the maximum rate at which units could be driven (Mann-Whitney; $p < 0.05$). We hypothesize that maintenance or re-establishment of a cochleotopically organized AI by electrical activation of the cochlea – as demonstrated in the present study - contributes to the remarkable performance observed among human patients implanted at a young age.

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3Mp: PREDICTING COCHLEAR IMPLANT OUTCOME FROM BRAIN ORGANIZATION IN THE DEAF

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We explored whether functional neuroanatomy in the deaf brain predicts speech perception with a cochlear implant. Using FDG-PET, and fMRI data in congenitally deaf children and deafened adults, we show that deafness duration induces brain reorganisation that is deleterious to subsequent speech perception with an implant. Typically, this involves compensation for defective left-sided phonological processes by the right temporal cortex. We also show that global brain metabolism patterns account for speech perception outcome irrespective of deafness duration. These patterns denote individual functional neuroanatomical traits that are not modified by deafness, and indicate how patients tend to use their neural resources to perform cognitive tasks before implantation, but potentially also after. While those individuals who will become good users tend to involve dorsal fronto-parietal regions, those who will become poor implant users tend to involve ventral brain regions. This dissociation observed at rest (FDG-PET) was confirmed at a functional level, during phonological tasks performed on written language material (fMRI). On the basis of these data we propose to detect patients at risk of poor performance using behavioural tests, and rehabilitate them using specific cognitive training.

4Mp: EFFECTS OF AUDITORY TRAINING IN NOISE FOR COCHLEAR IMPLANT USERS

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Auditory training has been shown to improve cochlear implant (CI) users' speech recognition in quiet. The benefits of auditory training for difficult listening conditions (e.g., background noise, competing speech, etc.) are not well documented. In this study, speech recognition in noise was assessed in CI users before, during, and after auditory training with a closed-set recognition task (digits identification) in speech babble.

Prior to training, baseline performance in steady noise and speech babble was obtained for HINT sentences, IEEE sentences, and digits (i.e., identification of three digits in sequence; e.g., "3-0-5"); baseline performance was measured once every week for four weeks or until achieving asymptotic performance. After completing baseline measures, subjects trained at home on their personal computer using custom software (Sound Express) for ½ hour per day, five days a week, for four weeks. Subjects were trained to identify digits in speech babble; the signal-to-noise ratio (SNR) was adjusted during each training exercise according to subject performance. Auditory and visual feedback was provided, allowing subjects to compare their (incorrect) response to the correct response. Baseline performance was re-measured during the 2nd and 4th week of training. Training was stopped after the 4th week, and subjects returned to the lab one month later to retest baseline performance and see whether any training benefits had been retained.

Preliminary results for nine subjects showed that after training to identify digits in speech babble, the mean speech reception threshold (SRT) for digits significantly improved by 3.2 dB in speech babble. A similar improvement (3.8 dB) was observed in steady noise with no explicit training. The improved performance also generalized to different speech materials. Mean SRT for HINT sentences significantly improved by 1.0 dB in steady noise, and 2.2 dB in speech babble. Mean IEEE word-in-sentence recognition improved by 6 percentage points in steady noise and 10.5 points in babble. One month after training was stopped, performance gains were largely retained.

These results demonstrated that digits-in-noise training significantly improved CI users' ability to recognize numbers in the presence of background noise. The generalized improvements in performance (e.g., open-set HINT, IEEE sentence recognition in both types of noise, improved number recognition in steady noise) suggest that closed-set training in noise with relatively simple stimuli may improve CI users' speech understanding under difficult listening conditions.

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1Ta: NEURAL CODING MECHANISMS IN AUDITORY CORTEX AND THEIR IMPLICATIONS FOR CORTICAL REPRESENTATIONS OF SOUNDS PROCESSED BY COCHLEAR IMPLANT

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In contrast to the visual system, the auditory system has a longer subcortical pathway and more spiking synapses between sensory receptors and the cerebral cortex. This unique organization reflects the needs of the auditory system to process time-varying and spectrally overlapping acoustic signals using strategies different from those used by other sensory systems. In recent years, our knowledge on cortical processing of complex sounds has been much enriched by the use of awake and behaving neurophysiology models. Studies have shown that the auditory cortex transforms sounds from acoustic features to internal representations and maps acoustical dimensions onto perceptual dimensions. It has also been shown that auditory feedback and vocal control signals shape neural representations of sounds in auditory cortex during speaking. These findings have important implications for understanding how the auditory cortex represents sounds processed by the cochlear implant during both hearing and speaking.

2Ta: ELECTRICALLY EVOKED CORTICAL POTENTIALS

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The past several years have seen a resurgence of interest in cortically generated evoked auditory potentials. After years of focusing almost exclusively on peripheral responses, such as the ECAP and the EABR, we have begun measuring electrically evoked, cortical auditory potentials from cochlear implant (CI) users. Our interest in this class of evoked potentials stems not only from the fact that these responses may reflect higher levels of neural processing, but also from the fact that they can be recorded using speech or more speech-like stimuli. Our focus has been on recording the electrically evoked P1-N1-P2 complex. The stimulation paradigms we use have been structured in such a way that we can record both onset responses as well as responses that are elicited by a change in some aspect of an ongoing stimulus. These paradigms have included a change either in the place of stimulation within the cochlea or in the temporal characteristics of an ongoing electrical pulse train. This talk will review results of a recent series of experiments designed to determine how much cross-subject variability can be expected in these recordings, how the choice of stimulation and recording paradigms impacts the recorded waveforms and the relationship between these electrophysiologic measures and perception.

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3Ta: STEADY STATE RESPONSES IN COCHLEAR IMPLANTS

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Auditory steady state responses (ASSR) are neural potentials in the EEG-signal that are evoked by continuous presentation of modulated or repeated auditory stimuli. Depending on the modulation or rate of the stimulus, different regions on the auditory path beyond the cochlea can be sampled. Recently, acoustically evoked ASSR are successfully used for objective assessment of hearing thresholds in neonates. The application to cochlear implantees has been a challenge because electrical artifacts of the pulsatile stimulation can mask the tiny ASSR-responses. In this study electrically evoked responses (EASSR) have reliably been recorded in several cochlear implant patients. The EASSR were confirmed and the dependence on stimulus periodicity and level was studied, in single and multi-channel stimulation mode. These results may initiate more reliable objective measures for hearing thresholds and at supra-threshold levels.

4Ta: AUDITORY NERVE RESPONSES TO PULSE TRAIN STIMULI

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Although auditory prostheses typically use modulated trains of short-duration (i.e., 20-100 μs/phase) electric pulses to encode auditory stimuli, there are significant gaps in our knowledge of how auditory nerve fibers (ANFs) respond to such stimuli. In recent years, work in our laboratory has focused on ANF responses to pulse trains, with emphasis on (1) how those responses change over the 300-400 ms period of those stimuli, (2) how key stimulus variables such as level and pulse rate influence response patterns, (3) how prior stimulation influences subsequent pulse-train responses, and (4) how responses to sinusoidally modulated trains differ from those of unmodulated trains.

The main goal of this research is to gain a comprehensive understanding of how ANFs respond to “real world” electric stimuli so that future designs of speech processors can account for ANF response properties, some of which limit stimulus coding. For example, we have found that although high-rate (i.e., 5000 pulse/s) trains of pulses can improve representation of stimuli, they can cause relatively profound levels of rate adaptation in a subset of ANFs. Such high-rate stimuli are also more likely to cause post-stimulatory changes in sensitivity, including so-called “subthreshold masking” at low stimulus levels (Miller et al., ARO, 2009).

One goal of this presentation is to provide a the field with a more complete picture of how ANFs responses are altered by ongoing pulse trains. We will consider basic properties, such as threshold and dynamic range as well as measures indicating the extent to which modulation is represented in the responses. Individual exemplar and group trends will be presented.

Another goal is to provide an update in our effort to create a computational model (based on a Hodgkin-Huxley type ANF model) that can simulate effects associated with rate adaptation. We intend to broaden the scope of this model so that it can demonstrate spatio-temporal response patterns of ensembles of excited ANFs. Preliminary progress along these dimensions will be illustrated and future directions that may be possible with such a model will be discussed.

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5Ta: TEMPORAL PROPERTIES OF INFERIOR COLLICULUS RECORDINGS DURING OPTICAL STIMULATION

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Recently, we have proposed stimulating neurons in the cochlea with optical radiation. The motivation for using infrared lasers is to increase the spatial selectivity of neural stimulation with optical radiation. To develop intelligent coding strategies, it is important to characterize patterns of neuronal activity to stimulation. With the present study we define a parameter space for the laser stimuli that results in a similar pattern of activation in the inferior colliculus (IC) of deafened guinea pigs, to that observed with acoustical stimulation in normal hearing animals.

Healthy guinea pigs were used. A cochleostomy was drilled into the basal cochlear turn. The animals were acutely deafened. An optical fiber was placed inside the cochleostomy to stimulate spiral ganglion cells. A multichannel recording electrode was placed in the inferior colliculus to record neural responses. Peri-stimulus histograms (PSTHs) were constructed to determine temporal response properties.

PSTHs of IC recordings show several maxima of neural activity following optical pulses. Characteristic is a single maximum at 5.55±0.41 ms (N=18) after the stimulus at low levels just above threshold. With increasing stimulus levels, multiple maxima appear and the delay time for the first maximum decreases. For 10 of the 18 neurons, a second maximum could be observed at 7.22±0.45 ms. A third maximum appeared in about half of the neuron clusters (N=10/18). The delay time was 9.24±0.18 ms. Changing the pulse length did not change the response pattern at the inferior colliculus electrode. The pulse repetition rate has been changed from 10 to 300 Hz. The delay time for the first maximum at about 5.6 ms changes little with increasing repetition rate. With increasing stimulus rates the second maximum disappeared and the delay time for the third maximum increased by about 0.5 ms.

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6Ta: MONOPOLAR INTRACOCHLEAR PULSE TRAINS CAN ELICIT FOCAL CENTRAL ACTIVATION

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Contemporary cochlear implant (CI) systems often employ amplitude-modulated, high-rate electrical pulse trains delivered using a monopolar electrode configuration. Because of the large electrical artifacts associated with monopolar CI stimulation, however, electrophysiological studies of central neuronal responses to intracochlear stimulation often employ either low-rate monopolar pulse trains or bipolar stimulation. To overcome this limitation, we have developed a novel electrophysiological recording system that is only minimally affected by electrical artifacts. We have applied this system to measure the distribution of activity along the cochleotopic axis in the central nucleus of the inferior colliculus (ICC) evoked by intracochlear stimulation using high rate pulse trains. We report here our results using 1000-pps pulse trains on individual CI channels, and 1000-pps pulse trains interleaved on two channels.

Unmodulated pulse trains applied using both monopolar and bipolar electrode configurations evoked activity over a broad region of the cochleotopic axis at the onset of the pulse train. However, following this broad onset response, both configurations produced more narrowly distributed sustained activity. As reported in earlier studies of midbrain activity evoked by isolated single pulses, onset responses to 1000-pps pulse trains showed broader activity patterns for monopolar than for bipolar configurations, when stimulus levels were set at equal increments above their respective thresholds. In contrast, sustained activity in some cases was just as restricted for monopolar stimulation as for bipolar stimulation. Furthermore, when monopolar or bipolar activity patterns were narrow, the interaction between pulse trains that were interleaved on two separate channels dropped sharply as the intracochlear distance between channels was increased. These findings could help explain apparent inconsistencies between previous physiological studies and the excellent speech reception enjoyed by many CI users who use monopolar configurations.

For pulse trains that were sinusoidally amplitude-modulated (AM) at 50 Hz or 125 Hz, activity recorded in the ICC was phase locked to the modulation envelope. Compared to sustained responses to unmodulated pulse trains, modulated pulse trains evoked activity over a significantly broader region along the cochleotopic axis. When modulated pulse trains were interleaved on two monopolar or bipolar channels, peak interaction values were higher than those for unmodulated pulse trains. This could help account for the psychophysical observation that for CI users, detection of probe modulation in the presence of a masker is more difficult when the masker is amplitude-modulated.

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1Tp: A QUANTITATIVE ESTIMATE OF THE CONTRIBUTION OF VOICE FUNDAMENTAL FREQUENCY VARIATIONS TO SENTENCE INTELLIGIBILITY IN TONE AND NON-TONE LANGUAGES

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Languages differ greatly in the acoustic and phonological features they exploit to convey meaning. One interesting difference concerns the use of voice fundamental frequency variations, which underlie voice pitch or melody. In so-called 'tone languages', variations in voice pitch signal differences in meaning that are important in the same way as a change in a consonant or a vowel. Pitch variations convey important information in non-tonal languages too, but they do not serve this lexical function.

Voice pitch variations must, then, contribute more to sentence intelligibility in tonal languages than in non-tonal ones. However, this contribution is difficult to quantify because eliminating tone whilst preserving all other acoustic features leaves speech from even a tonal language highly intelligible, not least because of contextual cues. Here, we estimate the contribution tonal variation makes to sentence intelligibility in terms of a common metric - degree of spectral detail. Vocoding was used to manipulate the degree of spectral resolution (1, 2, 4, 8 and 16 channels) and the presence or absence of voice pitch variations in simple sentences (the natural contour vs. a neutral falling one). Listeners were asked to repeat back as much of the sentence as possible, with scoring based on the correct identification of key words. A logistic regression model of the proportion of key words correct was constructed with predictors of the $\log_2$ of the number of channels (a unit we refer to as a 'doubling') and the presence or absence of natural voice pitch variations. Comparing the coefficients in the model results in a measure of the 'worth' of tonal variations in terms of spectral detail. Using this measure for results obtained with 2 non-tonal languages (English and Lithuanian), we find that tone is 'worth' 0.1-0.4 doublings, depending upon the particular talker. In contrast, tone is 'worth' 0.6-1.0 doublings in the 3 tonal languages we studied (Mandarin, Cantonese and Yoruba). The fact that tone can improve intelligibility by the same degree as doubling the number of channels in tone languages strongly supports the notion that improvements in the transmission of tonal variations in cochlear implants would be a great boon for users, especially for speakers of tonal languages.

Partial support for the Lithuanian part of the study was provided by Deafness Research (UK).

2Tp: EFFECT OF INTRACOCHLEAR STIMULATION SITE ON THE UPPER LIMIT OF TEMPORAL PITCH

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Most studies of temporal pitch perception by cochlear implant ("CI") users reveal an "upper limit" of about 300 Hz, beyond which changes in repetition rate do not produce an increase in pitch. Explanations for this limit have included the absence of an accurate match between the place and rate of stimulation (e.g. Oxenham et al., 2004), and the fact that many CIs do not stimulate very apical sites. In this study, we compared temporal pitch discrimination performance at two intracochlear sites (apical and middle of the array) and for different electrical pulse waveforms presented in narrow (BP+1 or BP+2) bipolar configuration. Temporal pitch discrimination was then assessed in a two-interval forced-choice task using the optimally efficient mid-point comparison procedure (Long et al., 2005). Subjects were asked to rank single-channel pulse trains with rates ranging from 105 to 1150 pps. The results show that the upper limit of pitch varies consistently as a function of both the place of stimulation and the waveform shape. The implications of these results for attempts to represent "temporal fine structure" cues in CI speech-processing strategies will be discussed.

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3Tp: ENCODING PITCH CONTOURS USING CURRENT STEERING

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Psychophysical studies have shown that when current is "steered" between simultaneously stimulated adjacent electrodes, cochlear implant (CI) users can have intermediate pitch percepts (i.e., "virtual channels") between the physical electrodes. This study aimed to investigate whether CI users were able to integrate the place pitch cues associated with virtual channels to identify different pitch contours. Four adult Clarion CII and HiRes 90K users were tested on apical, medial, and basal electrode pairs with stimulus durations from 100 to 1000ms. The stimulation rate was 1000 Hz and the loudness level was balanced to a reference stimulus that was described as comfortably loud. During the first half of the stimuli, current was linearly steered from either one of the component electrodes to the middle virtual channel between the electrode pair or kept on the middle virtual channel. During the second half of the stimuli, current was again linearly steered from the middle virtual channel to either one of the component electrodes or kept on the middle virtual channel. As such, 9 pitch contours (flat, falling, and rising in the first half × flat, falling, and rising in the second half) were generated for each electrode pair. The results showed that pitch contour identification (PCI) scores with virtual channels significantly improved as the stimulus duration was increased. However, PCI performance was not significantly different across the 3 tested electrode pairs. There was a large inter-subject variability in PCI scores, e.g. ranging from 11% to 53% correct for 100-ms stimuli, and from 31% to 90% correct for 1000-ms stimuli. CI subjects' cumulative d' values for virtual channel sensitivities (measured previously) were significantly correlated with their 100-ms PCI scores, and were marginally correlated with their 300- and 500-ms PCI scores. Detailed analyses showed that subjects were mostly confused between the stimuli with the same pitch transitions in the first or the second half, suggesting the identification of segments of the pitch contours. A second experiment confirmed that, when only 3 pitch contours (flat, falling, and rising during the whole stimuli) were tested, subjects achieved nearly perfect PCI scores with stimulus durations longer than 200ms. These results suggest that current steering may be useful in encoding simple pitch contours (as seen in speech) for CI users, and the identification of such pitch contours strongly relies on individual CI users' sensitivity to virtual channels.

Work supported by NIH-NIDCD.

4Tp: PITCH MATCHING BETWEEN ELECTRIC AND ACOUSTIC STIMULI BY PATIENTS WITH NORMAL HEARING IN THE UNIMPLANTED EAR

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As part of a study investigating the effects of cochlear implants (CIs) on tinnitus in patients with unilateral hearing loss, we have performed pitch comparisons between electrical stimulation of a CI and acoustic sounds presented to the contralateral, normal-hearing ear. In most cases, these matches were obtained at switch-on, thereby avoiding effects arising from “acclimatisation” to the frequency-to-electrode allocation in a patient’s everyday device. In addition to comparing pure tones to high-rate (1031-pps) pulse trains, similar to other studies, we asked patients to compare 25-pps electric pulse trains to 25-pps acoustic trains. This latter paradigm allowed us to vary place pitch by changing either the electrode or the acoustic bandpass filter frequency, while presenting temporal patterns of stimulation that were very similar in the two ears. Both pitch matching and the method of constant stimuli were used; in the latter case either one or two possible electrodes could be stimulated in each block of trials, each of which was compared to seven or eight acoustic stimuli. Some, but not all, patients report strikingly similar percepts for 25-pps acoustic and pitch-matched electric pulse trains. Contrary to some previous reports, pitch matches were roughly similar to the predictions of Greenwood’s frequency-to-place function and of a model that takes into account cochlear current flow and neural anatomy. We also showed that the range of comparison stimuli used can strongly influence the matches obtained, and strongly recommend that matches should always be checked using different paradigms and/or stimulus sets.

5Tp: COCHLEAR IMPLANTATION IN UNILATERAL DEAFNESS

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In recent years, a number of subjects with unilateral deafness and normal hearing or mild hearing loss on the contralateral ear have been provided with cochlear implants. This presentation will discuss a range of aspects of cochlear implantation in subjects with single-sided deafness.

Besides a significant release form tinnitus which concurrently occurred with the hearing loss, useful bimodal hearing was found by Van de Heyning (2008). Contralateral hearing aid users showed benefits in speech understanding and in the SSQ. Contralateral normal hearing subjects reported significantly better speech understanding and spatial hearing, although adaptive speech tests showed benefits only if speech was presented from the CI side (Vermeire, 2008).

Unilateral deaf subjects without tinnitus and contralateral normal hearing were tested using sound the source identification method (Jacob, 2007). Benefits ranged from restoration of correct lateralization to increased accuracy of nearly perfect unilateral source identification. Unbalanced loudness between acoustic hearing and CI led to detrimental effects in ILD lateralization. Speech testing in noise showed benefits at fixed but hardly with adaptive and hence largely negative SNRs.

The tonotopic representation of CI signal processing has been investigated using two paradigms, i.e. pitch scaling by Vermeire (2008), and pitch matching by Schatzer (CIAP 2009). Pitch matching results were lower and more consistent.

A combination of tonotopic and periodic information by applying phase-synchronous stimulation to low-frequency channels (Zierhofer, 2001) is used in FSP. Acoustic-to-electric pitch matching suggests that both cues should be matched, i.e. low frequency pulse trains to be applied to apical electrodes, and higher frequency pulse trains to more basal ones (Vermeire, CIAP 2009).

Finally, the integration of electric and acoustic sensations has been studied with a multi dimensional scaling procedure asking for the difference of electric and acoustic stimuli (Vermeire, CIAP 2009). Subjects who perceive more than one dimension showed consistently lower speech understanding scores.

1Wa: ESTIMATING AND CONTROLLING THE LOUDNESS OF ELECTRIC AND ACOUSTIC STIMULI

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Now that increasing numbers of people who have usable acoustic hearing are becoming successful cochlear implant (CI) users, there is a growing need to develop improved sound processors and fitting techniques that optimize performance when acoustic and electric stimuli are perceived simultaneously. In particular, it is important that the loudness of sound signals conveyed via each stimulation mode is appropriate. Not only is loudness closely related to listening comfort, audibility, and consequently the intelligibility of speech and other sounds, but it also affects the ability of listeners to determine the direction of sound sources when different stimuli are presented to each ear. Cues arising from interaural level differences, however, may be difficult to detect or utilize if acoustic signals heard in one ear have inappropriate loudness in comparison with electric stimuli perceived via a CI in the other ear. To address this issue, psychophysical studies have been conducted with CI users who had usable acoustic hearing in the non-implanted ear. The results of those studies were interpreted with the help of numerical models of loudness for both acoustic and electric stimuli. Finally, new sound-processing techniques that could improve the perception of CI users who also use acoustic hearing aids have been evaluated.

Eight CI recipients whose average hearing threshold levels in the non-implanted ears were less than 70 dB HL up to 500 Hz participated in the psychophysical experiments. They provided loudness estimates for a signal comprising noise filtered into a 250-500 Hz band that was presented at 10 levels within each subject's acoustic dynamic range. The subjects also adjusted the level of that signal so that its loudness matched that of a corresponding electric stimulus that was presented at several levels within each subject's dynamic range for electric stimulation. On average, the results closely fitted the predictions of established models of loudness for hearing-impaired listeners and CI users. Only minimal data were required to fit each model in relation to each subject's hearing characteristics. The experimental findings suggest that loudness models can be used to improve sound processing for those CI recipients who can use acoustic hearing aids in combination with their implant devices.

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2Wa: ACOUSTIC AND ELECTRIC HEARING – RESULTS FROM SHORT-ELECTRODE STUDIES

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To date, several hundred patients across the world have been implanted with cochlear electrodes designed to preserve residual acoustic hearing. The University of Iowa/Nucleus Hybrid program is one of the larger and earliest centers involved with this technique, and our patients use a short-electrode, which is inserted only 10 mm into the base of the cochlea. The typical patient has some usable hearing in the low frequencies, but the high frequencies, where the hearing loss is severe to profound, do not respond well to amplification. The addition of the electrical simulation increases the patient's speech recognition in quiet, but more importantly, the preservation of low-frequency acoustic hearing typically provides benefits (compared to traditional long-electrode implants) for the recognition of speech in backgrounds as well as for sound quality. These patients can teach us a great deal about how the brain adapts to this quite different representation of speech via A+E delivery. We also are interested in looking at possible pre-operative predictive factors that may help to identify which patients will do better with a short electrode as opposed to a traditional long-electrode implant.

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3Wa: 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 cannot 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.

Support provided by the NIH-NIDCD.

4Wa: BIMODAL LISTENERS ARE SENSITIVE TO INTERAURAL TIME DIFFERENCES IN MULTICHANNEL STIMULI

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Sensitivity to interaural time differences (ITDs) is important for localization of sound sources and is related to binaural unmasking of speech in noise. We measured sensitivity to ITD of users of a cochlear implant (CI) and a contralateral hearing aid (HA) to speech-like, ecologically relevant stimuli. Recently, it was shown that users of a cochlear implant (CI) and a contralateral hearing aid (HA) are sensitive to ITDs in simple stimuli that consist of a low-rate pulse train (100pps), presented on a single electrode, together with an acoustically presented filtered click train with F0=100Hz [1]. We investigated ITD sensitivity of bimodal listeners to different stimulus types that are more ecologically relevant. One stimulus consisted in one ear of an acoustic sinusoid of various frequencies that was modulated with a half wave rectified low-frequency sinusoid, and in the other ear of a high-rate electric pulse train (900pps) that was modulated with the same half wave rectified low-frequency sinusoid. JNDs in ITD were comparable to those measured with the 100pps pulse train. Another stimulus consisted in one ear of an acoustically presented filtered click train and in the other ear of the same filtered click train processed by a CIS-like algorithm into a multichannel electric signal. Care was taken to maintain the correct temporal relationships between the signals presented to different electrodes. The original filtered click train and the electric signal were presented simultaneously. JNDs in ITD were again comparable to those measured with the 100pps pulse train. Results of several bimodal listeners using the Nucleus CI will be presented and the influence of various stimulus parameters on ITD perception performance will be discussed.

Support provided by IWT-Vlaanderen and Cochlear, project 080304 and the EU-ITN project AUDIS.

[1] Francart T, Brokx J, Wouters J., Sensitivity to interaural time differences with combined cochlear implant and acoustic stimulation. J Assoc Res Otolaryngol. 2009 Mar;10(1):131-41.

5Wa: RELATIVE CONTRIBUTIONS OF PITCH AND INTELLIGIBILITY TO ELECTRO-ACOUSTIC SPEECH PERCEPTION IN NOISE

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While many cochlear implant (CI) users perform as well as normal hearing listeners at speech recognition in quiet, they have great difficulty understanding speech in noise. The addition of a hearing aid (HA) or even the introduction of fundamental frequency (F0) has been shown to improve CI speech recognition in noise for those with residual hearing. The benefit from this 'bimodal' configuration can be attributed to either intelligibility addition or pitch enhancement. These two mechanisms are fundamentally different and their relative contributions have yet to be fully explored. Here we tested 8 normal hearing (NH) subjects using a 4-channel CI simulation and 9 CI subjects with residual hearing in the non-implanted ear (Bimodal) along with an HA simulation (<500 Hz low pass) or the F0 cue. The subjects were tested in vowel and consonant recognition tasks in both quiet and in noise (signal-to-noise ratio 0 dB) under five listening conditions: 1) CI-only, 2) HA-only, 3) F0-only, 4) CI and HA, and 5) CI and F0. Percent correct scores and confusion matrices were obtained for each subject under each condition. Both the HA simulation and the F0 cue significantly enhanced CI consonant perception in noise [mean ± s.e., 21.2 ± 5.1% and 14.6 ± 1.7%,respectively] for the NH listeners, while only the F0 cue significantly enhanced CI performance on this task for the Bimodal users [13.8 ± 1.5%]. However, for vowel perception in noise, both groups showed that only the HA simulation significantly enhanced CI performance [NH: 54.4 ± 3.4%; Bimodal: 21.1 ± 8.1%], with no benefit seen from the F0 cue. Information Transfer Analysis of the consonant confusion matrices revealed that the HA simulation increased the transfer of information attributed to voicing, manner, and place, whereas the increase due to F0 was limited primarily to voicing. Analysis of the vowel confusion matrices showed that the HA simulation increased information transfer of both the first and second formant frequencies, with F0 providing no increase in information for vowels. The results suggest that for CI users with residual hearing, the addition of a hearing aid provides both an enhancement of pitch and an increase in intelligibility, whereas the addition of F0 provides an enhancement of pitch only.

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6Wa: THE EFFECTS OF MANIPULATING F0 ON THE BENEFITS OF ELECTRIC-ACOUSTIC STIMULATION

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Clear benefits to speech intelligibility exist when low-frequency acoustic stimulation is combined with electric stimulation. The benefits of electric-acoustic stimulation (EAS) are seen whether the acoustic stimulation is achieved in the implanted or the non-implanted ear. We have recently demonstrated that both fundamental frequency (F0) and amplitude envelope are important cues for EAS. This was demonstrated by replacing target speech in the low-frequency region with a tone at the frequency of the mean F0 of the target talker that carried these cues.

In the present study, speech intelligibility was measured in cochlear implant (CI) patients using a female target talker in a multi-talker babble background. Each listener heard either electric stimulation only, EAS when the low-frequency acoustic signal was target speech, or EAS when the low-frequency acoustic stimulus was the frequency- and amplitude-modulated tone. The tone was presented at a frequency equal to the natural mean F0 of the target talker, or it was shifted downward in frequency by 50, 75, 100, or 125 Hz. The mean F0 of each tone condition was thus 213, 163, 138, 113, or 88 Hz.

EAS benefit was observed whether the low-frequency stimulus was speech or a modulated tone. When the stimulus was a modulated tone, performance tended to decline only at the lowest mean F0 tested (though performance was still significantly better than that for electric stimulation alone). At all other mean F0 frequencies, performance was roughly equivalent to performance with the unshifted tone. At the lowest mean F0, the decline in performance observed may be due, at least in part, to audibility of the tone. These results have important implications for many current and potential CI users, because they suggest that it may be possible for patients with extremely limited residual hearing to achieve EAS benefit using the modulated tone. Other theoretical and practical implications of these findings will be discussed as well.

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1Wp: IN SEARCH OF FREQUENCY RESOLUTION

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Frequency resolution is the ability to 'hear out' different components of a complex signal. The ability to resolve frequencies is critical to the ability to understand speech. In support of this statement, several studies have demonstrated that implantees have variable limitation in this ability and that this variability may be correlated with speech understanding. In spite of the critical importance of frequency resolution, the methods that have been used to measure resolution in implantees are subject to either methodological or interpretational uncertainties. In psychophysical procedures such as spectral ripple discrimination tasks or 'profile analysis' tasks subjects can potentially discriminate stimuli using cues related to spectral shift or loudness changes rather than by resolving different frequencies or places of stimulation, particularly but not exclusively if using acoustic stimuli via the speech processor. Psychophysical or electrophysiological forward masking tasks using a single masker can measure the degree of 'excitation' spread either in the periphery or in central auditory pathways. Although we can infer that greater 'spread of excitation' will be associated with worse frequency resolution, it is difficult to make a clear connection, since we do not fully know how to compare the forward masking patterns in different subjects, and we do not know what aspect derived from the masking pattern determines whether stimuli can be perceptually resolved.

In this presentation we will review the issues above, and present new methods for assessing resolution of place of stimulation. Our psychophysical procedure uses an adaptation of 'spectral ripple' and 'profile analysis' tasks that limit the use of the alternative cues of spectral shift and loudness change. The task requires the subject to discriminate a 'flat profile' stimulus using 13 electrodes, from one that has a single peak in the centre electrode place and two 'valleys'. The currents in the peak and adjacent valleys are adjusted to balance loudness with the 'flat' profile while keeping the flanking electrode currents constant. By using the same stimuli in a forward masking task in addition to the discrimination task, the relationship between resolution and forward masking pattern can be established. Furthermore, by comparing the results with the standard psychophysical and forward masking patterns in the same subject, we can see what aspects of these forward masking patterns are predictive of the resolution ability. An objective version of the discrimination task using the cortical acoustic change response will also be assessed.

This research is supported by the Medical Research Council of the UK, and the HEAR Trust.

2Wp: SPECTRAL AND TEMPORAL CONTRIBUTIONS TO CLINICAL PERFORMANCE

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Clinical performance with cochlear implants has been measured using tests of speech perception in quiet and multiple types of noise, as well as with perception of a variety of different musical measures. Performance varies widely with all measures, but in general, only patients with traditional high performance (i.e., monosyllabic words in quiet) can excel at the more difficult tasks using music and speech in noise. Spectral and temporal discrimination capabilities using different speech processing strategies might contribute to this variability.

We have used acoustic measures of spectral-ripple and Schroeder phase discrimination as well as modulation detection to analyze performance. These psychophysical measures jointly predict clinical performance on a number of measures and appear to be more sensitive to speech processor modifications than traditional clinical measures. In particular, strategies which aim to improve spectral representation produce better spectral-ripple discrimination scores and those that emphasize temporal detail produce better Schroeder phase scores.

In the extreme case of a single-channel processor implementation, a strategy which demodulates acoustic input to the baseband has produced extremely high levels of isochronous melody perception but poor speech and timbre perception. We have also seen high levels of Schroeder phase discrimination using single-channel analog stimulation. This occurs due to the ability of both analog and demodulated stimuli to carry detailed low-frequency temporal information. Consistent with our clinical correlation studies, these findings confirm that the ability of different strategies to deliver spectral and temporal information can independently impact performance.

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3Wp: TOWARD RESTORING SPEECH INTELLIGIBILITY IN NOISE

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Cochlear implant (CI) user's performance degrades significantly in noisy environments. Previous attempts to develop noise reduction algorithms that would improve speech intelligibility have been partially successful. The goal of suppressing the background noise without distorting the target signal, particularly in situations where only one microphone is available, has been elusive for many decades. This is partly because algorithms were sought that would work for all listening environments and at all SNR levels, clearly an ambitious goal. A different approach is investigated in this study focusing on algorithms that can be optimized for a particular noisy situation. The development of these algorithms was motivated by a previous study in our lab that utilized the SNR as a channel selection criterion. Unlike the commercially available ACE strategy that uses the maximum amplitude criterion to select the stimulation channels, the proposed criterion picks target-dominant (SNR≥0 dB) channels and discards masker-dominant (SNR<0 dB) channels. To apply this new noise reduction method, a reliable SNR estimation algorithm needs to be developed, which is a challenging task.

In the present study, we treat the SNR estimation as a binary classification problem, and we train a different SNR classification model for each listening environment, based on data gathered from that environment. The performance with the proposed noise reduction algorithm was compared to the users' daily strategy. For some subjects, the performance was evaluated in three different types of real-world noisy environments: babble, train and exhibition hall. A different SNR classifier model was trained for each environment. An environment-specific SNR classifier was used to classify individual channels as target-dominant or masker dominant. IEEE sentences mixed with each of the three maskers at 5 and 10 dB SNR were used as test material. Results with cochlear implant users indicated substantial improvements at 5 dB SNR with the environment-optimized algorithm was near that obtained in quiet. The present study demonstrated the feasibility of noise suppression algorithms that can be optimized to a specific noisy environment. Such algorithms have the potential of restoring speech intelligibility for cochlear implant users in noisy environments.

Research supported by Grants R03-DC008887 (Y.H.) and R01-DC07527 (P.C.L.) from NIH/NIDCD.

4Wp: MARGARET SKINNER'S CONTRIBUTIONS TO OPTIMIZATION OF SPEECH RECOGNITION IN INDIVIDUAL CI RECIPIENTS

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Margo Skinner co-chaired the 1997 Conference on Implantable Auditory Prostheses at the Asilomar Conference Center. The theme of that conference was to understand factors underlying the wide variation of speech perception in cochlear implant (CI) recipients. This theme mirrored Margo's overall research objective which she began in 1989; that is, to understand the variability in patient performance and then determine how to optimize benefit from a CI for adults and children.

One area of variability was the selection of programming parameters when fitting the speech processor and the effects of different settings for an individual. For example, Margo's research focused on the importance of setting threshold and comfort levels so that soft speech was audible and conversational and loud speech was comfortable for optimized speech recognition. Studies of different stimulation rates suggested that faster stimulation rates did not necessarily result in optimal performance for all patients. Manipulation of electrode-to-frequency boundary assignments supported making changes to the number of electrodes assigned to the mid- and high-frequency regions to improve speech recognition. Studies of individual patient performance demonstrated the effects of input dynamic range and sensitivity settings for the perception of soft speech. In addition, her more recent research included the examination of cognitive variables as predictors of both speech recognition and improvement in performance. By conversing with patients, Margo recognized the mismatch between the researcher's evaluation of patient performance in the clinic and the patients' evaluation of their ability to hear and communicate in everyday situations. In response to this, she incorporated multiple measures and test conditions in her study designs to effectively evaluate CI benefit. To extend this further, we will report on outcomes and factors that affect performance in bilateral sequential CI recipients, with emphasis on speech recognition achieved in the second ear using test conditions that better reflect everyday listening.

Margo's research showed the importance of individual data. She gave careful attention to patient feedback, used individual patient results to formulate meaningful clinical questions, probed deeper into the outlier, and never lost sight of the patient. Margo's unique ability to incorporate research findings into clinical practice contributed to improved outcomes for cochlear implant patients.

Supported by NIH/NIDCD.

5Wp: MARGARET SKINNER'S CONTRIBUTIONS TO UNDERSTANDING THE BASIS OF SPEECH RECOGNITION VARIABILITY ACROSS CI RECIPIENTS

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Margo Skinner's 1997 Conference on Implantable Auditory Prostheses emphasized the underlying mechanisms contributing to variability in speech recognition abilities across patients. This was one of Margo's main areas of interest for over 20 years. Margo built and led teams of multidisciplinary investigators to explore the mechanisms that limit CI performance with the goal of improving each individual patient's ability to communicate with a CI.

Her primary focus was to characterize the electrode-nerve interface anatomically using CT imaging and correlate her findings with measures of speech recognition performance. Because CT metal electrode artifact contamination interferes with identification of the electrode array and obscures fine anatomical features of the cochlea, she led her team to develop a two-step imaging procedure to determine implanted electrode position in vivo. Using well-defined anatomical landmarks, a pre-op CT image optimized for anatomical detail is spatially registered with a post-op CT image optimized for resolution of the electrode. The electrode is then segmented and copied into the pre-op image space to provide a composite image of electrode placement within an individual's cochlea. Subsequent CT studies showed significant variability of depth of insertion and scalar placement of the electrode array across users of all manufacturers' devices. Lower outcome scores were associated with greater insertion depth and greater number of contacts being located in scala vestibuli. These patterns suggested surgical technique may be a contributing factor in suboptimal electrode placement, resulting in an ongoing trial of modified surgical procedures to improve electrode placement and outcomes.

With benefit of the anatomical insight provided by Margo's work, new physiological ECAP latency shift data are being interpreted in the context of a putative site of ectopic stimulation that may significantly limit speech recognition due to cochlear electroanatomy and current pathways.

Finally, Margo was most interested in how these factors limited performance and how this information could be used to improve clinical outcomes. By modifying speech processor maps to minimize coding errors caused by these factors, speech recognition can be substantially improved in individual CI users.

Margo's research was supported continuously by the NIH-NIDCD for 18 years resulting in more than 50 peer-reviewed CI publications.

6Wp: THIRTY YEARS OF COCHLEAR IMPLANT DEVELOPMENT

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In 1979, there was no clinically available multi-channel cochlear implant and the idea of a device that was anything other than an aid to lipreading was a dream. Since then we have seen CIs become a recognised medical intervention with a creditably high success rate. We have seen patient performance reach levels that allow children to attend mainstream schools and interact with their peers almost normally. We have seen children who were sentenced to a life of producing deaf speech, speak as normally as any other children.

What were the innovations and practical developments that have made this progress possible? We have gone down some blind alleys, on some wild goose chases and up the garden path. But we have achieved our goal. I have been fortunate to be part of this development and in particular I have been fortunate to work with brilliant researchers like Margo Skinner. The role of the audiologist and an audiologist of the caliber of Margo must not be underestimated. That work was essential to the success of the field.

In this presentation I will attempt to summarize the important technical and clinical lessons we have learned – on the back of an envelope.

1THa: CONTRIBUTING AND LIMITING FACTORS TO BINAURAL SENSITIVITY IN BILATERAL COCHLEAR IMPLANT USERS

Ruth Y. Litovsky

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Our lab is studying benefits from the use of bilateral cochlear implants (BiCIs) in young children and in adults. Studies in young children focus on the emergence of spatial hearing and language skills. We consider the amount of bilateral experience, chronological age and hearing age (months since activation of the first implant). Results in children ages 4-8 suggest that sound localization acuity depends on all of these factors. In the very young population of 2-3 year olds, numerous children reach a level of performance of normal-hearing peers, which supports the notion that early activation of bilateral circuits may be desirable. In both age groups, there are nonetheless numerous children who are unable to localize sounds, despite having had >1 year of bilateral stimulation. We will consider reasons for this variability in outcomes with BiCIs, including measures of speech perception and production, language acquisition and non-verbal IQ.

Benefits from bilateral implants in adults are studied in our lab by simulating realistic complex acoustic environments in which multiple interfering stimuli co-occur with target stimuli. Our findings demonstrate that, compared with normal hearing listeners, there is an effective 20 dB difference in the signal-to-noise ratio at which BiCI users are able to localize sounds or to understand speech in noise. A number of factors could contribute to this effective difference, including the lack of binaural coordination across the two ears when testing is conducting in free field. To investigate the gap in performance between BiCI users and NH listeners we utilize the SPEAR3 system, whereby we can directly stimulate selected pairs of electrodes using controlled binaural stimulation. Results show that when single pairs of electrodes are stimulated, some subjects show excellent sensitivity to binaural cues. There is an effect of age at which deafness was acquired, with sensitivity to interaural timing being particularly affected in pre-lingually deafened persons. In order to understand some of these effects we have used vocoder simulations of BiCI listening in normal hearing adults. Here, we have systematically explored issues such as the number of binaural channels that are available, effects of simulated “dead regions” in the cochlea and whether the carrier is sine- or noise-excited.

Technological advances may be needed in order to enable clinical processors to capture and preserve binaural cues with fidelity, but there may also be limitations inherent to current electrode design and stimulation strategies. At the same time, we place great emphasis on the advances made to date and the tremendous success that has been observed in many BiCI users.

Supported by NIH NIDCD R01008365 to R.Y. Litovsky.

2THa: OBSERVER WEIGHTING OF LEVEL AND TIMING CUES IN BILATERAL COCHLEAR IMPLANT USERS

Richard J. M. van Hoesel

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The perceptual weighting of level and timing cues applied to each pulse in brief electrical pulse-trains was determined in a lateralization task using an observer weighting paradigm. Four bilateral cochlear implant (BiCI) users were tested with two- and eight-pulse stimuli containing interaural time delays (ITDs), or in a separate experimental condition, interaural level differences (ILDs), at rates between 100 and 600 pulses per second (pps). To assess the hypothesis that weights were affected by the randomization of cues across pulses, as necessitated by the observer weighting approach, lateralization was also assessed using eight-pulse stimuli at 300 pps with identical ITDs on the last seven pulses. Results showed that in all cases the cue on the first pulse was weighted most strongly. At 100 pps, both ITDs and ILDs on post-onset pulses also contributed substantially. As rates increased to 300 and 600 pps, contributions from post-onset pulses remained substantial for ILDs, but were much reduced for ITDs. In accordance with observer weighting studies with normal hearing listeners, reduction of post-onset weights was immediate rather than gradual, discounting a steadily increasing adaptation mechanism. Weighting of post-onset ITD cues was similar whether cues were identical or independently randomised across the seven post-onset pulses, suggesting the randomization process itself did not affect the estimated weights.

The same BiCI users were further tested for the ability to “restart” electrical binaural ITD sensitivity after the introduction of an aberrant reduced inter-pulse interval half-way through an eight-pulse sequence. Increased ITD sensitivity following the shortened inter-pulse interval was not observed. The results are discussed with regard to previous studies concerned with binaural sensitivity.

3THa: SPATIAL HEARING IN FERRETS WITH COCHLEAR IMPLANTS

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We present an overview of a novel model of cochlear implantation (CI) in the ferret to study the behavioural and electrophysiological effects of CI on binaural development. Hearing loss was induced with subcutaneous neomycin injections, prior to implanting intra-cochlear multichannel electrode arrays in one or both ears. For chronic stimulation, electrode arrays were connected via percutaneous lead wires to stimulator-receivers and ESPrit 3G processors (Cochlear Ltd.) worn in a jacket. Electrically-evoked compound action potentials and behavioural thresholds were used to program speech processors with a continuous interleaved sampling strategy. Free-field sound localization of broadband noise bursts was assessed in ferrets with normal-hearing (NH), unilateral-CI (U-CI), and bilateral-CI (B-CI), using a positive conditioning paradigm. Preliminary results indicate that i) BCI enhances greatly sound localization compared with U-CI, ii) this performance deteriorates at >77 dB SPL, potentially due to detrimental effects of automatic gain control activation, and iii) behavioural training improves localization ability following CI. We are currently studying effects of age at onset of hearing loss and asynchronous B-CI on the development of sound localization. We are also training animals with BCI and NH on a free-field signal-in-noise detection task. The ability to localize sounds in the horizontal plane relies upon the detection of interaural time delays (ITDs) and interaural level differences (ILDs). In humans, B-CI is associated with good ILD sensitivity, but modest envelope ITD sensitivity. NH studies suggest that envelope ITD sensitivity can be enhanced using transposed stimuli. To assess neural correlates of this phenomenon, and potential benefits of transposed stimuli to individuals with B-CI, binaural interactions were assessed in the auditory cortex of i) acutely deafened ferrets with B-CI and ii) NH animals. In animals with B-CI, envelope ITD sensitivity to transposed and sinusoidal amplitude-modulated (SAM) biphasic pulse trains was assessed over a range of modulation frequencies and levels. For comparison, cortical sensitivity to ITDs was assessed in NH animals with transposed and SAM acoustic carriers. As in previous studies of the guinea pig midbrain, cortical neurons in NH animals showed greater ITD sensitivity with the transposed stimuli, compared with the SAM condition. In animals with B-CI, smaller spike rates were recorded in response to transposed stimuli, but the number of binaurally-sensitive units remained the same. Thus, transposed stimuli may prove beneficial to individuals with B-CI.

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4THa: ENCODING OF ACOUSTIC AND ELECTRIC INTERAURAL TIME DIFFERENCES IN THE MONGOLIAN GERBIL

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Interaural time differences (ITDs) are the primary spatial cue for low-frequency sounds. Clinical studies have shown that most bilaterally deaf cochlear implant users have poorer ITD-resolution and sound localization capabilities than normal hearing subjects. To better understand these discrepancies, the present study directly compares responses of the same neurons in the dorsal nucleus of the lateral lemniscus (DNLL) to acoustic and electric ITDs. As cochlear delays are eliminated using electroneural stimulation of the cochlea, such comparisons will help to understand the potential contribution of cochlear delays to ITD coding.

Normal hearing, adult gerbils were bilaterally implanted with round window electrodes, and an earphone was sealed to the ear canals for acoustic stimulation. To estimate acoustic ITD-sensitivity, pure-tone stimuli were presented at five frequencies around the neuron's characteristic frequency with varying ITDs at 20 dB above threshold. To more closely mimic the broad excitation pattern evoked by pulsatile electrical stimulation of the cochlea, bursts of Gaussian noise also were presented at different ITDs. For electric stimulation, biphasic constant current square-wave pulses (80 µs/phase) with varying ITDs were presented at 0-4 dB above the neuron’s threshold. Responses were recorded extracellularly from single DNLL neurons.

Using acoustic tones, most neurons respond maximally to ITDs (‘best ITDs’) outside the physiological range for gerbils (+/-120 µs) with the contralateral stimulus leading. In contrast, in response to acoustic noise and electrical pulses, best ITDs are shifted towards 0 µs and, for some neurons (44%), moved into the physiological range. Electrical stimulation further sharpens ITD tuning (half-width, half-rise) and results in an increased physiological modulation depth when compared to tonal stimulation. However, ITD tuning appears equally sharp for stimulation with noise or electric pulses. The ITD at the steepest slope was not affected by either mode of stimulation and, for most cases, remained within the physiological range of ITDs.

The high synchrony of neuronal firing and the lack of cochlear delays may partly explain the changes in ITD tuning in response to electric pulses versus acoustic tones. However, the finding that most electrical best ITDs were located outside the physiological range suggests that factors other than cochlear delays contribute to the observed asymmetries in ITD tuning.

Support provided by NOHR.

5THa: NEURAL CODING OF ITD WITH BILATERAL COCHLEAR IMPLANTS: EFFECTS OF AUDITORY EXPERIENCE AND TEMPORAL FINE STRUCTURE

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Human bilateral cochlear implant users do poorly on tasks involving interaural time differences (ITD), a cue which provides important benefits to the normal hearing, especially in challenging acoustic environments. Yet the precision of neural ITD coding in acutely-deafened, bilaterally-implanted cats is essentially normal (Smith & Delgutte, J Neurosci 27: 6740-6750). One possible explanation for this discrepancy is that the extended periods of binaural deprivation typically experienced by cochlear implant users degrade neural ITD sensitivity. To test this hypothesis, we recorded from single units in inferior colliculus (IC) of two groups of bilaterally-implanted, anesthetized cats: acutely-deafened cats, which had normal binaural hearing until experimentation, and congenitally deaf white cats, which received no auditory inputs until the experiment. In the congenitally deaf cats, the rate responses of only half as many neurons (42% vs. 82%) exhibited significant ITD sensitivity for low-rate periodic pulse trains compared to acutely deafened cats. These results suggest that deprivation of auditory experience comprising the neonatal period has a major impact on the function of the brainstem circuits processing ITD.

Current processors for cochlear implants deliver ITD information in the envelope of amplitude modulated pulse trains. Psychophysical and physiological results suggest that ITD would be a more effective cue for sound localization and signal detection if it were delivered in the fine time structure as well as in the envelope. However both behavioral and neural ITD sensitivities with electric pulse trains are poor for the high pulse rates used in today's cochlear implant processors. Inspired by the finding that introducing binaurally-coherent jitter improves behavioral ITD discrimination for high-rate pulse trains (Laback & Majdak, PNAS 105:814-7), we measured responses of IC neurons in anesthetized deaf cats as a function of pulse rate, pulse jitter, and ITD. For pulse rates above ~300 pps, jitter increased the firing rates of many IC neurons and gave these neurons ITD sensitivity comparable to that observed for low-rate periodic pulse trains. Thus, jitter appears to unmask neural ITD sensitivity by restoring sustained firing in IC neurons. These results may lead to new processing strategies that harness the effect of jitter to improve sound localization and speech reception in noise with bilateral cochlear implants.

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6THa: CORTICAL RESPONSES TO BILATERAL COCHLEAR IMPLANTS IN DEAF CATS

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To investigate cortical binaural representation, local field potentials (LFPs) in response to binaural cochlear implant (CI) stimulation were first recorded with microelectrodes in the feline field A1. Responses were compared between stimulation at the ipsilateral and contralateral ear in hearing controls (HCs) and congenitally deaf cats (CDCs). Electrical pulsatile stimulation evoked a fast cortical propagation wave (duration ~15 ms) that was specific for the stimulated ear in hearing cats. In congenitally deaf animals, the propagation pattern was significantly different, with a more synchronous activation of distant cortical regions. The “contralateral specificity” of field A1 was significantly reduced in CDCs. Additionally, the aural responses showed a difference with respect to cortical place in A1: when investigated in caudal cortical regions of HCs, the responses were more similar than in rostral parts of A1. This dichotomy was lost in CDCs. Binaural interactions were then investigated in most-activated spots. For this purpose, a 16-channel Michigan probe was inserted into the cortex and sensitivity for interaural time differences (ITDs) were compared in ~400 cortical units of HCs and CDCs. Although a rudimentary sensitivity to binaural cues were found in CDCs, the number of non-responsive sites was significantly higher than in HCs, and the maximum evoked firing rate was significantly reduced. The intensity dependence of ITD sensitivity observed in HCs was significantly reduced in CDCs. Additionally, the part of the response traditionally related to precedence effect was very rare in deaf cats. The data demonstrate that the cortical specificity for the contralateral ear is disrupted in congenital deafness. The cortical representation of ITD is affected by congenital deafness and a possible neuronal substrate of processing auditory reverberations is not functional. The rudimentary preservation of ITD sensitivity, however, demonstrates that subcortical extraction of binaural cues develops also in absence of hearing experience.

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1THp: BRAIN-DERIVED NEUROTROPHIC FACTOR (BDNF) AND ELECTRICAL STIMULATION PROMOTE IMPROVED SURVIVAL OF SPIRAL GANGLION NEURONS IN CATS DEAFENED AS NEONATES

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The postnatal development and survival of spiral ganglion (SG) neurons depend upon both neural activity and neurotrophic support. Our previous studies in neonatally deafened cats have shown that intracochlear electrical stimulation only partially prevents SG degeneration after early deafness. Thus, neurotrophic agents that might be combined with stimulation to enhance neural survival are of interest. Recent studies reporting that direct cochlear infusion of BDNF promotes SG survival after deafness and is additive to the effects of electrical stimulation have been conducted in rodents and limited to fairly short durations. Our study evaluated BDNF infusion over a longer duration and in the developing auditory system of cats, which may better model the slow progression of SG degeneration in humans. Kittens were deafened as neonates (neomycin, 60 mg/kg SID) and implanted at 4-5 weeks of age with a scala tympani electrode containing a drug-delivery cannula connected to a mini-osmotic pump. Pumps were changed to allow continuous infusion of BDNF (94µg/ml; 0.25µl/hr) or artificial perilymph for 10 weeks.

In BDNF-treated cochleae, SG cell somata had cross-sectional areas that were normal adult size and were significantly larger (34% increase; $p<0.024$) than cells on the deafened control side. Because other methods used to assess SG survival reflect changes in both cell size and number, we used a physical dissector stereological method to accurately assess the numerical density of surviving SG cells, counting SG nucleoli in serial 5 µm plastic sections. Mean SG density after BDNF infusion was 27% higher than in the contralateral ears, indicating a significant effect of BDNF ($P=0.001$; $n=5$) in promoting survival of SG neurons in these developing animals. Additional interesting findings following BDNF infusion included higher density and larger size of myelinated radial nerve fibers within the osseous spiral lamina, sprouting of fibers into the scala tympani, a longitudinal reduction in electrically evoked auditory brainstem response (EABR) thresholds and maintenance of apparently normal central tonotopic organization at the level of the inferior colliculus.

Additional experiments are exploring whether the survival advantage elicited by BDNF can be maintained over the longer term by subsequent electrical stimulation, after withdrawal of exogenous neurotrophic support. Preliminary data suggest that enhanced SG neural survival may be maintained, but the increase in cell size elicited by BDNF is not.

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2THp: REPLACEMENT OF AUDITORY NEURONS BY STEM CELLS IN THE DE-AFFERENTED ORGAN OF CORTI: FORMATION OF GLUTAMATERGIC SYNAPSES WITH HAIR CELLS

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The presumed inability of the vestibular and auditory organs to replace damaged cells is one reason for the prevalence of sensorineural hearing loss. We have attempted to restore innervation of hair cells by transplantation of stem cells that differentiate to auditory neurons. We injected EYFP expressing embryonic stem cell-derived mouse neural progenitor cells into the cochlear nerve trunk in immunosuppressed animals one week after destroying the cochlear nerve (spiral ganglion) cells while leaving hair cells intact by ouabain application to the round window at the base of the cochlea in gerbils. Stem cell derived neurons grew new fibers in the direction of both hair cells and the brainstem. We have assessed expression of axonal guidance molecules in an effort to understand how the neurons find and form synapses with hair cells. Members of the netrin, slit, ephrin, semaphorin, and repulsive guidance molecule (RGM) families of guidance molecules were expressed in the cochlea. Synapse formation was documented by detection of pre- and postsynaptic specializations in close apposition. New synapses were identified by staining of C-terminal binding protein (CTBP2) at the presynaptic (hair cell) side and postsynaptic density 95 (PSD95) at the postsynaptic (neuron) side. Inhibition of axonal guidance molecule RGMa resulted in a significant enhancement of growth in vitro by neurons that were transplanted into a denervated sensory epithelium. Replacement of peripheral auditory neurons and the afferent synapse with hair cells can thus be achieved by introduction of new cells that differentiate into neurons. Formation of gluatamatergic synapses by these cells raises the possibility that stem cells could be used as the basis for therapies that would increase the growth of new processes to sensory epithelium or to a prosthetic device.

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3THp: THE POTENTIAL OF STEM CELLS FOR AUDITORY NEURON GENERATION AND REPLACEMENT IN THE DEAF COCHLEA

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Cochlear implants function by electrically stimulating auditory neurons in the absence of hair cells, to enable hearing in severe to profoundly deaf individuals. The efficacy of this device therefore depends on a critical number of surviving auditory neurons. Stem cell transplantation therapy is emerging as a potential strategy for auditory nerve rehabilitation, as differentiated stem cells may provide a source of replacement neurons to the deaf cochlea. The successful engraftment of stem cells into the cochlea will require both the directed growth of new processes and the formation of functional connections with existing structures, and we are investigating these questions using both *in vitro* and *in vivo* models.

Specifically, we have developed an *in vitro* assay to differentiate human stem cells into sensory neural precursors (neural crest), which we have co-cultured with early post-natal cochlear explants. After 11 days in culture, we observe stem cell-derived processes growing toward the hair cells along the peripheral processes in the explant. Both the migratory phenotype and molecular profile of these differentiated stem cells (including expression of HNK1, Sox10, peripherin and NF-H) suggests that they are sensory neural progenitors and may be suitable for auditory neuron replacement. The potential to differentiate human stem cells into auditory neurons for transplantation, including the incorporation of new induced pluripotent stem cell technology, will be discussed.

We have also examined the engraftment of stem cells into the deafened mammalian cochlea using various surgical approaches. Our transplantation studies were designed with the primary intention of investigating whether stem cells could be applied in a clinical manner that would eventually allow combined therapy with a cochlear implant. Collectively, these studies have shown that stem cells can survive and differentiate into neural cells in the deafened cochlear environment, however, their long term survival, neurite outgrowth and functional connectivity needs further investigation. Our research illustrates the potential of, and future considerations for, combined stem cell therapy with cochlear implantation.

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4THp: NANOPARTICLES AS NOVEL DRUG DELIVERY SYSTEMS FOR COCHLEAR IMPLANTS: CELL-UPTAKE AND –TOXICITY IN VITRO AND IN VIVO

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Cell dysfunction in the inner ear leads to sensory-neural hearing loss. Cochlear-Implants (CIs) are the standard therapy for this kind of deafness. The benefit that can be achieved by CIs depends among others on the density and excitability of the spiral ganglion cells. Treating these cells with plasmids, genes or neurotrophic factors is effective but novel drug carriers unifying targetability, biodegradability, traceability and controlled drug release would advance the current application methods.

Fluorescent labeled hyperbranched polylysines (HBPL), lipid nanocapsules (LNC) and block copolymer micelles (BCM) were examined for their cell uptake and possible toxicity in vitro and in vivo as first step in developing novel nanosized multifunctional carriers for inner ear treatment. Nanoparticles were incubated for 48 hours with L929 fibroblasts. Afterwards, nanoparticle-uptake and cell viability were determined by confocal laser scanning microscopy (CLSM), concentration-dependent fluorescence measurements and vital staining. For in vivo detection and toxicity studies the nanoparticles were injected into the scala tympani of guinea pigs. Hearing function was determined by auditory brainstem response measurement before and 2, 14, and 28 days after treatment. Finally, the cochleae were harvested, the membranous tissue was stained, cytocochleograms were performed and the particles were localized by CLSM.

In vitro, each kind of nanoparticle was taken up by fibroblasts. The primary nanoparticle concentration was linearly correlated with the quantified extinction and calculated nanoparticle uptake into the cells after incubation – no saturation curve could be determined. LNC as well as HBPL and BCM were detectable in cells of the basilar membrane and stria vascularis. They did not cause hearing loss and the cytocochleograms revealed no hair cell loss.

HBPL, LNC and BCM comply with the basic requirements for novel drug carriers for inner ear treatment. These results support the assumption that nanoparticles may be used for future therapy strategies to increase the prosperity of CIs.

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5THp: PROTECTION OF SPIRAL GANGLION NEURONS WITH NEUROTROPHINS AND CHRONIC ELECTRICAL STIMULATION

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In the deaf cochlea spiral ganglion neurons (SGNs) undergo continual degeneration that ultimately leads to neuron death. The exogenous application of neurotrophins (NTs) has been shown to prevent SGN degeneration and even promote regrowth. Furthermore, combining chronic intracochlear electrical stimulation (ICES) with NT administration can enhance the survival effects of NTs and lower electrical thresholds. However, following the cessation of NT delivery SGNs continue to degenerate. Therefore techniques that deliver NTs over a long period of time are required to maintain the therapeutic benefit of NT treatment.

We have used cell-based therapy to provide NTs in combination with an intracochlear electrode array in a long-term deafened cat model. Cats were neonatally deafened with daily injections of neomycin, and at two months of age were implanted with encapsulated porcine choroid plexus cells (NTCell, LCT Inc.) and the stimulating electrode array. The choroid plexus cells were encased in an alginate capsule that enabled the diffusion of neurotrophins (including Brain-Derived Neurotrophic Factor and Neurotrophin-3) into the cochlear fluids. Environmentally derived ICES was delivered chronically via a clinical stimulator (Nucleus CI24M, Cochlear™) and processor (Esprit 3G, Cochlear™). Five cats received chronic ICES only. Six cats received NTs without chronic ICES and six cats received NTs in combination with chronic ICES. Control animals (n=7) were normal hearing and were not implanted.

The results indicated that chronic ICES alone (without NTs) did not provide greater SGN survival when compared to the contralateral untreated cochlea. Importantly, chronic ICES in combination with NT delivery provided greater SGN protection than NT alone or chronic ICES alone (ANOVA $P<0.003$). Treatment with NT alone led to an improvement in thresholds from electrically evoked brainstem responses (ANOVA $P<0.003$). These results indicate that cell-based NT delivery in combination with electrical stimulation delivered by a cochlear implant can promote SGN survival. These findings have important implications for future strategies that will combine cochlear implantation with systems that deliver drugs safely to the cochlea.

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1Fa: INTRANEURAL STIMULATION FOR AUDITORY PROSTHESIS

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The goal of electrical stimulation for auditory prosthesis is to excite tonotopically restricted populations of nerve fibers. This is a challenge for a conventional scala tympani cochlear implant, which is located in a different anatomical compartment than is the auditory nerve. We are attempting to improve on this situation by implanting electrode arrays within the body of the nerve, with stimulating electrodes in close proximity to restricted nerve-fiber populations.

Experiments were conducted in anesthetized cats. We monitored the specificity of activation of the ascending auditory pathway by recording the distribution of activity along the tonotopic axis of the central nucleus of the inferior colliculus (ICC). In each experiment, we tested responses to acoustic tones in normal-hearing conditions, then deafened an ear and tested a conventional scala tympani banded electrode array and a penetrating auditory nerve array. Auditory-nerve arrays were single silicon-substrate shanks with 16 electrodes spaced in 100-μm intervals.

Intraneural stimulation offered substantial improvements over intra-scalar stimulation. Thresholds averaged 24 dB lower than monopolar and 34 dB lower than bipolar stimulation. Intraneural electrodes could activate frequency-restricted populations centered throughout the audible frequency range, unlike intra-scalar electrodes that could not provide specific low-frequency stimulation. Tonotopic spread of activation by intraneural electrodes approached that obtained in normal hearing with acoustic tones. Frequency-specific dynamic ranges averaged >15 dB for intraneural stimulation compared to ~4 dB for intra-scalar stimulation.

In contrast to intra-scalar stimulation, intraneural stimulation showed low-to-negligible interference among simultaneously stimulated electrodes. Stimulation of pairs of electrodes showed superposition of the patterns elicited by each of the individual electrodes, with no influence of one electrode on the operating current range of the other electrode

Intraneural stimulation exhibited superior transmission of temporal fine structure, as demonstrated by phase locking of ICC neurons to higher rates of unmodulated electrical pulse trains. That result appears to be largely a result of intraneural stimulation of fibers leading to low-frequency brainstem pathways.

Overall, intraneural stimulation shows great promise for advances in auditory prosthesis. Our ongoing work is testing chronic implantations in animals, which is essential prior to human trials.

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2Fa: BEHAVIORAL AND NEURAL RECORDING TO EVALUATE A MINIMALLY INVASIVE VESTIBULAR PROSTHESIS BASED UPON COCHLEAR IMPLANT TECHNOLOGY

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<u>Introduction</u>. Development of a vestibular prosthesis requires novel technological, surgical and experimental approaches. We used a modified cochlear implant, with a redesigned electrode array and new processing strategies, to produce naturally and electrically elicited behavioral and single vestibular neuron responses to evaluate the feasibility of a unilateral vestibular implant in an animal model.

<u>Methods</u>. The device, based on a Nucleus Freedom processor (Cochlear Corp, Lane Cove), had a ball ground and three electrode leads, each with 3 independent stimulation sites. Each lead was implanted in a small fenestration in the bony labyrinth of the semicircular canal, while maintaining the integrity of the membranous labyrinth. 5 rhesus monkeys were implanted using this minimally invasive surgical technique, and two monkeys were implanted using fine wire electrodes and canal plugging. Placement of the device was confirmed with vestibular ECAP recording with NRT. Typically, the lateral and posterior canals were implanted. In four animals, recording chambers allowed single unit tungsten recording electrodes to be directed toward the vestibular nuclei. Eye movements were recorded with scleral coils. Natural stimulation could be provided by en-block rotation in a 3-dimensional rotator. Software was developed to drive single or multiple channels of the implanted device with biphasic pulses (20 to 300 μA, 100 to 400 μs per phase, 8 μs gap, 10 to 600 Hz) of varying train durations with either constant, or amplitude or frequency modulated stimuli. Hearing was evaluated with click-evoked auditory brainstem recording.

<u>Results</u>. Minimally invasive implantation of the device preserved the natural rotational sensitivity of the implanted horizontal canal in all animals, while canal plugging reduced responses to rotation toward the implanted ear. Hearing was preserved in 3 of 4 animals implanted with the minimally invasive technique and subsequently evaluated, and was impaired in one animal that received a revision implant surgery and one animal that received canal plugging. In 3 animals that received the minimally invasive implant procedure, and 2 animals that received canal plugging and implantation, monopolar or bipolar electrical stimulation produced robust nystagmus, predominantly in the plane of the implanted canal. Increases in stimulus frequency or stimulus current produced reliable increases in the slow phase velocity of the nystagmus. Modulation of frequency or current produced modulation of slow phase eye velocity. Summation of head rotation and electrical stimulation produced summation of the natural eye counter-rotation and the electrically elicited response. Single neurons tuned to rotation in the plane of an implanted canal followed electrical stimulation of that canal at thresholds corresponding to the threshold for eye movement. Neurons responding to rotation in the plane of a non-implanted canal were typically not activated by electrical stimulation.

<u>Conclusion</u>. Minimally invasive implantation of a cochlear implant based vestibular prosthesis can drive robust vestibular responses electrically without compromising hearing or vestibular function in the implanted ear. The precise mechanisms underlying the behavioral responses are being explored with recording of single vestibular neurons during natural and electrical stimulation.

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3Fa: DEVELOPMENTAL TRAJECTORY OF CHILDREN WITH ABI: PERFORMANCE vs ETIOLOGY

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Objective. To update the auditory performance, cognitive development and complications observed in children fitted with auditory brainstem implants (ABIs), at our department.

Study design. Retrospective case review.

Materials and methods. In our department, 42 children aged from 11 months to 16 years, received an ABI from 2000 to 2009. Two children had neurofibromatosis type 2 (NF2) and 40 had different non-tumor cochlear and cochlear nerve disorders. Perceptual auditory abilities were evaluated with the CAP, ESP, GASP and EARS battery tests. Cognitive evaluation was performed on 14 children using the LEITER-R test, the Child Behaviour Check List and the Vineland Adaptive Behaviour Scale. The follow-up ranged from 6 months to 9 years.

Results. The post-operative outcomes show significant inter-individual variations. All children consistently used their devices for 8 hours/day on average and demonstrated gradual improvement in communication skills, with more attention and interest in school and at home. Most children demonstrated the ability to perceive environmental sounds at the first session, identified different sounds and their parents' voices within the first 6-12 months, and improved their communication abilities in the following 24-36 months. All children showed continued improvements in auditory skills and cognitive performance over time. No postoperative significant complication was observed.

Conclusions. Children with cochlear or cochlear nerve abnormalities obtain significant benefit from ABIs. Children without associated cognitive deficits receiving ABIs at younger age can be expected to perform in the range of the cochlear implant children. The absence of permanent complications justifies the reduction of age implantation to below 12 months in order to reduce the length of auditory deprivation.

4Fa: AUDITORY MIDBRAIN IMPLANT: CURRENT PROGRESS AND FUTURE DIRECTIONS

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The auditory midbrain implant (AMI) is a new hearing prosthesis designed for stimulation of the central nucleus of the inferior colliculus (ICC). Over the past 8 years, we have taken the AMI concept from animal feasibility and safety studies to human implantation and implementation. Clinical trials began in 2006 and we have currently implanted 5 neurofibromatosis type II patients with a single shank array (20 electrode contacts). Overall the outcome has been encouraging with respect to the safety and functionality of the AMI. Across all patients, the implant has shown to be safe with minimal movement over time. Each patient exhibited various side effects, predominantly parasthesia in the body and face, which could be easily avoided by inactivating the appropriate sites. All patients obtain various auditory percepts and speech information with AMI stimulation and use the device on a daily basis that aids in environmental awareness and lip-reading capabilities. Although the intended target was the ICC, placement varied across patients and strongly affected hearing performance. The best performing patient is implanted with the array aligned along the tonotopic gradient of the ICC. However, this patient still does not achieve open set speech perception comparable to cochlear implant patients.

Through various psychophysical tests across implant patients (i.e., with AMI, auditory brainstem implant, cochlear implant) as well as electrophysiological studies in animals, we have begun to identify differences in coding properties between midbrain stimulation and cochlear and brainstem stimulation. These differences not only reveal several factors limiting AMI performance but also provide evidence that traditional cochlear implant strategies currently used in our patients are inappropriate for the auditory midbrain. Furthermore, a single shank array within the three-dimensional ICC structure provides limited and likely insufficient activation of higher auditory centers. Therefore, we need to develop and implement a three-dimensional array that can effectively stimulate across the ICC structure with temporal and spatial patterns more appropriate for how midbrain neurons transmit sound information to higher auditory nuclei. These patterns will be identified through further animal and human implant studies.

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POSTER SESSION ABSTRACTS

A1: INTRACOCHLEAR MONITORING OF ACOUSTICALLY-GENERATED POTENTIALS DURING COCHLEAR IMPLANTATION: IMPLICATIONS FOR ATRAUMATIC ELECTRODE INSERTION

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Cochlear implant patients with residual hearing have improved speech perception, especially when listening in noise, compared to electrical stimulation alone. However, the insertion and advancement of an electrode can compromise residual hearing. The goal of this project is to identify electrophysiological markers for imminent damage to cochlear structures due to advancement of a cochlear implant electrode. These markers are to be first identified in the gerbil cochlea, with the aim of developing acoustic stimulation and recording paradigms to be used during cochlear implant surgeries to better preserve residual hearing.

Experiments were conducted in urethane-anesthetized, normal-hearing gerbils. Metal (Pt-W) electrodes were placed on the surface of the round window and recordings of the cochlear microphonic (CM) and compound action potential (CAP) were made in response to acoustic stimulation. The recording was monopolar, with a return electrode placed in the neck muscles. The stimulation was free-field tone bursts at frequencies ranging from 1 to 16 kHz in one octave intervals and at intensities of 15-72 dB SPL in 3 dB steps. To identify changes associated with impingement on cochlear structures, the electrode was advanced through the round window in steps ranging from 50-250 micrometers. The electrode was directed radially toward the basilar membrane. The CM and CAP data at each step was compared to that taken at the round window. Following the recording experiment, the cochlea was fixed with paraformaldehyde and cochlear damage was examined histologically in a whole-mount preparation.

At the round window, the threshold to the CM was typically 5-10 dB lower than the CAP. There was an increase in thresholds and loss of amplitude in the CM and CAP after damage to cochlear structures such as the basilar membrane and osseous spiral lamina. In most cases, loss of activity was first apparent in the CAP as the electrode was advanced, with greater advancement needed for a change in the CM. In some cases the change in the CAP was reversible when the electrode was withdrawn, which was not the case for the CM. These results indicate that in this recording configuration the CAP is a more sensitive measure of an interaction between the electrode and cochlear structures than is the CM. The reversibility shows that a small reduction in the CAP can be a sensitive physiological marker of imminent cochlear damage.

A2: INFERRING THE ELECTRODE TRAJECTORY FROM ELECTRICAL SPREAD MEASURES

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Objective measures in cochlear implants, such as impedances and neural responses, are often used as a first quality measure for the success of the implantation. Impedances offer a way to check the electrode integrity. Similarly successful capture of the eCAP response implies that the device is fully functional and that the auditory nerve is responding to the electrical stimulation. In this study we evaluate an objective measures tool that can provide insight in the intracochlear placement of the electrode. It is based on electrical field measures, which are easy and quick, as there is no need for artifact reduction nor for averaging since electrical potentials are large.

It was already shown that when measured accurately, these electrical spread measurements are unique to each subject, reflecting differences in electrode placement, tissue properties, and intracochlear current flow. We now extended this method by converting electrical potential into a measure for electrical distances. From the electrical distances a planar map is derived representing the electrode contacts in 2D, whereby their respective distances reflect the electrical similarity between the electrode contacts. In this map electrode contacts with similar electrical properties are respectively placed close together apart, while contacts with dissimilar properties are place far apart.

The pilot validation study investigated several normal insertions, a case of a flipped tip and ossification cases. In case of a standard electrode insertion in a normal cochlear anatomy, the electrical fields are known to be monotonously decaying. The decay can be modeled well by a two-sided exponential with different decay constant. For this case the analysis technique shows in the 2D map an arc. If the decay constants are similar, the contacts are spaced at approximately equal distance. In the map the contacts closest to the origin reflect the location of the preferential electrical pathway to leave the cochlea. Normally this is the basal region of the cochlea, in which the orientation of the arc is rotated.

In case of a flipped electrode, the fold over is clearly observed in the 2D map. For ossification cases the 2D map shows increased electrical distances between the contacts in the region of ossification, since from an electrical point of view these contacts are more separated.

Support provided by Advanced Bionics.

A3: FOCUSED-STIMULATION THRESHOLDS AND MEDIAL-LATERAL ELECTRODE POSITION

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Focused-stimulation thresholds vary greatly depending on cochlear place of stimulation. Thresholds give a measure of the efficacy of stimulation by a given channel and may give insight into the state of the neural tissue. A high threshold could indicate that a given electrode is distant from the modiolus, that neural survival is poor near that electrode, or that other factors are limiting current flow to the neural tissue. High-resolution CT scans allow fine measurement of the distance of electrodes from the modiolus and allow judgement of their scalar positions. Thus one can determine the relationship between medial-lateral electrode position and focused-stimulation thresholds.

Four percutaneous cochlear implant (CI) users have undergone high-resolution CT scans at Washington University St. Louis. In addition, these CI users have undergone extensive psychophysical testing. In particular, phased-array (PA) thresholds have been measured for all functioning electrodes.

We have observed that 46% of the variance in focused threshold is accounted for by the distance from the modiolus in these four research participants. The other 54% may relate to differences in neural density or current paths at different points of the cochlea. Other psychophysical tests and analyses are ongoing.

We aim to determine if combinations of focused thresholds and other psychophysical tests could act as proxy variables for distance and neural survival. Knowledge of the neural state near each electrode could guide fitting strategies and potentially improve the transmission of information across the electrode-neural interface.

A4: TWO CHANNEL OPTICAL STIMULATION OF THE COCHLEA

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Optical stimulation has been pioneered over the last 5 years as a means of increasing the spatial selectivity of artificial neural stimulation. Specifically, we are targeting optical stimulation in the cochlea to increase selectivity of stimulation in cochlear implants. Some of the limitations of modern cochlear implant performance, including sequential rather than simultaneous stimulation, are attributed to the spread of electric current through the cochlea. In contrast, optical radiation does not spread significantly. This can allow for stimulation of more discrete neural populations and adjacent neural populations simultaneously. Here, we examine two-channel, simultaneous optical stimulation of the cochlea, via multichannel recordings from the inferior colliculus.

Normal adult, pigmented guinea pigs were used for the experiments. The left cochlea was accessed via the bulla for CAP threshold recordings. A 16-channel, penetrating electrode was inserted stereotactically into the contralateral inferior colliculus (IC), perpendicular to the frequency plane. Two cochleostomies were made in the basal turn of the cochlea, with separations varying between 0.5 – 3 mm. One optical fiber (50 – 200μm diameter) was inserted into each cochleostomy. Each fiber was connected to an independent optical source, operating at 1860nm, 100μs pulse duration, and 10Hz repetition rate. The animal was deafened, and the IC responses to each optical source individually and then both optical sources combined were recorded via Plexon software. Spatial maps and temporal analysis of the IC responses were analyzed.

Pilot data indicate that optical fibers need to be separated by a minimum of 1/4 octave, or 0.5 mm, in the guinea pig cochlea for the IC responses to be measured by two adjacent electrodes. Using optical stimulation, it is possible to simultaneously stimulate discrete, adjacent populations of neurons in the cochlea.

This project has been funded 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.

A5: SURVIVAL OF SPIRAL GANGLION CELLS AFTER CESSATION OF BDNF-TREATMENT; COCHLEAR IMPLANTS IN DEAFENED GUINEA PIGS

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Several studies indicate that application of exogenous neurotrophins enhances spiral ganglion cell (SGC) survival in deafened animals. However, it has been reported that cessation of treatment with brain-derived neurotrophic factor (BDNF) leads to a more rapid degeneration than in deafened untreated cochleae. This observation raises fundamental questions: What are the morphological characteristics of BDNF-treated SGCs before and after cessation? Does cessation of BDNF-treatment result in degeneration of SGCs? What is the functional development of SGCs during BDNF treatment and after cessation of treatment? In this study, we address these questions by electron microscopical analysis of SGCs in BDNF-treated cochleae, light microscopical analysis of SGCs in cochleae two weeks after cessation of BDNF treatment 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 cochleae 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 cochleae 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 weekly 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 cochleae 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. Two weeks after cessation of the treatment SGC survival was still enhanced and perikaryal size was comparable to normal. The amplitude of eABRs did not significantly decrease after cessation of BDNF treatment and comparable to that in normal-hearing control animals, whereas a significant decrease was found after deafening in animals which did not receive BDNF.

These morphological and functional findings demonstrate that neurotrophic intervention had a lasting effect, which is promising for future clinical application of neurotrophic factors in implanted human cochleae.

Support provided by the Heinsius-Houbolt Foundation and Cochlear®.

A6: NEURAL REPRESENTATION OF PULSE TRAIN ENVELOPE MODULATION DEPTH IN THE INFERIOR COLLICULUS OF CATS TREATED WITH INTRACOCHLEAR INFUSION OF BDNF

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A major motivation for the continued development of ICES is improvement of speech communication. While SG survival appears to depend in part upon neurotrophic molecular support, it has not been demonstrated that intrascalar application of neurotrophins (e.g., BDNF) to improve SG survival produces improved speech communication. In ongoing physiological studies, we are focusing specifically on aspects of auditory perception that are demonstrably correlated with speech reception in CI users and that have readily quantifiable physiological correlates. Here we report preliminary data from studies that investigate temporal envelope modulation depth detection, which has been shown to exhibit a highly significant correlation with performance in speech reception by human CI listeners. Cats deafened as neonates were implanted unilaterally at 4-5 weeks of age with custom-designed scala tympani electrodes that included an integrated drug-delivery system for infusion of neurotrophic agents. Animals received 10 or 18 weeks of BDNF and for 4 hours/day were electrically stimulated by environmental and animated cartoon sounds processed using an Advanced Bionics C-II device programmed with a two-channel strategy. Following this period, neuronal responses to sinusoidally amplitude modulated (SAM) 500 pps pulse trains were measured along the cochleotopic axis of the inferior colliculus. For low-level stimulation at 2 dB above minimum threshold, as the modulation depth of the stimulus train was gradually increased from 0% to 100%, modulation of the evoked response was first visible on the recording sites with the strongest response. In contrast, for high-level stimulation, at 6 dB above minimum threshold, the recording sites with the strongest response were driven well into saturation and small variations in pulse amplitude, corresponding to small modulation depths, had no apparent effect on response strength. Thus, for these high-level pulse trains, as the stimulus modulation depth was increased, modulation of the response was first visible on less-responsive (flanking) recording sites where the response was not saturated. For high-level stimulation using large modulation depths, however, the smallest stimulus pulses, lying in the troughs of the pulse train, were below saturation for even the best responding sites, and all responsive sites had modulated response.

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A7: PROTECTION OF SPIRAL GANGLION NEURONS WITH NEUROTROPHINS AND CHRONIC ELECTRICAL STIMULATION

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In the deaf cochlea spiral ganglion neurons (SGNs) undergo continual degeneration that ultimately leads to neuron death. The exogenous application of neurotrophins (NTs) has been shown to prevent SGN degeneration and even promote regrowth. Furthermore, combining chronic intracochlear electrical stimulation (ICES) with NT administration can enhance the survival effects of NTs and lower electrical thresholds. However, following the cessation of NT delivery SGNs continue to degenerate. Therefore techniques that deliver NTs over a long period of time are required to maintain the therapeutic benefit of NT treatment.

We have used cell-based therapy to provide NTs in combination with an intracochlear electrode array in a long-term deafened cat model. Cats were neonatally deafened with daily injections of neomycin, and at two months of age were implanted with encapsulated porcine choroid plexus cells (NTCell, LCT Inc.) and the stimulating electrode array. The choroid plexus cells were encased in an alginate capsule that enabled the diffusion of neurotrophins (including Brain-Derived Neurotrophic Factor and Neurotrophin-3) into the cochlear fluids. Environmentally derived ICES was delivered chronically via a clinical stimulator (Nucleus CI24M, Cochlear™) and processor (Esprit 3G, Cochlear™). Five cats received chronic ICES only. Six cats received NTs without chronic ICES and six cats received NTs in combination with chronic ICES. Control animals (n=7) were normal hearing and were not implanted.

The results indicated that chronic ICES alone (without NTs) did not provide greater SGN survival when compared to the contralateral untreated cochlea. Importantly, chronic ICES in combination with NT delivery provided greater SGN protection than NT alone or chronic ICES alone (ANOVA $p<0.003$). Treatment with NT alone led to an improvement in thresholds from electrically evoked brainstem responses (ANOVA $P<0.003$). These results indicate that cell-based NT delivery in combination with electrical stimulation delivered by a cochlear implant can promote SGN survival. These findings have important implications for future strategies that will combine cochlear implantation with systems that deliver drugs safely to the cochlea.

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A8: FUNCTIONAL ASSESSMENT OF A NEW DOUBLE-SHANK AUDITORY MIDBRAIN IMPLANT IN A GUINEA PIG MODEL

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The auditory midbrain implant (AMI) is in clinical trials, in which 5 patients have been implanted with a single shank, 20-site array designed for stimulation along the tonotopic axis of the central nucleus of the inferior colliculus (ICC). Although initial results have been encouraging, the patients still do not achieve hearing levels comparable to cochlear implant patients. We believe this is, in part, due to the inability to effectively activate the three-dimensional structure of the ICC. Therefore, we developed a new double-shank electrode array with Cochlear Ltd. (Lane Cove, Australia) to assess how simultaneous stimulation of two regions along the isofrequency dimension of the ICC affects auditory cortical activity compared to stimulation of a single region.

We implanted the double shank array into the ICC, in which we identified two sites (one from each shank) within the same isofrequency lamina but one in a rostral region and the other in a more caudal region. We presented a single pulse (205 μs/phase) on each site but with varying inter-stimulus delays and levels. This multi-site stimulation (MSS) was compared to stimulation of each individual site presented with two pulses with different inter-pulse delays and levels (multi-pulse stimulation, MPS). Local field potentials recorded within the main input layer of the primary auditory cortex (A1) with a similar frequency region to the stimulated regions were used to compare differences between MSS and MPS.

For MPS, weak or no activity to the second pulse was observed for short inter-pulse delays (<1 ms). However, as the delay was increased (>2 ms), activity recovered to normal levels suggesting a refractory period characteristic of ICC projections to A1. We also observed cases where the total activity to the first pulse was enhanced by the second pulse within a 2-6 ms window suggesting an additional nonlinear mechanism sensitive to varying intervals of activation within the ICC. For MSS, we did not observe a refractory effect but instead could elicit greater A1 activation as the inter-site delay decreased to zero. Activation properties varied dramatically depending on location and site order of stimulation.

Our findings demonstrate that stimulation of a single ICC location is not sufficient to effectively activate higher auditory centers. Instead the ICC is sensitive, and physiologically limited, to the timing of activation within the same and across different isofrequency regions indicating the need for three-dimensional stimulation of the ICC to improve performance with the AMI.

This research was supported by Cochlear Ltd.

A9: MODELING THE TEMPORAL RESPONSE PROPERTIES OF AUDITORY NERVE FIBERS TO PULSATILE ELECTRICAL STIMULATION

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Ideally, the cochlear implant should generate the same temporal response pattern of spikes in auditory nerve fibers (ANFs) as evoked by acoustic stimuli. However, contemporary speech processing strategies are unable to achieve this partly because of our limited understanding of ANF responsiveness to electrical stimulation. We present an extension of the refractory version of the Bruce[1,2] model which significantly improves its predictions of temporal responses to high-rate (1-5 kHz) electrical stimuli. ANF responses to electrical stimulation were recorded in acutely deafened guinea-pigs. Electrical pulse trains of 100 ms 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/s. Stimulus current was varied to evoke a range of spike discharge rates between 0 and 250 spikes/s. The Bruce model was extended to include two components dependent upon subthreshold stimulus pulses: facilitation and accommodation. As stimulation rate increased, facilitation acted to reduce ANF threshold while accommodation increased threshold. The two mechanisms incorporated temporal integration windows of 0.8 and 8 ms, respectively. Recorded ANF responses were compared to those predicted by both the original and the extended Bruce models. The original model predicted much greater variance in inter-spike intervals than was observed in vivo, while results from the extended model better resembled the physiological data. Because the accommodation mechanism “restarts afresh” after each discharge, the extended model predicts a decrease in ANF responsiveness over the entire duration of the pulse train – like that observed in post-stimulus time histograms of ANF recordings. The extended model, with facilitation, was better able to predict changes in ANF threshold with increased stimulation rate. The ability of the extended model to better predict spike timing information may provide insights into how to improve temporal coding with cochlear implants.

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[1]Bruce et al., (1999) IEEE Trans. Biomed. Eng. 46: 617-29
[2]Bruce et al., (1999) IEEE Trans. Biomed. Eng. 46: 630-637

A10: USE OF LOW LEVEL STIMULI TO ASSESS CHANNEL INTERACTION

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In previous work, we described a method to assess channel interaction of using refractory properties of the electrically evoked compound action potential (Abbas et al., 2003). This method generally required stimulus levels in the upper part of the individual's dynamic range but also demonstrated clear stimulus level effects, suggesting that lower level stimulation may provide more narrow channel interaction functions. More recently, we have reported data using stimulus pulses near threshold, usually termed "conditioning" pulses, to assess channel interaction. In those experiments, we used interpulse intervals (between the conditioner and the probe pulses) on the order of 100-200 us. The effects on the probe could include both enhancement (increased amplitude) as well as masking (decreased amplitude).

In this poster, we report more extensive measurements of channel interaction. We fixed the probe electrode and varied the electrode of the conditioning pulse. In general, we observe a high degree of spatial tuning or channel interaction. At the low levels, the enhancement effect is more evident and results in a maximum effect when the conditioner pulse and the probe pulse are on the same electrode. As stimulus level is increased, the effect of some conditioner electrodes, may be refractory, that is, we observe a mix of enhancement and masking effects upon the probe response which varies according to conditioner electrode position At the highest levels, the effects are primarily refractory, i.e. a decreased response. In general, the effects of changing conditioner electrode are highly dependent on stimulus level as well as on the interpulse interval.

These data suggest that low level interactions can be assessed using this method and that such interaction are dependent on interpulse interval.

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A11: A COMPARISON OF ARTIFACT REMOVAL TECHNIQUES FOR INTRACOCHLEAR EVOKED POTENTIAL RECORDINGS

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Several cochlear implant systems are equipped to measure the neural response to electrical stimulation using intracochlear electrodes. These measurements contain potentially useful neural response information; however, a method for artifact removal is needed to examine the neural response in each recording since the artifact from stimulation and the evoked compound action potential may overlap temporally.

Several methods for artifact removal have been proposed in the literature. The masker-probe method uses the assumption that no neural response occurs during a refractory period. Linearly combining measurements of the masker alone, probe alone, and masker with probe results in artifact removal. Two alternatives to the masker-probe method are subthreshold artifact scaling and alternating polarity summation. Subthreshold artifact scaling scales a subthreshold stimulus response and subtracts it from a suprathreshold stimulus response. By requiring fewer measurements, subthreshold artifact scaling could potentially reduce recording time and may be more suitable than the masker-probe method for asymmetric pulse shapes. The alternating polarity method sums the recorded responses to two identical stimuli with opposite stimulus polarity. While this method also requires fewer recordings than the masker-probe method, it is not applicable in studies examining the effects of stimulus polarity on neural response recordings.

This study compares the results of all three methods on the same set of intracochlear evoked potential recordings in subjects with Advanced Bionics implants through statistical analysis. Preliminary results indicate that masker-probe and subthreshold artifact scaling result in similar neural response waveforms, and the resulting noise level from the subthreshold artifact scaling method may be lower than that of the masker-probe method in this system.

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A12: STIMULATION ARTEFACT IN COCHLEAR IMPLANT PERIPHERAL (eCAPS) AND CORTICAL ELECTROPHYSIOLOGICAL MEASUREMENTS: A PARAMETRIC STUDY

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Electrophysiological measurements in cochlear implant recipients are a most helpful tool to objectively assess auditory processing as a complement to patients' descriptions and behavioural measures. However, electrical stimulation artefact remains a great impediment, since both auditory signal and artefact occur simultaneously on the recordings, and the artefact is much greater than the neural response. In this parametric study, the characteristics and origin of the artefact will be presented, for both electrically evoked compound action potentials (eCAP), and late action potentials (eLAR). Several blind source separation (BSS) technique such as principal component analysis (PCA) or independent component analysis (ICA) will be performed, and compared to usual artefact reduction techniques. In line with previous studies (Debener et al., 2008; Gilley et al., 2006), cortical potentials obtained in cochlear implant patients will be isolated from stimulation artefact, using ICA from several channels, as well as on single channel recordings, using the synchronous dynamic embedding technique. For a comparison with well-described methods, eCAPs obtained using modified forward masking and alternate polarity artefact reduction methods will be compared to unmasked eCAPs processed by BSS. Advantages and drawbacks of each method will be discussed.

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A13: RECORDING OF ELECTRICALLY EVOKED AUDITORY BRAINSTEM RESPONSES AFTER ELECTRICAL STIMULATION WITH BIPHASIC, TRIPHASIC AND PRECISION TRIPHASIC PULSES

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Biphasic electrical pulses are the standard stimulation pulses in current cochlear implants. In auditory brainstem recordings these pulses generate a significant artifact that disrupts brainstem responses which are magnitudes smaller. As the cell membrane is polarity sensitive for generating an action potential, the polarity of the phase plays an important role. As a result, the anodic phase of stimulation is more effective than the cathodic phase in electrical stimulation. This effect was applied by introducing asymmetric pulses (e.g. triphasic pulses) in order to lower the threshold for eliciting action potentials (Shepherd and Javel, 1999, Hear Res 130:171-188). An alternative to the biphasic pulse pattern is the charge-balanced asymmetric triphasic pulse pattern. This pulse pattern is divided in three consecutive phases alternating in polarity. Triphasic pulses are supposed to minimize artifacts by restoring the neural membrane to its resting potential faster than biphasic pulses (Eddington et al. 2004, 9th NIH report). A potential application of this feature is the compensation of channel interaction and a reduction of artifacts induced by electrical stimulation in the recording of brainstem responses.

In this study, biphasic pulses are compared with triphasic and precision triphasic pulses in human subjects. For this purpose, electrically evoked response audiometry was performed in 10 (11 ears) cochlea implant patients. Since triphasic pulse pattern stimulation is not available with the clinical fitting software, a customized application was developed to control the Pulsar/Sonata stimulator (MED-EL) and for recording of the EEG (Bahmer et al. 2008, J Neurosc Met, 173:306-314). The software allows stimulation with different pulse patterns and synchronized recording of brainstem responses. Subsequent analysis of the signal by averaging extracts brainstem responses.

Artifacts and brainstem responses evoked by electrical stimulation were systematically analyzed in this study. Artifact amplitude and decay time showed relation to pulse pattern shape, but artifacts did not implicitly lead to deteriorated brainstem response patterns. The detectability of brainstem responses depends on the pulse pattern: Contrary to our expectations, biphasic pulse stimulation allowed better identification of brainstem responses in comparison to triphasic pulse stimulation at the same level of stimulation.

A14: DEVELOPING A NEW NON-HUMAN PRIMATE MODEL FOR COCHLEAR IMPLANT RESEARCH

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The marmoset monkey is a valuable non-human primate model for studying neural processing of vocal communication sounds. It is also well suited for investigating neural mechanisms related to cochlear implants. In this present study, we investigated the feasibility of implanting a multichannel cochlear implant electrode into the marmoset scala tympani.

Using micro computed tomography (microCT), a non-invasive high resolution imaging technique, we constructed the cochlear fluid spaces, middle ear ossicles and the surrounding temporal bone in three dimensional space. The length of the marmoset cochlea is 15mm, and like humans, has 2.75 turns. The cross-sectional area of the scala tympani is greatest at 1mm from the base of the scala, measuring ~0.8mm^2 (1.3mm wide, 0.625 high), drops to ~0.4mm^2 (0.75 wide, 0.6mm high) at 5mm from the base, and decreases at a constant rate for the remaining length. This profile is a scaled down version of that of the human cochlea.

We identified a suitable implant electrode for the marmoset cochlea given these dimensions, the 10 channel half-band H12 electrode from Cochlear Corp. The electrode can be inserted about ¾ turn into the scala tympani through a cochleostomy at 1.5mm from the start of the scala. The depth of the most apical electrode band is 8mm. The frequency place map of the marmoset cochlea is not known, but using the Greenwood function with marmoset dimensions and squirrel monkey parameters, the electrodes are estimated to cover a range from about 4 to 20 kHz, which encompasses the frequency range of marmoset vocalizations.

Our study suggests the potential of the marmoset as a vocalizing non-human primate model in future investigations of neural representations of cochlear implant stimulation, neural plasticity as a consequence of cochlear implant usage as well as auditory-vocal interaction mechanisms.

This research was supported by a grant from the Kleberg Foundation.

A15: COMPARING SPATIAL TUNING CURVES WITH LOCAL AND GLOBAL MEASURES OF SPECTRAL RIPPLE RESOLUTION

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Spectral resolution, as estimated using spectral ripple discrimination and detection, has been shown to correlate with speech recognition performance in cochlear-implant (CI) users. But a different measure of spectral resolution, using forward-masked spatial tuning curves (STCs), does not seem to correlate well with either ripple discrimination or speech recognition. Two important differences exist between these measures: First, spectral ripple discrimination is typically measured via CI users' own speech processors, while STCs are measured via direct stimulation, bypassing the speech processor. Second, spectral ripple discrimination methods generally use a broadband stimulus, which provides a global measure, whereas STCs represent spectral resolution in a more focused region. The current study addressed this second issue by comparing STCs with more frequency-specific measures of spectral ripple discrimination. Ripple discrimination thresholds were measured in CI users for octave-wide bands of noise, spanning a wide range of center frequencies. Within-subject comparisons were made between the localized spectral ripple discrimination results and STC bandwidths and slopes from electrodes with similar center frequencies. Understanding the relationship between STCs, other local measures of spectral resolution, and speech perception may have important implications for optimizing frequency-to-electrode assignment in fitting speech processors.

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A16: COMPLEX PITCH PERCEPTION IN THE ABSENCE OF A PLACE/RATE MATCH

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A number of authors have suggested that a match between the temporal code conveyed by auditory nerve fibers, and the frequencies to which those fibers are tuned, is important for pitch perception. The absence of such a match might explain the poor pitch perception by cochlear implant users. Oxenham et al. (2004) presented normal hearing listeners with “transposed” stimuli, in which low-frequency tones are half-wave rectified and used to modulate high-frequency carriers. Listeners were unable to perceive a “missing fundamental (F0)” when modulator rates equal to the 3rd-5th harmonics of 100 Hz were applied to different high-frequency carriers. They argued that complex pitch perception required an accurate match between the place and rate of temporal information. However, their negative finding may have been due to the very high modulator rate difference limens (DLs) observed for individual transposed tones. We predicted that (i) rate DLs could be improved by using stimuli with steeper envelopes, and (ii) with such stimuli, complex pitch perception may be possible in the absence of a place-rate match. To test (i) we compared rate DLs for bandpass filtered pulse trains (harmonics summed in alternating phase and filtered between 7800 and 10800 Hz) or transposed tones (carrier rate = 9178.2 Hz), with repetition rates of 100 or 300 pps. Filtered pulse trains had significantly lower difference limens than for transposed tones, consistent with an effect of envelope slope. To test (ii), we presented three pulse trains filtered between 1375-1875, 3900-5400 Hz, and 7800-10800 Hz. When the pulse trains were presented simultaneously against a pink-noise background, listeners could not match a “missing fundamental” stimulus in which the pulse rates were, respectively, 150, 225, and 300 pps, to one in which all pulse trains had a rate of 75 pps. Hence although temporal pitch perception of simple stimuli may be improved by increasing envelope slope, our preliminary measures indicate that it will still not support the extraction of the missing fundamental.

Oxenham, A.J., Bernstein, J. G. W. & Penagos, H. 2004. Correct tonotopic representation is necessary for complex pitch perception. PNAS, 101, 1421 - 1425.

A17: STREAM SEGREGATION ON A SINGLE ELECTRODE AS A FUNCTION OF STIMULATION RATE

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While cochlear implants usually provide a high level of speech recognition in quiet, speech recognition in noise and music appreciation remain ongoing challenges. In response to these issues, several studies have proposed increasing the number of channels of information, either through variable pulse rate strategies or current steering. In this study, stream segregation is proposed as a method to test whether different pulse rates on the same electrode can be perceived as independent channels of information. This differs from previous studies of stream segregation with cochlear implant users that focused on stimulation of alternating electrodes, with the motivation of determining a relationship between electrode stream segregation and speech perception in challenging noisy conditions such as multi-talker babble. This study considers stream segregation on a single electrode as a function of stimulation rate. Subjects were presented with two 2.4 s-long stimulus sequences following an A-B-A-B… structure via direct stimulation of a medial electrode. A and B were loudness-balanced 60 ms-long pulse trains with different stimulation rates. One of the stimulus sequences had a regular rhythm throughout while the other had an increasing delay imposed on B, resulting in an irregular rhythm (Hong and Turner, 2006). Subjects were asked to identify the stimulus containing the irregular rhythm, which is a more difficult task if the streams are perceived as segregated. An adaptive procedure was used to find the minimum detectable delay for various pairs of stimulation rates. The results of this study indicate when fission or fusion for the selected subset of rates is perceived and may aid in the selection of stimulation rates for multirate speech processing strategies.

Supported by the NIH-NIDCD.

Hong, R. S. and Turner, C. W., "Pure-tone auditory stream segregation and speech perception in noise in cochlear implant users", J. Acoust. Soc. Am, vol. 120, pp. 360-374, July 2006.

A18: TEMPORAL MODULATION DETECTION REVISITED: THE EFFECT OF CARRIER RATE

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Previous research aimed at assessing temporal modulation perception by cochlear implantees has generally used a n-interval discrimination task without controlling for potential loudness cues. However, recent work by McKay and Henshall has shown that a stimulus modulated around a fixed current level is louder than the unmodulated stimulus of that current level. The degree of this loudness effect is greater for higher absolute currents (and thus for lower carrier rates as well as lower levels in the dynamic range). This means some results of previous research assessing modulation detection may be contaminated by various degrees of overall loudness cue, depending on the size of the modulation threshold, the carrier rate, and the perceptual level of the stimuli used.

One previous result showed that modulation detection was poorer when using a 2000 Hz carrier rate compared to a 250 Hz carrier rate. However, the lower carrier rate in this case would have had greater loudness-cue potential than the higher carrier rate. In the experiment reported here we tested the effect of carrier rate on modulation detection for several CI users. Psychometric functions of modulation depth versus percent correct were obtained for different carrier and modulation rates using a 3IFC task. For each data point, the modulated stimulus was loudness balanced to the unmodulated stimulus, and level jitter was used to control any remaining loudness cues. The results will be analysed to see the effect of carrier rate on modulation detection.

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A19: RELATIONSHIP BETWEEN TEMPORAL ACUITY AND LOUDNESS GROWTH IN COCHLEAR IMPLANT USERS

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Gap detection threshold (GDT) is a commonly used measure of temporal acuity in cochlear implant (CI) recipients. This measure, like other measures of temporal acuity, shows considerable variation across subjects and also varies across stimulation sites within subjects. It has been shown that temporal acuity, as assessed by GDTs, improves with increasing the level of the electrical stimulation. In this study we test two hypotheses: (1) that across-site and across-subject variability can be minimized with increasing level of stimulation; and (2) that variation in temporal acuity across stimulation sites is related to across-site variation in growth of loudness.

As a first step, T and C levels were measured in post-lingually deaf adults using all active sites along their electrode array. All available sites were then surveyed at 30% of the dynamic range (DR) to identify sites with relatively low GDTs and sites with high GDTs. Based on these results two sites contrasting in temporal acuity were selected and for those two sites, GDTs were measured at multiple levels of the DR (10%, 30%, 50%, 70%, and 90%). All stimuli consisted of symmetric-biphasic pulses, 40 µsec/phase, presented at a rate of 1000 pps using a monopolar (MP1+2) electrode configuration. In the GDT tests, subjects were asked to discriminate a 500 msec stimulus with a gap created in the middle of the pulse train from a pulse train with no gap. These gaps were generated by omitting pulses starting at initial value of 25 missing pulses and using a two-interval forced-choice procedure with adaptive tracking to determine the minimum gap duration that could be detected on 70.7% of trials. To test the relative growth of loudness, the selected sites were loudness balanced at the same multiple levels of the DR.

In general, GDTs and growth of loudness were variable across stimulation sites. Preliminary results indicate that for sites with better GDTs, stimuli at a given level in %DR were perceived as louder than stimuli at the same level in %DR at sites with poorer GDTs. In addition, across site temporal variation tended to decrease with increasing stimulation level. Taken together, these results suggest that the mechanisms underlying temporal acuity are related to loudness growth, which varies across stimulation sites. Results suggest that processor fitting strategies based on more detailed loudness matching could reduce across-site variation and improve perceptual acuity.

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A20: AN ACOUSTIC RECONSTRUCTION TECHNIQUE FOR PULSATILE STIMULATION WHICH MODELS THE RATE-DISCRIMINATION LIMIT IN COCHLEAR IMPLANTS

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To date, the delivery of fine-timing information to encode tones and music has met with little success in cochlear implants. This limitation is suspected to be associated with a widely reported rate-discrimination limit in cochlear implant users. While a change in frequency of 1% or less is detectable by normal-hearing listeners well up to moderate frequencies, frequency discrimination in cochlear implant users rapidly deteriorates after about 300Hz. A strategy that attempts to convey fine-time structure without taking this temporal limitation into account is therefore likely to be confounded.

Building upon an acoustic synthesis technique that takes the pulsatile outputs of present-day cochlear implants and reconstructs an auditory signal for normal listening, this work validates a model for the “phase confusion” that occurs in electrical stimulation, and thereby reproduces the same frequency discrimination limit that cochlear implant users experience.

Deriving from the artificial nature of electrical stimulation, the model introduces a normal random variable into the precise time at which the effect of a stimulation pulse is perceived by the listener, and the confusion is exacerbated by a typical 5dB/mm spread in the electric field (as originally measured by von Békésy). Spread of stimulation across channels excite independent populations of neurons and therefore have an independent random variable introduced on each channel.

Data suggest that a standard deviation of only 0.5ms in the random variable is sufficient to produce the 300Hz tonal discrimination limit, as measured by a classic forced-choice adaptive track procedure. Results closely match with single-electrode CI data. This technique is general enough to be useful in the design and evaluation of future strategies that attempt to encode fine-timing information.

A21: EFFECT OF ACOUSTIC INPUT FREQUENCY RANGE ON COCHLEAR IMPLANT USERS' MUSIC PERCEPTION

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A recent study [Galvin et al. (2008); J. Acoust. Soc. Am.] found that individual cochlear implant (CI) users' melodic pitch perception was differently affected by instrument timbre. This result suggests that for some CI users, different frequency components may interfere with melodic pitch. For these CI users, "pre-processing" the acoustic input signal may remove conflicting and/or ambiguous pitch cues produced by some frequency components.

In this study, melodic contour identification (MCI) was measured in CI users after bandpass filtering the acoustic input. Four bandpass filter ranges were tested: low (310-620 Hz), middle (620-2480 Hz), high (2480-4960 Hz) and full (310-4960 Hz). Methods were similar to those used in Galvin et al. (2008); MCI was measured for nine contours using piano instrument samples. The lowest note of the contour was D#3 (F0=312 Hz), and the spacing between successive notes in the contours was 1, 2, or 3 semitones, thus constraining all F0s to fall within the lowest filter range (310-620 Hz). Preliminary results showed strong inter-subject variability. Some CI subjects performed equally well with the low, middle and full filter ranges. Other CI subjects performed best with the middle range and much poorer with the low, high and full filter ranges. For these subjects, removing the low and/or high frequency components improved melodic pitch perception.

While bandpass filtering may optimize melodic pitch cues for some CI users, instrument timbre perception may require the full input frequency range. In the second part of this study, musical instrument identification (MII) was measured in the same subjects, using the same bandpass filters as in the MCI test; subjects were asked to choose among six instrument response choices: piano, clarinet, violin, organ, trumpet, and glockenspiel. Different from the MCI data, preliminary results showed best performance for the full filter range, with the middle range producing nearly equivalent MII performance.

These results suggest that CI users may benefit from the acoustic input for music. This optimization may differ for individual CI users, and may also differ in terms of enhancing pitch or timbre cues. Alternatively, for CI users whose melodic pitch perception is best with the middle frequency range, targeted training may help integrate low and/or high frequency components. Such an approach might allow for the best melodic pitch and timbre perception with their CI device.

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A22: EFFECT OF TRAINING ON NON-NATIVE ENGLISH LISTENERS' SPEECH RECOGNITION IN NOISE

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Auditory training has been shown to improve cochlear implant users' speech recognition in quiet and noise. Similar training approaches may also benefit normal-hearing (NH), non-native (NN) English speakers, whose speech understanding may be highly susceptible to background noise and/or competing speech. In this study, we compared two closed-set training approaches on NH NN listeners' speech understanding in noise.

Twelve NH bilingual Chinese listeners participated in the study; six subjects were assigned to one of two training groups: digits-in-noise (DIN) or keyword-in-noise (KIN). Before training was begun, baseline speech reception thresholds (SRTs) in steady speech-shaped noise and in speech babble were adaptively measured for digits and HINT sentences. During DIN testing, subjects were presented with three digits in sequence (e.g., “three-five-two”) and clicked on response boxes labeled 0 – 9. After baseline testing, both groups were trained for 2.5 hours per day for 4 days. The DIN group was trained to identify a three-digit-sequence pin babble; the SNR was adapted according to subject response. Similarly, the KIN group was trained to identify a keyword in a sentence from among six response choices; multi-talker TIMIT sentences were used for training. Auditory and visual feedback were provided to allow subjects to compare their (incorrect) response to the correct response. After training was completed, baseline performance was re-measured; follow-up measures were also obtained 3-6 months after training was stopped.

With the DIN training, the mean DIN SRT improved by 4.0 dB in babble and 0.1 dB in steady noise; mean HINT SRT improved by 3.9 dB in babble and 2.1 dB in steady noise. With the KIN training, the mean DIN SRT improved by 2.6 dB in babble and 0.2 dB in steady noise; the mean HINT SRT improved by 2.0 dB in babble and 1.7 dB in steady noise. Thus, the DIN training seemed to provide some advantage over the KIN training, possibly because of the more difficult speech materials used for the KIN training. Follow-up measures showed that for both groups, the improvements in performance were largely retained. These results suggest that closed-set training in noise with simple stimuli may improve NN listeners' speech understanding in noise.

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A23: BENEFIT TO INTELLIGIBILITY FROM HIGH RATE ENVELOPE CUES ABOVE AND BELOW THE CHANNEL RMS

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Dynamic range compression, especially that applied to the instantaneous dynamic range (IDR), reduces temporal contrast in a signal. This reduction promotes intelligibility in quiet due to increased audibility, but has more mixed effects on intelligibility in the presence of background interference [Spahr et al., Ear Hear 28:260-275 (2007)]. IDRs of around 50 dB are routinely used in implant fittings, but it is questionable as to how much of this range is used in practice, especially in challenging listening situations.

The experiments reported here investigate the relative contribution to intelligibility of high-rate cues in the peaks and valleys in the envelope signals of a tone vocoder. The envelope extractor simultaneously used two time-aligned low-pass filters: one, the 'E' filter, preserved modulations with rates up to 100 Hz, while the second, the 'P' filter, preserved modulations with rates up to 400 Hz. Since speech processed using the P filter produces higher intelligibility than that using the E filter, [Stone et al., J. Acoust Soc. Am. 124:1272-1282 (2008)], dynamically switching between the two envelope filters provides a tool that can probe the relative contribution of high-rate cues in different parts of the signal's dynamic range.

Within each channel, cross-fading between the E- or P-filter outputs was used to form a composite envelope. Switching was determined by the level of the E-filter output relative to a parametric threshold. In one condition, when the E-filter output was below the threshold, the P-filter output was selected and when the E-filter output was above the threshold, the E-filter output was selected. This condition was labelled 'E-over-P' (EP). The envelope peaks were equal to the E-filter output, while the valleys were equal to the P-filter output. In the converse condition, labelled 'P-over-E' (PE), the contribution of the filter outputs was reversed ('P' peaks, 'E' valleys). The switching threshold was varied between -18 and +3 dB in steps of 7 dB, relative to the RMS level of the overall channel signal. Conditions were also included with envelopes that were either entirely-E or entirely-P in rate. The composite envelopes were then used to modulate the respective channel carriers in either a 15- or a 30-channel tone vocoder.

Using a competing-talker task, results from condition PE show that normal-hearing listeners extract higher-rate information in a dynamic range extending from the peaks down to about 15 dB below the channel RMS, a range occupied about 50 % of the time. Performance in condition EP, which measured the ability to extract information from the valleys, was more variable.

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A24: SPEECH FEATURE DISCRIMINATION IN FRENCH CHILDREN WITH COCHLEAR IMPLANTS

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Although speech feature discrimination is assumed to be a fundamental perceptual skills underlying spoken and written words recognition skills in normal-hearing children, it was seldom explored in children using cochlear implants (CIs). The very rare studies on this topic reported difficulties in discriminating speech features but were not congruent on differences between features and much remains to be understood (Pisoni, 1999; Chin, Finnegan, and Chung, 2001; Geers, Brenner and Davidson, 2003; Medina and Serniclaes, 2005). The present study was aimed at exploring whether French-CI Children were able to discriminate minimal features distinctions between words and pseudowords with auditory presentation, and between words either with auditory presentation or with audio-visual presentation. Specifically, we wondered whether CI children rely on lexical information to discriminate minimal pairs by comparing auditory discrimination performances between words and pseudowords. Further we wanted to see whether audio-visual presentation of the words rather than audio presentation alone would improve the discrimination performances of the CI children, i.e. whether the visual information had an impact on discrimination skills. The participants were eighteen CI children fitted before 3 years of age and using an implant for 5 to 8;7 years. The CI children were compared to NH of the same audio-perceptual age (calculated from the implantation date for the CI children). Participants realized an auditory discrimination task of either words or pseudowords differing in the value of a single speech feature, either consonant features (manner, vs. voicing vs. place vs. nasality) or vowel features (height vs. frontness vs. nasality), and a pairing task where the children had to decide whether the name heard corresponded to the picture viewed. The d' measure of sensitivity was used for processing the discrimination data. The results showed that for consonants the performances improved from place to nasality to manner and to voicing, and for vowels from nasality to height and to frontness. Though the scores of the CI children were significantly lower than those of controls, the performances of both groups were not better for words than for pseudowords and for both groups auditory discrimination was more successful than the pairing between auditory and visual information. Thus CI children presented difficulties in auditory discrimination for all the speech features in comparison to normal-hearing children. Nevertheless, the way to process phonemic information seems similar to normal-hearing controls because the same gradient of difficulty between features, the same absence of lexicality effect and the same auditory effect were observed for both groups. Finally, like previous studies indicate, the major difficulty of CI children is to process place information rather than other consonant features (Geers et al., 2003; Medina and Serniclaes, 2005; Pisoni, 1999) and nasality information rather than other vowel features (Medina and Serniclaes, 2005). In the context of speech feature discrimination deficits that CI children exhibit, our findings indicate that the development of feature perception in CI children is more difficult than in NH children but involves the same processes for both CI and NH children.

A25: MATHEMATICAL MODELING OF TALKER VARIABILITY EFFECTS IN COCHLEAR IMPLANTS

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For cochlear implant (CI) listeners, speech recognition can be significantly affected by talker variability. Speech recognition worsens when consecutive speech stimuli are produced by multiple talkers rather than by a single talker. However, the underlying mechanisms for talker variability effects remain unclear. In this study, a mathematical model was used to investigate correlations between the acoustic features of multi-talker vowel stimuli and talker variability effects on vowel recognition performance observed in CI subjects.

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 successive vowel tokens, and each talker was presented in sequence. In the mixed context, different talkers produced each successive vowel token. Vowel recognition performance in these two contexts was correlated with the acoustic features of the vowel stimuli, which were derived as follows.

The vowel stimuli were first short-time processed with a sliding Hamming window. Then a filter bank with 12 band-pass filters with frequency bands distributed according to Greenwood’s formula was applied to extract the spectral envelope features. Acoustic distances between vowel feature vectors were calculated using Dynamic Time Warping. For each vowel, a metric Scatter Index (SI) was defined as the within-vowel distance divided by the average between-vowel distance.

Counter-intuitively, the SI was positively correlated with the recognition score for the mixed context. For the blocked context, when a weighting factor was applied to a vowel produced by a particular talker, a significant correlation was observed between the weighted SI and the recognition score. The results may suggest that the listeners recognize a vowel better due to greater tolerance of variation in acoustic vowel space. In addition, the results are consistent with the assumption that talker variability effects are caused by listeners’ adaptation to talker characteristics in a single-talker context.

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A26: CONTRIBUTION OF INFORMATION CARRIED BY WEAK CONSONANTS IN SIMULATED ACOUSTIC-ELECTRIC HEARING

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Though the benefits of combined electric and acoustic stimulation (EAS) have been widely established, the underlying mechanisms responsible are not well understood. Ongoing studies aim to identify the underlying factors contributing to improved speech recognition performance with EAS, especially for speech understanding in noisy environments. This study tests the hypothesis that access to the acoustic information present in weak consonants (e.g., stops, fricatives) can further enhance speech perception in noise in simulated EAS hearing.

IEEE sentences were mixed with two types of maskers (steady-state noise and 2-talker masker) at -5, 0 and 5 dB signal-to-noise-ratios (SNR). Normal-hearing listeners were presented with: 1) vocoded speech alone (V), 2) low-pass filtered speech alone (LP), 3) combined LP and vocoded speech (LP+V), 4) LP+V with corrupted LP portion but clean vocoded weak consonants (LP+Vc), 5) LP+V with clean LP portion but corrupted vocoded weak consonants (LPc+V), and 6) LP+V with clean LP portion and clean vocoded weak consonants (LPc+Vc). Results indicated substantial improvements in intelligibility in both LPc+Vc and LP+Vc conditions, particularly at low SNR levels (-5 and 0 dB). Intelligibility scores doubled in the LPc+Vc condition compared to the LP+V condition (0 dB SNR). Performance in the LPc+V condition (steady noise) improved by 10 percentage points relative to the scores obtained in the LP+V condition.

Given the large contribution of weak consonants to speech intelligibility in noisy conditions, we examined two pre-processing algorithms that can be used to enhance the weak-consonant segments. Results with NH listeners indicated substantial improvements in intelligibility with both algorithms. Overall, the results from this study suggest that further gains in intelligibility can be obtained in combined acoustic-electric hearing if the listeners have better and more reliable access to the weak consonants.

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A27: AUDITORY DEVELOPMENT IN THE ABSENCE OF HEARING IN INFANCY

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We assessed auditory nerve and brainstem function in children who were deaf (likely from birth) by evoking activity with electrical pulses from a cochlear implant at initial stages of cochlear implant use. Our objective was to determine to what extent auditory development can proceed without normal access to sound. Based on previous findings (Gordon, et al., 2003; Ray, et al., 2004; Gordon, et al., 2006; Gordon, et al., 2007), we expected to confirm that pathways from the auditory nerve to the brainstem develop without hearing but that refinements to these pathways require activity. In the present study we asked: What is the time course of activity-independent brainstem development? and Where along the auditory pathways do these changes occur?

We recorded electrically evoked compound action potentials of the auditory nerve (ECAPs) and electrically evoked auditory brainstem responses (EABRs) within the first week of cochlear implant use in 126 children who had early onset hearing loss. Of these children, 70 received unilateral cochlear implants and 56 received bilateral cochlear implants simultaneously; data was thus collected from 192 ears. ECAPs were recorded using the Cochlear Neural Response Telemetry system and Neuroscan 4.3 software with Synamps I amplifier were used to record EABRs. Both responses were evoked by biphasic monopolar pulses delivered by an electrode at the apical (#20) and at the basal end (#3) of the cochlear implant array. Pulses were presented at comfortably loud levels at a rate of 80 pulses per second (pps) to evoke ECAPs and 11 pps to evoke EABRs. Latencies of the ECAP eN1 and EABR waves eII, eIII, and eV as well as interwave latencies, eN1-eII, eN1-eIII, eII-eIII, and eIII-eV were measured and analyzed. Significance was defined as $p<0.05$.

Infants of ≤ 12 months showed significantly longer EABR wave latencies than their older peers but no significant differences in ECAP wave eN1 latency. Analyses of interwave latencies indicated that EABR wave latency differences were largely due to prolongation of eN1-eIII in the infant group relative to older children. There were no significant changes in latencies as the age/duration of bilateral deafness increased beyond 12 months. Latencies and most interwave latencies were longer than reported in children after 6-12 months of cochlear implant use.

Results confirm that activity-independent development occurs in the auditory brainstem (Ray, et al., 2004) but that this development is largely confined to the auditory nerve and/or caudal portions of the auditory brainstem and that further development is arrested without auditory-driven stimulation as previously reported (Gordon, et al., 2003; Gordon, et al., 2006; Gordon, et al., 2007).

A28: THE DEVELOPMENT OF LANGUAGE IN CHILDREN WHO USE BILATERAL COCHLEAR IMPLANTS

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Children who are deaf and implanted with a cochlear implant (CI) can develop language skills that enable them to communicate verbally and to function in mainstream environments. Children who are implanted early (younger than about 18 months of age) often have linguistic ability that is comparable to their typically-hearing peers. Recently, it has become common for children to receive bilateral cochlear implants (BICIs) in an effort to promote the development of spatial hearing skills and in the hope that that the ability of these children to function in complex auditory environments will be greater than that of unilaterally-implanted listeners. Whereas growing evidence suggests that sound localization and speech understanding in noise improve when BICIs are used compared with unilateral CIs, it is unclear whether non-auditory abilities such as expressive and receptive language are also promoted through the use of a second CI.

Standardized language scores were measured for >30 children ages 4-9 years who had varying amounts of bilateral listening experience. Testing was conducted at one of the following intervals: 3-6 months; 12-15 months; 24-27 months; 36-39 months; or 50 or more months. Participants had no diagnosed developmental disabilities or other cognitive impairments, and the mean non-verbal intelligence as measured by the Leiter-R was 111.48 (range 83-143). Children received the six subtests comprising the Core Language composite from the Test of Language Development- Primary (TOLD-P), which also yield both expressive and receptive composite scores.

The mean Core Language standard score for the sample was 91.5. Receptive language approached the mean of typically-hearing children at 97.86; however, the expressive (speaking) composite mean was somewhat lower at 88.25. Core language scores on this standardized measure (with chronological age taken into account) tended to increase with increasing bilateral experience; the mean language score rose from 80 in children with 3-6 months of bilateral experience to 99.5 in children with >50 months of experience, suggesting that bilateral implantation may contribute to improvements in language ability in children who use CIs. An important caveat is that variability in language scores was high, suggesting that other unknown factors likely are also playing a role in improvements in acquisition of language skills.

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A29: EFFECT OF MODIFIED TIME-FREQUENCY TRADE OFF USING DIFFERENT FFT WINDOW LENGTHS & COMPARISON WITH FILTER BANK ANALYSIS

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The present study aims to evaluate the trade off between time and frequency resolution in cochlear implants for an N of M strategy like Advanced Combination Encoder (ACE). A secondary aim of this study is to compare FFT and Filter Bank analysis in cochlear implants using vocoder simulations of the ACE processing strategy with normal hearing listeners and objective measurements of processor output. Earlier studies by Nie et al. (2006) and Xu & Pfingst (2008) manipulated the spectral cue by varying the number of channels, but for varying the temporal cue, pulse rate and low pass cut off frequency for temporal envelopes were varied respectively. In the present study a different approach was followed that involved reducing the FFT size, which results in an improved time resolution but compromises on the frequency bandwidth of each filter/channel, without reducing the total number of stimulated channels.

All simulation conditions used ACE 12-of-20 strategy with noise band vocoders, but differed by length of FFT window. Additionally an IIR filter bank was used as a baseline comparison. A total of four strategies were tested. The first and the second strategies used 128 and 64 samples FFT size respectively. The third strategy tested was FFT size of 128 samples with increased bins at low frequency channels so as to mimic the spectral characteristics of an FFT analysis with 64 samples, in the lower frequencies. The fourth strategy was implementing an IIR Filter Bank analysis instead of FFT. With 16,000 Hz sampling frequency, reduction of FFT size from 128 to 64 samples reduces FFT window length from 8 ms to 4 ms, improving the time resolution; however the frequency bandwidth for each channel increased from 125 Hz to 250 Hz. The efficacy of each of the strategies was studied objectively using temporal modulation characteristics of processor output for stimuli with different modulation characteristics. Subjective analysis involved speech perception measures in quiet and in presence of speech babble using BKB sentences and VCV syllables, processed with each of the strategies. Results will be analysed and discussed in order to further our understanding of effect of CI filter bank characteristics on spectrotemporal trade-off of CI processed speech information.

A30: AUTOMATIC INPUT SELECTION FOR A COCHLEAR IMPLANT SOUND PROCESSOR

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Currently only some 'higher end' users are thought to be using their telecoil input on the telephone and even fewer with other telecoil related options such as hearing loops and induction accessories. This may be due to a variety of reasons. Sometimes users have a preference for the microphone signal over the telecoil. Sometimes users find it too difficult or cumbersome to enable the telecoil or set up the accessory. Sometimes users are simply unaware that the telecoil might provide them with some benefit.

The experimental algorithm presented herein aims to simplify the use of the telecoil feature by automatically analysing the telecoil signal in order to determine whether or not it contains useful information. If this task can be performed effectively it could then be used to enable or disable the telecoil input. This should improve phone and hearing loop usability for recipients, in addition to removing a source of user interaction with the device.

A method was developed to evaluate such an experimental algorithm. This involved the recording of a wide variety of magnetic sources and use-cases to form a set of test scenarios on which the performance of the algorithm could be assessed. An implementation of the algorithm in Mathworks Simulink was tested against these recordings. An experimental version of the algorithm was also implemented on the Freedom processor and assessed by 4 normal hearing listeners in a wide variety of magnetic environments and use-cases. Results of this testing will be presented as well as a discussion of some of the more difficult magnetic noise sources.

A31: EVALUATION OF LONG-TERM ADAPTATION IN THE STAR COCHLEAR IMPLANT SOUND PROCESSING STRATEGY

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The Spike-based Temporal Auditory Representation (STAR) sound processing strategy is based on an auditory model. The strategy extracts spikes for each channel by placing them at threshold-crossings of the filter outputs. The amplitude of each pulse is derived from the peak level after each threshold crossing. The auditory nerve is stimulated using electrical pulses that replicate this spike-based representation as closely as possible, thus providing a fine-grained timing representation of the sound. An earlier study compared speech perception performance in 15 users of an implementation of STAR that used zero as the threshold for spike generation, with results showing equal performance between STAR and the clinical ACE strategy.

The present study added an adaptable threshold as a model of long-term adaptation (LTA) in the auditory nerve. The threshold level was adjusted for each channel based on a temporal integration of the filter output.

Experiments were conducted to evaluate speech perception performance using STAR with LTA vs. ACE with auto-sensitivity. Ten Nucleus CI24 users took part in this study. The participants were aged 43-78 and the length of cochlear implant use was 1-6 years. Testing followed an ABBA protocol and allowed at least four weeks take-home familiarisation with each strategy in the SPEAR3 research processor. Tests included open-set monosyllabic CNC words at 55 dB SPL in quiet and open-set CUNY-like sentences at 65 dB SPL in four-talker babble noise.

ANOVA with factors strategy and patient were performed for all tests. STAR was significantly better than ACE for CNC words (p=.004) and for sentences in noise (p=.007). There was a significant strategy x patient interaction for sentences (p=.003): five of the 10 subjects showed large (significant) improvements with STAR, while the other five showed less improvement. No patients showed a significant decrease in performance with STAR.

The STAR plus LTA strategy offers a promising improvement for cochlear implant speech processing. Improved speech perception of soft speech in quiet is possibly attributable to the basic STAR model. Further evaluation is examining the incorporation of travelling wave delays to the auditory model.

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A32: PERCEPTUAL DIFFERENCES BETWEEN MONOPOLAR AND BIPOLAR STIMULATION AND PRELIMINARY RESULTS OF MIXED-MODE SPEECH CODING

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There are two types of electrode configuration to construct stimulation channels in a cochlear implant (CI)—spatially restricted bipolar (BP) or wide monopolar (MP)—that are used in clinical applications. While a number of studies have examined their physiological and psychophysical characteristics, perceptual differences between them are yet poorly understood. In the present study, stimulation in both configurations was delivered in either separate or interleaved presentations, to understand perceptual implications and to evaluate a speech coding strategy utilizing both modes.

The following two research questions were addressed: 1) how is the pitch of BP stimulation related to that of MP (and are they equally salient)? 2) is there any functional advantage of using BP stimulation for speech coding (such as less channel interactions) or even partial use of BP in some location of cochlea? Auditory stream segregation, as demonstrated in a rhythm discrimination task using a two-alternating tone sequence (ABAB…; Hong and Turner, 2006), was tested in Nucleus 24 or Freedom users through direct stimulation, where detection of a temporal irregularity between A and B was measured as the distance between A and B channels of stimulation was varied. The MP-BP pitch relation was examined in “across-mode” A-B sequence (consisting of MP and BP stimuli). Also the rhythm discrimination in “within-mode” sequence (both A and B in the same mode) as a function of the distance between A and B channels was tested to compare spatial extent of MP and BP modes. Finally an experimental speech coding strategy utilizing both modes was tested, where BP channels were used in a limited tonotopic range in addition to MP channels that are typically used for patients’ maps.

The results indicated that the pitch of BP stimulation appears to be similar to that of MP stimulation on or around the same electrode, and the precise raking of pitch across modes was limited by the difference in pitch saliency, which might be inferred by the performance within-channel rhythm discrimination (i.e., A-A sequence) for each MP and BP stimulation. Spread of excitation in BP appears to be narrower than that in MP in several subjects, revealed by the results of within-mode segregation, implying less channel interactions with BP for speech coding. Finally, a potential for mixed-mode speech coding was observed in preliminary testing, as some subjects demonstrated improved intelligibility and reported superior speech quality when a small number (less than 4) of BP channels in the apical range were added to the existing map.

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A33: BIMODAL SPEECH PERCEPTION: EFFECTS OF ELIMINATING OVERLAPPING MISMATCHED FREQUENCY COVERAGE

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For some cochlear implant (CI) users a contralateral hearing aid provides significant benefits to speech perception. Such benefits likely derive, at least in part, from an enhanced representation of relatively low-frequency speech spectral information. Important factors in the bimodal transmission of such information are likely to include the extent to which the frequency selectivity of residual hearing allows additional place-coded channels, and mismatches between frequency-to-place maps across modalities. When acoustic place coding extends above a few hundred Hz an overlap of frequency coverage between acoustic and electric hearing may result in interaural conflicts, which might be expected to be much more difficult to adapt to than simple monaural shifts of frequency-to-place mapping. A major potential conflict could arise when an acoustic frequency region is represented in both ears, but with the place map shifted basally in the CI ear compared to the acoustically stimulated ear.

In this study the effect of eliminating this type of conflict was assessed by adjusting the frequency coverage of both CI and acoustic stimulation according to psychoacoustic measures of the upper frequency limit of acoustic hearing. The CI fitting was adjusted to disable channels that overlapped frequencies accessible to acoustic hearing, typically resulting in either one or two channels being switched off. Acoustic input was low-pass filtered so as not to exceed this upper frequency limit. Vowel recognition in quiet and in noise was assessed in nine Nucleus CI users. Performance in the no-overlap condition described above was compared with that obtained with a standard bimodal configuration. Since it would be difficult to ensure comparable operation of an n-of-m strategy between the different configurations, continuous-interleaved-sampling processing was used rather than the spectral-peak-picking strategy used in subjects' clinical processors. Electrical stimulation was delivered via the NIC2 research interface and synchronised with acoustic stimulation presented via headphones. For each processing configuration performance was assessed bimodally, with CI alone, and with acoustic stimulation alone. Initial results suggest that while a small decrement in performance typically results from the reduction in channels in CI alone conditions, in bimodal conditions performance is at least as good if not better for the no-overlap configuration than the standard configuration. This suggests potential for benefits from bimodal configurations that attempt to maximise the total spectral resolution available across the two modalities, thereby providing additional effective frequency channels.

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A34: ACOUSTIC CUES FOR BIMODAL BENEFIT IN SPEECH PERCEPTION

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There is now a great deal of evidence that making use of residual low frequency acoustic hearing can have significant speech understanding benefits for cochlear implantees. The exact mechanism of this benefit is still unclear. This study aims to investigate which cues contained in the low frequency acoustic signal benefit speech understanding in noise for bimodal users. It is thought that greater knowledge of the acoustic cues necessary for bimodal benefit may help to produce digital signal processing algorithms for hearing aids optimally designed for bimodal use.

Cochlear implantees with some residual hearing participate. IEEE sentence tests are presented through the implant and with the addition of a manipulated acoustic signal. The acoustic signal is manipulated to give (1) cues only to fundamental frequency (F0) and amplitude envelope, (2) cues to low frequency phonetic information but not F0, (3) cues only to voicing and amplitude envelope, and (4) cues only to voicing. In each condition, if a significant benefit is seen by addition of the acoustic signal to the electric (implant) signal, we can surmise that some of the specific cues in that signal are beneficial for speech understanding.

In the second part, maskers are manipulated to investigate the effect of: (1) Dutch speech maskers of varying fundamental frequency compared to the target's fundamental frequency. If the F0 cue is aiding sound source separation, we may expect to see benefit from larger differences in fundamental frequency between masker and target. (2) Dutch speech maskers versus speech-shaped noise maskers. This investigates ability to take advantage of spectral and temporal dips in the masker to attend to and integrate the signal across times of favourable signal-to-noise ratio.

Results of this on-going study will be presented comparing speech scores in the various conditions.

Financial support for this study was provided by the University of Manchester's School of Psychological Sciences.

A35: CONSONANT RECOGNITION AS A FUNCTION OF THE NUMBER OF SPECTRAL CHANNELS: COMPARISON OF LONG-ELECTRODE AND HYBRID COCHLEAR IMPLANTS

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The Hybrid (short-electrode) cochlear implant is designed to provide high-frequency information while preserving residual low-frequency acoustic hearing. One question of interest is whether the current Hybrid device, with just 6 electrodes along a 4 mm length, is sufficient for speech recognition in the ~10% of cases where residual hearing is lost. If not, would increasing the number of electrodes or the device length improve performance with the implant alone?

The electrode spacing of the Hybrid electrode array is the same as for the equivalent standard (long-electrode) cochlear implant (0.75 mm). Previous studies with the long-electrode suggest that spatial considerations like current spread limit the electrode benefit to every 3rd electrode. For speech recognition, long-electrode users are only able to use 3-8 electrodes, depending on the difficulty of the speech materials (Fishman et al., 1997, Friesen et al., 2001). In contrast, normal-hearing subjects listening to equivalent cochlear implant simulations are able to extract information from all 22 spectral channels and thus achieve higher speech recognition scores.

Previously, we have shown that Hybrid and long-electrode users are both able to use 3-4 electrodes for consonant recognition in quiet and in background noise (Reiss et al., ARO 2007, 2008). Therefore, considering that the 4 effective electrodes in the Hybrid are compressed in a 4 mm length, Hybrid users effectively use more channels per mm than long-electrode users.

Here we present new data showing that when compared to normal-hearing subjects listening to equivalent cochlear implant simulations, Hybrid users were able to perform as well as normal-hearing listeners under all channel conditions, but long-electrode users did not reach the same peak performance as normal-hearing listeners, consistent with the results of Friesen et al (2001). Further, when long-electrode users were tested on consonant recognition using only the basal half of their channels, they were again able to use 3-4 electrodes. These results together suggest that either 1) cochlear implant users are able to use more electrodes per mm in the base than in the apex; or 2) the electrode benefit may not necessarily be limited by spatial considerations, but by the number of spectral channels that can be transmitted through a cochlear implant.

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A36: CO-ORDINATED BILATERAL STIMULATION FOR IMPROVED SPEECH RECOGNITION IN NOISE

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Bilateral cochlear implants (BI-CIs) partially restore the advantages of binaural hearing and most BI-CI recipients can now achieve high word recognition scores in quiet listening conditions and in noisy situations where there is a single interferer and little reverberation. Most BI-CI users normally utilize information from just two directional microphones placed on opposite sides of the head in a so-called independent stimulation mode. Recently, we have shown that two-microphone adaptive noise reduction strategies that concurrently utilize both implants driven by a single processor improve speech intelligibility in noise substantially.

To further enhance the ability of BI-CI users to communicate in noise, we focus on noise reduction processing strategies that can exploit information simultaneously collected by the microphones located in the two BTEs (one per ear). In the Nucleus Freedom® implant, for instance, as many as four microphones are available, namely two omni-directional (left and right) and two-directional microphones (left and right) available in each of the two (one per ear) BTE units. In this study, we report on how we can effectively use four microphones to suppress background noise in BI-CIs. In the proposed two microphone binaural strategies, all four microphones (two behind each ear) are being used in a co-ordinated stimulation mode. The working hypothesis is that such algorithms can potentially combine spatial information from all four microphones to form a better representation of the target speech than that made available with only a monaural or two binaural inputs. To evaluate the potential of the proposed multi-microphone strategies, speech intelligibility is assessed in five postlingually deafened adult BI-CI users using IEEE sentences corrupted by steady speech-shaped noise. We report results in situations wherein the target speech is placed directly in front of the listener and (1) a single noise source is located to the right (90°) of the listener and (2) three noise interferers are placed asymmetrically across both hemifields (−30°, 60°, 90°). Our preliminary results indicate that multimicrophone strategies in bilateral CIs can boost speech understanding in background noise dramatically in both single- and multi-interferer scenarios.

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A37: LOUDNESS PERCEPTION OF BILATERAL CI USERS

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Introduction: Experienced adult CI users essentially decide for themselves at which subjective loudness levels their devices operate in every day hearing. On one hand they undergo a series of fitting sessions where they have the possibility to ask for loudness adjustments, and on the other hand, they can set the volume on their processors. We investigated subjective loudness perception and possible context effects of bilateral and unilateral CI users and of normal hearing subjects in an extensive loudness scaling experiment.

Methods: We used narrow band warble tones (1kHz, 6Hz FM frequency) and broadband noise (CCITT noise) of 1s duration as test stimuli. Both stimuli were offered 169 times sequentially at 13 different SPLs from 30dB to 90dB in 5dB level steps, with constant interstimulus intervals. Possible context effects through mutual level influence were controlled for. Fourteen bilateral CI users were tested in three listening conditions: bilateral and left/right unilateral. 1014 loudness judgments were collected from each bilateral CI user. 26 unilateral CI users and 26 normal hearing listeners served as controls. Normal hearing subjects listened in binaural diotic, and unilateral CI users in monaural listening conditions. CI subjects used their everyday processor settings.

Results: In all three groups, a 5dB increase in level resulted in a statistically significant increase in loudness judgment. Broad band stimuli were judged significantly louder than narrow band stimuli in all groups. A positive dependency of the judgment from the previously offered level and from the previously given judgment was observed. Loudness perception of bilateral CI users seems identical to that of normal hearing subjects over a wide range of levels. Differences occur below 45dB for broad band noise and also above 75dB for warble tones. At around speech level (60 to 70dB SPL), unilateral CI users needed ca. 5dB higher stimulus levels to achieve the same loudness perception than normal hearing and bilateral CI users.

Conclusions: The differences in loudness perception between unilateral and bilateral CI users are sufficiently explained by binaural loudness summation. Over a wide range of levels, bilateral implantees enjoy the same subjective loudness as normal hearing subjects. We find it surprising, that unilateral CI users seek no compensation of overall loudness, which would be easily possible through re-adjustment of the processor settings. One possible explanation is the subjective distortions that might occur at higher levels, resulting in decreased speech perception.

A38: BILATERAL COCHLEAR IMPLANTS IN CATS: PRELIMINARY OBSERVATIONS ON SOUND LOCALIZATION ABILITIES

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Bilateral cochlear implants (BICI) are provided to a growing number of individuals with severe-profound sensorineural hearing loss, in order to provide acoustic cues that are used by the auditory system for sound localization and for improving speech understanding in noise. Numerous studies to date have reported that BICI users are able to localize sounds significantly better when using BICIs than when using a single CI. However, there remains a large gap in performance between best BICI users and persons with normal hearing (NH). While studies in humans provide important markers for successful outcomes in patient populations, numerous factors that cannot be controlled in humans may be responsible for the gap in performance between BICI users and NH listeners. In adults, these factors include the onset of deafness in the two ears, amount of time between onset of deafness and implantation, among others. We have been developing an animal model of adult-onset deafness followed by simultaneous bilateral implantation. The cat was selected as the species of choice because this animal species has been used extensively in the Yin lab to study sound localization behavior and physiological mechanisms underlying binaural hearing, in both anesthetized and awake-behaving NH adult animals.

In these experiments, adult cats are first trained extensively to localize sounds by training them with operant conditioning to food reward to look at sound and light sources. Hence pre-implantation data for localization with acoustic and visual stimuli are available for comparisons. Animals are then deafened acutely using ototoxic antibiotic application and bilaterally implanted using the Nucleus® CI24 implant, modified for the cat cochlea. Electrically evoked ABR (EABR) and NRTs are recorded for each stimulating electrode to confirm the functionality of electrodes within the cochlea and to set the threshold and maximum levels of stimulation. Animals are then stimulated throughout much of the day with Nucleus® Freedom speech processors programmed to deliver stimulation at 500-pulses/ second/ electrode.

Testing on the sound localization task is measured following activation of BICIs. In these experiments, animals are tested on either visual-only, auditory-only or visual+ auditory targets, in azimuth. We have explored microphone placements in a backpack and near the pinnae. This presentation will focus on preliminary data from our first cats who have been trained prior to implantation, deafened, implanted and tested using the procedures described above.

A39: PERFORMANCE OVER TIME IN WORD RECOGNITION AND SOUND LOCALIZATION OF ADULT PATIENTS WITH SIMULTANEOUSLY IMPLANTED BILATERAL COCHLEAR IMPLANTS

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The purpose of this study was to determine how localization and word recognition performance changed overtime (up to 10 years) for subjects with simultaneous bilateral cochlear implants (CI+CI). The subjects were 48 adults who received their cochlear implants at the University of Iowa. Sound localization in quiet and word recognition in quiet were investigated overtime. Results for localization suggested that the root mean square (RMS) error scores continuously improved up to 2 year post-implantation with most benefits occurring within the first 6 months. After 2 years, the scores reached to the plateau of 10-20° RMS error for 70% of the subjects. For word recognition, the trend in performance over time generally occurred at a faster rate to localization within one year post implantation. After 2 years, the scores reached to the plateau of 79% correct in CNC for 70% of the subjects. But, in the same 15 subjects, word recognition scores were significantly different from 12 months to 48 months and above, which implies binaural advantages need more time to be developed. In the same 10 subjects, localization scores were not improved from 12 months to 48 months and above. Most of the better performers in word recognition showed better localization however, not all the subjects who were good at localization showed better word recognition. There were large individual differences in performance over time.

A40: A MODEL FOR RESPONSE OF THE AUDITORY BRAINSTEM TO BILATERAL COCHLEAR IMPLANTS: STIMULATION OF THE LOW FREQUENCY PATHWAY MAY BE CRITICAL FOR ITD SENSITIVITY

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Bilateral configurations of cochlear implants are becoming more and more common, yet their benefit is unsatisfactory compared to binaural benefits of normal hearing listeners. In particular, interaural time difference (ITD) sensitivity is limited in bilateral cochlear implant hearing. It has been reported that single neurons in the binaural pathway can tune to the ITDs of electric stimulation in a narrow range of conditions. In this study, we are focused on the rate-limitation of responses to the fine structure of bilateral, constant-amplitude, regular pulse trains.

We used a network of models to study binaural response to electrical stimulation. Out hypothesis was 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.

Our modeling study shows that ITD sensitivity is highly dependent on appropriate synaptic parameters for different input stimulation rates. The model needs to be fine-tuned to demonstrate ongoing ITD sensitivity for a given stimulation rate. Stronger excitatory synaptic inputs are required for the model neurons to be ITD-sensitive for high stimulation rates. This is also true with acoustic stimulation. Even with acoustic tone signals, the model needs to be specifically tuned for the characteristic frequency to be able to show ongoing sensitivity to ITDs. When the model MSO unit is stimulated at a rate for which it is not tuned, the responses are onset-like or not sensitive to ITDs. This result suggests specialized pathways for ongoing response to ITDs in relatively higher rates (~1000pps). Specifically, this suggests that the limitation in ITD sensitivity may be due to the limit in insertion depth of the cochlear implant electrodes, and that stimulation of the cochlear region below 1000 Hz might be required to achieve ongoing ITD sensitivity at high stimulation rates. This is also consistent with the stimulation rate limitation observed in other tasks such as in pitch perception.

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A41: DEVELOPMENT AND EVALUATION OF A PAEDIATRIC AUDIO-VISUAL SPEECH TEST IN NOISE

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The importance of audio-visual speech integration in the communication of children with cochlear implants may sometimes be underestimated. Not many tools are available to assess lip-reading abilities. The aims were to develop and evaluate a paediatric audio-visual speech test to evaluate the benefit obtained from adding lip-reading information to auditory signal.

Materials from the existing McCormick and English as a Second Language tests were selected. The words available were recorded from male and female children. Editing was performed to add competing noise to the speech signal. A system capable of driving two screens simultaneously ("subject" screen allowing lip-reading and "clinician" control screen) was created and software prepared to drive it. The preliminary version (PAVT 1.0) of the software platform was piloted on twelve paediatric cochlear implant users, first with lip-reading, then with auditory signal only.

The video recordings provided acceptable quality. The words were randomly presented to the subjects whose task was to indicate the corresponding picture or toy, or to repeat the word. Testing was conducted in noise, with adaptive signal to noise ratio. The results showed differences in scores obtained in the audio-visual condition compared to the auditory only condition, highlighting the benefits that might be obtained from adding lip-reading information to auditory signal. Feedback was collected on how to improve the interface and a new version was released (PAVT 2.0). Preliminary data collection with PAVT 2.0 involved testing of normal-hearing subjects through vocoded speech to simulate hearing with a cochlear implant.

The feasibility of using recorded audio-visual material to assess lip-reading abilities was confirmed. The option to test in noise allows for a better representation of real-life conditions. The next steps will involve validation of PAVT 2.0 on hearing impaired subjects, particularly cochlear implant users.

A42: RISKS AND BENEFIT OF DEEPLY INSERTED COCHLEAR IMPLANT ELECTRODE ARRAYS

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In normal hearing subjects the frequencies covered by the cochlea range from about 20 Hz to 20 kHz. With most Cochlear Implant (CI) electrode arrays the lowest part of this frequency range is not directly covered by the stimulating electrodes. In terms of a more natural sensation of hearing and improved speech perception, an additional electrical stimulation of the low frequency range could be desirable.

To investigate the risks and benefits of apical stimulation, enabled by a deep insertion of CI electrode arrays, an extensive literature review has been done including a study with a special research array. The analysis of 38 peer reviewed articles covered the aspects of frequency-position of electrical stimulation, cochlear anatomy, outcomes of clinical trials and the risk of cochlear trauma by deep insertion.

Research focussing on the anatomy of the organ of corti reveals that the somata of the spiral ganglion cells spiral to 1.75 turns, i.e. the middle of the 2^{nd} turn. Furthermore, the perceived pitch of electrical stimulation in the apical region is up to three octaves lower compared to frequencies for the same position in normal ears.

Clinical results with deeply inserted standard arrays and with a research array for apical stimulation consistently showed that speech perception results and subjective acceptance were better when the most apical electrode contacts were not activated. A decrease in performance without apical stimulation was only seen in acute experiments shortly after changing the frequency mapping to more basal stimulation. Another common clinical finding for stimulation of the most apical electrodes has been poor pitch discrimination and pitch reversals. Electrode insertion studies in temporal bones demonstrated an increased risk of insertion trauma including dislocation and severe basilar membrane trauma due to buckling for deep inserted electrode arrays.

The findings regarding the place of stimulation relative to the spiral ganglion cells and the frequency-position are not supporting the hypothesis for the need of deep inserted electrodes for low frequency perception. The clinical trials show outcomes that are frequently worse with deep insertion. Given the lack of benefit and an increased risk of insertion trauma, the need for deep inserted electrodes and the clinical application has to be put into question; especially in the light of recent developments in atraumatic electrode insertion and hearing conservation.

B1: OPTICAL COCHLEAR IMPLANTS: A STUDY OF EFFICACY AND SAFETY IN CATS

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Optical stimulation for cochlear implants is a novel method with potential for selectively stimulating a small group of neurons. Cochlear stimulation using light bypasses the damaged hair cells in the auditory system by directly stimulating of the auditory nerve. In these experiments, we have studied the efficacy and safety of stimulating auditory neurons in cats using optical radiation.

Cat cochleae were accessed surgically and a cochleostomy was drilled in the basal turn. The optical fiber, 200µm in diameter, was inserted through the cochleostomy into scala tympani. Compound action potentials in response to optical stimulation were measured. In normal hearing cats, acoustic thresholds were obtained and neurons were stimulated with optical radiation at various pulse durations (50-400µs), radiation exposures, and pulse repetition rates (10-250Hz). The cats were acutely deafened with intracochlear neomycin injection and the measurements were repeated. The results indicate that pulse durations as low as 50 µs were efficacious in evoking CAPs in the hearing and deaf cochlea. Although the peak-to-peak amplitude was reduced by about 50% in the deafened cochlea, the threshold for evoking CAPs was little affected. Pulse repetition rates up to 250 Hz successfully elicited CAPs over long durations.

Safety of optical stimulation over long duration was studied by continuously stimulating the cat cochlea at 204 Hz over a period of 3-6 hrs. CAP amplitudes remained stable over the entire duration providing evidence that optical stimulation does not result in significant acute tissue damage and providing the likely stimulation parameters that can be used safely in future chronic implants.

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B2: LOUDNESS MEASURES USING VARYING PARTIAL-TRIPOLAR CONFIGURATIONS IN HIGH- AND LOW-THRESHOLD CHANNELS

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The tripolar (TP) electrode configuration is more focused than traditional monopolar (MP), but is not clinically practical because of high current level requirements and poor growth of loudness. Partial-tripolar (pTP) stimulation is a hybrid between MP and TP configurations, where a fraction of return current normally delivered to the flanking electrodes in TP is directed to an extracochlear return electrode. By varying the fraction of return current (σ) delivered to the flanking electrodes, the configuration can be systematically changed between σ=0 (MP) and σ=1 (TP).

pTP stimulation allows for optimization of spectral resolution and intensity cues by producing more restricted current fields than MP and achieving lower thresholds than TP. The effects of pTP fraction on threshold has been established, however, examining loudness measures using pTP stimulation may aid us in determining the viability of implementing the configuration in future sound processing strategies.

In three adult listeners with Advanced Bionics implants, thresholds were measured using σ=0.9 to identify the low-, median-, and high-threshold channels. Growth of loudness functions were then measured for various pTP fractions in each of these channels. The stimuli were 200 ms biphasic pulse trains, presented at a rate of 918 pulses per second. Subjects rated the loudness of each stimulus on a scale from 0 (“can’t hear it”) to 100 (“too loud”).

Loudness balancing provides another means for comparing supra-threshold measures across fractions and channels. Equal loudness functions for 50% of the MP dynamic range were measured with various pTP fractions for the low-, median-, and high-threshold channels. A two-interval, forced-choice, double-staircase procedure was used.

Results indicate that as the pTP fraction is increased, the growth of loudness functions become shallower. In addition, these functions are steeper for high-threshold channels. Equal loudness contours across electrode configurations for the low-threshold channels show a systematic increase in current level with increasing fractions. In contrast, the high-threshold channels show a sudden increase in level with large fractions.

Overall the results suggest that in order to implement pTP in sound processing strategies, we need to take into account the channel-to-channel variability in TP measures, and thus patient-specific programming for each channel is necessary to optimize spectral and intensity cues.

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B3: SURFACE PATTERNED COCHLEAR IMPLANT ELECTRODE ARRAY

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During the first three weeks after implantation of a cochlear implant electrode array, the electrical impedance at the electrode contacts increases. This increase is typically explained by the formation of fibrous tissue around the electrode array. To improve the electrode nerve interface, it is aimed at a reduction of tissue formation around the electrode carrier after implantation. This can be achieved by a physical surface patterning of the electrode array. In cell culture experiments a reduction in fibroblast growth was shown for linear structures with a width of 4-7 µm on Platinum surfaces. Our current investigations are directed towards the transfer of these surface patterns to active (animal) electrode arrays.

Patterning of platinum was done by femtosecond laser technology before cutting the rings from the platinum tube also by means of a laser. These rings were then used to produce active animal electrodes. To generate surface patterns in the silicone part of the electrode, the molds were structured either parallel or perpendicular to the axis of the electrode and then used for electrode production. With different patterned electrode prototypes, insertion force measurements were carried out in order to evaluate the influence of the pattern on the insertion characteristics of the electrodes. Furthermore, first active prototypes were implanted in guinea pigs to investigate the effects of the surface modifications on the fibrous tissue growth around the electrode carrier. Impedances and hearing thresholds were monitored throughout the survival time and grinding and staining techniques were used to evaluate tissue growth after the four weeks survival time.

Patterning of molding dies and platinum ring contacts was achieved in a highly reproducible manner. The quality of the patterns in the silicone surface of the electrode is not yet optimal. Nevertheless, first results indicate slightly reduced insertion forces and a later increase in impedances compared to controls when using structured silicone surfaces (perpendicular to electrode axis), even though the impedance levels at the end of the observation period were comparable.

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B4: ADVANCED NEURAL INTERFACES

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Lawrence Livermore National Laboratory (LLNL) has developed streamline processes to fabricate advanced neural interfaces. In particular, LLNL has developed two independent neural interfaces which will be qualified for chronic implantation for animals: a flexible and a rigid microelectrode arrays. The flexible microelectrode array is fabricated in a thin film polymer with gold metal conductors and iridium oxide microelectrodes. LLNL has extensive experience with a variety of polymers include: silicones, polyimides, SU-8, and parylenes. The flexible microelectrode array is terminated with a percutaneous connector to allow connection to external stimulating and recording electronics. The rigid microelectrode array is fabricated with the thin film polymer above a variety of substrates such as surgical grade titanium, silicon, silicon dioxide, quartz, and sapphire. The rigid microelectrode array is also terminated with a percutaneous connector. The thickness of both the polymers and the rigid substrates can be varied due to the requirements of the application. LLNL can customize these advanced neural interfaces for a variety of applications including but not limited to intraneural, deep brain, cochlear, inferior and superior colliculus stimulation and recording.

Support provided by the NIH-NIDCD.

B5: HOMEOSTATIC PROPERTIES OF HAIR CELLS, WHAT TO SEEK IN REGENERATED HAIR CELLS

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This presentation develops a set of hair cell parameters that underlie the homeostatic properties of cochlear hair cells. It is based on the electrical properties that are largely determined by the much larger ionic concentrations of potassium (K), sodium (Na) and chlorine (Cl). Calcium (Ca) is roughly one thousand times less abundant in the cochlea than K, Na and Cl, but is thought to control the higher level processes of spiral ganglion excitation through ribbon synapse activation. As calcium movement is fundamental to the activation of neurotransmission properties, it is important to understand the homeostatic environment in which Ca naturally operates. The link between ionic currents and the related electrical properties, such as nonlinear capacitance, will be discussed. The hair cells mediate both lower level mechanical activity and higher level spiral ganglion activity. An accurate understanding of the transduction between the mechanical and neurological systems is required to ensure both systems have responses that imitate those required by the inner ear. Results are presented for the nonlinear coupling between cellular ion flux and for the resulting electric potentials. The Goldman-Hodgkin-Katz ionic flux equation is replaced by the more accurate Nernst-Planck flux equation to derive these results. Whilst the total current generated in a lumped cell is interesting, the individual currents generated by each ion species are more illuminating.

B6: SPIRAL GANGLION CELL SURVIVAL AFTER ROUND-WINDOW APPLICATION OF GELFOAM SOAKED WITH BRAIN-DERIVED-NEUROTROPHIC FACTOR IN DEAFENED GUINEA PIGS

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Several studies have shown that treatment with neurotrophins protects spiral ganglion cells (SGCs) in hair-cell deprived cochleae. In most of these studies the neurotrophins are applied by means of a cannula which is attached to an osmotic minipump and is inserted into the cochlea. Other application methods that might be more suited for clinical use have been developed. One method would be round-window application of Gelfoam infiltrated with neurotrophins. We have examined whether this method indeed results in survival of SGCs in deafened guinea pigs.

Guinea pigs were deafened by means of co-administration of kanamycin and furosemide. The functional effect of the deafening procedure was confirmed by recording auditory brainstem responses (ABRs) to acoustic click stimuli. Two weeks after deafening, Gelfoam cubes (1x1x1 mm) were soaked in 6 µl of a 1 mg/ml solution of brain-derived neurotrophic factor (BDNF) and deposited on the round window of the right cochlea. Subsequently, a gold-ball electrode was placed on the round window, to be used as stimulus electrode. Alternating monophasic pulses were delivered through this electrode to electrically evoke ABRs (eABRs). Two or four weeks after deposition of the Gelfoam, both left (untreated) and right (BDNF-treated) cochleae were fixed and processed for histological examination.

We found that the local BDNF treatment was effective in the basal turn, but not in the middle or apical turn. Both two and four weeks after deposition of the Gelfoam, the SGC packing densities were significantly larger in the basal turn of cochleae treated with BDNF than those in the untreated cochleae. The treatment had no effect on size and circularity: SGCs were smaller and less circular than normal both in treated and untreated cochleae. eABR amplitudes were found to be stable during four weeks.

We conclude that Gelfoam-based delivery of BDNF can be applied to preserve SGCs in the basal turn of the cochlea.

This work was supported by the Heinsius-Houbolt Fund, The Netherlands.

B7: EFFECTS OF PARTIAL DEAFNESS AND CHRONIC INTRACOCHLEAR ELECTRICAL STIMULATION ON AUDITORY AND ELECTRICAL RESPONSE CHARACTERISTICS IN PRIMARY AUDITORY CORTEX

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The use of cochlear implants in patients with severe hearing losses but residual low-frequency hearing raises questions concerning the effects of chronic intracochlear electrical stimulation (ICES) on the cortical representation of auditory and electrical stimuli. We recorded cortical responses to tonal stimuli and to ICES in primary auditory cortex (AI) of two groups of neonatally-deafened cats with residual high-threshold, low-frequency hearing. One group was implanted with a multi-channel intracochlear electrode at eight weeks of age, and received chronic ICES for up to nine months before cortical recording. Cats in the other group were implanted immediately prior to cortical recording as adults. In all cats in both groups, multi-neuron responses throughout the rostro-caudal extent of AI had low characteristic frequencies (CFs) in the frequency range of the residual hearing and high-thresholds at their new CFs. It is unclear whether this dramatic change in frequency organization reflects cortical plasticity or is simply a passive consequence of the lesion. Acoustic threshold and minimum latency at CF did not differ between the two groups, but in the chronic ICES animals there was a higher proportion of electrically but not acoustically excited recording sites (28% and 10% respectively; $P < 0.01$; Chi-square test). Chronic ICES also resulted in a small but significant ($P = 0.04$; T-test) decrease in minimum latencies to ICES. In sum, chronic ICES did not alter the basic auditory response characteristics of AI neurons or change the frequency organization of AI in animals with residual low-frequency hearing. However, there was a significant increase in the proportion of AI sites only responsive to ICES, particularly in the region of AI that would represent the cochlear base (i.e. proximal to the electrode array) in normal hearing animals. It is possible that the more effective and frequent activation of cortical neurons by electrical input during the period of chronic ICES resulted in a relative strengthening of synapses conveying electrical input to the neurons at these sites. The perceptual consequences of the increased cortical area responsive only to ICES are yet to be determined.

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B8: SPATIAL SELECTIVITY OF AUDITORY NERVE FIBERS TO MULTICHANNEL STIMULATION IN DIFFERENT STIMULUS CONDTIONS

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Different stimulus electrode configurations and stimulus waveforms have been studied for minimizing channel interactions and improving multi-channel cochlear-implant performance. However, there is not agreement on the extent of spatial tuning obtained with monopolar and bipolar stimulus delivery. Furthermore, recent data from cochlear-implant users indicate that stimulus polarity can strongly influence auditory-nerve evoked responses (Macherey, 2008, JARO). To provide direct comparisons of auditory-nerve-fiber (ANF) spatial selectivity under different stimulus conditions, we obtained single-fiber spatial turning data using an 8-electrode intracochlear array implanted in the cochleae of acutely deafened cats. Results were obtained using both monopolar and bipolar stimulus fields, as well as using monophasic and biphasic stimulus waveforms. By doing so, we can relate findings obtained with “fundamental stimuli” (i.e., monophasic pulses via monopolar electrode) to those obtained with human subjects, which employ biphasic stimuli. Spatial tuning curves (STCs) from ANFs were based on responses obtained at 50% firing efficiency across the 8-electrode intracochlear array. The results demonstrate that both bipolar and monopolar configurations produce place-specific tuning, but to different degrees. This contrasts with the findings of van den Honert & Stypulkowski (1987, Hear. Res.) and some reports based on inferior colliculus or cortical responses, but is consistent with the report of Liang et al. (1999, IEEE Trans. Biomed. Eng.). The “degree of tuning” was assessed from the STCs produced by monophasic stimuli and was found to be greater for bipolar stimulation than for monopolar stimulation, as expected. A similar trend was observed with biphasic stimuli, but the effects were not as clear, suggesting the importance of the choice of stimulus waveform. Another key finding was that the degree of tuning was related to firing threshold, with more sensitive ANFs yielding sharper tuning. This relationship was conserved across monophasic and biphasic stimulus conditions, suggesting that some measures of tuning may be possible using stimulus conditions required for human studies.

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B9: A PHYSIOLOGICAL CORRELATE OF PULSE TRAIN FORWARD MASKING SHOWS FASTER RECOVERY AT HIGH PULSE RATES

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Forward masking in electric hearing allows direct measurement of temporal processing in the auditory system, independent of the compressive nonlinearities present in acoustic stimulation. Previous studies have provided evidence for several components of forward masking at the level of the auditory nerve as well as more centrally in the nervous system. We measured the recovery from forward masking from a 200 ms electric pulse train in the primary auditory cortex of anesthetized guinea pigs at several electric pulse rates (250, 1000, and 4000 pps). The time course of recovery was slower for low pulse rates. Our model indicates that this is due to stronger activation of a central component of masking at lower pulse rates than at higher rates.

We were able to explain recovery from masking for all pulse rates and current levels with a sum of two exponential decays. The time constants obtained for these components were consistent across cortical units and stimulus conditions in each animal. The rapid component had a time constant <10 ms, similar to auditory nerve adaptation. The longer component had a time constant between 100-400 ms, consistent with a more central mechanism. These time constants were similar to those observed in human cochlear implant listeners. (Chatterjee, 1999)

The magnitude of these two exponential decay components varied systematically with level and pulse rate. Both short and long components increased with increasing stimulus intensity. The magnitude of the slow adaptation was significantly greater with lower pulse rate, indicating a stronger component of central masking in these conditions. The magnitude of the rapid adaptation component did not vary systematically across electric pulse rate. Given the rapid adaptation of firing rate to high rate pulse trains that has been observed in auditory nerve fibers, we conclude that at short masker-to-probe separation times, auditory nerve adaptation dominates. However, higher areas of the auditory system receive less input at the end of a long, high-rate pulse train. This leads to more rapid recovery at a cortical level.

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

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B10: ECAP MEASUREMENTS PREDICT THE EFFICACY OF VESTIBULAR IMPLANT STIMULATION IN PRIMATES

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The electrically evoked compound action potential (ECAP) has been successfully used, both in the laboratory and the clinic, as a practical physiological indicator of cochlear implant function. Here, we describe its application to a vestibular implant prototype, designed to restore function in vestibularly impaired individuals. The device consists of three 3-site electrode arrays, intended for insertion into the bony labyrinth of the semicircular canals, and a receiver-stimulator based on the Cochlear Freedom technology. This system enables the measurement of ECAPs via neural response telemetry (NRT) using standard clinical software.

In four rhesus macaque monkeys implanted with electrode arrays in at least one semicircular canal, NRT measures were made intraoperatively and at various intervals spanning several months post-implantation. In separate experiments, a scleral search coil was used to monitor eye movements in response to electrical pulse trains, as a means to quantify behaviorally channel-specific activation of the vestibular-ocular reflex pathway.

ECAPs recorded during surgery were, in general, a reliable predictor of subsequent behavioral responses. Specifically, implant channels producing a characteristic biphasic ECAP waveform were able to evoke, in response to pulse trains, a robust nystagmus having a slow-phase velocity that increased with pulse rate or current amplitude and that was in a direction consistent with activation of the stimulated canal. Furthermore, across animals, ECAP threshold and amplitude growth with current were correlated, respectively, with eye movement threshold and velocity growth. These results suggest that the ECAP is a useful tool for verifying the surgical placement of electrodes in the semicircular canals, and for providing an ongoing assessment of the electrodes' functional interface with the vestibular system.

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B11: DIFFERENT MEASURES OF AUDITORY NERVE REFRACTORINESS AFTER ELECTRICAL STIMULATION, USING PERIPHERAL ELECTROPHYSIOLOGICAL MEASUREMENTS (eCAPs)

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In a pulse train a pulse can induce a masking effect on the auditory nerve fibers, and therefore limiting the auditory nerve ability to respond to a subsequent pulse. This auditory nerve refractoriness is thought to potentially affect the cochlear implant outcomes in patients. Thus, better understanding refractoriness would be likely lead to a better insight in patients' psychoacoustical performance. Indeed, loudness sensation has been shown to be sensitive to neural refractoriness in the auditory nerve, in addition to temporal integration in the central nervous system (McKay et al., 2005). Consequently, loudness is sensitive to the rate of stimulation. In this poster, we aim at assessing several ways to measure refractoriness in the same patient, using the electrically-evoked compound action potential (eCAPs) obtained by the modified forward masking technique (Miller et al., 2000). (i) The recovery function (amplitude of the subtracted eCAP between a reference masker and a variable masker-probe interval) will be fitted in order to measure the recovery time constant (Morsnowski et al., 2006). (ii) The number and rate of masker pulses will be varied, in order to assess the variability of neural activity following the successive pulses of pulse trains of different rate. (iii) eCAP amplitude growth and recovery functions will be recorded for several interphase gaps, since the effect of interphase gap on eCAP amplitude has been shown to be correlated to the amount of neural survival (Prado-Guitierrez et al., 2006). Finally, correlations will be presented between these three measures of refractoriness, and the way that patients' behavioural hearing thresholds change with rate of stimulation.

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B12: AUDITORY NERVE RESPONSES WITH INTERMEDIATE-ELECTRODE STIMULATION

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Newer-generation cochlear implants (CIs) have the capability to stimulate neural populations that are intermediate to those recruited by adjacent physical electrodes. In the Nucleus Freedom device, this is accomplished by creating an electrical short between adjacent electrodes. In Advanced Bionics (AB) devices, adjacent electrodes can be stimulated simultaneously with the total amount of current split evenly between the two adjacent electrodes. If intermediate neural populations are indeed recruited by this type of stimulation (as opposed to greater spread beyond the two physical electrodes), we would expect neural responses for intermediate-electrode stimulation to be consistent with those obtained for adjacent physical electrodes. The purpose of this study was to determine whether electrically evoked compound action potential (ECAP) measures obtained with intermediate-electrode stimulation were significantly different from those obtained for the adjacent physical electrodes. Specific measures included ECAP thresholds, slope of the input-output (I/O) function, refractory recovery, and spatial masking patterns.

Data were obtained for basal, middle, and apical electrode sets. Each electrode set consisted of three adjacent electrodes and two intermediate "electrodes." Preliminary data from 6 subjects (4 Freedom, 2 AB) showed no significant difference in ECAP thresholds or refractory recovery between each intermediate electrode and the respective flanking physical electrodes. For one basal electrode pair, the intermediate electrode yielded significantly higher I/O slope compared with the flanking physical electrodes; however the comparison was statistically under-powered due to the small number of subjects. Probe stimuli delivered to intermediate electrodes generated spatial masking patterns that were generally midway between the patterns for flanking probe electrodes. The results thus far indicate that intermediate-electrode stimulation produces basic ECAP measures that are consistent with those from the flanking physical electrodes.

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B13: A POSSIBLE METHOD FOR THE REMOVAL OF COCHLEAR IMPLANT ARTIFACT

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When using auditory evoked potentials (AEPs) as an objective measurement of hearing in individuals having a cochlear implant (CI), the electrical artifact generated by the implant can overlap the neural response and make it difficult or impossible to measure. Since physiological responses increase in amplitude as the interstimulus interval (ISI) increases, we examined the effect of recording responses at two ISIs. Since the artifact does not change with ISI, the difference between the responses should show evidence for the physiological response without artifact contamination.

The aims of the project were: 1) to determine the effects of ISI manipulations in a random design on the N1-P2 response and examine ISI-difference waveforms, 2) to determine the effects of varying the ISI and stimuli within or across recording blocks, examine ISI-difference waveforms, and 3) to determine whether a subtraction technique eliminates the artifact in the N1-P2 responses recorded in CI listeners.

N1-P2 responses were recorded using a speech syllable and tone, paired with ISIs that changed randomly between 0.5 and 4 seconds in 10 normal hearing listeners. Difference waveforms were then analyzed. The same stimuli, at either 500 or 3000 ms ISI, in block designs were also used to evoke the N1-P2 responses in 8 normal hearing individuals and difference waveforms were examined. N1-P2 responses were then recorded using pulse trains with 500 and 3000 ms ISIs in 4 CI listeners, and difference waveforms were computed.

Results included: 1) N1-P2 response amplitudes generally increased with increasing ISI. Subtraction waveforms were similar in latency and scalp distribution to the unsubtracted waveforms. 2) N1-P2 responses were larger for the 3000 ms condition compared to the 500 ms ISI condition. Difference waveforms were largest for the random stimulus design. 3) The subtraction technique eliminates the electrical artifact in individuals with cochlear implants and leaves a measurable N1-P2 response. It therefore appears that the subtraction technique is a feasible method of removing from the N1-P2 response the electrical artifact generated by the cochlear implant.

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B14: A BEHAVIORAL DETECTION TASK IN GUINEA PIGS USING AIR PUFFS AS AVERSIVE UNCONDITIONED STIMULUS

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Compared to other species, guinea pigs are hard to train on a behavioral task because of their erratic behavior. Since guinea pigs are commonly used for cochlear histology and physiology, there is a need for psychoacoustical tests for guinea pigs. We used a conditioned avoidance procedure, in which, instead of a conventional electric shock, an air puff was applied as aversive unconditioned stimulus (Philippens et al. 1992).

Ten albino female guinea pigs were trained to cross from one to another compartment in response to a narrow-band noise (center frequency 10 kHz, width at -6 dB: 1 octave) in order to avoid a strong narrow stream of air (80 m/s; 0.8 cm^2). The response window was 15 s, and the stimulus lasted until the animal responded. During the initial training sessions a sound level of 78 dB SPL was used. From the 6th session onward 4 levels from 58 to 88 dB SPL were presented. After the 10th session the animals were implanted with an 8-electrode array designed for guinea pig cochleae (Cochlear®). After the 12th session the animals were ototoxically deafened and subsequently trained to respond to electrical pulse trains (111 Hz, 20 μs monophasic alternating pulses) at four current levels from 142 to 400 μA. Sessions consisted of 20 trials.

The animals learned to respond to the 78-dB SPL noise within 4 sessions (score: ~80%). When the other sound levels were introduced the animals did not immediately respond to the lower levels, but their scores improved in following sessions. Scores increased with sound level (50 to 100%), and response latency decreased with level (8 to 2.5 s). Already on the first session in which electrical stimuli were presented the animals responded well to 400 μA. Scores on lower current levels improved during 5 sessions. Response latencies to electric and acoustic stimuli were similar. We conclude that guinea pigs can be trained fast to detect suprathreshold acoustic or electric stimuli using air puffs as an aversive unconditioned stimulus.

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B15: AMPLITUDE MODULATION DETECTION ANALYZED WITH A POINT PROCESS MODEL OF THE AUDITORY NERVE

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Currently-used cochlear implant speech processor strategies provide temporal information to listeners by stimulating the auditory nerve with amplitude-modulated pulse trains. More generally, the slow fluctuations in sound intensity are thought to provide important information for speech perception. Studying how modulation information is encoded in the response of auditory nerve fibers is therefore of fundamental importance to understanding cochlear implant function and speech perception in cochlear implant users. We investigate the neural encoding and decoding of amplitude modulation using a computational model of the auditory nerve. The model provides a probabilistic description of auditory nerve spike trains and can be analyzed using the mathematical theory of point processes. We study how modulation information is encoded in the neural response by simulating the performance of an ideal observer on a two-alternative forced-choice amplitude modulation detection task. We vary the amount of information available to the observer to test what features of the neural response (spike timing, neural refractoriness, phase locking, and average firing rate) encode modulation information. Simulation results indicate that modulation detection relies on the temporal sequence of spikes. The model does not predict that response properties of the auditory nerve limit the transmission of modulation information to cochlear implant listeners. Next, we formulate a neural decoding algorithm that can be used to simulate amplitude modulation detection experiments. We find that the strength of phase locking computed from the jittered spike trains from a heterogeneous population of auditory nerve cells can replicate two qualitative results from the psychophysical data: modulation detection degrades at high modulation frequencies and it improves as stimulus level increases. The point process methods developed in this study are useful tools for analyzing the neural code for time-varying stimuli. Ongoing work seeks to extend these methods to include more realistic representations of ion channel noise, adaptation, and to understand how these mechanisms affect the transmission of sound information at high carrier pulse rates.

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B16: INFLUENCE OF INTENSITY ON PITCH PERCEPTION IN COCHLEAR IMPLANT USERS VS. NORMALLY HEARING LISTENERS

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Changes in stimulus frequency may result in changes in perceived pitch and loudness. This is the case for normally hearing listeners, and has also been clearly demonstrated in cochlear implant (CI) users. When investigating the relation between frequency and pitch, loudness cues may be averaged out by roving the stimulus intensities. On the other hand, it also allows for the analysis of the relation between intensity and pitch. We quantified the relation between intensity and pitch in three groups of subjects: CI-users (n=23), hearing impaired (HI, n=10) listeners and normally hearing (NH) participants (n=30). We used data from a freefield just-noticeable frequency difference (JNDF) test, in a 3-alternative unforced choice (3AUC) paradigm with feedback. The stimuli were sinephase 1- to 5-harmonic complex-tones (first five harmonics) lasting 1000 ms. Reference frequencies were 200 Hz or 380 Hz. The latter frequency was later added because it falls in the center of a frequency band of both Advanced Bionics and Cochlear users. Intensity roving levels were -3, 0 and +3 dB relative to 58.5 dBA (200 Hz stimuli) and 67 dBA (380 Hz stimuli). The intensity and frequency order were quasi-randomized. Intensity preference (IP) was defined as the difference between the percentage of choices for the loudest sound minus the percentage of times for the weakest sound, for those cases where an incorrect answer was given. IP was -17% for the NH, 7.0% for the HI and 56% for CI-users. IP of 87% of CI-users was larger than 10% and in only 4% it was smaller than –10%. For HI, these percentages were 30% and 40% and for NH 17% and 47%. Preliminary results show that in the NH, IP is larger for 200 Hz than for 380 Hz, and IP is inversely related to the number of harmonics (leading to positive IP for 380 Hz). For the HI, IP is positive for 200 Hz and negative for 380 Hz. For CI-users, the IP is fairly constant over the number of harmonics and frequencies. We conclude for the presented frequency range that cochlear implant users tend to perceive a louder sound as having the higher pitch, whereas normally hearing listeners tend to perceive the softer sound as having the higher pitch.

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B17: EFFECTS OF FINE STRUCTURE STIMULATION ON PITCH PERCEPTION

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Upon exposure to fine structure stimulation, cochlear implant users typically report hearing sounds as being lower in pitch. The present study quantitatively explores this pitch shift and shows that fine structure stimulation expands the perceived pitch range.

To date, seven experienced cochlear implant subjects participated in the study. The speech coding strategies under investigation were a ten-channel implementation of Continuous Interleaved Sampling (CIS) and a fine structure strategy (FS) with identical number of channels and filter bands. The stimuli were 500 msec harmonic tones with a spectral roll-off of 9 dB per octave, presented via the direct input of the speech processor. For every run of the experiment, a combination of fundamental frequency and coding strategy was chosen as a reference stimulus, which was always presented first. The second stimulus combined the other coding strategy and randomly selected fundamental frequencies, and the subject had to indicate which stimulus was higher in pitch. Thus, psychometric functions for pitch perception were sampled, and the point of subjective equivalence (PSE) for the two coding strategies was estimated by fitting a logistic function to the data. The procedure was performed for reference stimuli with fundamental frequencies of 161, 287, 455 and 811 Hz.

At 161 Hz and in six of the seven subjects FS sounded lower in pitch as CIS, whereas at 287 Hz FS sounded lower in all seven subjects. The average pitch shift was three semitones (one minor third) at the two lowest frequencies tested and one semitone at 455 Hz. At 811 Hz no pitch difference was found, which was to be expected since the stimulation patterns for CIS and FS were nearly identical for signal frequencies above the fine structure limit (800 Hz).

The results indicate that fine structure stimulation does expand the range of perceivable pitches as compared to standard CIS.

Support provided by the C. Doppler Research Association.

B18: CURRENT FOCUSING IMPROVES VIRTUAL CHANNEL DISCRIMINATION

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Introduction: Recently, much research has investigated using simultaneous stimulation on multiple electrodes on along a cochlear implant electrode array. Stimulating two adjacent electrodes in phase (current steering) creates a current peak (and corresponding pitch percept) between the two electrodes. Tripolar stimulation (current focusing), where two flanking electrodes stimulate in opposite phase of a center electrode, reduces current spread relative to monopolar stimulation. We hypothesized that if current steering and current focusing are combined, a cochlear implant patient will have better discrimination of VCs when compared to VCs created by monopolar stimulation (MPVCs).

Methods: Stimuli consisted of VCs created with monopolar stimulation (MPVCs) or focused quadrupolar stimulation (QPVCs). QPVCs consist of MPVCs with additional stimulation on the flanking electrodes in the opposite phase. The flanking electrodes are used to focus the VC similarly to the way the flanking electrodes focus tripolar stimulation.

Seven Advanced Bionics Clarion II or HiRes 90K users were tested. A 3 interval forced-choice task was used to measure VC discrimination using either MPVCs or QPVCs. Discrimination between 6 loudness-balanced VCs (created between a pair of adjacent electrodes) was compared for each VC type. The procedure was repeated 30 times for each subject for an apical, medial, and basal pair of electrodes.

Results and Discussion: The MPVC and QPVC cumulative d’ was calculated for each electrode pair. Six of the seven subjects showed better VC discrimination for the QPVCs than for the MPVCs. One subject showed better QPVC discrimination for the apical and medial electrodes. A two-way repeated-measures ANOVA revealed a main effect of VC type ($p < 0.005$) but no effect of electrode place or interaction was detected. Although there was great variability across subjects in both absolute performance and size of improvement, all subjects demonstrated some benefit from using QPVCs.

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B19: TEMPORAL PITCH PERCEPTS ELICITED BY DUAL-CHANNEL STIMULATION OF A COCHLEAR IMPLANT

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McKay and McDermott (1996) found that when two different amplitude modulated pulse trains are presented to two channels separated by < 1.5 mm, cochlear implant (CI) patients perceive the aggregate temporal pattern. The present study attempted to replicate this general finding and to test whether dual-channel stimulation would extend the upper limit of temporal pitch perception in CIs.

Six CI subjects (4 Advanced Bionics CII/HiRes90k and 2 Cochlear CI24M) were asked to rank twelve dual-channel stimuli differing in their rate (ranging from 92 to 516 pps on each individual channel) and in their inter-channel delay (pulses on the two channels being either nearly simultaneous or delayed by half the period). We used the optimally efficient "mid-point comparison procedure" (Long et al. 2005).

The data showed that, for an electrode separation of 0.75 or 1.1 mm, a) the perceived pitch was on average slightly higher for the long- than for the short-delay stimuli but never matched the pitch corresponding to the aggregate temporal pattern; b) the upper limit of temporal pitch did not increase using long-delay stimuli c) the pitch differences between short- and long-delay stimuli were largely insensitive to channel order (basal- or apical-first) and to electrode configuration (narrow bipolar "BP+1" or "BP+2" and monopolar). These results are consistent with the temporal code conveyed by each CI channel being largely not distorted by channel interactions.

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B20: THE INTEGRATION OF TOUCH AND AUDITION: THE DIFFERENCE BETWEEN MUSICIAN AND NON-MUSICIAN CI USERS

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Behavioural studies have shown that multisensory integration enhances the detection of sensory events, especially when sensory stimuli are ambiguous. Perceptual interaction between audition and touch has also been shown to influence auditory and tactile frequency discrimination. However, the influence of auditory-tactile integration on higher levels of auditory cognition, such as speech and music perception, remains unexplored. Cochlear implant subjects, with degraded auditory input to their brain, provide an opportunity to examine the potential benefits of multisensory integration. Here we show that tactile stimulation can enhance a cochlear implant user's melody recognition by up to 17% for a musician. The enhancement is 2 and 5 times higher, respectively, for rhythmic and non-rhythmic melody recognition in musicians compared with non-musicians. In addition, musicians' performance is 27% better than that of non-musicians when tactile stimulation alone being utilized to recognize rhythmic melodies. The results can be interpreted as behavioural evidence of superior somatosensory performance and cross-modal neural plasticity induced by musical training. A CI processor transforms clear temporal structure (rhythm cue) but only coarse pitch variation (pitch cue). The auditory-tactile integration enhances melody recognition in condition which only the pitch cue is available, suggesting that auditory-tactile integration may play an active role in pitch processing.

B21: INDEXICAL LEARNING IN SPECTRALLY DEGRADED SPEECH BY LISTENERS WITH NORMAL HEARING

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Listeners with normal hearing reliably extract abstract phonological and semantic information from speech despite enormous variability in the acoustic speech signal introduced by talker-specific characteristics (i.e., gender, emotion, dialect, etc.) Traditional perceptual normalization theories view talker-specific, or indexical information as unwanted "noise" that must be stripped away to uncover the underlying linguistic meaning. More recent research suggests that indexical cues are stored in memory and are used by listeners with normal hearing in recognizing spoken words (Nygaard, 2005). Although current cochlear implants provide many recipients with high levels of speech understanding, they are relatively poor at conveying talker-specific information. Recently, Loebach et al. (2008) examined the effects of indexical training on spoken word recognition in participants listening to cochlear implant simulations. They found that talker identification training improved spoken word recognition to a greater degree than training in gender discrimination. In the present study, we employed a voice-learning paradigm (Nygaard and Pisoni, 1998) to investigate further the relationship between linguistic and indexical processing in spectrally degraded speech. Listeners with normal hearing were presented with speech processed through a 12-channel noise band cochlear implant simulator and trained to recognize voices in an auditory-only or audiovisual format. Sentence recognition tests were administered before and after voice training. Voice identification improved significantly in both training presentation formats; learning seemed to be accelerated in the audiovisual format. Confusion analysis revealed that listeners had more difficulty identifying voices within the same gender and when fundamental frequencies closely overlapped. Spoken word recognition also improved after voice training. However, this may have resulted from increased exposure to cochlear-implant-simulated speech. Further investigation is needed to understand better the effects of indexical learning on speech recognition in listeners with cochlear implants.

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B22: IMPROVEMENTS IN SPEECH PERCEPTION IN NOISE FROM RATE AND PLACE PITCH CUES: COCHLEAR IMPLANT SIMULATIONS

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One of the major challenges facing cochlear-implant (CI) listeners today is the understanding of speech in background noise. The research in our laboratory has examined this issue by using the paradigm of auditory stream segregation to provide insight into the cues that may be most relevant for sound segregation and thus speech perception in noise. This study uses CI simulations heard by normal-hearing listeners to assess the understanding of speech in a competing talker background when varying degrees of place and rate pitch cues are available. Our previous research has suggested that temporal envelope cues at 80 Hz could induce auditory stream segregation in CI listeners. The results of this study suggest that those same temporal cues are helpful for speech perception in noise. The best speech perception is observed when rate pitch cues are available in the condition where the target has a fundamental frequency (F_o) of 80 Hz and the competing talker background of 300 Hz. When the ability to use rate pitch cues for streaming the target from background is removed, either via filtering of the temporal envelope or shifting of the average fundamental frequency of the competing background to match that of the target, the understanding of speech in noise drops significantly. These findings suggest that signal processing strategies designed to enhance temporal envelope cues in cochlear implants may lead to improvements in speech perception in a competing talker background.

B23: DO COCHLEAR IMPLANTS PROVIDE SPECTRAL ENVELOPE CUES FOR VOICE GENDER IDENTIFICATION?

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The spectral envelope of human speech contains information on gender of the speaker, reflecting differences in the vocal tract lengths of male and female. It is not clear whether cochlear implants (CI), which have reduced spectral resolution compared to unimpaired human hearing, are able to transmit spectral envelope cues from speech sounds and whether CI users can make effective use of them.

A juvenile population of 41 CI users was tested using naturalistic short speech segments spoken by a variety of speakers. Stimulus output patterns of each CI device in response to vocalic /a/ segments of the speech items were also recorded and analyzed for the presence of spectral envelope cues. A majority of recorded CI devices preserved spectral envelope cues to voice gender, but subjects who were able to identify gender correctly did not appear to utilize spectral envelope information for gender identification. Future research will be required to show the possibility to train CI users to utilize spectral envelope information, and why they tend to not to use it in spite of daily exposure.

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B24: CONTRIBUTIONS OF TEMPORAL CUES AND TONOTOPIC INFORMATION TO VOICE GENDER DISCRIMINATION: A VIEW FROM A PERCEPTUAL LEARNING STUDY

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Both voice gender discrimination and complex pitch perception depend on fundamental frequency (temporal) and spectral profile (tonotopic) information. Human listeners are able to somewhat adapt to spectrally-shifted speech. This implies that the contribution of tonotopic cues to voice gender discrimination/complex pitch perception may be weakened after adapting to a spectral shift. Alternatively, the correct tonotopic information (i.e., absolute place cues) may not be necessary for complex pitch perception. In this study, we investigated the contribution of temporal and tonotopic information to voice gender discrimination in the context of perceptual adaptation. Twelve normal-hearing listeners were divided into two groups to learn voice gender discrimination with spectrally-shifted speech, with (Group 1) or without (Group 2) temporal periodicity cues. Speech stimuli included 12 vowels produced by 5 male and 5 female talkers; the fundamental frequencies of the 10 talkers were within 150Hz ~ 200Hz. A 16-channel sine-wave vocoder was used to generate spectrally-matched or -shifted speech, with different envelope cut-off frequency 200 Hz (Group 1) or 50 Hz (Group 2) to keep or remove temporal cues. Subjects were trained by repeatedly testing voice gender recognition with spectrally-shifted speech over five days. Vowel recognition and voice gender discrimination were measured for spectrally-matched and –shifted speech before and after the adaptation period. Post-adaptation results with spectrally-shifted speech showed a significant improvement in voice gender discrimination for Group 1, but not for Group 2. However, post-adaptation performance with spectrally-shifted speech for Group 1 remained poorer than baseline performance with spectrally-matched speech (with or without periodicity cues). Interestingly, voice gender discrimination performance for spectrally-matched speech (50 Hz envelope) significantly dropped for Group 1 after the adaptation period. Speech recognition performances for spectrally-shifted speech improved after the adaptation period. Altogether, the data suggest that the correct tonotopic representation is critical for voice gender discrimination/complex pitch perception, even after short-term adaptation experience, and that human listeners are able to automatically learn temporal cues used to extract fundamental frequency information. The results also provide important implication for spectral-temporal information processing and learning mechanisms in the neural system.

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B25: EFFECT OF ENHANCED TEMPORAL PITCH CUES ON SPEECH PERCEPTION IN COCHLEAR IMPLANT LISTENERS

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In a recent study we assessed the performance of Cochlear Implant (CI) listeners in pitch perception–related tasks with a new CI coding strategy called F0mod. The strategy provides an enhanced temporal pitch cue (ETPC) by amplitude modulating the filter bank channel envelopes at the fundamental frequency (F0) of the incoming signal. We evaluated F0mod and the Advanced Combination Encoder (ACE) strategy, which is the clinical standard, implemented in the Freedom speech processor of Cochlear Corporation. The results showed a significantly improved performance with F0mod over ACE in Pitch Ranking, Melodic Contour Identification (MCI) and Familiar Melody Identification of isochronous tunes (FMI) in five CI subjects. In the work presented here we focus on possible effects of ETPCs on speech perception. For this purpose we conducted speech recognition tests using the Leuven Intelligibility Sentence Test (LIST). Stimuli were presented in quiet and speech–weighted stationary noise at 10 dB signal–to–noise ratio (SNR). Again, the competitive strategies were F0mod and ACE. The experimental procedure was carried out with four CI listeners. Our results show no statistically significant difference for F0mod and ACE. However, performance in the noise condition was significantly worse with both strategies ($p < 0:05$) compared to the condition in quiet. These outcomes indicate that ETPCs, as realized in F0mod, do not degrade speech perception. Tonal–language CI–users might benefit from the effect of ETPCs on pitch perception without negative effects on speech recognition.

B26: A SIGNAL ENHANCEMENT ALGORITHM FOR COCHLEAR IMPLANT USERS: FIRST RESULTS OF A PILOT STUDY WITH HIRES 120

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Experience with real time noise reduction algorithms in hearing aids showed that generally only little improvement could be achieved. In several studies behavioral advantages were found in certain situations, but these could not be supported with objective data. Hearing aid users still have a reasonable number of independent auditory filters, essential for speech perception in noise. Cochlear implant users have less independent auditory channels (estimation: 6 to 8), struggle when listening in noise and do not have the comparison to natural sound quality to the same degree as hearing aid users. Hence, less sophisticated algorithms might show improvements in the cochlear implant population which could not be demonstrated for hearing aid users.

The algorithm under investigation used a single microphone and was implemented on a research version of the Harmony behind-the-ear processor. The modulation of each channel was determined using a time window of 1.6s. The gain for channels with modulation frequencies below 2Hz was reduced, leading to an emphasis of dynamic channels more likely to contain speech or other wanted signals.

Ten adults participated in this study so far, the group will increase to 15 participants in total. Two versions of the signal enhancement algorithm were fitted in one session: a medium and a more aggressive parameter set. The HSM sentence test in speech shaped noise was measured for the clinical program as well as both research programs. During a take home phase the subjects were asked to use all three programs in their everyday listening situations and to give a subjective rating of sound quality and speech perception via a questionnaire (APHAB).

Although global adjustments of the M-levels were required during the fitting, no difficulties were encountered and all participants accepted the research programs without any acclimatization. All ten participants achieved better results with both research programs in the HSM sentence test in noise compared to the clinical program. Questionnaires of four subjects are available up to now: For three participants at least one of the research programs led to significantly better results than the clinical program. None of the participants rated any research program significantly poorer than the clinical program.

The preliminary results show a significant improvement with a signal enhancement algorithm in cochlear implant users, even without individual optimization. Further investigation is required to develop fitting guidelines and achieve parameter optimization.

B27: EVALUATION OF DIFFERENT SIGNAL PROCESSING OPTIONS IN UNILATERAL AND BILATERAL COCHLEAR FREEDOM IMPLANT RECIPIENTS USING R-SPACE BACKGROUND NOISE

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Difficulty understanding in background noise is a primary complaint of cochlear implant recipients. Several processing options are available to improve speech recognition in noise for cochlear implant recipients. The processing options available for recipients using a Cochlear Freedom processor include: Automatic Dynamic Range Optimization (ADRO), Autosensitivity Control (ASC), and BEAM.

The effectiveness of processing options to improve speech recognition in noise has been measured in traditional laboratory simulations, but often individual reports of performance in everyday life are not as favorable. To address this issue, Compton-Conley and colleagues developed a test system to replicate a restaurant environment, the R-Space. The R-Space consists of eight loudpeakers positioned in a 360° arc and utilizes an audio recording of restaurant noise.

The present study used the R-Space to measure speech recognition in noise with four processing options: the standard dual-port directional (STD), ADRO, ASC, and BEAM. Thirty unilateral and three bilateral implant recipients repeated HINT sentences presented at a 0° azimuth with R-Space restaurant noise coming from all eight loudspeakers surrounding the subject at two different noise levels, 60 and 70 dB SPL. The signal-to-noise ratio (SNR) was obtained for each processing condition and noise level.

In 60 dB SPL noise, ASC and BEAM processing showed an improvement in SNR relative to STD and ADRO processing. BEAM processing resulted in a statistically significant improvement relative to both STD and ADRO processing. In 70 dB SPL noise, ASC and BEAM processing had significantly better mean SNRs compared to STD and ADRO processing. STD and BEAM processing resulted in significantly poorer SNRs in 70 dB SPL noise compared to the performance with these processing conditions at 60 dB SPL. There was no statistical difference between noise levels for ADRO and ASC processing. Bilateral subjects demonstrated a bilateral improvement compared to monaural performance for both noise levels and all processing conditions, except ASC in 60 dB SPL noise.

These results show that the best processing option in background noise depends on the intensity of the noise. The use of processing options that utilize noise reduction, like that available in ASC and BEAM, do improve a CI recipient’s ability to understand speech in noise in a test environment that replicates a real-life listening situation.

B28: CONVEYING LOW FREQUENCY INFORMATION TO COCHLEAR IMPLANT USERS THROUGH ELECTRICAL STIMULATION

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Even though the technological advances in the field of cochlear implants (CI) led to significant improvement in performance, the speech perception abilities of many CI users is still poor in noisy conditions. Research in the field of combined electric and acoustic hearing (EAS) has shown that low frequency information, even below 300 Hz, perceived through residual hearing can greatly improve hearing in adverse listening situations. It is assumed that a better perception of the speaker's fundamental frequency accounts for the improvement – by helping to segregate the speaker's voice from background talkers and other unwanted noise sources.

This study investigated whether cochlear implant users can also make use of very low frequencies through electrical stimulation alone. A new strategy called "extended low frequency HiRes" (ELF-HiRes) was implemented using HRStream, a research environment provided by Advanced Bionics. HRStream permits one to deliver signals processed from a personal computer to the Platinum Series speech processor through a USB interface. While the lower cut off frequency of the clinical HiRes system is at 300Hz, the new strategy processes a frequency range of 50 to 300Hz in the dedicated low frequency channel. Processing and stimulation patterns of all channels but the lowest remained unchanged. In a first approach, the lowest channel was stimulated with a monopolar pulsatile signal resulting in richer sound sensations but poorer speech understanding. Better results were achieved when using an analogue signal on the most apical electrode E1, with bipolar coupling to E2, while E3 to E16 were still presenting a pulsatile stimulation pattern like in HiRes. To avoid that the high energy of signals with very low frequencies dominate the stimulation, a loudness compensation function was introduced, which balances the charge delivered to the analog channel for frequencies below 300 Hz.

Currently, only acute tests can be performed due to the experimental test set-up. Several iterations were required to find suitable stimulation parameters for the lowest channel (e.g. stimulation mode, pre-emphasis, loudness growth). The recent implementation was described as more melodious and richer than the clinical HiRes. There was also a tendency towards better speech understanding with the new strategy. Further data on frequency discrimination and speech perception will be presented.

Preliminary results of this ongoing work indicate that it is indeed possible to give cochlear implant users access to signals in the lower frequency domain via electrical stimulation. However, the determination of the stimulation parameters seems to be critical.

B29: SPARSE STIMULI FOR COCHLEAR IMPLANTS

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The aim of the present research is to explore the application of sparse coding principles to the processing within a cochlear implant. The principle suggests that only few neurons are active given certain stimuli, which means neurons fire sparsely in order to encode stimuli efficiently. In order to mimic the sparse firing property of neurons, a sparse representation of the speech spectrum is required.

The proposed sparse coding strategy was based on a combination of ICA (independent component analysis) and PCA (principal component analysis), both operating on the envelope of the speech signal. The algorithm is tested for speech in quiet and modulated babble noise conditions (signal-to-noise ratios, SNR=15 dB, 10 dB, 5 dB). Results show that the algorithm is beneficial, particularly when baseline performance of listeners is poor. This approach is applicable both to acoustical hearing aids and cochlear implants.

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B30: SIMULATING HAIR-CELL ADAPTATION IN COCHLEAR IMPLANT PROCESSORS

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A functional role of neural adaptation may be to enhance the auditory system's responses to changes in stimulation in both the intensity and frequency domains. Auditory-nerve adaptation is attributed at least in part to depletion of hair-cell neurotransmitter, albeit other factors such as action potential generation may also be involved, and adaptation may be added at many levels of auditory processing. However, explicit simulation of hair-cell adaptation is missing from current cochlear implant (CI) speech processing strategies. The goal of the present study is to develop an implant processing strategy that includes a simulation of hair-cell adaptation and to evaluate the effect on speech intelligibility in CI listening. CI processing was simulated in Matlab using the Nucleus Matlab Toolbox (NMT) and Nucleus Implant Communicator (NIC) software developed by Cochlear Corporation. When available, parameters from the audiologist-produced map were utilized to match as closely as possible our simulator to the subject's own map. A simplified model of synaptic adaptation was produced by adding a first order digital lead compensation filter, post-filterbank, to each individual processing channel. Filter time constants were set on the order of 10-50 msec with an onset to steady state response ratio of about 1.1:1 which resulted in an approximately 2:1 onset to steady state ratio with respect to channel threshold and comfort levels.

A group of adult Nucleus 24 users who had been using their implants for at least 6 months and used the ACE processing strategy participated in this study. Listeners were tested on a vowel-consonant-vowel (VCV) discrimination task using 16 consonants coupled with the vowel /a/ (e.g., /apa/, /ada/, /avtha/…). Sounds were set at a comfortable listening level when played through the simulated processor. Subjects sat before a computer screen that diplayed the 16 VCV's labeled in a four by four layout and were asked to select the button corresponding to the speech sound they heard. Sixteen by sixteen phoneme matrices were generated to analyze the listeners' phoneme confusion errors. Listeners' percent correct phoneme recognition improved for several phonemes using the simulated adaptation. In addition, the simulated adaptation strategy reduced the number of phonemes that listeners confused with a target phoneme. The effect of the simulated adaptation on the amount of information transmitted for place, manner and voicing will also be discussed.

B31: EXPERIMENTAL RESULTS WITH A SINGLE SIDEBAND ENCODING STRATEGY FOR COCHLEAR IMPLANTS

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We have implemented the single sideband encoding (SSE) strategy that aims to improve the coding of within-channel temporal fine structure (TFS) in cochlear implants. In the SSE strategy, a sound signal is divided into a number of subbands and real coherent envelopes are extracted by single-sideband demodulation. These coherent envelopes not only carry information of temporal envelopes that are traditionally defined, they also encode TFS cues at low rates. The proposed SSE strategy was programmed on the Nucleus Implant Communicator 2 (NIC2) platform. Pulse trains were generated by off-line processing and then presented to each subject. The SSE strategy was initially evaluated with the UW-CAMP musical instrument timbre and melody recognition tests. Our pilot study from 4 Nucleus Freedom patients showed higher preference scores for the SSE strategy than a standard CIS strategy on melody and musical timbre recognitions. However, no improvement in performance was seen on either of these tests with SSE. When we tested single-channel performance on an 8-alternative temporal pitch discrimination task, however, all subjects performed at high levels (50-100% correct) with SSE whereas they scored at chance (~12.5%) with CIS. We found that the fixed amount of frequency shift used in current implementation of SSE destroys the harmonic relationship between channels, possibly resulting in significant channel-to-channel interference.

Recently we proposed a modified spectral-shifting scheme, Harmonic SSE, that can preserve the harmonic relationship between sub-bands. In the new implementation, the amount of frequency shift is adjusted according to a fundamental frequency (F0) tracker and the carrier frequency is dynamically set to integer multiples of F0. A nonlinear frequency mapping function was also used to further downshift the F0 contour to a perceivable frequency range for CI users. Initial experimental results with one patient showed high levels of melody recognition with a 1-channel or 2-channel Harmonic SSE map. This new finding has the potential to substantially improve multi-channel performance of the SSE coding strategy.

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B32: A TONOTOPIC MAP OF THE ELECTRICALLY STIMULATED COCHLEA FROM CI USERS WITH CONTRALATERAL NORMAL HEARING

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Recent studies by Vermeire et al. (2008), Dorman et al. (2007) and Boex et al. (2006) have determined frequency-place maps for the electrically stimulated cochlea from unilateral CI subjects with contralateral acoustic hearing. While Boex et al. (6 subjects) and Dorman et al. (1 subject) found an approximate one-octave downshift of the electrical frequency-place map with respect to Greenwood's frequency-position map of the Organ of Corti (OC), mean data from Vermeire et al. corresponded to Greenwood.

Eight MED-EL recipients from the 14 subject studied by Vermeire et al. (2008) - all with near-to-normal hearing in the contralateral ear - have been re-evaluated to date with a methodology different from the original mixed acoustic-electric scaling procedure. After loudness balancing, percepts from unmodulated trains of biphasic pulses (1500 pulses per second, 50 us/phase) were pitch-matched to contralateral acoustic pure tones, using a staircase procedure with adapted step size. Matched acoustic frequencies were evaluated as a function of electrode insertion angles. Electrode placement and insertion angles were determined from high-resolution CT scans of the subjects' temporal bones (Xu et al., 2000).

Electrode insertion angles range from 36 to 758 degrees, and electrode pitches were matched to frequencies ranging from 126 Hz to 8.4 kHz. The mean frequency-place function is approximately one octave below Greenwood's map at the basal electrode positions, about half an octave below Greenwood at medial positions, and is close to Greenwood at the apical-most electrodes.

Present results for pitch percepts elicited with high-rate electrical stimulation on arrays of intracochlear electrodes are mostly consistent with findings from Dorman et al. and Boex et al. Matched place-pitch frequencies are somewhat lower, but also less variable across subjects than the scaling data in Vermeire et al.

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B33: METHODS FOR TRACKING BEHAVIORAL AND PHYSIOLOGICAL CHANGES IN ACOUSTICELECTRIC PITCH MATCHING

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The increasing number of CI users with residual hearing who are being implanted under more relaxed guidelines allows us to compare the pitch percepts elicited by electrical stimulation with those from acoustic hearing. Hence, we propose to set up a platform to track the changes in pitch percepts elicited by a given electrode over the first year of implantation, and use it as a metric to examine the perceptual adaptation process. The platform will psychoacoustically, physically and functionally evaluate and correlate the changes. In this paper, we present preliminary data collected with one Nucleus CI user in our psychoacoustic experiment, and the Auditory Evoked Potential (AEP) recordings with one normal hearing subject with different frequency mismatches acoustically presented across both ears. The CI user had more than two years of experience with the device and had residual hearing up to 2000 Hz. In our psychoacoustic experiment, the CI patient was presented with an acoustic tone stimulus in the un-implanted ear via a headphone and a power amplifier, and with simultaneous electrical stimulation in the implanted ear. The subject was asked to balance the loudness across both ears and then adjust the frequency of the acoustic tone to match the percept caused by electrical stimulation. The process was repeated for all 22 active electrodes. The three most apical electrodes were closely matched to the center frequencies of the corresponding analysis bands (250 to 500 Hz), but more basal electrodes were mismatched (for example, the electrode whose analysis band is centered at 1000 Hz was matched to 500 Hz). This result cannot be explained solely by limitations in the listener's residual hearing, and likely represents a real frequency mismatch even after two years of experience. We have also developed a Matlab system that uses the NIC V2 toolbox (Cochlear Americas), to present interleaving short intervals (1 sec) of single channel CI electrical stimulation and acoustic tone stimulation, while we record AEPs using a Neuroscan system. In pilot testing of this system with a NH listener, we replaced electrical simulation with acoustic stimulation; fixed one acoustic tone of 1000Hz in one ear and varied the acoustic tones at 250, 900, 1000, 1100 and 4000Hz in the other ear. N1 latency was minimized when both ears were stimulated with the same frequency; mismatches in either direction resulted in longer N1 latency. This result suggests N1 latency could be a potential marker of acoustic-electrical frequency mismatch in CI users. Ultimately, both the psychophysical experiment and the AEP will be done on the same group of CI patients. We will also estimate cochlear size and electrode location from patients' X-ray scans to help interpret results from the behavioral and physiological studies.

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B34: PITCH SCALING PSYCHOMETRICS IN ELECTRIC ACOUSTIC STIMULATION (EAS)

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Combined electric acoustic stimulation (EAS) is a therapeutic option for patients with severe-to-profound high and mid frequency hearing loss but remaining low frequency hearing. Knowledge of electric and acoustic pitch transformation is very important for effective fitting which joins both kinds of stimulation into one perception. The fitting software of current cochlear implant (CI) sound processors requires that filter parameters be set to control the frequency range of acoustic and electric processing. Recent data suggests that the frequency/place function proposed by Greenwood for normal hearing (Greenwood, JASA 1961) does not sufficiently explain results obtained in CI recipients.

To determine the electric place/pitch function in EAS, pitch adjustment experiments were conducted in 4 patients implanted with EAS and a $FLEX^{EAS}$ 24 mm electrode (MED-EL, Innsbruck) who had sufficient residual hearing in the opposite ear. Two subjects with single sided deafness and standard CI treatment with a PULSAR OR SONATA CI and a standard 31.7 mm electrode carrier (MED-EL, Innsbruck) served as controls. The patients' task was to listen to a pure tone presented in the ear opposite the implant and then adjust a knob until the pure tone presented through a single electrode stimulation in the implanted ear matched the frequency of what was heard. Frequencies of the pure tones being presented to the non-implanted ear were randomized. Adjustments were repeated to ensure reproducibility and accuracy. Postoperative radiographs (modified Stenver's view) were analyzed to compare individual data in terms of insertion angle.

Results showed considerable variation in terms of the individual pitch elicited by a certain electrode insertion angle. The lowest frequency adjustment in EAS patients was approximately 500 Hz, whereas control patients with deep electrode insertion made adjustments at or even below 200 Hz. Since the residual hearing in the EAS patient group was rather limited in the higher frequency hearing range, only a limited number of more basal electrodes could be assessed in order to determine the slope of the electrical place/pitch function. Slopes varied greatly between patients. The data was also analyzed in terms of the effect of start frequency and the effect of habituation to the electrical stimulation over time.

Our outcomes suggest that in order to obtain reasonable default filter parameter settings for the acoustic/electric crossover frequency, postoperative audiograms of the implanted ear and Stenvers radiographic insertion depth control of the electrode array are necessary prerequisites. The position of the most apical electrode gives a good first approximation of the reference for setting of the crossover frequency.

B35: AMPLIFICATION OF INTERAURAL LEVEL DIFFERENCES IMPROVES SOUND LOCALIZATION IN ACOUSTIC SIMULATIONS OF BIMODAL HEARING

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While users of a cochlear implant (CI) and a contralateral hearing aid (HA) are sensitive to interaural level differences (ILDs) [1] and interaural time differences (ITD) [2], they exhibit poor sound source localization performance. One of the main reasons is that while ILD cues are physically large at high frequencies, most of these subjects only have residual acoustic hearing in the low frequencies. Another reason is that modification of the CI and HA signal processing to allow ITD perception with clinical devices is still under investigation, and even with experimental devices, a minimum level of residual hearing is necessary to allow ITD perception [2]. Therefore, when using their clinical speech processor and hearing aid, most of these subjects cannot optimally use ILD or ITD cues for localization in the horizontal plane. Perception of ILD cues can be enabled by “transposing” the available cues from high frequencies to lower frequencies that can be perceived acoustically, or by even further amplifying the cues to compensate for the lack of perceptible ITD cues. Both the CI speech processor and the hearing aid have a microphone that records the full band acoustic signals at the two ears. Therefore, a signal processing system can determine the ILD (or sound source location) from the full band signals and introduce it in the low frequencies in the two devices. We developed such an ILD introduction algorithm and evaluated it with six normal hearing subjects using noise band vocoder CI-simulations and a simulation of hearing loss. It is shown that localization performance can be improved by up to 14 degrees RMS error by artificially amplifying ILD cues in the low frequencies.

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[1] Francart T, Brokx J, Wouters J., Sensitivity to interaural level difference and loudness growth with bilateral bimodal stimulation. Audiol Neurotol 2008;13:309-319

[2] Francart T, Brokx J, Wouters J., Sensitivity to interaural time differences with combined cochlear implant and acoustic stimulation. J Assoc Res Otolaryngol. 2009 Mar;10(1):131-41

B36: THE LOCALIZATION OF CHANNEL-VOCODED STIMULI IN THE MEDIAN PLANE

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Median-plane sound localization requires the spectral profile analysis of frequencies between approximately 4 and 16 kHz. The aim of this study was to determine if median-plane sound localization is possible with reduced frequency resolution, similar to what occurs with the use of cochlear implants. We measured the median-plane sound localization performance in eight normal-hearing listeners as a function of the number of channels using a Gaussian-envelope tone vocoder. The channels were logarithmically-spaced from 0.3 to 16 kHz. Localization performance for vocoded stimuli was significantly worse than that for non-vocoded wideband Gaussian white noises and wideband 100-pps click trains. Nevertheless, listeners could localize better than chance with six or more channels and there was no significant difference in localization performance in the range of 9 to 24 channels.

A second experiment was performed, which included extensive training using the condition with 12 channels. Two types of channel spacings were tested; one was like in experiment 1; the other one assigned 8 logarithmically-spaced channels to the frequency range associated with speech (0.3-2.8 kHz) and four logarithmically-spaced channels to higher frequencies (2.8-16 kHz). The latter spacing was intended to preserve adequate resolution of the speech signal over the first two formants of speech. For both spacings, localization performance improved with training, but remained worse than that for noises and clicks. These results indicate that the number of eletrodes provided by the current generation of cochlear implants may be sufficient to encode the spectral cues required for vertical-plane sound localization.

This study was funded by the Austrian Science Fund (FWF Project P18401-B15) and supported by the Austrian Academy of Sciences.

B37: BINAURAL SUMMATION, HEAD SHADOW AND SQUELCH EFFECT IN CHILDREN USING BILATERAL COCHLEAR IMPLANTS

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Introduction: The aim of this study was to investigate, to what extent binaural summation, head shadow and squelch effect contribute to improvement of speech perception in children using bilateral cochlear implants.

Methods: The Würzburger Kindertest (WüKi) was used to evaluate speech perception in noise in 3 different listening conditions (right / left only, both implants). Speech was always presented from the front at 70dBSPL with noise coming either ± 90 degrees from the side or the front with an SNR of 15dB. Twelve children aged 6-10 years who received bilateral cochlear implants at the age of 1-6 years with a mean time gap of 1.2years between first and second implant surgery were able to complete speech perception testing.

Results: Bilateral implant use ranged from 1.2 to 6.4 years (mean 4.2 years). In all noise conditions significant binaural benefit could be demonstrated. Average binaural summation was 13%, head shadow was23% and squelch effect was 6%. No statistical significant difference between the performance of the first and the second implant was found. The contribution of the second ear was largest when noise was directed towards the tested ear. Within our subjects no influence of age at implantation, time gap or bilateral implant use was evident.

Conclusion: Speech perception is significantly improved after bilateral cochlear implantation in children, especially in noisy conditions, thus leading to better listening and learning conditions.

B38: ELECTRODE POSITION AND PERFORMANCE IN A BILATERALLY IMPLANTED NUCLEUS FREEDOM USER

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Electrode position within the cochlea and its correlation with speech perception has been a widely discussed topic within the last 2 years. Margo Skinner's 2007 paper entitled "In Vivo Estimates of the Position of Advanced Bionics Electrode Arrays in the Human Cochlea" described a new technique to determine the position of each electrode in the cochlea in 15 Advanced Bionics (AB) cochlear implant (CI) users. This report was the first to show a negative correlation between speech perception, specifically CNC monosyllabic word scores, and scalar vestibuli (SV) electrode placement. As a follow up, Finley and colleagues published a paper in 2008 examining scalar placement of the electrode array and insertion depth of 14 AB CI recipients. Using the technique described in Skinner et al 2007 to determine electrode placement, Finley confirmed that lower CNC scores were associated with greater number of electrode contacts in SV and greater insertion depth. Skinner, Finley and others have hypothesized that deep insertions can cause trauma in the apical part of the cochlea as well as a void in stimulation sites in the basal end of the cochlea. SV placement can possibly increase the risk of cross turn stimulation, and in cases where an array is inserted in scala tympani (ST) but transitions into SV, mechanical damage to cochlear tissues can occur.

In addition to the AB subjects, we assessed electrode position and performance in Nucleus CI users and found similar results. A poster presented at the 2007 CIAP Conference gave results for 54 subjects who participated in a study examining factors that predict word recognition in adult CI users (Skinner et al 2007). These subjects were implanted with either the Nucleus Contour (N=46) or the AB HiFocus 1j (N=8) electrode arrays. Results revealed that in this larger group of patients, word recognition was higher when all electrodes were in their intended position in ST and when apical electrode insertion was less than 400 degrees.

This poster will present a case study of a bilateral Nucleus Freedom user sequentially implanted within 7 months and with a similar hearing history in both ears. This patient is noteworthy in that with the same cochleostomy placement and the same surgeon, the arrays end up in two different scala and ear-specific differences in both speech recognition and sound quality are observed. These differences cannot be attributed solely to scalar placement and may also be affected by deeper insertion, tighter coiling (i.e. closer to medial wall) and the possible effects of sequential implantation. The correlation between electrode position and outcome between ears will be examined in a larger group of bilateral CI users.

B39: RELATIONSHIP OF MONAURAL AND BINAURAL CHANNEL INTERACTION EFFECTS IN BILATERAL COCHLEAR IMPLANT USERS

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Improved sound localization and understanding of speech in noise are observed with two cochlear implants versus one, but performance remains poor relative to normal hearing listeners. In particular, sensitivity to interaural timing differences (ITDs) in the range of 10-30 μs is observed in trained normal hearing listeners but not in bilateral cochlear implant (BICI) users listening through commercially available speech processors. With a bilaterally coordinated research processor, however, sensitivity to ITDs can be in the tens of microseconds in some adult BICI users with postlingual onset of deafness, when single electrode pairs are stimulated at low pulse rates or low modulation rates. A key next step is to test sensitivity under more realistic listening conditions, in which more than one electrode pair is stimulated or where more than one ITD may be presented simultaneously.

In the unilateral cochlear implant literature changes in sensitivity due to stimulation of one or more additional electrodes on the same cochlear array are known as effects of "channel interactions." In our current work we are extending measures of channel interactions to binaural stimulation in order to: 1) examine possible effects on binaural sensitivity, and 2) determine whether such effects, if any, are likely due in whole or in part to channel interactions at the monaural level.

We have examined ITD sensitivity in 10 postlingually deaf Nucleus-24 and Freedom BICI users when unmodulated pulse trains were presented at 100 pps on bilateral pairs of pitch-matched electrodes. A probe train and an added train were temporally interleaved so that the added train led the probe. ITD JNDs for a probe in the middle of the electrode array presented at 90% of the dynamic range (DR) were measured using a 2-alternative forced choice procedure while varying the added train's: a) place of stimulation from -8 to +8 electrodes relative to the probe, b) level from 20 to 90% DR, c) temporal offset relative to the probe (5m or 60 μs), and d) ITD (matched to probe or fixed at 0 μs). In the monaural experiments threshold stimulation levels for detecting a probe in the middle of the electrode array in the presence of an added train presented at 90% DR were measured using a 3-interval oddball paradigm while varying the added train's: a) place of stimulation, and b) temporal offset relative to the probe.

Preliminary results indicate that 1) there are substantial effects of channel interactions on binaural sensitivity, and 2) these effects are not well predicted by monaural interactions alone or single-channel binaural sensitivity alone.

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B40: AUDITORY MIDBRAIN IMPLANT: PRESENT CLINICAL RESULTS AND FUTURE DIRECTIONS

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Introduction: Tumor-induced damage in the cochlear nucleus may be responsible for the limited success of the auditory brainstem implant (ABI) in neurofibromatosis type 2 (NF2) patients. Therefore, an alternative implantation site that bypasses the damaged pathways in the brainstem may provide better hearing performance in NF2 patients. The central nucleus of the inferior colliculus (ICC) provides access to almost all ascending auditory information and has a well-defined tonotopic organization which is important for an auditory prosthesis. The auditory midbrain implant (AMI) is a single-shank multi-electrode array designed according to the dimensions of the human inferior colliculus with the goal of stimulating the different frequency layers of its central nucleus.

Methods: The AMI clinical study has been performed in 5 NF2 patients. In all of the patients, tumor removal and AMI implantation have been performed in a single surgical setting through the lateral suboccipital infratentorial-supracerebellar approach.

Results: None of the patients developed complications either due to tumor removal or AMI implantation. Until now, a follow up of up to two years have shown no evidence of electrode migrations in these 5 patients. Paresthesia was the most common nonauditory side effect which could be managed successfully by turning off the responsible sites at the first fitting. All the patients can receive environmental sounds and show some degrees of lip-reading enhancement using their AMI. Psychoacoustic evaluation of the AMI patients revealed 3 interesting phenomena in the auditory pathways of the midbrain. First, the hearing performance depends strongly on the location of the implant in the midbrain. Stimulation of the ICC can produce better results compared to the lateral lemniscus and dorsal cortex of the inferior colliculus. Second, adaptation is an issue for stimulation of certain areas of the auditory midbrain. Third, stimulation of the IC can induce high levels of plasticity.

Conclusions and future directions: Based on our new insights into the properties of the auditory midbrain in human, we have developed a new generation of AMI for 3-D stimulation of the ICC which enables a better spatial access to the neuronal organization of the inferior colliculus. In addition, the proper surgical placement of the implant, which has been an issue in our patients, can be improved by using the stereotaxic surgical techniques in future candidates. This would also enable implantation in awake subjects which provides us the subjective feedback of the patients regarding the quality of auditory sensations due to electrical stimulation intra-operatively. In addition developing flexible stimulation strategies to cope with adaptation and plasticity in IC can further improve the results in future AMI patients.

B41: MYMAPS - ENABLING RECIPIENTS TO MEASURE THEIR OWN STIMULATION LEVELS

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Proper measurement of threshold and comfort levels is crucial for defining the cochlear implant recipient's dynamic range of electrical hearing. However, the task may present a difficult burden for clinics with constrained available time and resources. To alleviate clinical demands and increase clinical efficiency, the MyMAPs application has been developed, enabling cochlear implant recipients to safely measure their own electrical stimulation levels. MyMAPs follows a step-by-step customizable protocol to emulate a clinic's own recommended audiological procedures, whether loosely approximating or rigorous.

Study of the MyMAPs application assesses how closely self-measured threshold and comfort levels reflect those measured by an audiologist, and further, how self-measured levels impact speech performance and recipient preference. Threshold and comfort levels, combined with processing parameters from each subject's everyday MAPs, underwent speech testing in quiet and in noise. Subjects were also interviewed by the attending study clinician and completed a subjective questionnaire regarding their experience. Differences in resulting levels were retrospectively analyzed and correlated to the objective speech performance results and subjective preference responses.

Results show that recipients can use MyMAPs to measure their own stimulation levels and meet traditionally-measured clinical levels within acceptable tolerances. The study also demonstrated that adults generally appreciated the freedom and control offered by self-measurement. However some adults had difficulties with the task, compelling future refinement of software usability. Further development will also focus on making MyMAPs accessible to younger recipients. The study was acute, in that no take-home experience was involved, and as such, lays the foundation for pursuit of a more a more extensive investigation.

C1: OPTICAL BEAM PATH IN GUINEA PIG COCHLEA

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In recent studies, pulsed infrared radiation has shown promising results as selective nerve stimulation technique. In our studies, a laser has been used to stimulate spiral ganglion cells in rodent inner ears. Recordings from the inferior colliculus using multi-channel electrodes suggested cochlear neural stimulation with optical radiation is spatially more selective than stimulation with electrical current. To stimulate the cells, however, the optical beam passes different structures. For designing a cochlear implant based on optical technology, it is important to determine the beam path of the radiation through the cochlea. In the present study, we examined in the guinea pig animal model the beam path of optical radiation through the cochlea.

Guinea pig cochleae were accessed surgically. A cochleostomy was drilled in the basal turn and an optical fiber was inserted through the cochleostomy into scala tympani. The three dimensional orientation of the optical fiber was carefully recorded. After the placement of the fiber, the radiation energy was purposely set to a level where tissue damage resulted. At the end of the experiments, the cochlea was harvested for histology. The damages were quantified and the beam path was determined.

The results suggest that the basal turn can be irradiated including the nerve trunk in the center of the cochlea. Structures including the bony modiolus and the main trunk of the auditory nerve result in a widening of the radiation beam. The results correlate with the activation patters recorded with a multi-channel inferior colliculus electrode.

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C2: OPTICAL COCHLEAR STIMULATION: EFFECT OF FIBER SIZE ON RESPONSES IN THE INFERIOR COLLICULUS

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Recent work has illustrated the feasibility of cochlear implants based on optical stimulation of the auditory system. Optical radiation could be beneficial since it can provide more spatially selective stimulation of the cochlea as compared to electrical stimulation. A practical optical cochlear implant should transfer a maximum amount of information using a minimum amount of energy, which depends upon the size of the optical fiber that couples the laser to the cochlea. Individual optical fibers have to be small enough so that a fiber bundle made of many optical fibers can be inserted safely into the scala tympani. On the other hand, the fibers should be large enough to stimulate a relevant population of neurons to encode acoustic information and to reduce optical losses that occur when coupling the fiber to a light source located outside the cochlea. In the present study, we aim to determine the optimal fiber size to utilize for an implant. We compared the energy required to evoke compound action potentials and responses in the central nucleus of inferior colliculus (ICC) and studied the spread of activity in the ICC for different fiber sizes. Three fiber diameters, viz. 50, 100 and 200 μm, were used to optically stimulate auditory neurons of normal hearing guinea pigs deafened with intracochlear injection of neomycin. Input/output responses of ICC neurons and cochlear spiral ganglion cells were recorded by varying optical radiation energy. The ICC recordings were made using a NeuroNexus 16 contact recording electrode that was inserted perpendicular to the frequency plane. Preliminary results indicate that the radiant exposure levels to evoke responses in ICC were similar for the different fiber diameters but the area of activation reduces with the fiber diameter. Spatial tuning curves show that the activity of ICC was spatially restricted for smaller fibers.

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C3: OPTICAL RADIATION LIKELY TARGETS SPIRAL GANGLION CELLS

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Selective stimulation of the cochlea is possible with optical radiation. In the current approach, an optical fiber is directed towards the spiral ganglion cells. The objective is to stimulate the auditory nerve. With the current experiments we study whether stimulation likely occurs at the spiral ganglion cell bodies or at the axons of the spiral ganglion cells, which are located in the center of the modiolus.
Healthy adult guinea pigs were used. A cochleostomy was drilled into the basal cochlear turn to deafen the animals with neomycin (20mM) injected into scala tympani and to stimulate the auditory periphery with optical radiation. At the same time neural responses from the inferior colliculus (IC) were recorded with a multichannel electrode. Response areas were compared for different placements of the optical fiber. Orientations were selected such that either the cell bodies or the nerve trunk was primarily in the optical beam path.

Response areas from IC recordings suggest that optical radiation stimulates primarily spiral ganglion cell bodies. Stimulation of the nerve trunk is possible but requires bout an order of magnitude larger radiant energies.

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C4: REDUCED SIMULTANEOUS CHANNEL INTERACTIONS WITH OPTIMIZED FOCAL ELECTRODE CONFIGURATIONS

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Simultaneous stimulation of more than one monopolar (MP) channel with scala tympani electrodes produces large channel interactions in cochlear implant subjects. This vector summation of electric fields at target neurons degrades the performance of simultaneous multi-channel stimulation strategies. Such degradation has largely been dealt with in clinical sound processors by the use of sequential stimulation strategies that interleave the stimulation times of multiple channels such that only a single channel is stimulated at any given time. While sequential stimulation largely solves the problems associated with direct electric field interactions, it 1) limits the types of stimulation that can be used by sound coding strategies, 2) creates a tradeoff between spectral and temporal resolution, and 3) does not eliminate non-simultaneous channel interactions that may exist due to residual charge of neural structures.

Here we introduce a psychophysical method for optimizing phased-array (PA) channels with the goal of minimizing simultaneous channel interactions. A PA channel is a multipolar electrode configuration using all electrode contacts in a coordinated fashion to focus the stimulation currents. To optimize, interactions are measured between neighboring channels and the sign of the interaction is used to adjust the degree of focusing of the channels in an iterative fashion until interactions are minimized. Spatial patterns of simultaneous channel interactions confirm that optimized PA channels have significantly less interaction than non-optimized PA channels and channels using conventional electrode configurations.

Despite evidence that optimized PA channels have narrower excitation patterns than MP channels, acute speech reception threshold (SRT) tests of sentences in speech-shaped noise have yet to show any immediate benefit of optimized PA channels over MP channels using subjects' clinical ACE strategy. However, speech testing with modified versions of the ACE strategy that introduce varying degrees of simultaneity show that optimized PA channels, unlike MP channels, may allow for some degree of simultaneous stimulation without degradation in performance. Results suggest that it may be possible to use a subset of optimized PA channels (e.g. every other channel) with a fully simultaneous or asynchronous sound coding strategy without any degradation from channel interactions. This could allow for more flexible coding of sound in future strategies for cochlear implants.

C5: INTRACOCHLEAR INFUSION OF BRAIN-DERIVED NEUROTROPHIC FACTOR (BDNF) AFFECTS FUNCTION AND MORPHOLOGY OF SPIRAL GANGLION NEURONS IN CATS DEAFENED AS NEONATES

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The survival of spiral ganglion (SG) neurons depends on both neural activity and neurotrophic molecular support. In this study, electro-physiological and histological data were evaluated to assess the effects of BDNF in the developing auditory system of cats. Kittens were deafened as neonates by systemic neomycin injections and implanted unilaterally at 4-5 weeks of age with scala tympani electrodes containing 4-6 wires for electrical stimulation and an integrated drug-delivery system for infusion of neurotrophic agents. Electrically-evoked auditory brainstem responses (EABR) were recorded longitudinally while animals received 10 or 18 weeks of either BDNF alone, artificial perilymph (AP), or combined BDNF delivery and chronic electrical stimulation (BDNF+ES).

Comparison of initial and final EABR thresholds in animals that received BDNF demonstrated a significant decrease in thresholds (mean difference = -166 μA, P = 0.012; paired t-test). Animals that received AP showed no significant shift in threshold (mean difference = +9 μA, P = 0.676). Animals that received combined BDNF+ES showed a tendency toward decreased thresholds (mean difference = -45 μA), but the shift was not significant (P = 0.140), suggesting that the functional effects elicited by BDNF alone were altered by concomitant ES.

Histological studies of BDNF-treated cochleae showed larger SG cell size, improved SG cell survival, greater density of radial nerve fibers in the osseous spiral lamina (OSL), and marked sprouting of fibers into the scala tympani. Five micron sections of the OSL cut orthogonal to the radial plane demonstrated an increase in both fiber size and number in cochleae treated with BDNF, as compared to the contralateral deafened control cochleae. The number of peripheral fibers measured within a 100 μm sector of the OSL was positively correlated with the number of SG cells in the corresponding cochlear region in the deafened untreated cochleae (r = 0.524, P = 0.045, Pearson Product Moment Correlation), but not in BDNF-treated ears (r = -0.0484, P = 0.864).

The sprouting of radial nerve fibers after BDNF infusion may contribute to the decrease in EABR thresholds. Further, neural threshold vs. depth functions recorded in the inferior colliculus of the same subjects are being evaluated to determine whether the central tonotopic organization is maintained despite the marked peripheral neural sprouting.

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C6: DEXAMETHASONE ELUTING COCHLEAR ELECTRODE ARRAY: IN-VITRO AND IN-VIVO RESULTS

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Experimental results demonstrate that the silicone of the cochlea implant electrode when mixed with pure dexamethasone in crystal form, can deliver reliably, for example, from .1 to 1 μg of dexamethasone per day over a period of several months to several years, depending on design parameters. Dexamethasone release curves were established in saline solution at 37°C, with drug loading from .25% to 2% per electrode weight over several months, using HPLC. These showed an initial burst followed by a constant dose per day. Confining the dexamethasone release between 2 weeks and 2 months is also possible by using selective loading of the silicone electrode or different coating techniques.

In vivo experiments showed better hearing preservation in guinea pigs implanted with 2% steroid eluting silicone rods compared to animals implanted with non-eluting silicone (n=18, n=9 at 24 weeks, each condition). The significantly lower ABR threshold shift was observed in the 8 to 24 KHz cochlear region closest to the site of trauma. The effect of dexamethasone on hearing protection became apparent 3 weeks post CI and was sustained until to the end of the study. In the 1-4 KHz region, a constant 5 to 10 dB ABR threshold shift was observed in this model with no significant difference between eluting rods and controls. Histological evaluation has thus far indicated an up-regulation of TNF-alpha after trauma, but no clear correlation between steroid use and fibrosis inhibition. In-vivo measurements of drug concentration were made at sacrifice using apical fluid sampling of 10 μl at selected intervals after implantation. A burst release was followed by a relatively stable concentration during the first week.

The drug loading was then increased to 10% and a similar study was carried out using a tapered rod and non-traumatic insertion to evaluate efficacy/toxicity and to address the issue of wound healing at the cochleostomy site. The mean threshold shift two weeks after implantation of the control rods was 7dB +/-2dB (for 8kHz and above), while for the steroid eluting rods, a mean shift of -2db +/-2dB was obtained. Microscopic evaluation suggested adequate sealing of the cochleostomy, while further histological techniques (under analysis) challenged the tissue seal further.

C7: A COMPUTATIONAL MODEL OF INCOMPLETE ADAPTATION TO A SEVERELY SHIFTED FREQUENCY-TO-ELECTRODE MAPPING BY COCHLEAR IMPLANT USERS

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To date, Fu, Shannon, and Galvin (2002) is the only study of its kind to suggest that cochlear implant (CI) users can adapt, to some extent, to a severely distorted frequency map after three months of continual use. In that study, three CI subjects were given a map that provided better spectral resolution in a frequency range important for speech perception (< 1 kHz) at the expense of introducing a large basalward frequency shift relative to their clinically assigned maps. CI subjects' speech perception was initially poorer with the experimental map, but improved over the three-month study period indicating that some adaptation occurred. Yet, it was unclear whether this adaptation was complete or partial as the experimental map may have resulted in poorer speech perception, even if adaptation were complete. In the present study, the Multidimensional Phoneme Identification (MPI) model (Svirsky, 2000, 2002) was applied to Fu et al.'s vowel identification data to quantify the adaptation, and to predict performance levels with complete adaptation to the frequency shift. Two model parameters were used to assess CI subjects' ability to accommodate to the frequency shifted vowels in the F2 vs. F1 perceptual space. The first parameter measured listeners' ability to shift their internal expectations of vowel locations, and the second parameter measured their uncertainty, or just-noticeable difference (JND), for vowel locations. In terms of model parameters, adaptation to the experimental map was incomplete. Two of the subjects could adjust their expectations to overcome the frequency shift within the first week. The third subject could not overcome the shift even after three months. For all listeners, the JND increased substantially with the experimental map, decreased by the end of the study period, but remained larger than baseline levels; suggesting a reduced ability to formulate lexical labels for the new vowel categories. When model parameters were set to baseline values, the model predicted lower percent correct scores with the experimental map than with the clinical maps, suggesting that had adaptation been complete, the experimental map would still have resulted in poorer speech perception.

In summary, the MPI model can be used to assess the anticipated gains in speech perception expected from changing a given CI fitting parameter, to estimate the amount of adaptation required to achieve this benefit, and to determine whether adaptation to the new fitting parameter was complete or incomplete.

C8: TEMPORAL PROPERTIES OF SINGLE AUDITORY NERVE FIBERS DURING STIMULATION WITH OPTICAL RADIATION

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We have recently demonstrated that spatially selective stimulation of the cochlea is possible with optical stimulation. However, for optical radiation to be a useful paradigm for stimulation of neurons, including cochlear implants, the neurons must be stimulated at high stimulus repetition rates. In this paper we study the temporal properties of the gerbil auditory nerve during optical stimulation.

A diode laser (Aculight Corporation) was used for the stimulation of auditory nerve. It operates between 1.844 – 1.873 µm, with pulse durations of 35-1000 µs, and at repetition rates between 1–1000 Hz. The laser was coupled to an optical fiber that was placed against the round window membrane and oriented toward the spiral ganglion cells. The auditory nerve was surgically exposed and recordings were taken from single fibers during acoustic and laser stimulation. The action potential rate versus radiant energy relation was examined. Inter-spike-interval-histograms and peri-stimulus-histograms were plotted. Firing efficiency, delay times, delay time jitter, and the entrainment index were calculated.

Results showed that action potentials occurred 2.5-4.0 ms after the laser pulse. Maximum rates of neuronal discharge were as high as 300 Hz. The action potentials did not respond strictly after the radiation pulse with high stimulation rates, i.e. >300 pulses per second. The correlation between the action potentials and the laser pulses decreased drastically for laser pulse repetition rate higher than 300 pulses per second.

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C9: COMPARISON OF ELECTROPHYSIOLOGICAL RESPONSES EVOKED IN THE INFERIOR COLLICULUS OF THE CAT BY SURFACE MACROELECTRODES AND PENETRATING MICROELECTRODES IMPLANTED IN THE COCHLEAR NUCLEUS

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Persons who lack a functional auditory nerve cannot benefit from cochlear implants, but an auditory prosthesis utilizing a array of stimulating electrodes implanted on the surface of the cochlear nucleus can restore some hearing. Worldwide, more than 500 persons have received these “auditory brainstem implants” (ABIs) , which include an array of up to 21 macroelectrodes implanted within the lateral recess of the 4th ventricle, over the cochlear nucleus. In patients with type II Neurofibromatosis , (NF2) these ABIs provide improved speech perception when combined with lip reading, but little open-set speech recognition. The limited, albeit very useful, benefit that patients with NF2 derive from the extant ABIs clearly demonstrate the need for improved central auditory prostheses for patients who are not candidates for cochlear implants. We have been investigating the feasibility of supplementing the array of surface electrodes with multisite penetrating (intranuclear) microstimulating electrodes fabricated by a process that would be suitable for eventual clinical use, and so it is essential to develop a better understanding how the neurons of the cochlear nucleus are activated by macroelectrodes on the surface of the cochlear nucleus and by the penetrating microelectrodes. Also, it is virtually certain that at least for the foreseeable future, any auditory brainstem implant that includes penetrating microelectrodes also will include an array of surface electrodes within the lateral recess, so it is important to investigate how the two types of electrodes can best be used in synergy. The results from our cat model are consistent with the finding from a small group of human patients with NF2 who have received ABI containing surface and penetrating electrodes and this concordance supports the validity of the our cat model as a means of exploring these issues. In particular, the human patients tend to describe the percept for the penetrating electrodes as more akin to pure tones than those from the surface electrodes, which is consistent with the greater tonotopic specificity of the penetrating electrodes implanted in the feline cochlear nucleus. In the cat, the penetrating microelectrodes were able to access a greater portion of the tonotopic gradient of the cat’s’ VCN, notably the representation of low acoustic frequencies that are essential for good speech perception., while the human patients similarly report a greater range of pitch percepts with the penetrating electrodes . These patients also report that the percepts from the surface electrodes tend to be louder than that of the penetrating electrodes, which also is consistent with our findings in the cat that the usable dynamic range of the surface electrodes is greater than that of the penetrating microelectrodes. The auditory brainstem implants now in clinical use employ sound processors and sound processing strategy that have been optimized for cochlear implants. The findings from our study suggest how sound-processing strategies might be designed so as to better utilize in synergy the capabilities of arrays of surface macroelectrodes and penetrating microelectrodes. Supported by contract N01-DC-4-0005 and research grant 1RO1DC009643-01 from the National Institutes of Health.

C10: NRT MEASUREMENTS IN SUBJECTS IMPLANTED WITH A NUCLEUS HYBRID-L COCHLEAR IMPLANT

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Patients with a certain residual hearing at low frequencies but with a severe to total hearing loss at mid to high frequencies can be supplied with a cochlear implant which covers only the medial and basal part of the cochlea and which is implanted through the round window membrane.

Our study group consists of 14 subjects implanted with a Hybrid-L cochlear implant. NRT measurements were done at each of the 22 electrodes. In addition the amplitude growth function (AGF) was measured at electrodes 5, 10, 15, 20, and 22.

The NRT profile is similar for all patients and shows a characteristic dip around electrode 8. Mean TNRT value averaged over all electrodes is 180CL while 162CL for electrode 8.

The slope of the AGF increases from the basal to the apical electrodes, but was lower for the most apical electrode 22. We assume that the special insertion technique positions the electrode in a way that electrode 8 has the nearest proximity to the modiolus. Since the slope of the amplitude growth function is direct proportional to the number of surviving spiral ganglion cells, one would assume that the AGF slope will be highest for the apical region and will decline to the basal end. This assumption turns out to be true except for electrode 22.

C11: AUDITORY STEADY STATE RESPONSES CAN BE RECORDED IN COCHLEAR IMPLANT USERS

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Steady state potentials evoked by periodic acoustic stimuli like AM/FM-modulated tones, beats or low-rate click trains can be recorded with scalp electrodes. Up to now such responses have not been recorded in cochlear implant (CI) users.

The aims of this study were: (1) to show that auditory steady state potentials to electrical pulse trains (EASSRs) can be reliably recorded by electrodes placed on the scalp of a CI user, (2) to develop a measurement setup to facilitate stimulation and reliable recordings of such responses and (3) to analyze the predictive value of thresholds obtained using EASSRs for behaviorally hearing thresholds.

For six users of a Nucleus cochlear implant, EASSRs to symmetric biphasic pulse trains with rates between 35 and 44 Hz were recorded with seven scalp electrodes. The influence of various stimulus parameters was characterized: pulse rate, stimulus intensity, monopolar or bipolar stimulation mode and presentation of either one pulse train on one electrode or interleaved pulse trains on multiple electrodes. To compensate for the influence of the artifacts introduced by the stimulation pulses and RF transmission, different methods of artifact reduction were evaluated. The validity of the recorded responses was confirmed by (1) recording on/off responses, (2) determination of apparent latency across the measured pulse rates, and (3) comparison of amplitude growth of stimulus artifact and response amplitude.

The results show that EASSRs in CI users evoked by low-rate electrical pulse trains can be successfully recorded and separated from the artifacts generated by the stimulation pulses and RF transmission. The obtained response amplitudes and apparent latencies are comparable to the ones obtained in acoustically stimulated normal hearing patients. Hearing thresholds determined from EASSR amplitude growth correlate well with behaviorally determined threshold levels.

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C12: IMPROVED MODELING OF REFRACTORY RECOVERY IN ECAP

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In a recent series of studies (Hearing Research, volumes 247 and 248, 2009), Cohen developed a mathematical model of the peripheral neural response to cochlear implant stimulation. Methods were described that allowed determination of the model parameters for the individual patient. The model included refractory recovery and, by subtracting the model predictions from measured ECAP recordings of the refractory recovery, it was possible to deduce the contributions from facilitation (combined with small apparently inhibitory effects).

While the modelled fit to the refractory recovery of the ECAP was quite good for intense maskers and masker probe intervals beyond the absolute refractory period, there was a characteristic small deviation of the model function from the data. Further, because the functions describing facilitation had been derived from differences between modelled and experimental recovery functions, they appeared to have suffered relatively greater distortion.

The model assumed for simplicity that the "relative spread" (RS) of the neurons, a quantity proportional to the ratio of dynamic range to threshold and responsible for stochastic behaviour, remained constant during the relative refractory period. Cohen observed, however, that an increase of RS during the relative refractory period should enable the modelled recovery to match the experimental data more closely.

The present study introduced variability of RS to the modelling of refractory recovery, and investigated the difference between model and data. The variation of RS during the relative refractory period was based on animal data from Miller et al. (J. Assoc. Res. Otolaryngol. 2, 216–232, 2001). They showed that on average, for masker pulse interval ranging from about 500–1000 µs, and relative to its resting value, RS fell from about 2.0 to 1.0. In the present study, this function was employed but the difference between it and 1.0 was scaled, as the only variable. E.g., the relative RS could vary from 1.5 to 1.0 over the same time interval.

This refinement of the model resulted in much closer agreement for intense maskers between the modelled recovery function and the ECAP data. As a result, the derived functions for facilitatory contributions to the ECAP appeared more plausible. Generally, there was increased facilitation and reduced inhibition. The revised fits to refractory recovery resulted in longer recovery time-constants.

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C13: AUDITORY NERVE TEMPORAL RESPONSE VARIATION ACROSS ELECTRODES AND SUBJECTS

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Cochlear implant (CI) recipients' speech perception can differ for various rates of stimulation within the same speech-processing strategy. Differences in auditory-nerve temporal response properties across individuals may explain performance differences across rates. In this study, electrically evoked compound action potentials (ECAPs) were measured in response to successive pulses in pulse trains of varying rates. An alternating amplitude pattern as a function of pulse number is expected for slower rates, due to refractory properties of individual auditory nerve fibers. The alternating pattern typically diminishes at faster rates, due to combined effects of neural refractory-recovery mechanisms and adaptation. Lack of alternation in the ECAP amplitude pattern represents desynchronization of individual nerve fibers, or a state of relative stochasticity. The rate at which the ECAP amplitudes ceased alternation was defined as the "stochastic rate" for each electrode. The primary goal of this study was to determine the extent to which stochastic rate varied across electrodes within a subject as well as across subjects. A secondary goal was to determine whether stochastic rate was related to ECAP threshold and input-output (I-O) slope (estimates of nerve survival), and ECAP refractory-recovery.

To date, results have been obtained for 11 ears in 9 adult CI users. A basal, middle, and apical electrode were tested for each ear. Eight ears showed differences in stochastic rate across electrodes. If stochastic rate can be shown to relate to speech-perception performance, then this result suggests that the use of different stimulation rates across electrodes should be considered for future strategies. Stochastic rates ranged from 900 pps to 3500 pps across subjects. There was a significant negative correlation between ECAP thresholds and stochastic rates, with faster stochastic rates for electrodes with lower thresholds. There was no significant correlation between stochastic rate and either slope or recovery.

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C14: CORTICAL AUDITORY EVOKED POTENTIALS (CAEP) AND SPEECH PERCEPTION IN NOISE IN CHILDREN FITTED WITH COCHLEAR IMPLANTS

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It is known that speech perception deteriorates in background noise in hearing-impaired adults and children with hearing loss more significantly than for individuals with normal hearing. Reduced speech perception may result in poor phonological representations, contributing to speech and language delays in hearing-impaired children. When there is minimal benefit from hearing aids, cochlear implants (CI) can provide access to speech sounds needed for the acquisition of spoken language. Currently it is difficult to assess CI effectiveness using behavioural techniques in young children. CAEPs reflect the higher-level auditory processing of sensory stimuli underlying the identification and discrimination of speech sounds. CAEPs can be reliably recorded in young infants and therefore provide a useful tool for objectively evaluating CI performance. The objective of this study was to investigate the effects of various signal-to-noise ratios (SNRs) on speech evoked cortical responses in children who have received a CI. Previous studies have found significant detrimental effects of noise on CAEPs in children diagnosed with learning problems, suggesting that CAEPs in noise may provide a good objective indication of speech perception and auditory processing (Cunningham et al., 2001). Additionally, a number of studies have shown that CAEPs correlate well with speech perception. (Warrier et al., 2004; Kelly et al., 2005).

In the current study, the effect of noise on the amplitude and latency of CAEPs in six children fitted with a unilateral multi-channel CI were compared to that seen in six age and gender-matched control group children with normal hearing. CAEPs were compared to speech perception scores in noise. Speech perception was evaluated using words from the Lexical Neighbourhood Test presented at 70 dB SPL in quiet and at +5dB SNR. CAEPs were recorded using the consonant-vowel stimulus /da/ in quiet and at three different SNRs. CAEP morphology and latency changes were compared between groups using peak latencies and amplitudes and waveform intraclass correlations (comparing waveforms in quiet and in noise). Intraclass correlations reduced with poorer SNRs and poorer speech perception was associated with greater degradation of the CAEP waveform with noise. With further development, CAEP testing may help determine whether the CI is programmed optimally and whether the auditory information received from the CI is sufficient to facilitate normal speech and language development.

C15: MISMATCH OF ENVELOPE AND TEMPORAL FINE STRUCTURE INFORMATION DESTROYS THE PRECEDENCE EFFECT

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The precedence effect (PE) describes our ability to suppress detrimental effects of reflections on localization of sound sources in rooms. For short delays between a direct sound (lead) and its reflection (lag) only one sound is heard and localized at the location of the lead.

The information used by the auditory system to obtain the PE is still under debate. Models based on cross-correlation analysis rely on binaural cues extracted from the temporal fine structure (TFS) at low frequencies while envelope information is used to start a lateral inhibition process (e.g. Lindemann, 1986). Another modeling approach bases the PE entirely on envelope or repeated onset information (Zurek, 1987). The fact that some of our patients with bilateral cochlear implants (CIs) showed the PE for ongoing sounds suggests that envelope information can be sufficient (c.f. CIAP 2007); however, since most of our patients localized one sound in-between lead and lag, rather than at the lead, envelope information seems not to be sufficient in most cases. It can be expected that a perfect representation of TFS information will not be possible with CIs in the near future, making the study of the mechanisms and the limits of the PE – and with it the ability to function in multi-source environments – a high priority.

The contribution of TFS and envelope information to the PE was studied for noises of 300 ms duration. The envelopes of lead and lag were sinusoidally amplitude modulated (AM) and the modulation phase (delay) between lead and lag was varied across conditions. Subjects adjusted the delay of the TFS in the lag to find the echo threshold while the envelope delay was kept constant. To simulate imperfect TFS representation, the correlation between the TFS in the lead and the lag was varied.

Both AM and TFS strongly influenced the precedence effect:

1) No echo thresholds could be obtained for inconsistent delays between TFS and envelope, suggesting that both cues contribute to the PE of ongoing sounds and need to be consistently represented in future CIs.

2) For consistent delays the presence of AM elevated echo thresholds above the unmodulated baseline. This suggests that AM aids the PE potentially through the evaluation of multiple onsets or by serving as a grouping cue.

3) Despite partial TFS decorrelation between lead and lag the presence of AM made it possible to obtain echo thresholds, a potential route to overcome effects of imperfect TFS representation in electric stimulation.

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C16: ENVIRONMENTAL SOUND PERCEPTION IN COCHLEAR IMPLANT PATIENTS AND WHY IT MATTERS

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Environmental sound perception is an important component of daily living and a major concern for cochlear implant (CI) patients. Environmental sounds can alert listeners to immediate dangers as well as contribute to one's sense of awareness and well being. Perception of environmental sounds, as acoustically and semantically complex stimuli, may also involve some factors common to the processing of speech. This project (1) investigated the ability to perceive environmental sounds in patients with modern-day CIs and (2) explored associations among speech, environmental sounds and basic auditory abilities of CI patients.

Seventeen experienced postlingually-deafened CI patients participated. Environmental sound perception was assessed with a large-item test composed of 40 sound sources, each represented by four different tokens. The relationship between speech and environmental sound perception and the role of working memory and basic auditory abilities was examined based on patient performance on a battery of speech tests (HINT, CNC, and individual consonant and vowel tests), tests of basic auditory abilities (audiometric thresholds, gap detection, temporal pattern and temporal order tests), and a backward digit recall test.

The results indicate substantially reduced ability to identify common environmental sounds in CI patients relative to normal hearing adults (i.e. P(c) = 46% vs. 98%, respectively). All speech test scores correlated strongly and significantly with the environmental sound test scores: r = 0.82 for HINT in quiet; r = 0.75 for HINT in noise, r = 0.79 for CNC, r = 0.70 for vowels and r = 0.82 for consonants. Both speech and environmental sound tests moderately correlated with gap detection, temporal order test and backward digit recall test. However, the correlation between speech and environmental sounds changed little after partialing out the variance due to other variables. These results suggest that speech and environmental sounds may overlap considerably in their perceptual processing, being largely independent of peripheral limitations that may affect both sound classes. Most CI participants also expressed an interest in further environmental sound rehabilitation.

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C17: CONTRIBUTIONS OF TEMPORAL AND PLACE CUES TO PITCH IN THE APICAL REGION

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Pitch is a fundamental attribute of auditory perception. Animal studies have shown that pitch can be encoded by either the place of excitation as a function of stimulus frequency along the cochlea, i.e. the 'place code', or the temporal structure of neural discharges that is phase-locked to the frequency, i. e. the 'temporal code'. In the new MED-EL FSP strategy, Channel-Specific Sampling Sequences (CSSS) (Zierhofer, 2001) are used in the low and mid frequencies in an attempt to produce better temporal coding through improved phase locking. These channels provide the time and place code for the fundamental frequency as well as for the lower harmonics of the sound signal.

Eight subjects with near-to-normal hearing in the contralateral ear have been provided with a MED-EL cochlear implant in the deaf ear in order to reduce intractable tinnitus. Pitch matching experiments were performed using six single-electrode stimuli (E1-E6) in the implanted ear and five acoustic sinusoids (100Hz-150Hz-200Hz-300Hz-450Hz) in the contralateral ear. Subjects were asked to match the repetition rates of single pulses or sequences of high-rate pulses on a certain electrode to a fixed acoustic stimulus.

Results show a fairly good representation of low frequencies by rate. Rate and place of stimulation cannot be exchanged arbitrarily in order to elicit a particular pitch. For instance, in most subjects low-frequency tones (100 and 150 Hz) cannot be matched to any sequence repetition rate on more basal electrodes, and neither can higher-frequency tones (300 and 450 Hz) on the apical-most electrodes. Very low pitches can only be elicited with low sequence repetition rates on apical electrodes.

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C18: ACOUSTIC TEMPORAL MODULATION TRANSFER FUNCTIONS IN COCHLEAR IMPLANT USERS

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Acoustic temporal modulation transfer functions (TMTFs) were evaluated in 22 cochlear implant (CI) users. This approach differed from previous CI studies in measuring TMTFs that the current study used the clinical sound processor with acoustic presentations of modulated noise over a loud speaker rather than using direct modulation of the electrical charge on a single electrode. It was hypothesized that the acoustic modulation detection thresholds (MDTs) would be more predictive of clinical outcomes which also evaluate performance using the clinical sound processors.

In Experiment 1, the MDTs for sinusoidally amplitude modulated noise were measured to determine the TMTFs. Modulation frequencies of 10–300 Hz were tested with a single-interval, 2-alternative forced-choice, 2-down, 1-up adaptive procedure (Bacon and Viemeister, 1985). The relationships of the acoustic MDTs with spectral-ripple discrimination, Schroeder-phase discrimination, speech recognition, and music perception were examined. The results showed that MDTs decreased as a function of modulation frequency. The MDTs at 300 Hz were significantly correlated with speech perception in steady-state noise ($r = 0.59$, $p = 0.03$) and in quiet ($r = 0.66$, $p = 0.007$). Complex-tone pitch-direction discrimination ability correlated with the MDTs, ranging from 0.60 to 0.70, depending on F0. A significant correlation was also found between the MDTs at 200 Hz and Schroeder-phase discrimination at 100 Hz ($r = -0.74$, $p = 0.007$). Most importantly, the combination of the spectral-ripple threshold and the MDT at 300-Hz strongly predicted the speech perception in quiet ($r = 0.81$, $R^2 = 0.65$) and in noise ($r = 0.74$, $R^2 = 0.60$).

In Experiment 2, a fast MDT test (30 minutes) was developed to evaluate different sound processing strategies. Five subjects were tested with HiResolution and Fiedelity120. It was hypothesized that envelope-based pulsatile strategies would not show any difference in the MDTs. The two strategies showed no difference ($p = 0.38$). This acoustic MDT test could be used to evaluate future sound processing strategies which attempt to improve the temporal envelope encoding.

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C19: EFFECTS OF VARIATION IN SIGNAL POSITION AND FREQUENCY ON DETECTION OF SIGNALS IN REPRODUCIBLE NOISE

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We utilized a molecular psychophysical approach to evaluate individual differences in performance on three simultaneous masking tasks and a forward masking task using reproducible noise samples. The simultaneous tasks involved detection of a 500-Hz sinusoid, detection of a 500-Hz sinusoid presented at two starting positions, and detection of either a 500-Hz or 2000-Hz sinusoid. The forward masking task involved detection of a 500-Hz sinusoid. The noise samples were presented alone or with the signal. For each task, data were collected at a single presentation level with the S/N for each subject fixed to maintain P(C)=70%.

Results from subjects with normal hearing were compared to results from subjects with cochlear implants. For the listeners with normal hearing, within- and across-subject variability in the responses to the individual noise samples was somewhat limited. The listeners with cochlear implants could perform the tasks, but they required much higher signal levels than the listeners with normal hearing for the same overall performance, and there was a great deal of within- and across-subject variability in the responses to the individual noise samples.

For both groups of listeners, a two-parameter (bandwidth and decay constant), electrical analog model (EAM) [Jeffress, 1967,1968; Gilkey & Robinson, 1986] was used to explain subject response variance. A single-channel model was used to evaluate the first and second simultaneous tasks and the forward masking task (500-Hz tone). As expected, models with narrow bandwidths and fairly short decay constants explained a high percentage of the variance in the individual subject responses for the first task. For the second task, the decay constants were much longer than those with the single signal interval. For the forward masking task, models with very short decay constants fit the data well. For the fourth task, a two-channel model, with channels centered at 500-Hz and 2000-Hz explained a large percentage of the variance in the subject responses. Bandwidths were somewhat narrow than those predicted by critical band estimates, and the relative weight assigned to the 2000-Hz channel varied substantially for the different listeners.

Differences in response performance and model results between the listeners using cochlear implants and the listeners with normal hearing and further implications will be discussed.

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C20: PITCH-RELATED SPEECH PERCEPTION ABILITIES AND LINKS TO MUSIC INVOLVEMENT IN EARLY-IMPLANTED CHILDREN

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While pitch-related information is crucially important for speech prosody and thought to contribute to the recognition of speech in noise, pitch perception is often reported to be problematic for adults and children with Cochlear Implant devices. The ability to use prosodic stress cues may also play an important role in language acquisition of children with CI devices, especially when the CI limits access to segmental phonetic information This study investigates potentially pitch-related perceptual skills in a group of Finnish implanted children. Many of these children take part in musical activities and links between perceptual abilities and musical activity are also addressed. The aim of this research is to compare statistically how these abilities are inter-related in children with CI-devices who are now aged 4-12 and were implanted before 3 yrs of age. An age-matched normal-hearing control group is also tested

Perceptual measures included 1) discrimination of intensity, duration and pitch differences in the synthesized speech stimulus /tata/ 2) identification of focus and syllabic stress from natural speech 3) recognition of Tyler matrix sentences in noise. In addition, auditory digit span was measured and children's parents completed a questionnaire on the amount and quality of music involvement.

The preliminary results from 17 CI and 17 control subjects show that nearly all measured skills were age-related. Discrimination of duration showed no age-effect, which indicates that the discrimination test used here was not too difficult for the younger children. When age was controlled, results from MANCOVA show that CI and control groups differed significantly in the perception of speech in background noise and in the perception of pitch and duration differences. The auditory digit span in the CI-group increased more slowly with age than in the control group. CI and control groups did not differ in the perception of syllabic stress, focus or discrimination of intensity. Speech perception in background noise in the CI group correlated with the perception of syllabic stress and with pitch discrimination after effects of age were partialled out. The perception of focus and stress, recognition of speech in background noise and aspects of pitch discrimination also showed links to the amount of music involvement.

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C21: EFFECT OF REVERBERATION AND NOISE ON SPEECH RECOGNITION OF CHILDREN WITH COCHLEAR IMPLANTS

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Communication rarely takes place in environments with optimal acoustics and minimal noise. Yet much of the information about speech recognition performance of children is obtained under these conditions. The purpose of the present study is to determine the effect of reverberation, noise, and their combination on the speech recognition performance of children with prelingual hearing loss implanted by 3 years of age. Speech recognition in quiet was determined using the BKB-SIN sentences for the anechoic condition, and in reverberation with RT_{60}= 0.3, 0.6, and 0.9s. SNR-50 is determined for the noise and combined reverberation/noise conditions. Results to date indicate that reverberation times typical of classrooms significantly degrade speech recognition in quiet. The signal-to-noise ratios required by the children with and without reverberation are significantly higher than those required by normal hearing children. Results will be interpreted relative to signal-to-noise ratios and reverberation times typical of classroom environments.

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C22: EFFECTS OF LINGUISTIC EXPERIENCE ON THE USE OF ACOUSTIC CUES IN QUESTION-STATEMENT IDENTIFICATION BY PEDIATRIC COCHLEAR IMPLANT RECIPIENTS

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We have previously demonstrated that English-speaking cochlear implant (CI) recipients and normally hearing (NH) listeners exhibit different patterns in utilizing multiple sources of prosodic information, including variation in fundamental frequency (F0), intensity, and duration, in question-statement identification. In our experiments, CI listeners used F0 and intensity information in question-statement identification, whereas NH listeners used F0 information exclusively in the same task. The purpose of this study was to examine the effect of linguistic experience in a similar experiment conducted with Mandarin-speaking, pediatric CI recipients.

Twenty Mandarin-speaking, pediatric CI recipients and their age-matched NH peers served as subjects (N = 10 in each group). F0, intensity, and duration patterns of a disyllabic word, *popcorn*, were manipulated orthogonally, resulting in 360 resynthesized stimuli. In a two-alternative forced-choice task, each CI and NH subject identified whether each full-spectrum stimulus sounded like a question ("asking") or a statement ("telling"). Each NH listener also identified spectrally degraded stimuli under acoustic CI simulations. Listeners' sensitivity to each acoustic parameter (F0, intensity, and duration) was estimated based on the slopes of psychometric functions fit to the data, taking into consideration potential subject response biases. Data were analyzed at both the group and individual levels.

Preliminary analyses of data obtained with 5 CI and 10 NH subjects indicate that unlike the English-speaking CI listeners who used F0 and intensity properties in question-statement identification, the Mandarin-speaking, pediatric CI recipients used F0, intensity, and duration properties in identification. Interestingly, duration has been reported as a cue for Mandarin lexical tone recognition. It is plausible that the linguistic experience shapes the patterns of prosodic cue integration by Mandarin-speaking CI listeners in question-statement identification. The Mandarin-speaking NH subjects' performance was comparable to that of the Mandarin-speaking CI subjects under acoustic CI simulations. These findings suggest that linguistic experience, in addition to spectral resolution, plays an important role in CI listeners' speech prosodic perception.

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C23: RECOGNITION OF SPEECH WITH A COMPETING TALKER USING FINE STRUCTURE IN COCHLEAR IMPLANTS

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Several studies have shown the importance of F0 or voice pitch information for the segregation of competing speech sounds. In contrast to present-day implant systems, which only transform information of the envelope of a signal, the addition of temporal fine structure (FS) may support a more robust encoding of F0 in cochlear implants.

The investigated FS coding strategy presents temporal fine structure information on low-frequency channels and combines them with mid- to high-frequency CIS channels. On the FS electrodes, series of stimulation pulses are triggered by zero-crossings in a channel's band-pass filter output and scaled with the channel envelopes. Hence, both fine structure and envelope information are represented.

Speech reception thresholds (SRTs) for German OLSA sentences with a male talker and a female masker sentence were measured in 7 MED-EL recipients to date. Acutely compared coding strategies included CIS, a fine structure strategy with 4 apical FS channels from 100-800 Hz (FS-1), and a setting comprising 2 FS channels from 300-800 Hz (FS-2).

Mean SRTs were -5.1 dB for FS-1 with 4 FS channels and -4.7 dB for CIS, indicating a small, however not significant acute benefit with fine structure stimulation. FS-2 with temporal FS representation only in a filter bank starting at 300 Hz resulted in a mean SRT of -1.2 dB.

Results indicate the importance of low-frequency information when encoding temporal fine structure, and in particular the need to include the pitch range of male voices. FS-1 was acutely on a par with the CIS control condition, which always utilized the same number of channels and identical frequency bands as FS-1. Representing temporal FS only above 300 Hz (FS-2) substantially degrades performance.

The present results are promising when considering recent findings of longitudinal studies, which at first often show an acute decrement in performance with FS stimulation, to then substantially improve only after several months of FS listening experience.

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C24: PROCESSING OF SPECTRALLY DEGRADED VOICE PITCH BY OLDER LISTENERS

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Cochlear implants (CIs) are highly successful among hearing impaired listeners of all ages, including those in the elderly population. However, it is well established that temporal processing declines with advancing age regardless of hearing status. Further, it has been hypothesized that CI users greatly rely on temporal cues to code for voice pitch information, which plays an important role in everyday listening. The impact of age-related changes in temporal processing on voice-pitch processing by older CI users, is as yet unknown. Several experiments were conducted among younger (ages 21-30) and older (ages 60-75) NH listeners using simulations to estimate performance in actual CI users. One experiment consisted of a modulation rate discrimination task, in which stimuli were 200 ms, sinusoidally amplitude modulated broadband noise bursts; the standard modulation rate was always 100 or 200 Hz, while the experimental modulation rate was varied. Thresholds were measured using a 3-AFC procedure (method of constant stimuli). Overall, results show significant differences in performance between younger and older listeners, with older individuals exhibiting higher (worse) thresholds across both test frequencies.

A second experiment measured gender identification of spectrally degraded vowels in the two age groups. The number of spectral channels was manipulated between 1 and 32, while the cut-off frequency of the lowpass temporal envelope filter ranged from 20-400 Hz. Stimuli were six vowel phonemes spoken by eight talkers (four male, four female). In the first condition ("easy"), the F0s of the eight talkers ranged from 100 to 275 Hz. In the second condition ("hard"), the F0 of the eight talkers ranged from 150 to 220 Hz. Results showed significant differences in performance between the two age groups, with older listeners performing worse in nearly all degraded conditions. Further, in some cases the younger listeners were able to utilize the residual temporal envelope cues in order to aid in voice-pitch processing, particularly in the "hard" condition; however, the older listeners were less able to use such temporal cues. These results, as well as results of ongoing parallel investigations measuring fundamental-frequency difference limens and speech-on-speech masking in the two groups of listeners, will be presented. Implications for actual outcomes and rehabilitation among CI recipients will be discussed.

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C25: SPECTRAL RESOLUTION AND INTELLIGIBILITY OF REVERBERANT SPEECH IN SIMULATED ELECTRIC-ACOUSTIC LISTENING

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Reverberation is one type of competing background that impairs speech intelligibility for cochlear implant (CI) users. A recent study done in our laboratory using simulations of CI listening suggests that the combined use of electric and acoustic stimulation (EAS) may attenuate the detrimental effects of reverberation. We found that the addition of low-pass speech to a 4-channel vocoder substantially improved the intelligibility of reverberant speech, and that the EAS benefit was greater in reverberation than in speech-shaped noise equated to the reverberation. We hypothesized that this additional benefit may be due to the availability of the target talker's fundamental frequency in the reverberation, but not in the noise. The purpose of the present study was to determine in simulation
the relationship between EAS benefit in reverberation and low-frequency spectral resolution.

IEEE sentences were convolved with impulse responses from a simulated reverberant space. The absorption coefficient of the room's surfaces was varied to achieve estimated reverberation times of 0.0, 0.125, 0.25, 0.5, and 1.0 second. The sentences were then low-pass filtered at 500 Hz or processed through a vocoder with 4, 5, 6, 8, or 12 channels. To examine the importance of spectral resolution in the low-frequency region, the vocoder was configured with four logarithmically spaced channels between 750 and 5500 Hz, and 1, 2, 4, or 8 additional channels from 100 to 500 Hz. To control for the effect of simply adding more channels, a "standard" configuration was also examined, in which varying numbers of channels (4, 5, 6, 8, or 12) were logarithmically spaced from 100 to 5500 Hz. Normal-hearing participants listened via headphones. Sentence intelligibility scores in vocoder-only and in 4-channel vocoder-plus-low-pass speech conditions were measured at each reverberation time. In the "low frequency" configuration, the addition of a single channel substantially improved the intelligibility of reverberant speech. Across reverberation times, performance increased monotonically with increasing numbers of channels, but never reached the level of performance observed in the vocoder-plus-low-pass speech condition. This improvement was not due to an increase in channels per se, as performance for a given number of channels was generally better in the low-frequency configuration than in the standard configuration. Thus, increasing resolution in the low frequencies appears to be important for recognition of reverberant speech. This is consistent with the possibility that fundamental frequency cues provide considerable benefit in reverberant conditions.

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C26: EVALUATION OF A NOVEL NOISE REDUCTION METHOD

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State-of-the-art sound processing for cochlear implants allows recipients to achieve a high degree of auditory performance. Speech reception has been restored to the point that it is commonplace for implant users to be able to understand conversational speech solely using auditory cues. Consequently, the emphasis in sound processing design is evolving towards more challenging conditions, such as understanding speech in noise. With grant support from the U.S National Institutes of Health, Sensimetrics has been studying methods that use multiple microphones for reducing noise for cochlear implants. One such algorithm, called Fennec, has shown clear intelligibility improvements for implant users in laboratory studies. Fennec uses two microphones on a single BTE unit and exploits the phase and amplitude information from those microphones to enhance sound arriving from in front of the listener. In laboratory evaluations conducted at Sensimetrics, four microphone configurations (all of them applicable to a unilateral device) and associated algorithms were considered: 1) a cardioid response, 2) a Link-It microphone, 3) Fennec, and 4) an implementation of the BEAM algorithm. Systems 1, 3, and 4 all use two omnidirectional microphones mounted on a BTE unit; system 2 is a small endfire array that fits adjacent to the BTE unit. The test signals for the evaluations were generated off-line prior to testing. The target signals were IEEE sentences spoken by 5 male talkers. The maskers were either speech-shaped noise (SSN) or time-reversed speech (TRS). Targets and maskers were presented at virtual locations, which were represented by source-to-microphone impulse responses recorded in a reverberant room. Targets were always presented at a 0° virtual location. Maskers were presented at either one virtual location, (135°), or simultaneously at two virtual locations (135° and 225°). All sources were located 1m away from the center of KEMAR's head. Appropriate target and masker levels were determined individually for each subject based on the results of an adaptive procedure for the cardioid condition. The conclusions are: 1) Fennec outperforms all other algorithms when time-reversed speech is used as a masker; 2) Link-It outperforms all other algorithms when speech-shaped noise is used as a masker; 3) Fennec outperforms BEAM on all conditions tested; 4) averaged across conditions, Fennec outperforms the other algorithms.

C27: SOUND-DEPENDENT ENVELOPE COMPRESSION FOR IMPROVED SPEECH RECOGNITION IN NOISE

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Cochlear implant (CI) user's performance degrades significantly in noisy environments. The present study examines the hypothesis that when listening to speech in fluctuating maskers (e.g., competing talkers), CI users can not fuse the pieces of the message over temporal gaps because they are not able to perceive reliably the acoustic landmarks introduced by obstruent consonants (e.g., stops). These landmarks are evident in spectral discontinuities associated with consonant closures and releases and are posited to aid listeners determine word/syllable boundaries.

To test this hypothesis, CI users are presented with IEEE sentences containing clean obstruent segments, but corrupted (by steady noise or fluctuating maskers) sonorant segments (e.g., vowels). Results indicated that CI users received a substantial gain in intelligibility when they had access to the acoustic landmarks provided by obstruent consonants. Larger improvements in intelligibility were particularly noted in fluctuating masker conditions compared to steady-noise conditions, suggesting that CI users received masking release.

A second experiment was conducted to examine the reasons contributing to the CI users' inability to perceive reliably the acoustic landmarks present in the signal. It is hypothesized that the envelope compression smears the acoustic landmarks that signify syllable/word boundaries. To test this hypothesis, we presented to CI users noise-corrupted sentences processed via an algorithm that compresses the envelopes using a logarithmic-shaped function during voiced segments (e.g., vowels) and uses a less-compressive mapping function during unvoiced segments (e.g., stops). Results indicated that the use of a less compressive function applied only during unvoiced segments yielded a significant improvement in intelligibility. This outcome is consistent with our hypothesis that envelope compression, particularly in noise, smears the acoustic landmarks present in the envelope, making it difficult for CI listeners to determine word/syllable boundaries.

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C28: HRSTREAM: THE HIGH RESOLUTION STREAMING INTERFACE

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To explore the potential benefits of different ways of electrically stimulating the auditory nerve in order to improve particular aspects of electrical hearing, researchers often have a need to set up research evaluations in the area of psychoacoustics of sound processing under the guidance of their ethical commission. The stimulation tokens typically deviate from the standard clinical patterns, e.g. in terms of the electrode configuration (multipolar) or the pulse shape (multiphasic). In such an experimental setup typically tokens are prepared on the computer and sent in quasi real-time to the implant through a fast interface. So the experimenter needs a component that can be integrated in their own larger experimental setup with which the stimulation pattern of the cochlear implant configuration can be defined on the computer and stimulated in quasi real-time.

The Advanced Bionics HR90K device has a flexible and fast electronic platform with many attractive stimulation features. However its native programming language is also complex and hard to use. Therefore Advanced Bionics Europe has developed a streaming interface called HRSTREAM hiding much of the complexity and presenting a much more intuitive user interface. HRSTREAM relies on a USB hardware interface, termed the Serial Interface Board (SIB). The SIB connects to the Portable Speech Processor (PSP) using the standard PSP Programming cable.

The sound processing in the HR90K platform follows a strict amplitude modulation paradigm. The HRSTREAM component provides 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 amplitude in micro Ampere. By analogy with amplitude modulation, the strategy file contains the carrier signal and the stimuli source contains the modulating information.

This software interface exposes a .NET interface, a COM and a C++ interface. Therefore many interfacing possibilities exist to other applications. e.g. Matlab.

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C29: CLINICAL OUTCOMES OF THE MP3^{000}™ SOUND CODING STRATEGY OPTIMIZATION STUDY IN FREEDOM™ RECIPIENTS

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Introduction: MP3^{000} is a sound coding strategy based on psycho-acoustic masking, which has been implemented on the Nucleus® Freedom cochlear implant system. The objectives of the study were to optimize the MP3^{000} parameter settings, to investigate the preference and speech intelligibility for MP3^{000} in comparison to ACE™ and to assess battery life.

Materials and method: A prospective, multi-centre study was conducted in 9 different European countries, including a total of 37 cochlear implant centres, recruiting 247 Freedom recipients. At study entry threshold (T) and comfort (C) levels were optimized. Different numbers of maxima and masking function slopes were tested to optimize the MP3^{000} parameters. Speech intelligibility was assessed in Dutch, English, French, German, Polish, Italian and Spanish for MP3^{000} and ACE according to an ABABA design to compensate for learning effects. Battery life was logged in diaries and recipients were asked to indicate their preferred coding strategy and parameter settings.

Results: No significant difference in either speech intelligibility ($p=0.4$) or preference ($p=0.2$) for MP3^{000} and ACE were observed. T and C level profiles increased by 6 and 7 CLs when converting ACE to MP3^{000}. Most recipients preferred MP3^{000} with higher numbers of maxima and narrow masking functions. The average battery life increased significantly by 24%.

Conclusion: MP3^{000} provides a sound coding strategy with the benefit of significantly increased battery life, without affecting speech intelligibility. MP3^{000} is equally preferred as ACE, the coding strategy that the Freedom recipients were accustomed to before entering the study.

C30: INVESTIGATING THE ACUTE AND LONGITUDINAL BENEFITS TO SPEECH RECOGNITION OF A TUNED MULTI-RATE SPEECH PROCESSING ALGORITHM FOR COCHLEAR IMPLANTS

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Multi-rate stimulation is one proposed method for transmitting additional spectral cues to cochlear implant listeners with the goal of improving speech recognition in noisy conditions and music perception. However, previous multi-rate implementations have not resulted in improvements in speech recognition performance compared to clinically available algorithms. In this study, the hypothesis that using subject-specific psychophysical data to tune a multi-rate speech processing strategy is necessary for listeners to utilize rate-based cues was tested.

The pitch structure that results from multiple stimulation rates and electrodes was assessed using a series of pitch-ranking tasks. Results suggest that stimulating different electrodes at two different rates often evokes pitch percepts that do not follow the tonotopy of the cochlea. This behavior suggests that previous implementations of multi-rate strategies may have induced overlapping pitch percepts and thus potentially presented distorted speech information.

The effects of duration and context on place pitch and rate pitch and rate discrimination were also studied. No clear effect of duration was observed on pulse rate difference limens (PRDLs) measured without an interstimulus interval or on place pitch. Results also suggest that PRDLs increase when the interstimulus interval between changes in rate is removed. The minimum duration required for detecting an embedded rate change was measured, and no clear minimum duration was observed.

The Multi-Carrier Frequency Algorithm (MCFA) was implemented with and without the inclusion of subject-specific pitch-rank data (termed tuned and generic respectively) and compared to the ACE strategy. In general, the generic MCFA resulted in an improvement in closed- and open-set speech recognition performance in a quiet condition with a further improvement observed for tuned implementations. Improvements in performance with respect to ACE were also observed for a subset of the subjects tested in 5 dB of speech-shaped noise. Two subjects participated in a three-week take-home study in which they listened to a tuned MCFA using the SPEAR3 research sound processor. Performance improved over the three-week period for both subjects, and results motivate the further investigation of using tuned multi-rate strategies for the purpose of transmitting additional spectral information to CI listeners.

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C31: TRAVELING WAVE DELAYS FOR COCHLEAR IMPLANTS: A STUDY OF ACROSS-FREQUENCY DELAYS

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A new sound coding enhancement incorporating cochlea-based delays was developed and assessed in cochlear implant recipients using the ACE strategy. Delays were applied to the outputs of band-pass filters, resulting in an offset between frequency bands. In previous research, across-frequency delays based on traveling wave delays were found to improve speech perception in noise in adult users of ACE. This study was an evaluation of a broad ensemble of across-frequency delays.

Maximal across-frequency delay ranged from -12 to +12 ms, defined as lowest frequency delay relative to highest frequency delay. Delay conditions were randomized with a balanced Latin square design. These were evaluated in eight users of ACE with eight maxima selected and a stimulation rate of 900 pps/ch. All subjects had Nucleus CI24 implants, with stimuli transmitted directly from a PC.

For CUNY sentences in babble noise, the best condition was a maximal delay of +6 ms, however mean group improvement was small (+3%, $p = 0.055$). Four subjects improved with this delay, three showed no change and one was worse. Speech in quiet was assessed with CNC words, where four subjects improved with across-frequency delays and four showed no change. Mean word recognition increased by 4% with delays compared to without ($p = 0.027$). Information transmission analysis indicated that discrimination of place of articulation was improved with across-frequency delays compared to baseline.

A computational investigation into cochlear implant stimulation patterns was performed to help interpret these results. TIMIT speech was processed under a range of parameter combinations, and stimulation metrics were tallied. Across-frequency delays increased the number of stimulus pulses by 5% for some voiced phonemes. The extra stimuli were generated at the glottal pulses, as contention for maxima selection was reduced when channels were de-synchronized. In general, across-frequency delays aided maxima selection during those high-energy segments of speech that are common in a single talker.

This sound processing enhancement can be incorporated into existing cochlear implant strategies at little computational cost.

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C32: VOICE IDENTIFICATION OF PATIENTS WITH THE HYBRID AND LONG-ELECTRODE COCHLEAR IMPLANT

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Studies on the new, electric plus acoustic (A+E), Hybrid cochlear implant (CI) have shown many improvements over the traditional, long electrode, CIs in everyday abilities, such as music perception and the recognition of speech in a background of other talkers. One hypothesis regarding speech in backgrounds is that the Hybrid CI allows for better separation of the target voice from the other talkers. The purpose of this study is to measure patients with Hybrid CIs' ability to identify voices based solely on auditory information. Their scores are compared with those of patients with long-electrode CIs, as well as the performance of normal hearing listeners listening to simulations of long electrode CIs and Hybrids CIs.

Twelve spondees from eight normal hearing talkers (four male and four female) were processed through MatLab programs to produce simulations of 8-channel long-electrode processing and A+E Hybrid processing. Normal hearing subjects were than tested using these unprocessed, hybrid, and 8-channel processed stimuli from four talker combinations: either two females / two males, four male, or four female. The subject's task was to listen to a spondee produced by a random test talker on that trial and identifying the test talker by choosing from an alternative token spoken by the test talker and 3 other talkers. Hybrid and long electrode CI patients were tested using the unprocessed stimuli from the same four talker combinations. All implanted subjects had had their implant for minimum of a year before testing and had their contralateral ear plugged during testing.

In all talker combinations, normal listener simulations yielded best performance in the unprocessed condition, followed by the Hybrid condition, with the long electrode simulations poorest. This suggests a significant theoretical advantage for hybrid CIs over long electrode CIs. In limited results to date, actual CI patients (both Hybrid and long electrode) show a somewhat similar pattern to each other, with slight advantages for the Hybrid over long-electrode.

Support provided by NIDCD-NIH.

C33: EVALUATING PERFORMANCE IN TRADITIONAL AND HYBRID COCHLEAR IMPLANT PATIENTS

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In the past, the use of cochlear implants was limited to patients with little or no acoustic hearing across the entire frequency range. However, there are number of people with severe high-frequency hearing loss who do not benefit from the new hearing aid technology; providing amplification to high-frequency sounds does not always restore speech understanding. The Iowa/Nucleus Hybrid cochlear implant can preserve residual low frequency hearing and electrically stimulate the high frequencies enabling the patient to combine acoustic and electric information. While studies have shown benefit for patients implanted with the traditional (long-electrode) cochlear implant as well as the Iowa/Nucleus Hybrid cochlear implant, further investigation is warranted to determine the optimal eligibility requirements for Hybrid implantation, i.e. whether a patient should be implanted with a Hybrid or long-electrode cochlear implant. Performance in these patients can be compared from a number of different perspectives and will be examined in this study.

Previous work (Turner et al, 2004) showed a 9 dB signal-to-noise ratio advantage in competing-talker noise for a group of Hybrid patients compared to a group of long-electrode patients. A more recent study (Turner et al, 2008) comparing a larger group of Hybrid patients to a matched group of long-electrode patients showed an advantage of 4.2 dB for the Hybrids. Over the years, there have been changes to the Hybrid candidacy criteria, internal receiver-stimulator technology, external processor technology, and processing strategies. In order to make fair comparisons to the Hybrids, a new group of long-electrode implant patients with Nucleus CI24M, CI24R, or CI24RE internal receiver-stimulators using a Freedom external processor were recruited. Speech recognition performance was evaluated using a test of 16 consonants presented in /a/-consonant-/a/ context. Speech in noise performance was obtained by asking the listeners to identify spondee words in the presence of steady-state noise and competing-talker noise conditions.

When a comparison group of these new long-electrode patients, selected so that their speech recognition in quiet matched the Hybrid group, the advantage in noise remained and was about 5 dB. Comparisons will also be presented which look at the effects of changing the two groups' composition based on various predictive pre-operative factors and/or to equalize speech recognition in quiet. The goal is to optimize the criterion for candidacy for the two approaches to cochlear implantation.

Support provided by the NIH-NIDCD.

C34: ENHANCEMENT OF ACTUATOR DISPLACEMENT FOR INTRA-COCHLEAR APPLICATIONS

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Combined electric and acoustic stimulation has proven to be an effective strategy to improve hearing in some cochlear implant users. We describe our continued work to develop an intra-cochlear acoustic actuator that could be used as a component of a single integrated acoustic-electric electrode array. The acoustic actuator takes the form of a silicon membrane driven by a piezoelectric thin film (e.g., lead-zirconium-titanium oxide [PZT]) that is 800 microns by 800 microns wide, with a thickness of 1 micron in silicon and 1 micron in PZT. Design specifications suggest that an intra-cochlear acoustic actuator of these dimensions must deliver at least a displacement of 200 nm to give a 20 dBA improvement over normal hearing. Our previously fabricated actuator, however, had a displacement of 70 nm as its best performance.

We used a two-prong approach to enhance the actuator performance. First, we measured actuator dimensions using a scanning electronic microscope followed by a parametric study via finite element analyses to optimize the actuator dimensions. By optimizing the thickness of the top electrode, the actuator displacement in our current iteration exceeds 200 nm with a 4V driving voltage. Second, we measured natural frequencies of the actuator and compared them with predictions from the finite element analyses. We found that residual stresses arising from microfabrication in the form of tensile in-plane stresses can significantly stiffen the actuator thus reducing its displacement. Therefore, residual stresses should be carefully controlled in fabrication.

We also used the finite element analyses to estimate acoustic impedance of the intra-cochlear actuator. With the current design, the acoustic impedance is about 250 MKS $G\Omega$ at 1 kHz. For comparison, measured impedance of human cochlea is about 100 MKS $G\Omega$ at 1 kHz. Therefore, the PZT micro-actuator should be strong enough to overcome fluid loading in human cochlea.

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C35: IMPROVED HORIZONTAL DIRECTIONAL HEARING IN UNILATERAL CONGENITAL CONDUCTIVE HEARING IMPAIRED PATIENTS FITTED WITH A BAHA

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Sound localization in the horizontal plane (azimuth) requires neural processing of binaural difference cues in timing and sound level. Hence, unilaterally deaf patients have been reported to be severely impaired in localizing sounds in azimuth. However, there exists conflicting evidence concerning localization performance of patients with unilateral conductive hearing loss. These contradictory results suggest that it might be possible for this latter group of patients to learn to localize sounds in azimuth. To investigate the ability as to whether patients with unilateral conductive hearing loss localized sounds in the horizontal plane, we tested patients fitted with a BAHA on the impaired side in the aided (BAHA turned on) and unaided (BAHA turned off) condition. We interleaved different sound levels to eliminate the possibility to use the acoustic head shadow effect as a localization cue. We applied 100 ms duration broadband, low-pass, high-pass, 500 Hz narrow-band (1/3 octave) and 3 kHz narrow-band (1/3 octave) noises to dissociate the use of interaural time differences (ITDs) and interaural level differences (ILDs) as localization cues.

Our preliminary results from five subjects indicate that sound localization performance in azimuth was typically poor when patients were tested in the unaided condition. However, we observed a significant improvement in sound localization when their BAHA was turned on.

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C36: BILATERAL COCHLEAR IMPLANTS: PSYCHOPHYSICS AND SPEECH UNDERSTANDING

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Clinical fitting of bilateral cochlear implants has not been designed to maximize binaural abilities, nor has research determined that fitting modifications would deliver significant binaural enhancements with today's processors. One measure that could be used to guide bilateral fitting is interaural pitch comparison. Studies have examined the relation of interaural pitch to binaural sensitivity in a small number of subjects (e.g., van Hoesel RJ and Clark GM. J Acoust Soc Am. 1997 Jul;102(1):495-507; Long CJ, Eddington DK, Colburn HS, Rabinowitz WM. J Acoust Soc Am. 2003 Sep;114(3):1565-74.). But, systematic measures of interaural pitch comparisons on an electrode-by-electrode basis with a large number of subjects with relation to other interaural abilities are lacking. In addition, the effect of exposure to a given frequency mapping on interaural comparisons and on speech understanding remains unclear. This study aims to address the above issues.

Thus, the present study examines electrode-by-electrode interaural pitch-matching and pitch-ordering for users of Nucleus cochlear implants for every functioning electrode. It relates the pitch results to (1) the frequency allocation tables these recipients use in everyday life; (2) measures of interaural time difference sensitivity and binaural fusion; and (3) measures of monaural sensitivity; (4) speech understanding.

Some subjects in this study have shown dramatic differences between their pitch ordering and the frequency allocation tables they have used. The results will be discussed in terms of the relations between the different measures; the utility of pitch comparisons in probing the binaural system; and the effect of adjustments to frequency allocation tables on speech reception and subjective judgments. The evidence for and against plasticity will also be discussed.

C37: SPATIAL LISTENING WITH BILATERAL IMPLANTS OR BIMODAL DEVICES: A SIMULATION STUDY

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We have created tests of spatial listening that are administered in a ring of loudspeakers. Children who use bilateral cochlear implants (CI-CI) or an implant and an acoustic hearing (CI-HA) show poorer performance than normally-hearing children on these tests (Lovett, Kitterick and Summerfield, 2009). To investigate the proportion of the deficit in performance that is due to the signal processing carried out by implant systems, and the limited bandwidth of CI-HA children's residual hearing, we carried out a simulation study with adults.

A head and torso simulator was placed in the centre of the ring of loudspeakers to record the stimuli presented during the listening tests. The recordings were processed using either an eight-channel noise vocoder or a low-pass filter at 440 Hz. Ten normally-hearing adults completed tests of the ability to localise sound and of the ability to benefit from spatial release from masking. The stimuli were presented via headphones in two conditions: 1) vocoded stimuli binaurally ('simulated CI-CI'); 2) vocoded stimuli in one ear with low-pass filtered stimuli in the other ear ('simulated CI-HA'). The results add to an ongoing research programme and can be compared with those of children who completed the original tests in the ring of loudspeakers: 33 who use CI-CI, nine who use CI-HA, and 56 with normal hearing.

Adults performed better with simulated CI-CI than with simulated CI-HA, similar to the results from implanted children. On most tests, adults' average performance with simulated CI-CI and simulated CI-HA was similar to the average performance of CI-CI children and CI-HA children, respectively. These similarities suggest that deficiencies in the signal delivered by implants and hearing aids to the auditory nervous system are the major factors that limit the performance of implanted children. A few implanted children exceeded the performance of the best-performing adults, indicating that neural plasticity and experience of listening with implants or hearing aids can enable children to overcome deficiencies in the signal. Further work will manipulate the low-frequency cutoff for the HA simulation and use the microphones and automatic gain control of implant systems to record the stimuli.

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Lovett, R., Kitterick, P., & Summerfield, A. Q. (2009). Bilateral or unilateral cochlear implantation for deaf children: an observational study. Submitted.

C38: CHANNEL INTERACTION EFFECTS ON BINAURAL UNMASKING SENSITIVITY IN BILATERAL COCHLEAR IMPLANT USERS

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Bilateral cochlear implant (CI) users gain an advantage in noisy situations from their second implant. However, since the left and right processors are independent and not tightly coordinated, their binaural hearing performance falls short of normal hearing (NH) levels. Previous studies reported up to 9 dB of binaural masking level difference (BMLD) in CI users when stimulating with a single, bilateral pair of electrodes. But with speech, BMLDs were reported to be <1.5 dB. In comparison, NH listeners can have similar BMLDs for both tones and speech. One potential explanation is that channel interactions limit BMLD sensitivity in CI users. This study explores that possibility. Three bilateral CI users were tested using concurrent stimulation of multiple pairs of electrodes, representing a more realistic stimulation condition compared to single electrode pairs used in prior studies. N0S0 and N0Sπ thresholds were measured using a 3-IFC procedure. The signal consisted of a 125 Hz tone presented to a pair of pitch-matched and loudness-balanced electrodes. A 50 Hz band-pass noise masker, centered on 125 Hz, was presented through combinations of up to 2 adjacent electrodes pairs on both the basal and apical sides, as well as on the pitch-matched pair itself. The stimuli were sent via direct audio input to the Spear3 research interface (Hearworks, Pty) running custom CIS-based software.

Baseline BMLD with just a single pair of electrodes ranged from 6-10 dB, consistent with prior studies. The average BMLD (mean ± s.d.) over all permutations of noise maskers was 2.0±1.5 dB, similar to speech BMLD levels found for CI users. In permutations of 1, 2 and 4 pairs of noise electrodes, BMLDs were 2.5±1.7 dB, 1.8±0.4 dB, and 0.9±1.1 dB, respectively. With noise on electrodes spaced 1 and 2 away from the pitch-matched pair, BMLDs were 2.2±1.1 dB and 2.3±1.8 dB, respectively, and not significantly different (r.m. ANOVA $F_{1,2}=13.020$, $p=0.069$). Proximity and number of noise electrodes tended to increase N0S0 threshold. When the noise was added to the signal electrode pair, BMLD increased from 1.4±0.9 dB to 2.7±1.7 dB ($F_{1,2}=25.135$, $p=0.038$), and average N0S0 thresholds increased from -3.7±3.6 dB to 2.8±1.4 dB. The results suggest that noise on neighboring electrodes negatively impacts BMLD sensitivity. The implication is that if the amount of channel interactions can be reduced, bilateral CI users may experience further performance improvements related to binaural hearing.

This work was supported by NIH 5 R01 DC003083 (Litovsky).

C39: 3-D SOUND LOCALIZATION IN COCHLEAR-IMPLANT LISTENERS

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The ability to localize sound sources in 3-D space was tested in four bilateral cochlear-implant (CI) listeners. The stimuli were noises filtered with subject-specific behind-the-ear head-related transfer functions. The stimuli were directly sent to the audio inputs of the subjects' clinical speech processors (MED-EL Tempo+, CIS+-strategy). The subjects were trained on sound localization in a virtual audio-visual environment presented via head mounted display. The targets were randomly distributed in the hemisphere that began 30° below eye-level. In the first experiment, four CI listeners were tested with a moderate level roving (range of 5 dB). The results showed substantially worse performance compared to the results from the literature for normal hearing listeners, both in the horizontal and vertical dimensions. For each CI listener, the front-back confusion rate was significantly better than the chance rate. Responses in the vertical dimension were similarly correlated to the vertical target positions (r = 0.44) and to the roved stimulus levels (r = 0.40). In the second experiment, two of the CI listeners tested from the first experiment localized noises with a larger level roving (range of 10 dB). The horizontal-plane localization performance was similar to that for the moderate level roving. The front-back confusion rate substantially increased, which was chance rate for one subject. Compared to the
first experiment, the correlation of the subjects' responses in the vertical dimension and the vertical target positions decreased (r = 0.18). However, the correlation of the subjects' responses and the stimulus level remained similar to that for the moderate level roving (r = 0.42). This indicates that the stimulus level was the most salient cue for localization in the vertical dimension. It also shows that spectral cues contributed little to the vertical-plane localization performance. Our results emphasize the necessity of new strategies for CI systems to better encode localization cues in electric hearing.

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C40: BINAURAL CUES AND ACOUSTIC-ELECTRIC SIMULATIONS

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Listeners with residual low-frequency hearing in both ears may one day have to decide between different hearing device options: for instance to decide between a conventional cochlear implant in one ear with a hearing aid in the other (bimodal devices), or a hybrid device in one ear with a hearing aid in the other (combined devices). There are many factors that could affect this decision. The present study examines the potential for binaural interaction effects to provide an advantage with different device configurations.

The participants in this study have normal hearing and listened to acoustic simulations of cochlear implants, of hybrid devices, and of reduced hearing. A key advantage of a simulation is that it allows comparisons of multiple different device combinations in the same subject very rapidly - and even the inclusion of device combinations that don't exist yet. In addition to the device combinations listed in the first paragraph, we also compared simulated bilateral hybrid devices and bilateral cochlear implants. A disadvantage of the simulation approach is that it is a merely a simulation and one must be careful when generalizing from conclusions found with normal-hearing listeners to cochlear implant listeners. This is ameliorated by comparisons to data that is available in real CI users.

Sixteen normal-hearing subjects were tested on their ability to discriminate spondee words in noise with the aforementioned device simulations over headphones. Speech reception thresholds (SRTs) were measured adaptively in all conditions. Two stimulus presentations were compared: one in which the signal and noise were in phase in both ears (as if both were in front of the listener); and a second in which the signal was out of phase at the two ears and the noise was in phase at the two ears (as if the noise were in front of the listener and the signal was off to one side, except without the effect of head-shadow).

The results show: (1) no binaural-interaction advantage in the CI + residual hearing case; (2) a significant binaural advantage (of 6 to 7 dB) when the binaural low-frequency acoustic pathways are available. Binaural advantages may allow significant benefits with some device configurations and not with others.

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C41: ASSESSMENT OF COCHLEAR IMPLANT PERFORMANCE WITH THE MANDARIN HEARING IN NOISE TEST (MHINT)

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The purposes of the present study were to evaluate the abilities of speech perception in postlingual deaf patients with cochlear implant using the newly developed Mandarin Hearing in Noise Test (MHINT) and to obtain the performance-intensity function (i.e., the P-I function). The MHINT adult version that was used in the present study contains12 lists with 20 sentences per list. Twenty-two cochlear implant patients with age ranging from 14 to 56 years old participated in the present study. Three adaptive rules that differed in stringency on speech perception were used during the test in order to obtain the reception threshold of sentences (RTS) and speech recognition score (SRS) as well as the PI function. Among those 22 subjects, 5 could be tested in traditional HINT adaptive rule (Rule 1), got about 85% accurate repetition of sentences, 3 got about 67% accurate repetition (Rule 2), 7 got about 52% accurate repetition (Rule 3), and 7 of the CI users could not get even 50% accurate repetition. All of the PI functions for CI users are shifted 10 dB or more above the normal PI functions. Most CI users thought that MHINT was hard for them. When using new adaptive scoring rules for MHINT, most CI users could be tested with the modified HINT scoring rules, although three subjects could not be tested. Compared with normal hearing subjects, all CI users required positive signal-to-noise ratios to perform the HINT measures.

C42: PRE– AND POSTOPERATIVE ASSESSMENT OF COCHLEAR IMPLANTEES BY MEANS OF MULTI DETECTOR ROW COMPUTED TOMOGRAPHY (MD-CT)

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The remarkable progress of cochlear implants over the last decades has widely broadened their application to prelingually deaf people, children with congenital inner ear malformations and people with residual hearing. This put higher demands to all people involved in the selection, treatment and rehabilitation of cochlear implant candidates. In regard to imaging the assessment of (potential) cochlear trauma, optimization of preoperative planning and detailed visualization of the surgical result have become the main points of interest. We describe the potential of MD-CT for detailed assessment of both the preoperative cochlear morphology and the postoperative condition.

To enable accurate and reproducible analysis of the cochlear anatomy and cochlear implant positioning a CT-based 3-dimensional cochlear coordinate system, easily applicable on both pre- and postoperative images without the need of cochlear templates and not influenced by postoperative round window distortion is presented. This coordinate system fulfills the requirements set by an international consensus to allow for comparisons between scientific and clinical studies performed in the various fields of inner ear research.

Preoperative imaging is known to contribute to the choice of type of implant and side of operation in case the inner ear is malformed or partially obliterated. However, little attention is paid to the normal size and shape of the cochlea. We studied the length and course of the cochlear spiral in 8 temporal bones with micro-CT and MD-CT by means of virtual cochleoscopy to appraise the risk for cochlear trauma and to allow for individualized surgical planning.

Postoperative imaging must provide detailed information of the cochlear implant and fine anatomic cochlear structures to allow for precise evaluation of the surgical technique, the electrode design and position. We studied the potential for cochlear implant imaging of MD-CT scanners of 4 major vendors and applied this technique for the assessment of insertion depth and intracochlear position of over 300 implants, while using the abovementioned coordinate system.

It is concluded that MD-CT is a valuable technique for individual, patient specific surgical planning. In addition, it allows the evaluation of cochlear implant electrodes in regard to insertion trauma and intracochlear position.

D1: POLARITY SENSITIVITY OF THE ELECTRICALLY STIMULATED AUDITORY NERVE AT DIFFERENT COCHLEAR SITES

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Commercially available cochlear implants (CIs) stimulate the auditory nerve (AN) using symmetric biphasic current (BP) pulses. However, recent data have shown that the use of asymmetric pulse shapes could be beneficial in terms of reducing power consumption, increasing dynamic range and limiting channel interactions. In these charge-balanced stimuli, the effectiveness of one phase (one polarity) is reduced by making it longer and lower in amplitude than the other. For the design of novel CI speech processing strategies using asymmetric pulses, it is particularly relevant to know which of the two polarities (negative/cathodic or positive/anodic) is most effective. Animal research and theoretical modeling suggest that the cathodic phase is the most “effective” one in terms of producing most of the excitation in the auditory nerve. However, recent behavioral (psychophysical) and electro-physiological data obtained from CI users in our lab suggest that the anodic phase is more effective than the cathodic one (Macherey et al., 2008).

The present study tested the generality of the finding that the anodic phase is most effective to different sites along the cochlea. Polarity effects were examined by means of the Electrically Evoked Compound Action Potential (ECAP) obtained by using the masker-probe paradigm, in which a large ECAP is obtained only when both the masker and the probe produce a large neural response. Monopolar stimulation was applied to the apical, middle and basal electrodes of the Advanced Bionics device. The results of all experiments were similar for all electrodes. Experiment 1 used a standard biphasic cathodic-1st masker and showed that the ECAP latency was shorter for anodic-1st than for cathodic-1st probe, respectively, on all electrodes. Experiment 2 used anodic and cathodic maskers with standard biphasic probes. ECAP responses were only obtained when the masker was anodic. Experiment 3 used a standard biphasic cathodic-1st masker and showed that latency was shorter for the anodic-1st than for cathodic-1st probe and it increased when the phase duration of the probe was increased. Experiment 4 used a masker and probe with the same polarity and showed that ECAP responses were only obtained only when the masker and the probe were anodic.

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D2: MAGNITUDE AND SHAPE OF TRIPOLAR FIELDS AS PREDICTORS OF LOUDNESS AND SPREAD OF EXCITATION

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To reduce channel interactions from monopolar stimulation, more focused electrode configurations, such as tripoles, are considered. Tripoles require higher current levels to achieve the same loudness as monopoles, but how much extra current is needed (CU_{tri}/CU_{mono}) differs between subjects. In an earlier study (Berenstein et al, ARO 2008) this variability could be explained in 6 out of 10 subjects by the individually estimated peak magnitude of the electrical field, at the location of the central active electrode V'_{peak}. In this study, we explore to what extent tripolar spread of excitation can be explained by the peak magnitude and the shape of the electrical field.

Two measures of the spread of excitation were collected in eight subjects using an Advanced Bionics 90K implant: psychophysical forward masking and eCAP masker-probe, both with fixed probe and varying masker location. A Remote Current Fraction (RCF) was varied from 0%, 25%, 50%, 75% to 100% to create “partial tripoles” ranging from full tripole (0%) to monopole (100%). Maskers were presented at loudest acceptable level. Both monopolar and tripolar maskers and probes were used.

As expected, the largest non-simultaneous masking was found for masker and probes on the same electrodes (e_m=e_p) in almost all cases. For e_m=e_p masking increased with decreasing RCF (increasing focusing). The relation between masking and RCF closely agreed with the current required to obtain equal loudness, and thus V'_{peak}. On average, spread of excitation (psychophysical and eCAP measures) decreased for smaller RCFs, as expected. Unexpectedly, no clear decrease of spread of excitation was seen for maskers with smaller RCFs. In an additional analysis, we will investigate the relation between spread of excitation and the width of the electrical field.

A preliminary conclusion is that V'_{peak} is sufficient to describe the effect of RCF on loudness, as well as to describe the neural recruitment of a masker stimulus (presumably: the excitation of increasing numbers of fibers along the basilar membrane). Both are supra-threshold effects and the results suggest that they can be understood by the magnitude of the field at threshold (that is, the peak magnitude). Further analysis will show a possible additional effect of the shape of the field on the spread of excitation.

D3: A 3D FORCE MEASUREMENT SYSTEM APPLIED IN THE DEVELOPMENT OF A MINIMIALLY TRAUMATIC ELECTRODE ARRAY

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Even though several studies investigated the locations likely to show trauma during insertion of an electrode array into a cochlea, the actual forces imposed onto the cochlea are still quite poorly understood. Therefore human temporal bone insertion measurements performed on the force measurement system (FMS) were correlated with histology and microCT analysis.

The state-of-the-art FMS used was able to resolve milli-Newton forces in three dimensions. A video camera was synchronized such that movement of the electrode array could be linked to the corresponding FMS values. Additionally, a real-time audio feedback signal was used with pitch modulated by insertion force.

Multiple fixed human temporal bones were implanted using full-turn prototype electrode array designs, as well as HiFocus1j as controls. Variables studied included: stiffness, lateral wall vs. mid-scala locations, and length. Insertions were made via a cochleostomy or via the round window; both free hand or using prototype insertion tools.

For prototype lateral wall electrodes with the same length as the HiFocus1j, forces could be low for most of the insertion, with normal and lateral forces on the order of 10mN. However, to complete the last few millimeters of the insertion, forces would appreciably rise, and the three-axis force profile would reflect the more aggressive efforts to complete the insertion.

The mid-scala electrode array generally felt smooth during insertion, and with 1-2mm remaining to the insertion, normal forces were below 20mN, and lateral forces were below 15mN. However, to complete the insertion, both normal and lateral forces could rise much higher. Audio feedback was found to be very useful and could play a valuable role in development and training on minimally traumatic surgical approaches.

Even in these initial experiments, the FMS has shown itself to be an invaluable tool for understanding the complex forces associated with cochlear implantation, and an aid to electrode array development.

D4: PERFORMANCE OF VIRTUAL CHANNELS IN COCHLEAR PROSTHESIS SYSTEMS

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Simultaneous electrical stimulation of neighboring electrodes in cochlear prosthesis systems generates channel interaction. However, intermediate channels, or virtual channels between the neighboring electrodes can be created through controlled channel interaction. This effect may be exploited for sending new information to the hearing nerves by stimulating in a suitable manner. The actual stimulation sites are therefore not limited to the number of electrodes. Clinical experiments, however, show that virtual channels are not always perceived. In this poster, electrical simulation with finite element analysis on a half turn human cochlea model is adopted to model the virtual channel effect, and the conditions for generating virtual channels are discussed. Five input current ratios (100/0, 70/30, 50/50, 30/70, 0/100) are applied to generate virtual channels. Three configurations of electrode arrays are taken into consideration: distance between electrode contact and modiolus, spacing between adjacent electrode contacts and scale of electrode contact size. By observing the activating function contours, the virtual channel patterns and performances can be measured and examined. The results showed that poor spatial selectivity of each electrode increases the electrical interaction and the virtual channel effect. A novel current steering strategy based on the aforementioned cochlear prosthesis model is developed and studied.

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D5: EFFECTS OF LOCALIZED NEUROTROPHIN GENE THERAPY ON AUDITORY NEURONS AFTER HEARING LOSS

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The cochlear implant relies on a healthy population of spiral ganglion neurons (SGNs) to transmit electrical signals from the implant to the brain. However, SGNs progressively degenerate after deafness due to loss of neurotrophins that are normally supplied by the sensory hair cells. Exogenous neurotrophins protect SGNs from degeneration but cause abnormal resprouting of dendrites due to a lack of a target for the nerves to grow towards. It was hypothesized that introduction of viral gene transfer vectors into the scala media of guinea pig cochleae would result in more localized neurotrophin gene expression compared to injection into the scala tympani, creating a target-derived neurotrophin source to control the direction of resprouting SGNs following deafness.

Adenoviral vectors were generated containing the gene for green fluorescent protein (GFP) alone or in combination with the genes for brain-derived neurotrophic factor or neurotrophin-3. These were injected into the scala tympani or scala media of guinea pigs deafened for 1 week via aminoglycosides. After 3 weeks, cochleae were examined for gene expression, SGN survival and dendritic response to gene expression.

Injection of gene transfer vectors to the scala media of deafened guinea pigs resulted in more localized gene expression compared to the scala tympani. After scala media injections, gene expression was consistently observed in cells within the partially degenerated organ of Corti as well as in the spiral limbus. There was significantly greater SGN survival following neurotrophin gene transfer to the scala media compared to scala tympani injections and compared to GFP gene transfer alone ($p<0.05$). There was also evidence of localized dendritic responses to neurotrophin gene expression within the organ of Corti from scala media injections, a first step in controlling the direction of SGN regeneration via neurotrophin gene therapy.

A localized source of neurotrophins may control the regeneration of SGNs after deafness and hence improve frequency-specific sound perception with a cochlear implant.

This work was funded by the Royal National Institute for Deaf People and the Garnett Passe and Rodney Williams Memorial Foundation.

D6: EFFECTS OF BRAIN DERIVED NEUROTROPHIC FACTOR (BDNF) AND ELECTRICAL STIMULATION ON THE SURVIVAL OF SPIRAL GANGLION CELLS IN CATS DEAFENED AT 30 DAYS

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Survival of spiral ganglion (SG) neurons is dependent upon both neural activity and neurotrophic factors that are expressed by the hair cells and supporting cells in the normal cochlea. In earlier studies, we have shown that electrical stimulation promotes SG survival in animals deafened early in life; however, SG density was still significantly below normal. In the present study we explored the effect of prolonged intracochlear infusion of BDNF on spiral ganglion cell survival in cats. Kittens were deafened at 30 days of age by systemic administration of neomycin (60 mg/kg SID). After profound deafness was confirmed, animals were implanted at 8 weeks of age with a scala tympani electrode for electrical stimulation and a drug-delivery cannula attached to an osmotic pump. The pump was changed 2-3 times to allow BDNF infusion for 12-14 weeks, either alone or combined with electrical stimulation.

In control animals deafened with neomycin at 30 days of age and studied at 8 weeks of age (when BDNF treatment was initiated in other animals), a marked reduction of SG cell size (75% of normal) and a modest (9%) decrease in SG cell numerical density was observed. Intracochlear BDNF infusion, both alone and combined with electrical stimulation, reversed the reduction in SG cell size caused by deafness and resulted in significantly larger cell soma areas, bringing SG cell size close to the normal cell size in the adult cat cochlea (90-100% of normal). Electrical stimulation alone for the same period of time resulted in a more modest increase in SG cell size to approximately 80% of normal adult size.

SG numerical density measurements indicated that intracochlear infusion of BDNF alone (using a short intracochlear electrode) maintained 94% of the SG neural population present when treatment was initiated (at the age of 8 weeks). In the cochleae that received BDNF combined with electrical stimulation, SG numerical density was similar to that observed after BDNF infusion alone (85% of normal), and the major difference in cell number between treated and untreated cochleae in this group of animals was limited to the more basal sectors of the cochlea. SG numerical density measurements were lower in the middle portion of the cochlea, which could be related to trauma caused by the insertion of the longer electrode used for electrical stimulation.

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D7: BEHAVIORALLY RELEVANT AUDITORY EXPERIENCE IMPROVES TEMPORAL PROCESSING IN DEAF JUVENILE CAT PRIMARY AUDITORY CORTEX (AI)

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Experience with a cochlear implant (CI) is typically required before a human user shows improvement in speech recognition. This suggests that relevant experience leads to improved functional representation of the electrical signals in the brain and to better performance in electrical hearing. We tested this hypothesis in a deaf cat model by comparing temporal processing in the primary auditory cortex (AI) obtained from groups of cats that received only chronic, passive intracochlear electrical stimulation (ICES) of the cochlea with groups of cats that also received behavioral training with the electrical signals

Deafness was produced in neonatal kittens and in normal hearing adult cats by injection of ototoxic drugs. A feline prosthesis was implanted in the left scala tympani, and a regimen of continuous, passive ICES was initiated (~4 h/day, 5 day/wk). For the passive stimulation and behavioral components of the study, stimuli were biphasic unmodulated (30 pps) or sinusoidally modulated (300 pps, 30 Hz, 100% modulation depth) 0.2 ms/phase current pulses. Responses of multineuronal clusters in the right AI to unmodulated pulse trains (~2 to 40 pps) were recorded with metal microelectrodes in anesthetized animals. The principal response parameters of interest were: best modulation frequency (BMF), the stimulus frequency that produced the maximum number of phase-locked spikes; the limiting or cutoff frequency at which the number of phase-locked spikes was just less than 50% of the number at BMF; and minimum neuronal response latencies in trained and untrained juvenile cats.

The main results show: 1) BMFs and cutoff frequencies in behaviorally trained juvenile cats are equivalent to those recorded in adult deafened cats with an extensive history of normal hearing; 2) the behaviorally trained cats have significantly higher BMFs and cutoff frequencies, shorter minimum response latencies and reduced response onset jitter than juvenile cats that received only passive ICES; 3) cortical BMFs and cutoff frequencies in the behaviorally trained cats are significantly higher at cochlear electrode sites used for training compared to electrode sites that were not stimulated during training.

The results highlight the role of behavioral context for auditory temporal processing and indicate that, in juvenile deaf cats, behaviorally relevant ICES significantly improved temporal processing in AI.

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D8: AUDITORY EXPERIENCE AFFECTS TEMPORAL PROCESSING IN THE LONG-DEAFENED CAT PRIMARY AUDITORY CORTEX

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Prelingually deaf cochlear prosthesis users implanted as adults generally have poor speech discrimination but tend to gradually improve with increasing auditory experience. To model the effects of auditory experience after long-term prelingual deafness, we studied temporal processing in three groups of neonatally deafened cats implanted after prolonged periods of deafness (>2.5 years): 1) unstimulated cats that were studied acutely, 2) chronically stimulated cats without behavioral training, and 3) chronically stimulated cats that also received behavioral training. Acutely deafened adult cats served as controls. To assess temporal processing, responses of single neurons and multineuronal clusters to pulse trains (~2 to 40 pps) were recorded in primary auditory cortex (AI), and the following parameters were compared across groups: best modulation frequency (BMF) that evoked the highest number of phase-locked spikes; cutoff frequency at which the number of phase-locked spikes was just less than 50% of the number at BMF; peak latency (modal latency of the period histogram at 2 pps) and minimum response latency.

All long-deaf animals demonstrated severe reductions in spiral ganglion cell density (1-18% of normal), and unstimulated long-deaf cats showed degraded temporal resolution for all parameters tested (i.e., lower BMFs and cutoff frequencies, longer peak and minimum response latencies, more jitter) when compared to control animals. Chronic, passive stimulation without behavioral training moderately elevated BMFs in long-deaf animals but otherwise had no effect. In contrast, the introduction of behavioral training in long-deaf cats with otherwise similar chronic stimulation histories resulted in significantly higher temporal resolution in all parameters tested. With the exception of minimum response latencies all parameters were virtually identical to those of control animals.

Despite severe peripheral pathology, these results show that behaviorally relevant electrical stimulation has the potential to reverse the deleterious effects of long-term neonatal deafness on cortical temporal processing. Thus, the absence of relevant auditory experience rather than severe peripheral pathology appears to be the more important factor in degraded temporal processing in AI.

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D9: TEMPORAL PRECISION OF SPEECH CODED INTO NERVE-ACTION POTENTIALS

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For both normal hearing subjects and cochlear implant patients the most drastic step of sound coding for neuronal processing is when the analog signal is converted into discrete nerve-action potentials. As any information lost during this process is no longer available for neural processing, it is important to understand the underlying principles of sound coding in the intact auditory system and the limitations in the case of artificial stimulation of the auditory nerve.

We have therefore developed a detailed model of auditory processing based on physiological and psychoacoustic measurements, which codes sound signals into spike-trains of the auditory nerve. We also investigate detailed models of cochlear nucleus neurons, which are driven by auditory nerve spike-trains. We analyze the quality of coding with the framework of automatic speech recognition and the methods of information theory.

Our results with automatic speech recognition show that given a model which replicates the large compression found in the human inner ear, a pure rate-place code is able to explain human performance from low to very high speech levels, but only for clean speech. In noise however, recognition performance breaks down significantly already at levels above 60 dB(A).

With information theory, we analyzed the transmitted information rate coded in neural spike trains of modeled neurons in the cochlear nucleus for vowels. We found that at least onset neurons are able to code temporal information with sub-millisecond precision (<0.02 ms) across a wide range of characteristic frequencies. Temporal information is coded by precisely timed spikes per se, not only temporal fine structure. Moreover, the major portion of information (60%) is coded with a temporal precision from 0.2 to 4 ms. Enhancing the temporal resolution from 10 ms to 3 ms and from 3 ms to 0.3 ms is expected to increase the transmitted information by approximately twofold and 2.5 fold, respectively.

In summary, our results provide quantitative insight into temporal processing strategies of neuronal speech processing. We conclude that coding of information in the time domain might be essential to complement the rate-place code for robust speech discrimination in noise.

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D10: OPTIMIZATION OF COMPUTER MODEL PARAMETERS FOR THE SIMULATION OF AUDITORY NERVE RESPONSES TO PULSE TRAINS

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Biophysical computational models are used to understand auditory nerve fiber (ANF) responses across a large “stimulus space” not practical with animal models. We are developing a feline ANF model that accounts for short-term rate adaptation. Our initial effort employed a single-node model (Woo et al., IEEE Trans. Biomed. Eng., in press), while more recent work has based simulations on a more sophisticated model that includes a peripheral process, cell body, and central axon (Woo et al., 2009 ARO Abst. # 697; Woo et al., submitted). This work has demonstrated that a “whole-fiber” model can also produce realistic rate adaptation.

As model complexity increases, so does the challenge in optimizing model parameters so that responses to single pulses, pulse pairs, and pulse trains are comparable to data from animal experiments. In this poster, we present results from ongoing experiments aimed at further exploring the whole-fiber model and stimulus variables that influence modeled responses. A high-rate (5000 pulse/s) pulse-train stimulus was used, with care taken to examine model responses using the same stimulus parameters employed in our parallel feline experiments (Zhang et al., 2007, JARO; Miller et al., 2008 JARO; Miller et al., 2009 ARO Abst. # 966).

Several parametric variations were explored, including electrode-fiber spatial orientation and electrical properties (e.g., axonal resistance, properties of the stochastic node, etc.). We have found that these variables can strongly influence spike timing and the shape of the rate-level function.

This presentation will present the results of ongoing efforts to optimize model parameters, with the ultimate goal of producing a multi-fiber computational population model that demonstrates across-fiber differences in fiber responses. We report obvious differences, such as changes in thresholds and latencies, along with more complex ones, such as the pattern of rate adaptation observed across a fiber ensemble.

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D11: RESOLUTION OF RECORDING SYSTEMS FOR EVOKED COMPOUND ACTION POTENTIALS: IN-VITRO MEASUREMENTS WITH THE MED-EL PULSARCI^{100} COCHLEAR IMPLANT

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The Evoked Compound Action Potential (ECAP) is formed by the action potentials of synchronously excited nerve fibers of the acoustic nerve. Modern cochlear implants provide the possibility to record the ECAP of the auditory nerve. Typical peak-to-peak amplitudes of ECAP signals range from a few microvolts to up to 2 millivolts.

Objective ECAP measurements are commonly used in cochlear implant research and as an intra-operative diagnostic tool, e.g. to assess the correct positioning of the electrode array during implant surgery. Moreover, high-resolution ECAP recording systems may be a promising tool for gathering objective data to assist in the implant fitting process (i.e. in the determination of the subject-specific minimum and maximum stimulation current levels necessary for a good implant performance).

The purpose of this work was to determine the resolution of the ECAP recording system of the MED-EL PULSARCI^{100} cochlear implant. A PULSARCI^{100} implant and electrode array were placed in a petri dish and bathed in a physiological saline solution. Sinusoidal signal bursts at a frequency of 4.3 kHz and amplitude steps of 6 dB were generated with a Rohde&Schwarz signal generator and recorded in-vitro. 200 recordings were averaged for each signal amplitude.

Results show that the ECAP recording system of the PULSARCI^{100} cochlear implant is linear for signal amplitudes within a range of more than 60 dB. Signal amplitudes as small as 5 µV could be resolved reliably. The performance is first of all based on an adaptive delta-sigma system (Zierhofer, 2000) which was developed specifically for this application. This makes the PULSARCI^{100} cochlear implant a suitable device for further investigations and applications involving ECAP signals.

Support provided by the C. Doppler Research Association.

D12: SPATIAL SPREAD MEASUREMENTS IN HR 90K USERS

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All multi-channel cochlear implants (CI) aim to take advantage of the tonotopic organization of the cochlea by selectively stimulating relatively independent neural populations. Hence, spectral representation of the incoming signal is mainly achieved through stimulation of various electrodes located along the longitudinal axis of the cochlea. Ideally, each electrode should selectively activate a distinct group of neurons in the cochlea, which is near the cochlea, without activating those electrodes adjacent to other electrodes. Current from each electrode creates an electric field that stimulates surrounding neural tissue. In reality, the same neurons may be stimulated by multiple electrodes because the injected current spreads through the cochlear tissue. If two or more electrodes stimulate overlapping neural populations, whether simultaneously or in sequence, then channel interaction may occur. It has been shown that the intracochlear electrical fields, generated by each electrode, are not completely distinct from each other, but rather overlap to a large extent. This overlap causes interactions between the electrical fields themselves or between neural populations stimulated by different electrodes, which may ultimately affect perception with the CI. Therefore, it is important to gain insight in the spatial distribution of injected current.

In this study, spatial spread measurements were performed by means of RSPOM (research studies platform – objective measures) v.1.3.0 within 9 HR 90K adult recipients. Three electrode (El) stimulation locations were used: one apical (El 3), one mid (El 7) and one basal (El 11). For each measurement, two artifact reduction techniques were applied: alternating-polarity (AP) versus masker-probe (MP). Spatial profiles were modeled using a two-sided exponential decay curve and width values were calculated at different levels (60, 70 and 80%) of the peak of each fitted curve.

First, feasibility of both AP and MP measurement techniques was investigated, and results revealed that both techniques were found applicable to measure spatial spread within HR 90K users.

The second objective was to gain insight in obtained width values with respect to electrode location (El 3, El 7, El 11), measurement technique (AP, MP) and width level (60%, 70%, 80%). A three-way ANOVA revealed a statistical significant main effect for measurement technique ($p<.000$) and width level ($p<.000$), but not for electrode location ($p>.05$).

Finally, the possible correlations between spatial profiles and speech perception in quiet and noise were evaluated, but no significant correlations could be found. Possibly, speech tests used are too robust to detect subtle intra-individual differences in the neural electrical interface. Implications for speech tests will be discussed.

D13: ELECTRICALLY EVOKED COMPOUND ACTION POTENTIALS ARE REGION-DEPENDENT: MULTICENTER STUDY RESULTS AND MODELING INSIGHTS

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So far, no investigation has explored ECAP recordings in the apical region of the cochlea with a large number of subjects using a commercially available cochlear implant system. We analyzed electrically evoked compound action potential (ECAP) recordings in 67 subjects measured along the entire length of the cochlea, including the most apical region. The standard electrode array of the MED-EL PULSARCI^{100} / SONATATI^{100} cochlear implants is 31 mm in length, allowing an insertion angle of approximately 720°.

A significant difference in the ECAP amplitude, threshold, and slope of the amplitude growth function depending on the stimulation site was found. The apical ECAP recordings had higher amplitudes on average, lower thresholds, and steeper growth functions. The refractory time showed an overall dependence on cochlear region.

To better understand the underlying effects resulting in the different ECAP properties depending on the site of stimulation for the whole cochlea, the multi-center study results are compared with results from models of axonal and dendritic signal propagation in the auditory nerve and discussed in the context of the existing literature. Thus, the focus is on two main effects that could explain the observed effect: 1) a higher density or an increased neural survival rate of neural tissue in the apex and 2) the distance between the stimulating electrode and the neural tissue in the cochlea.

Generally, these findings imply that future studies being conducted on ECAPs should, whenever possible, include a regional analysis of the results to incorporate any region-dependent effects.

D14: ELECTROPHYSIOLOGICAL AND SPEECH OUTCOME MEASURES FOR THE EVALUATION OF COCHLEAR IMPLANTEES

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Cochlear implant recipients exhibit variability in speech perception skills. Coding of speech in the auditory nervous system depends on synchronous firing of auditory neurons; thus, speech perception is expected to be affected by the degree of neural survival. Since auditory potentials evoked by electrical stimulation reflect neural synchrony, recording of these potentials may provide insight into the status of the auditory nervous system at different levels and may serve as predictors of speech perception.

Speech perception on tests utilizing word and sentence materials may be influenced by linguistic context and familiarity of the subject with the vocabulary. Stimuli used in the Forced-Choice test of Speech Pattern Contrast (FCSPAC; Boothroyd 2004) evaluate speech perception at the phonetic level and eliminate linguistic redundancy. The CV syllables used allow assessment of perception of contrasts based on vowel height, vowel place, consonant voicing, consonant continuance, and consonant place.

In the present study, electrically evoked potentials representing different levels of the auditory system (EABR and EMLR) were recorded from cochlear implant users and compared to speech perception test results from the FCSPAC. To date, 9 subjects using Freedom devices have been assessed. Preliminary analysis suggests that EABR findings may be correlated with ability to discriminate consonants based on frontal place of articulation (labial-alveolar).

Boothroyd A (2004). FCSPAC: Forced-Choice test of Speech Pattern Contrast Perception. Available by cooperation of the Rehabilitation Engineering Research Center at Gallaudet University.

D15: EFFECTS OF STIMULATION MODE AND PROBE LEVEL ON FORWARD-MASKED SPATIAL TUNING CURVES IN COCHLEAR IMPLANT USERS

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A multichannel cochlear implant is designed to take advantage of the tonotopic arrangement of auditory nerve fibers within the cochlea. At least two factors—poor nerve survival and limited spatial selectivity— can alter the desired “electrotopic” (electrode-to-place) map. The psychophysical forward-masked spatial tuning curve (fmSTC) is used to quantify spatial selectivity and assess electrotopic aberrations in the cochlea. The goal of present study was to determine whether the characteristics of the fmSTCs are affected by stimulation mode and probe level.

The fmSTCs were measured in 6 Clarion C-II or HiRes 90K subjects, using three stimulation modes (monopolar, bipolar and tripolar) and three probe levels. Probes were located at electrode 8 (monopolar), electrode 8/9 (bipolar) and electrode 7/8/9 (tripolar), where maskers were changed along the electrode array. The probe level was fixed approximately at 10%, 20% or 30% dynamic range and the masker levels were varied using adaptive procedure with two up one down decision rule to track 71% point on the psychometric function. In general the amount of masking is inversely proportional to the distance between the probe and the masker, namely, the greater the distance the less the masking. The monopolar mode has the least variability in fmSTCs whereas the tripolar mode has the most variability within and among subjects. In particular, the bipolar and tripolar stimulation modes produce irregularities in the fmSTCs including remote maskers having more masking than local maskers, tip shift from the probe location and the presence of multiple tips. Probe levels, on the other hand, have no significant effect on tuning curves. These results will be discussed in relation to current spread and nerve survival in the cochlea.

D16: TEMPORAL FINE STRUCTURE: NO SILVER BULLET

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The dismal quality of cochlear implant (CI) pitch perception is one of the great challenges of the field. In normal hearing, inner hair cells preferentially respond to deflections of the basilar membrane in one direction, and can be modelled using half wave rectification (HWR). In contrast, the CIS, SPEAK, and ACE strategies use envelope detection. Normal hearing subjects, listening to acoustic reconstructions of envelope processing, also suffer from poor pitch perception. This led to the wide-spread belief that CI pitch perception could be improved by restoring the missing "temporal fine structure". With this goal, HWR was incorporated into the Advanced Bionics HiRes and Medel FSP strategies. An experimental HWR strategy was also implemented on the Nucleus Freedom processor. However, trials showed no significant difference in speech or pitch perception between HWR and the standard ACE strategy. These strategies attempt to provide temporal cues independently on each channel, but are hampered by the broad spread of excitation from monopolar stimulation. A neuron receives stimulation from multiple neighbouring electrodes, so that the temporal cues presented on each channel are smeared together. Conversely, strategies that apply in-phase modulation on all channels provide more resilient temporal cues. A guide to the best achievable results with these strategies is given by rate-pitch measurements.

The present study used the Modified Melodies test with melodies presented by varying the pulse rate on a single electrode. Scores were similar to those of normal hearing subjects with tones containing only unresolved harmonics. Modified Melodies scores can be interpreted as a measure of pitch strength. This implies that purely temporal cues provide only a weak pitch sensation, and that "temporal fine structure" offers at best modest improvements in CI pitch perception.

Temporal models of pitch perception cannot explain why the pitch of a low-rate electrical pulse train is so weak. The autocorrelation model and the first-order inter-spike interval model both predict a strong pitch. Instead, evidence suggests that a strong pitch sensation requires a specific phase relationship between the nerve firing times across a local region of the cochlea. This distinctive spatio-temporal excitation pattern is produced by a resolved harmonic. It is impossible to reproduce this pattern in a CI using monopolar stimulation or current steering. The best approach at present is to make use of any available residual acoustic hearing.

D17: MULTI-CHANNEL INTERACTIONS IN AMPLITUDE MODULATION DETECTION AND DISCRIMINATION BY COCHLEAR IMPLANT LISTENERS

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Two experiments were designed to investigate the effects of a two-electrode masker complex on cochlear implant listeners' sensitivity to temporal modulations. In Exp. 1, amplitude modulation detection thresholds (MDTs) were measured for a 100 Hz modulation rate (carrier pulse rate: 2000 pps) in the presence of the maskers. The two masker electrodes flanked the signal channel (electrode 18), and were presented at different distances (varying from 1 to 4 electrodes) from the signal electrode. When the flanking maskers were amplitude modulated (20% depth) at the same rate as the signal, large interference effects were observed. However, unmodulated maskers presented at the peak amplitude of the modulated maskers (SS_{peak} maskers), produced little to no interference. These results were consistent with previous work with single-channel maskers.

In Exp. 2, the maskers were identical to those in Exp. 1, but the task was to detect an increment in the AM rate of the signal (AM depth fixed at 20%, reference AM rate =100 Hz). In this case, the results were strikingly different. With SS_{peak} flanking maskers, interference was generally observed, but when the flanking maskers were modulated at the same rate as the signal, listeners showed enhancement in modulation rate discrimination rather than interference. These results suggest that different mechanisms are at play in the interaction between the maskers and the signal in these two tasks. Modulation detection interference is clearly present in Exp. 1. However, the enhancement observed in Exp 2 suggests co-operative across-channel effects when a similar envelope is applied on multiple electrodes. These results have important implications for complex pitch perception and temporal pattern processing by CI listeners.

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D18: ESTIMATING PSYCHOPHYSICAL DISCRIMINATION PERFORMANCE FROM SIMULATED NEURAL RESPONSES: EVALUATING THE EFFECT OF SPIKE TRAIN METRICS

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The development of novel sound-encoding strategies for cochlear implants (CIs) is a costly and a time-consuming process, in large part due to the burden of subject testing necessary to establish the psychophysical and speech perception performance of the new strategy. We propose to estimate a strategy's discrimination performance by measuring the similarity of neural spike trains produced in response to CI-encoded psychophysical stimuli. To determine appropriate methods for our procedure, we compare the effects of “direct” and Dspike metrics on the estimates of discriminability. Our laboratory has developed a stochastic, biophysical model of auditory nerve (AN) fibers whose response properties reproduce temporal and probabilistic behavior measured for single, as well as a population of mammalian AN fibers. Using this model, we generate neural responses to CIS- and analog- encoded Schroeder-phase stimuli, which allows us to estimate sensitivity to temporal fine structure of each of the tested strategies. Temporal fine structure has been shown to be an important component of sound source localization, segregation, tonal language recognition, and melody perception. We estimate the discriminability of the stimuli from neural responses in two steps, as follows. First, we measure dissimilarity (distance) of neural responses with either the direct or the Dspike metrics. Next, a maximum likelihood, ideal-observer classifier estimates which stimulus was the most likely source of the simulated response based on the calculated distances. Our hypothesis, is that the direct metric will consistently overestimate differences between neural spike trains (and thus, overestimate discrimination performance), as compared to the Dspike metric. Preliminary results support our hypothesis: both spike train metrics follow similar trends, but the Dspike metric produces more conservative estimates of stimuli discriminability.

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D19: PLACE SPECIFICITY AND VARIABILITY IN SPEECH PERCEPTION PERFORMANCE IN COCHLEAR IMPLANTS

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The variability in speech perception performance among cochlear implant users is expected to be explained by the differences in processing spectral and temporal information. Spectral information is transmitted by electrical stimulation of electrode channels that are placed along the cochlea. However the cochlear implant electrodes do not produce independent perceptual dimensions caused by neural overlap in the peripheral and central auditory system.

In this study we design and test a novel paradigm to measure electrode interaction (spatial resolution) in cochlear implants using a technique similar to profile analysis used to find cochlear filter bandwidths in acoustic hearing. Previous studies trying to measure the ability to discriminate a high current electrode from a lower current background stimulation demonstrated that the implantees rely mostly on overall loudness cues to perform these kinds of tasks (Drennan & Pfingst 2006; Goupell et al. 2008). In our method, the level of a central electrode in an 11-electrode stimulus is increased to create a peak in the flat spectral profile (a profile in which all the electrodes have equal perceptual loudness) and the levels of two other electrodes on the sides of the 'peak' electrode are decreased (spectral valleys) until the new (non-flat) stimulus becomes equally loud as the flat profile. The discrimination ability of the non-flat and flat profiles is expected to be determined by the degree of interaction between peak and the valley electrodes. By varying the location of 'valley' electrodes in each subject, the peak-valley distance for a criterion discrimination performance is used as a measure of spatial resolution.

The spatial resolution is also measured neurophysiologically in the level of cortical responses (Acoustic Change Complex) and auditory nerve responses (Neural Response Telemetry) and the degree of consistency between each of these and the psychophysical measure is explored. Speech perception performance is also measured using lists of CNC words and the extent to which the psychophysical and electrophysiological measures of spatial resolution can explain the variability in the perception of consonants and vowels is evaluated.

This study supported by the HEAR Trust and MRC.

D20: EARLY EXPOSURE AND RESPONSES TO MUSIC IN YOUNG LISTENERS WITH AND WITHOUT COCHLEAR IMPLANTS

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Early exposure to music is especially important for education, social interaction and parent-child bonding. However, the development of auditory receptive skills and spoken language is often delayed in children with cochlear implants (CIs), which may affect their appreciation of and responses to music. It is also conceivable that a parent of child with a CI may be less confident about using music for nurture and interaction.

To the authors' knowledge there have been no studies which directly compare the exposure and responses to music in young listeners with CIs and with normal hearing. In order to determine whether such differences exist between these groups, a questionnaire for parents exploring various aspects of their child's music exposure and appreciation was developed at the South of England Cochlear Implant Centre (SOECIC) by a team of audiologists, speech and language therapists, and teachers of the deaf.

The questionnaire was distributed to the main carers of children with normal hearing (screened by an additional questionnaire) at local playgroups and nurseries, and to the main carers of children who had been implanted at least one year prior at the SOECIC. All children were aged between 22 and 59 months with no known additional special needs that would affect their music perception ability. The CI group comprised 23 children, (13 females and 10 males) with a mean age of 44.78 months (± 9.35 standard deviation). This group was gender and age matched (within ± 2 months) to a group of children with normal hearing.

The results are encouraging; young children with CIs receive a similar amount of exposure to parental singing when compared with their normally hearing peers and spend roughly the same amount of time interacting with musical instruments at home. However, the results also indicate that although young children with CIs are exposed to a similar amount of television programmes, videos and DVDs which include music, they have less exposure to children's music from a tape/CD/MP3 player where there is no visual stimulus, $U = 173.00$, $p < .05$, $r = -.31$.

The responses of the children with CIs to recorded music and parental singing (ranging from 'an aversion to or disinterest in sound' to 'can identify and join in with the tune') were also found to be less advanced.

The results of this study will be used to tailor the services provided by the SOECIC to the habilitation needs of young implantees. It is anticipated that these results will also provide guidance for other carers and professionals concerning the amount of exposure to formal and informal musical activities experienced by children with CIs.

D21: MUSICAL AND LEXICAL PITCH PERCEPTION BY COCHLEAR IMPLANT RECIPIENTS

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Music perception and lexical tone perception remain to be challenging for cochlear implant users. Previous studies have suggested that due to inadequate representation of pitch information, implant users were unable to perceive melody without rhythmic cues. Lexical tone perception in Mandarin-speaking users was also found to be poor, presumably also due to the inadequate coding of pitch. It is not known, however, whether musical and lexical tone perception share similar mechanisms in electric hearing. We hypothesize that in electric hearing, implant users' ability to perceive music is related to their ability to perceive lexical tones.

Nineteen postlingually-deafened implant users who are native Mandarin-Chinese speakers were recruited. For the music perception test, digitally synthesized piano tones were used for constructing melodies. The rhythmic cues were removed. The melody test utilized an adaptive procedure where the participants were presented with two versions of one melody in two intervals. One interval contained the original melody and the other contained a modified version. In the modified version, one note of the melody was changed in the fundamental frequency (F0). The task of the participants was to decide whether the two melodies were the same or different. The discrimination thresholds were calculated from the last six reversals from a total of ten reversals. Mandarin tone perception was also measured using a four alternative forced choice paradigm. The subjects were required to identify the tone category of a Mandarin Chinese word from four possible choices. All subjects completed the tone perception test, while three could not perform the music perception test.

Tone perception performance was on average 58% correct (± 19.78%). The tone perception performance of the implant users was negatively correlated with the length of their hearing deprivation and positively correlated with the experience of hearing aid use. On average, the 16 implant users who completed the melody discrimination test had a threshold of 5.88 semitones (± 5.66 semitones). There was a strong correlation between the implant users' tone perception performance and their music discrimination threshold ($r = 0.78$). Our results confirmed the deficits in music and tone perception in implant users. More importantly, our results indicate that musical and lexical pitch perception might share similar mechanisms in electric hearing.

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D22: THE ROLE OF EARLY REFLECTIONS IN THE PERCEPTION OF SPECTRALLY-DEGRADED SPEECH

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The intelligibility of speech in rooms is affected by reverberation. Reverberant sound energy typically creates a temporal "smearing" of speech that imposes masking on contiguous phonemes, lengthens the duration of words, and fills quiet and/or low-intensity speech segments with unwanted sound. As a result, intelligibility decreases in conjunction with the reductions in speech envelope modulation depth imposed by temporal smearing. The temporal effects of reverberation on speech may pose a particular challenge for cochlear implant users, who receive their auditory cues from temporal envelope modulations in a limited number of spectral channels.

Unlike the documented abilities of acoustic listeners, it is presently not known how well implant users can integrate early reflections with direct sound. One straightforward method we have used to examine integration of reflections of vocoded signals (intended to simulated cochlear implant processing) has been to compare intelligibility scores for vocoded speech received at small source-listener distances (having strong contributions from direct sound) with those for vocoded speech received at large source-listener distances (having strong contributions from reflected sound). Our findings indicate that when presented with this type of spectrally-degraded speech, listeners may have some limited ability to utilize early reflections, albeit only in the presence of detectable direct arrivals. This suggests that signals comprised largely of early reflections may be less intelligible for cochlear implant users than signals comprised largely of direct sound. This hypothesis, if true, has important implications for cochlear implant users since recommendations for improving room acoustics often include increasing the level of early reflections.

In order to further explore this hypothesis, what we next need to know is the temporal extent of reflections that can be integrated with the direct signal to provide addition useful information regarding spectrally-degraded speech. To this end, we have embarked upon an investigation where listeners with normal hearing are presented with vocoded signals containing direct sound only and those containing direct sound plus varying numbers of echoes in a variety of modeled rooms where the density of the reflections vary. Results obtained in quiet should provide information regarding the early- versus late-reflection boundaries for the perception of vocoded signals; we expect these to be quite different than similar boundaries for listeners with normal hearing. With results obtained in noise, we can examine the useful (i.e., direct signal + early/beneficial reflections)-to-late (i.e., detrimental) reflection ratios that should prove acceptable for understanding of vocoded speech in naturalistic environments.

Work supported by NIH/NIDCD.

D23: EFFECTIVE TEMPORAL CUES FOR CHINESE TONE PERCEPTION

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Lexical tone plays an important role in tonal languages. A word carrying different tone patterns may have totally different meanings. Lexical tones are described by distinctive pitch contours. Acoustically, pitch is determined by the periodicity of speech, which is measured as the fundamental frequency (F0) of acoustic signals.

People with sensorineural hearing loss have difficulty in utilizing spectral information for speech recognition and rely heavily on temporal information. Currently available signal processing strategies in the cochlear implant (CI) processors are not optimized for language-dependent speech communications.

The goals of this study are to investigate what are the effective temporal cues for lexical tone perception of Chinese in clean and noise conditions and how to manipulate these cues for better tone perception. Acoustic simulations with normal-hearing subjects are adopted. A multi-channel noise-excited vocoder is used to generate test stimuli for tone identification.

We compare the contributions of temporal envelope and periodicity components (TEPCs) from different frequency regions to tone recognition in Cantonese and Mandarin. It is observed that TEPCs from high-frequency region (1 – 4 kHz) are more important than those from low-frequency region (< 1 kHz). In noise condition, tone recognition performance with temporal cues degrades and more spectral information is needed.

Two approaches are investigated to improve Chinese tone recognition. In the first approach, TEPCs go through a process of non-linear expansion in order to increase the modulation depth of periodicity-related amplitude fluctuation. Results show that TEPC expansion leads to a noticeable improvement on tone identification accuracy. In the second approach, the effectiveness of enhancing temporal periodicity cues in noise is investigated. Temporal periodicity cues are simplified into a sinusoidal wave with frequency equivalent to the F0 of speech. This leads to a consistent and significant improvement on tone identification performance at different noise levels. This part of research is expected to be helpful in designing CI processing strategy for effective speech perception of tonal languages.

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D24: ACOUSTIC CHARACTERISTICS OF SIBILANT FRICATIVES IN CHILDREN WITH COCHLEAR IMPLANTS

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Children with cochlear implants (CIs) exhibit delays in speech production relative to children with normal hearing (NH). To date, analyses of speech production in children with CIs have primarily used phonetic transcription which relies on listeners' judgments to characterize speech production. However, acoustic analysis (e.g., analyzing spectral structure), can be used to describe speech at a much finer level. In this study acoustic analysis was conducted on productions of "s" and "sh" made by children who have CIs and compared with those of NH children. The contrast of "s" and "sh", which is acquired late by children with NH, may be particularly difficult for children with CIs because the concentration of energy characteristic of "s" is above 4000 Hz, while the filters in CI's assigned to frequencies above 4000 are very wide.

Participants included 18 4- to 8-year old children with bilateral CIs and two groups of children with NH (a hearing-age and a chronological age comparison group). An auditory word-repetition task was administered. Children were presented with a picture of a familiar object that was paired with a familiar word presented over computer speakers. Auditory stimuli were words that began with either "s" or "sh". All productions were recorded for subsequent transcription and acoustic analysis.

Only productions transcribed as correct were included in the acoustic analysis. The first spectral moment (i.e., centroid) was calculated from the middle 40 ms of the fricative using the Praat software.

The centroids calculated for "sh" productions were similar across the children with CIs and the children with NH. Productions of "s" for most children with NH showed high centroids (averaging 8780 Hz) that had considerable variability which is similar to what studies have found in adult productions of "s". Two patterns emerged in the "s" productions of the children with CIs. A small number of children with CIs had productions of "s" that were similar to the children with NH. However, most of the children with CIs had productions of "s" with centroids that were markedly lower in frequency and had limited variability relative to those of the children with NH. We plan to examine individual children's frequency assignment tables to determine if the production results are related to limitations on input at the high frequencies characteristic of "s".

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D25: NONWORD REPETITION ACCURACY OF CHILDREN WITH BILATERAL COCHLEAR IMPLANTS: EFFECTS OF AGE AND VOCABULARY SIZE

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Within the population of children with profound hearing loss, children who use cochlear implants (CIs) have much better speech and language development than children who use hearing aids. However, CI users still perform more poorly than children with normal hearing (NH). Few studies have examined nonword repetition accuracy in children with CIs, although this measure is important because of its relationship to vocabulary development. Measures of nonword repetition accuracy allow for the study of acoustic encoding abilities when semantic support is not provided.

This study analyzes initial consonant accuracy in real words and nonwords for 18 children with bilateral CIs between 4 and 8 years old. Results from a NH comparison group were included as well. The children with CIs were matched to children with NH by "hearing age," the amount of time that CI users have been exposed to stimulation with at least one implant. The two groups were also matched for sex and for score on the Peabody Picture Vocabulary Test-4th Edition (PPVT-4), a standardized measure of receptive vocabulary. The accuracy of word-initial /t/, /d/, /k/, and /g/ were examined because they are early acquired sounds and the place and voicing contrasts are relatively easy for CI users to produce. The accuracy of clusters /tw/, /kw/, and /kj/ were also included as these sequences are later acquired and more difficult to produce, at least for children with NH.

A two-way ANOVA (word-type by group) revealed a significant effect of word-type on accuracy, but no significant effect of group. That is, the children with CIs produced initial singleton stops and clusters at the same level of accuracy as their peers of the same hearing age. We also correlated consonant accuracy in real words and nonwords with hearing age and raw scores on the PPVT-4. While all of these correlations were significant for the children with NH, only the correlation between accuracy on real words and hearing age was significant for the children with CIs. These results suggest that there may be a different relationship between nonword repetition accuracy and vocabulary growth for children with CIs, relative to their NH peers. This result has important clinical implications for teaching new words to children with CIs.

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D26: LEXICAL TONE DEVELOPMENT IN PRELINGUALL-DEAFENED CHILDREN WITH COCHLEAR IMPLANTS

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Due to inadequate pitch coding in current cochlear implant (CI) devices, lexical tone perception in Mandarin-speaking children has been shown to be poor. The purpose of the study was (1) to explore lexical tone development (i.e., perception and production) in Mandarin-speaking prelingually-deafened children with cochlear implants and (2) to determine significant predictive variables that contribute to tone development in these children.

Lexical tone perception was measured in 109 implanted children (age 2.4 – 16.2 years) in a computerized two-alternative forced-choice tone recognition test. The implanted children performed with an average score of 67% correct, significantly lower than the near-perfect scores from the control group that consisted of 129 typically-developing, normal hearing children (3.2 – 10.0 years). Tone production, elicited from 78 implant children, was analyzed acoustically and was evaluated using an artificial neural network. The results showed that the degree of differentiation of tones produced by the CI group was significantly lower than that of the normal-hearing group. Further, there was a moderate correlation between perception and production performance in the 78 implanted children ($r = 0.53$, $p < 0.001$).

General Linear Model analysis was performed to determine significant factors contributing to tone development in CI children. Duration of implant use, age at implantation, and communication mode were significant predictive variables and jointly explained approximately 40% of the variance in the tone perception performance of the implanted children. When duration of implant use, the most significant predictor, was controlled for, age at implantation and communication mode each accounted for unique variance of the perception performance. In contrast, age at implantation was found to be the only significant predictor for tone production performance in the implanted children.

In sum, there are marked deficits in tone development in Mandarin speaking children with CIs. Our results also indicate that early implantation helps improve tone development in tone language speaking children. Other factors, such as duration of implant use and oral communication can predict tone perception performance in children with CIs.

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D27: AUDITORY MODEL BASED ACOUSTIC CI SIMULATIONS FOR PATIENTS WITH PROFOUND HEARING LOSS.

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Cochlear implants (CI) are devices that partially restore hearing via electrical stimulation of the inner ear. In the Cochlear implants there are many patient and system specific parameters that can be optimized for individual patients. As Cochlear implants are surgical procedures it is important to estimate the effect of these parameters before patient evaluation. In the current study system specific parameters are evaluated. Initially a channel vocoder based acoustic CI model is developed with varying number of channels from 6 to 18 in steps of 3 with frequency ranging from 100 Hz to 7000 Hz. This system is developed using bank of Chebyshev type-2 filters of non-overlapping uniform bandwidth of 200 Hz each. Acoustic CI simulations are generated for all the vowels (/a/, /i/, /u/, /e/ and /o/) using waveform and feature extraction strategies. The first five formant frequencies of each vowel that are used as features are extracted using Linear Prediction based formant extraction technique. An open set listening test is conducted with 10 normal hearing subjects listening to the acoustic CI simulations. From the listening test we observed that with waveform strategy the perceptual quality is increased with the number of filters and the formant frequency based filters outperformed the uniform bandwidth filters. To further improve the performance of the system an auditory-model based acoustic CI system is implemented with frequency bands spacing similar to Mel-scale. These filters are implemented considering the centre frequencies of the critical bands of the auditory system with equivalent rectangular bandwidths (ERB). The 25 easy and 25 hard words from the list-1 of Lexical Neighborhood Test (LNT) are used to generate the acoustic CI simulations. The same word set is used for generating CI simulations using uniform bandwidth filters for comparison. The speech data of 5 male and 5 female speakers is recorded with head mounted microphone with a sampling rate of 16 kHz. The voiced/unvoiced classification of the speech signal is performed taking the multivariate unimodal Gaussian distribution of zero crossing rates, and main-lobe width of the autocorrelation of the short-time (frame size of 25 ms) speech signals. The simple inverse filtering technique (SIFT) is used for the extraction of pitch period in order to synthesize the voiced portions in the vocabulary. An open set listening test is conducted with 10 normal hearing subjects. From the listening tests it is observed that the perception of the easy and hard words with Mel-filter based system had a word recognition rate of 90%. The perceptual quality of the Melfilter based CI simulations was observed to be better than that with the uniform bandwidth filters.

D28: MULTI-MICROPHONE NOISE REDUCTION STRATEGIES FOR COCHLEAR IMPLANTS

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Noise reduction algorithms can improve the perception of speech in noisy situations. This is crucial for cochlear implant (CI) and hearing aid schemes with the more fundamental HA or CI processing performed beyond this stage. Not surprisingly the same types of noise reduction algorithms can be applied in both HAs and CIs.

This research focuses on two types of multi-microphone noise reduction: Generalized Sidelobe Cancellation (GSC) based beamforming and Multichannel Wiener Filtering (MWF). The first technique has already been implemented and evaluated for both HAs and CIs. The second technique has only been evaluated thoroughly for hearing aid applications due to its potential in terms of binaural signal processing. Since both techniques are based on solving the same mathematical problem, large similarities exist. Still, the way of solving this mathematical problem is different, leading to different results.

In this research we studied 9 different speech-in-noise enhancement schemes which represent a transition from the GSC-based BEAM system (implemented in the Cochlear Freedom™ CI Sound Processor) to the MWF without pre-processing at its front end (which is state of the art in terms of binaural noise reduction algorithms for hearing aids). Triplemicrophone BTE devices were used allowing us to study the benefit of adding an additional microphone to both noise reduction schemes. Evaluation data have been obtained with 10 normal hearing subjects and 3 CI-users for the 9 different real-time noise reduction schemes.

The main conclusions are: 1) Adding a third microphone to a spatially preprocessed MWF algorithm significantly improves noise reduction performance. 2) With the speech distortion parameter set to 0, the same performance is obtained with the MWF and BEAM algorithm. This is in agreement with theory which shows that both algorithms should convergence to the same solution in this specific condition. 3) Removing the spatial pre-processing from the MWF significantly degrades noise reduction performance for some scenarios. However, it has been proven that this leads to the preservation of binaural cues which are essential for sound source localization and to benefit from spatial release from masking. 4) The three-microphone MWF with speech distortion parameter and spatial pre-processor produces the largest gain in speech intelligibility. It significantly outperforms the BEAM and shows a high potential for implementation in commercial CIs.

D29: SPEECH PROCESSING USING PSEUDOMONOPHASIC STIMULI IN BIPOLAR MODE

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This study explores novel speech processing strategies using pseudomonophasic pulses in bipolar mode. It is instigated by previous results of forward masking experiments in which a pseudomonophasic masker showed a more selective excitation proximal to the electrode of the bipolar pair for which the short, high-amplitude phase was anodic (Macherey et al., submitted). The use of a bipolar configuration combined with pseudomonophasic pulses may provide access to more apical (low-frequency) regions of the cochlea, by presenting the effective short, high-amplitude anodic phase of the pulse to the most apical electrode of the implant.

Three speech processing strategies are compared: 1) the strategy commonly used by the subjects (e.g. a CIS in monopolar mode, 16 channel or a paired-pulse strategy), 2) a 12-channel CIS strategy with pseudomonophasic pulses in narrow bipolar mode (BP+2 or BP+ 3), and with each pulse anodic re the most apical electrode of the pair, 3) a 12-channel CIS strategy similar to 2) except with symmetric biphasic pulses.

The novel speech processing strategies were evaluated using a standard procedure including speech intelligibility and questionnaires. Electrode configuration and the effect of overlapping and non-overlapping channels were examined in detail. Preliminary results suggest that the novel strategies do not improve performance, but suggest alternative stimulus manipulations that are currently being investigated.

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D30: THE COHERENT FINE STRUCTURE APPROACH FOR BETTER REPRESENTATION OF PITCH FREQUENCY

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Current stimulation strategies are based on the envelope signals of an N channel filter bank. The envelopes are sampled and determine the amplitudes of stimulation pulses, which are applied sequentially in N electrodes. The band-pass envelopes are detected, e.g., by rectification and subsequent low-pass filtering, or by direct computation of the Hilbert envelopes. For voiced speech segments, the pitch frequency appears as a modulation of pulse amplitudes in each channel. However, the modulation depths vary between channels, and due to different group delays and effects of spatial channel interaction, the overall amount of pitch represented as temporal information is limited.

The "Coherent Fine Structure (CFS)" aims at a better representation of the pitch frequency. The audio range is analyzed by an N channel filter bank. An estimate $e_i(t)$ (with i = 1, 2, ..., N) of the spectral energy is computed for each band filter, where the averaging period is sufficiently long to remove all temporal fluctuations related to the pitch frequency. The pitch information is introduced by means of a carrier signal c(t), derived from an additional band-pass filter covering the pitch frequency range. For example, to compute c(t) the output is half-wave rectified and the maxima reflecting the pitch frequency are normalized to one. The resulting signal c(t) is zero during about 50 % of the pitch periods. Stimulation in each channel is based on the product signals $c(t)e_i(t)$. Since c(t) applies equally for all CFS channels, the resulting stimulation pattern shows bursts of pulses at the pitch period, appearing coherently across all CFS electrodes. As a result of coherence, the temporal pitch representation is not impaired by spatial channel interaction.

Patient tests comparing CFS and standard CIS configurations of speech processors have been carried out. Preliminary results show a comparable speech perception in noise for both settings in acute tests. For periodic non-sinusoidal signals (harmonic roll off -9dB/octave) a significant improvement of frequency resolution for the CFS settings for fundamental frequencies between about 100 - 300 Hz is observed.

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D31: WITHIN-SUBJECTS COMPARSION OF THE HIRES AND FIDELITY120 STRATEGIES: VOWEL AND CONSONANT PERCEPTION

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Current steering is designed to improve the accuracy of place-based spectral information provided to cochlear implant (CI) users. Recent studies indicate that a speech-processing strategy that incorporates current steering (Fidelity120) can support higher levels of speech recognition than a traditional strategy (HiRes) in some users of the Advanced Bionics CI. Such improvements are thought to stem from improved perception of the spectral cues in speech; however, this assumption has not been confirmed.

The present study compared CI users' perception of spectral speech cues for the Fidelity120 versus HiRes strategies and examined the hypothesis that improvements in spectral-cue perception with Fidelity120 are proportional to place-pitch sensitivity for current-steered stimuli. Subjects were 10 postlingually-deafened adults with an Advanced Bionics HiRes90k CI. Eight subjects entered the study using the HiRes strategy and two entered using the Fidelity120 strategy. Subjects' performance with the original strategy was compared to their performance with the alternate strategy after 8 weeks' daily use. Five subjects were also tested again with Fidelity120 after three months' additional use. Speech perception measures consisted of overall vowel and consonant identification and the spectrally-based features of vowel F1 frequency, vowel F2 frequency and consonant place-of-articulation. Each subject's place-pitch sensitivity for current-steered stimuli was measured in the basal, middle, and apical regions of the implanted array using a 2AFC psychophysical procedure.

Mean speech perception data indicated no benefit of Fidelity120 over HiRes after 8 weeks' use. After 3 months additional use, Fidelity120 yielded small but significant improvements over HiRes for overall vowel recognition and for the vowel F2 feature. In contrast to the mean data, clear improvements with Fidelity120 relative to HiRes were apparent for several individual subjects. At the 8-week time point, 5 of 10 subjects exhibited improvements greater than 5% with Fidelitiy120 (ranging from 6.0 to 20.5%) in the perception of vowel F1 and F2 cues. These gains typically increased during the 3-month supplemental period of Fidelity120 use.

Place-pitch thresholds predicted improvements with Fidelity120 over HiRes for the vowel F2 feature, but only subjects whose place-pitch thresholds were better than α = 0.3 (equivalent to three discriminable pitches per electrode pair) showed improvements. There was no systematic relationship between place-pitch sensitivity and improvement with Fidelity120 for the other speech measures.

Findings indicate that Fidelity120 supports improved perception of spectral speech cues in some, but not all, users of the HiRes90k device. Improvements are most likely to occur in individuals who can perceive two or more intermediate pitches between adjacent electrodes, and are larger for vowel spectral cues (F1 and F2 frequency) than for consonant spectral cues (place of articulation). The time course of improvement for the perception of spectral speech cues with Fidelity120 may span 2 to 5 months, or longer.

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D32: BENEFITS OF ELECTRICAL STIMULATION OVER TWO COCHLEAR TURNS IN POSTLINGUALLY DEAFENED CI USERS - A PROSPECTIVE LONG-TERM STUDY

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Aim: In this study long-term effects of electrical stimulation of the apical region of the cochlea on speech perception are evaluated by using different channel arrangements.

Methods: Fourteen newly implanted subjects with a MED-EL cochlear implant and a fully inserted (>30 mm) standard electrode participated in this prospective study. Four different electrode configurations had been defined for the 12-electrode array: A) 8 most apical electrodes only, B) 8 most basal electrodes only, C) 8 electrodes spread across the whole array, D) all 12 electrodes. The study followed an ABCABCD crossover design with one month familiarization with every condition prior to evaluation, after an initial 3-months period for the first condition. Starting conditions were randomized across patients. Conditions A, B, and C were repeated during the trial in order to compensate for learning effects. D (full-12) was tested as the final condition. Tests included Freiburg monosyllables, vowels, consonants, and HSM sentences in quiet and in noise. Additionally, a pitch ranking test was performed at each interval.

Results: Based on >10% score differences for the three conditions basal-8, spread-8, and full-12 (speech coding CIS+), eight subjects achieved their best speech test scores with "full-12". Three subjects performed best with “basal-8”, but equally well with “basal-8” plus two apical electrodes. One subject had his best scores with “spread-8”, and two subjects performed about equally well with all three conditions. Speech perception with “apical-8” was significantly worse than with the other three conditions; only two subjects achieved reasonable good speech perception with “apical-8”. When "basal-8" was compared with "spread-8", eight out of 14 subjects scored better with “spread-8”; these subjects had an additional benefit from “full-12” (>10% score differences, CIS+). Four subjects performed better with "basal-8"; 2 of these 4 subjects decreased in speech perception with “full-12”. In two subjects the test scores with "basal-8" and "spread-8" were about balanced. The benefit from the de-activation of apical electrodes as observed in three subjects seems to correlate with pitch ambiguities in the apex. At the end of the study, 11 subjects chose a “full-12” fitting and 3 subjects chose 10-channel fittings, i.e. “basal-8” plus 2 apical electrodes.

Conclusion: After the initial use of several 8-channel maps over 8 months, all new implanted cochlear implant recipients benefited from stimulation over the entire length of the cochlea, including the apical region.

D33: EFFECTS OF ELECTRICAL STIMULATION ON THE ACOUSTICALLY EVOKED COMPOUND ACTION POTENTIAL

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The criteria for implantation with a cochlear prosthesis have been broadened and people with considerable residual low-frequency hearing receive an implant nowadays. Preservation of residual hearing in the implanted ear improves speech intelligibility in noise and increases the esthetic perception of complex sounds. We assume that residual low-frequency hearing has optimal beneficial effects in cochlear implant users when the interactions of electrical stimulation on acoustically evoked responses are minimal. We have investigated the effects of ipsilateral intracochlear electrical stimulation on the amplitude of the acoustically evoked compound action potential (CAP) in normal-hearing guinea pigs.

Electric stimuli were delivered via a 1 mm platinum wire electrode inserted in the basal turn of the cochlea and consisted of single biphasic pulses (40 μs/phase) or trains of biphasic pulses 10 ms in duration. Current level was typically 800 μA. CAPs were evoked with acoustic tone bursts. Effects of electrical stimulation on CAP amplitude were tested using a forward masking paradigm. CAPs were evoked at various acoustic frequencies (0.5 – 16 kHz) at various levels (100 dB SPL down to threshold). The effect of the interval between electrical and acoustical stimulus (EAI) was tested using a single electric pulse and by varying the interval from 0 to 10 ms. Effects of pulse rate on CAP amplitude was tested using pulse trains varying from 0.5 to 4 kHz (500 – 4000 pulses/sec) using an EAI of 1 ms.

Electrical stimulation suppressed CAPs evoked with high-frequency tones, especially at low sound levels. Suppression of low-frequency evoked CAPs was less pronounced. Suppression at high frequencies was dependent on EAI and decreased with increasing EAI. Recovery of high frequency-evoked CAPs was typically complete at EAIs as short as 2 milliseconds. CAP suppression was not tuned to the frequency of the electrical pulse train and was most pronounced at high acoustical frequencies of low level regardless of the pulse frequency.

These data indicate that basal (high-frequency) cochlear regions can be stimulated electrically without affecting low-frequency acoustical hearing. The finding that CAP suppression was not tuned to the electrical stimulus frequency (i.e. the pulse rate) indicates that the carrier frequency of cochlear implants does not play an important role in electro-acoustic interactions. These findings may be relevant for hybrid implant stimulation strategies.

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D34: MULTIDIMENSIONAL PITCH SCALING AND SPEECH UNDERSTANDING

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Recently there has been an increase in the number of cochlear implant recipients who retain usable acoustic hearing postoperatively. It is important that the sensations evoked by the electric stimuli delivered via the implant are comparable with the acoustic signals perceived. Conflicting sensations might negatively influence speech understanding. The main objective of the study was to investigate the perceptual relations among acoustic and electric stimuli presented to cochlear implant users who have functional hearing at the contralateral side and look for correlations with speech understanding and subjective findings.

Fourteen subjects participated in the study. Subjects were unilateral profoundly deaf and participated in a study investigating the effectiveness of cochlear implantation in treating unilateral tinnitus [Van de Heyning et al, 2008]. The multidimensional scaling was performed with five acoustic stimuli (150, 336, 753, 1690, and 3790 Hz) and five electric stimuli (1200 pulses per second, 26.7 us/phase; presented on E2, E4, E6, E8 and E10) which were tested for dissimilarity. Speech recognition was tested using monosyllables, presented to the CI only over headphones. To evaluate the subjective improvement with CI use, the Speech Spatial and Qualities of Hearing Scale (SSQ) was used.

Generally the MDS results can be divided into two groups. One group shows a distribution of data points differing in only one dimension, on the basis of frequency. The second group shows a distribution of data points differing in two or more dimensions, not only separating the stimuli on the basis of frequency but also clearly separating the acoustic stimuli from the electric stimuli. The perceptual differences among electrical stimuli and acoustic signals also correlate to speech recognition. Subjects perceiving differences between the presented stimuli in only one dimension (frequency) show significantly better speech recognition with CI only compared to those subjects using two or more dimensions to separate the stimuli. Regardless of these objective findings, all patients report equal benefit.

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D35: COMPARISON OF SPEECH INTELLIGIBILITY BY EAS, BIMODAL, UNI- AND BILATERAL COCHLEAR IMPLANT PATIENTS IN A 'MULTI-SOURCE NOISE FIELD' (MSNF)

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Speech perception in noise is one of the most difficult tasks for people suffering from hearing impairment. The Oldenburg Sentence Test (OLSA) is a useful tool to investigate speech intelligibility threshold in noise. In the present study, a multi-source noise field consisting of a four loudspeaker array with independent noise sources was combined with the OLSA. The MSNF allows presenting a more realistic noise environment and shows a higher effect of binaural interaction regarding the separation of signal and noise from different sources.

Three different noise characteristics were applied in two conditions (S0N0: Signal and noise from the front; MSNF) to investigate the speech reception threshold: OLnoise (generated by superposed sentences of OLSA), CCITT-noise according to ITU-T Rec. G.227, and speech simulating noise according to Fastl.

Four different groups of cochlear implant patients separated into listening conditions unilateral, bimodal, bilateral and EAS (electric-acoustic stimulation) and 22 normal hearing served as subjects in the present study.

Results showed a clear discrepancy between the examined patient groups unilateral and EAS for Fastl-noise in MSNF-condition (ΔSNR=7.9 dB). For OLnoise in S0N0-condition, the results differ less (ΔSNR=3.4 dB). The MSNF with Fastl-noise is particularly suitable to measure the performance of various aided CI-patients in realistic sound environments.

D36: RESISTANCE TO INTEGRATION OF BINAURALLY MISMATCHED FREQUENCY-TO-PLACE MAPS: SPEECH IN NOISE

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Previous research has shown that normal hearing listeners are resistant to integrating binaurally mismatched frequency-to-place maps when listening to speech in quiet.[1] The present investigation extends this work to speech in noise. A dichotic sine-carrier vocoder with a spectral resolution of 10 adjacent bands was used to simulate cochlear implant processing in normal hearing listeners. Odd-numbered bands were presented to one ear with the equivalent of a 3.8 mm basalward shift, while even-numbered bands were presented to the contralateral ear without a shift. Listeners were trained with automated Connected Discourse Tracking, and perceptual adaptation was measured with tests of sentence and vowel perception before, during and after training. In Experiment I, 16 listeners were trained alternately with the binaurally mismatched processor and just the monaural, shifted bands over eight 40-minute training sessions (5 h 20 m total). In Experiment 2, 8 of the 16 listeners were trained for a further 40 minutes and re-tested with headphone orientation reversed to examine retention of adaptation and whether adaptation involved ignoring and/or attending to a specific ear. Training and sentences were presented in speech-shaped noise at an SNR of 10 dB, and vowels at an SNR of 0 dB.

Subjects showed significant adaptation to all speech materials after 5 hours and twenty minutes of training, including the 5-channel monaural shifted band condition. However, intelligibility with the 10-channel binaurally mismatched processor was typically equivalent to or worse than that with the monaural 5 unshifted bands, suggesting that listeners were resistant to integrating the binaurally mismatched frequency-to-place maps. With easier sentences, there was a small (6%) but significant advantage for the binaurally mismatched processor, but this was found for only one talker and could not be replicated in Experiment 2. Intelligibility of the binaurally mismatched processor was not affected by reversing headphone orientation, indicating adaptation was based on the frequency content of the signals rather than specific ear listening. The results are consistent with a theory of better ear listening, rather than binaural integration, when listening to binaurally mismatched frequency-to-place maps. Alternative frequency-place mapping strategies for bilateral cochlear implants that avoid such mismatches may ultimately lead to more optimal speech recognition.

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[1]Siciliano, C., Faulkner, A., Rosen, S. and Mair, K. (Accepted). Resistance to learning binaurally mismatched frequency-to-place-maps: Implications for bilateral stimulation with cochlear implants. JASA.

D37: BINAURAL PROCESSING IN THE AUDITORY CORTEX OF HEARING AND CONGENITALLY DEAF CATS

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It is well accepted that the auditory cortex plays a critical role in sound localization as demonstrated by various lesion experiments (e.g. Jenkins and Merzenich, J Neurophysiol 1984; 819–47). In case of deafness sound localization can be achieved by binaural electrical stimulation via cochlea implants, but sensitivity to binaural cues depends on the age of onset of deafness (Litovsky et al 2005 ARO, Abs. 168). Congenitally deaf subjects lack any auditory experience and previous studies from our laboratory have demonstrated functional deficits in cortical processing of monaural electrical stimuli (e.g. Kral et al., Cereb Cortex 2005; 552-62). The present study investigated how congenitally deafness affects binaural processing on the cortical level. Investigations were focused on differences between naïve adult and normal adult cats. In a first approach cortical propagating waves were studied using local field potentials (LFPs), in a second study responses to interaural time differences (ITD) using multi-unit recordings were investigated.

In total four adult deaf cats and four adult hearing control cats were used. The controls were acutely deafened by intracochlear application of neomycin. All animals were stimulated with charge-balanced biphasic pulses (200µs/phase) in wide bipolar configuration through a custom made cochlear implant inserted into the scala tympani on either side. The cortex was mapped with glass microelectrodes using LFPs elicited at 10dB above lowest cortical threshold (100–150 positions). Amplitudes of LFPs were analyzed to generate activation maps. Most responsive cortical regions as defined from the LFP maps were identified to record multi-unit activity using 16 channel electrode arrays (Michigan probes). First the threshold of each unit (i.e. at each recording site) was determined after stimulation of ipsi- and contralateral ears. Then sensitivity to interaural time difference between -600 and +600 µs was tested with pulse trains (500 Hz, 3 pulses) at intensities of 0 – 10 dB above the threshold. Template ITD functions were fitted to the data.

Analysis of propagation waves revealed a complex spatio-temporal distribution of activity in hearing cats with sequential activation within the isofrequency column as well as between different auditory fields (A1, AAF, caudal fields) while in deaf cats activity was less structured and occurred more simultaneously along the auditory cortex. Differences between groups were also found with respect to ITD sensitivity: in deaf animals fewer neurons responded to binaural stimulation (75% vs. 50% of recordings sites), units showed significantly smaller maximum firing rates, fittings to template ITD functions were significantly worse and the modulation depth in ITD functions was smaller. Unlike hearing animals no systematic changes of ITD functions with increasing binaural level were found in deaf cats.

The data demonstrate that mechanisms for cortical binaural processing are substantially affected by congenital auditory deprivation.

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D38: SPATIAL SPEECH PERCEPTION IN NOISE IN BILATERALLY IMPLANTED CHILDREN

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Several studies have demonstrated better speech perception performance in children using two compared with one cochlear implant (CI). The extent to which bilaterally implanted children benefit from binaural cues to segregate speech and noise in a spatial configuration is less clear. Recently, we measured sound localization in children with bilateral CIs (Van Deun et al., 2009), showing high variability in localization accuracy, with best scores close to those of normal-hearing children. In the present study, speech perception in spatially separated noise was examined in bilaterally implanted children with good sound localization performance. Since also little is known about the ability of normal-hearing children to benefit from listening with two ears in a spatial setup, tests were first administered to normal-hearing children.

Speech reception thresholds for different spatial configurations of speech and noise were estimated through an adaptive procedure. Speech was always presented at 0° azimuth, while noise was presented at 0°, -90°, or +90° azimuth. Subjects listened with one or two ears. The speech material of the Leuven Intelligibility Number Test (LINT) was limited to the first 10 numbers ('LittleLINT'), to be able to test young children, and the LINT speech-weighted noise was used as a masker. Prior to testing the implanted children, performance intensity functions of the LittleLINT were estimated in normal-hearing children and adults. The steep slope (12-14%/dB), the familiarity to children and the repeatability of lists make this speech material suitable for fast and accurate threshold estimation in children.

Speech perception in spatially separated noise was measured in 15 normal-hearing adults, 50 normal-hearing children from 4 to 8 years of age and 8 children with bilateral CIs aged 5 to 12 years. Normal hearing subjects showed several benefits of listening with two ears in spatially separated noise (spatial release from masking (SRM), head shadow, summation, and squelch). An age effect was observed for SRM. Bilaterally implanted children showed SRM and head shadow effects in the same range as normal-hearing children. However, no summation or binaural squelch could be established.

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Van Deun, L., van Wieringen, A., Scherf, F., Deggouj, N., Desloovere, C., Offeciers, F.E., Van de Heyning, P.H., Dhooge, I.J., Wouters, J. "Earlier intervention leads to better sound localization in children with bilateral cochlear implants". Audiology and Neurotology 2009, in press.

D39: SELF-SELECTION OF FREQUENCY MAPS IN USERS OF BILATERAL COCHLEAR IMPLANTS

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Bilateral cochlear implantation has helped many patients with bilateral severe to profound hearing loss to better understand speech and localize sound. These benefits are observed despite the lack of an optimized clinical fitting procedure that coordinates the two implants so that they work best together. The omission of an optimized fitting procedure is notable, because it could inhibit performance of bilateral cochlear implant (CI) users if the electrodes have different insertion depths, or if there are different rates of neural survival between ears. Such mismatches have been shown to degrade localization abilities in bilateral CI users.

As a first step toward creating an optimized fitting procedure, we are developing a tool that can adjust the frequency map of the CI in real time. Such a tool could ensure that the percepts elicited by stimulation of one CI match those of the contralateral CI, thereby maximizing intelligibility of the speech signal. To test this concept, we asked three bilateral users of the Advanced Bionics device to select a preferred frequency map in one ear while simultaneously listening with the contralateral CI. All listeners selected a map in their more recently-implanted ear that maximized speech intelligibility and sounded 'matched' with the contralateral CI. Listeners could move the overall frequency range higher and lower, and could expand and contract the overall range. Stimuli for map selection consisted of live voice and the first three sentences of HINT list 2, which were presented at 70 dB SPL. At the time of testing, L1, L2, and L3 had used their newly-implanted device for approximately six months, six weeks, and 1.5 weeks, respectively.

The self-selected maps in the recently implanted ear varied from the standard clinical map, which ranged from 250-5500 Hz. Specifically, L1 preferred a map ranging from 239-8118 Hz, L2 from 368-10754 Hz, and L3 from 386-5905 Hz. Speech data obtained from L1 and L2 immediately after map selection suggest there may be mild improvements with the self-selected map vs. the standard map (14 vs. 10%; 56 vs. 50%, respectively). Taken together, these results suggest that when bilateral CI users have the opportunity to adjust the map in one implant to maximize intelligibility and match the contralateral CI, they may 1) prefer a map that differs from the standard map, and 2) perform equally well if not better on tests of speech understanding, despite a lack of experience with this map.

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D40: BENEFITS OF SHORT INTER-IMPLANT DELAYS IN CHILDREN RECEIVING BILATERAL COCHLEAR IMPLANTS

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We are currently following 146 children who have received bilateral cochlear implants after a long (> 2 years), short (6-12 months), or no (simultaneous) inter-implant delay. Our objective in the present study was to examine speech detection and perception skills in quiet and noise and to assess the influence of bilateral deafness and inter-implant delay.

Speech perception is being assessed at 6 month intervals in 3 different conditions in quiet and 2 conditions in noise using age-appropriate tests. In quiet, children listen with their right implant alone, left implant alone, and both implants. At a signal to speech noise ratio of +10 dB (no spatial separation), children wear one implant in the experienced (right for simultaneous group) ear and both implants. Effects of separating the noise and speech signals in space on detection of speech (spatial unmasking) have been evaluated in 22 children who have 2 (± 0.5) years of bilateral experience (10 simultaneous, 12 long delay).

Children in the simultaneous and short delay groups showed no significant differences in speech perception scores when left versus right implants were used alone at any test time. Speech perception scores when using both implants in noise were not significantly different from the first implant (right in simultaneous group) in quiet. Detection of speech in noise was aided by bilateral cochlear implant use by 2.0 dB (95% CI: 1.1, 2.9) in the simultaneous group and there was a 7.2 dB (95% CI 6.0, 8.4) improvement when noise was moved away from the speech source with no difference between movement to the left or right.

For children with long inter-implant delays, speech perception in the newly implanted ear was poorer than the first with the largest differences found in children with long periods of bilateral deafness (> 3 years). These differences were still present after 24 months of bilateral implant use. Using both implants in noise, children in this group scored more poorly on speech perception testing than when using their first implant in quiet. Detection of speech in noise with bilateral implants compared to their first implant alone was improved by a smaller degree than in children with shorter delays (0.7 dB (95% CI: -0.4, 1.7)). Spatial unmasking of speech in noise was poorer than in children in the simultaneous group and was significantly affected by the direction in which the noise was moved; 4.8 ± 0.5 dB when noise was moved to the second implanted ear rather than 3.0 ± 0.4 dB when moved to the first implanted ear.

Results suggest that benefits of bilateral cochlear implantation are clearest over the first 2 years of use in children with limited inter-implant delays.

D41: VARIABLES AFFECTING FM PERFORMANCE WITH COCHLEAR IMPLANTS

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Optimal performance with cochlear implant is impeded by conditions with competing noise, poor acoustics, soft speech and increased distance between the listener and speaker. Electrically-coupled FM systems provide concentrated access to a signal of interest through the use of a remote microphone and have been shown to improve understanding in noise for implant recipients.

New FM systems include an adaptive FM transmitter that monitors the environment during speech pauses and then continuously communicates with local FM receivers via a 2.4 MHz data link to prescribe the optimal amount of gain. Unlike the traditional approach of providing a fixed level for the FM signal, the goal is to maintain a stable, improved signal to noise ratio across a range of environmental conditions. While adaptive FM technology has been shown to improve understanding for hearing instrument wearers by up to 50% over traditional FM systems, it was unknown what the implications were for cochlear implant (CI) users.

This poster will provide a review of literature describing parameters that effect the success of CI users with FM systems, and particularly with an adaptive FM system. Maximum benefit is achieved when several variables are considered, including mixing ratio, input dynamic range of the processor and receiver settings. Wolfe and Schafer (2008) examined the effect of mixing ratio and reported that settings which attenuated the headpiece microphone of the speech processor can have a detrimental effect on the listeners' understanding of soft speech not directed to the FM transmitter. With Advanced Bionics devices, speech perception for soft inputs declined 23% when a mixing ratio of 30/70 was used in lieu of the 50/50 default. In 2008 Wolfe and Schafer reported similar findings for Nucleus Freedom users. Specifically, the use of a 3:1 mixing ratio resulted in a 33% decline in soft speech perception.

Wolfe et al (in press) examined the benefit of adaptive FM for CI users. When background noise levels reached 70dB, Harmony and Auria users performed more than 50% better on HINT sentences with the adaptive compared to a traditional FM system. In a separate paper, initial testing for Freedom users was reported (Wolfe et al, in press), in which subjects demonstrated no benefit for adaptive versus fixed FM. Further investigation revealed that this finding was a function of the magnitude of the processor's input dynamic range and that aggressive compression was embedding the FM signal into the noise. Activation of auto-sensitivity control resulted in adaptive FM results similar to those with Advanced Bionics devices.

This poster will assist the reader in selecting optimal settings for the provision of FM systems to CI recipients. Recommended FM fitting protocols will be suggested.

D42: ACTIVE MIDDLE EAR IMPLANTS FOR HEARING AUGMENTATION IN CHILDREN WITH CONGENITAL AURAL ATRESIA

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Congenital aural atresia is a complete absence of the external auditory canal. Atresia may be accompanied by middle ear deformities, is usually unilateral and co-existing with microtia, and may or may not be syndromic. 1 in 20,000 live births are affected annually (Holmes 1949). The cochlea and auditory nerve are usually not affected. Therefore, the hearing loss is typically a congenital conductive hearing loss with a conductive component of up to about 60 dB HL. Untreated hearing loss may impact children's speech and language development, directional hearing, and speech understanding ability in noise. Treatment options depend on severity and include reconstructive surgery, bone-conduction or bone-anchored hearing aids, and active middle ear implants. Surgical reconstruction is recommended with a score of 8, 9, or 10 on the Jahrsdoerfer scale, indicating a mild deformity. The surgery is one of the most difficult otologic surgeries with varying outcomes and a high revision rate (Chang et al. 2006; Patel, Shelton 2007). When the Jahrsdoerfer score is less than 8, suggesting a more severe case, then success may be limited and the pinna may be reconstructed but not the ear canal and middle ear structures. Therefore, hearing augmentation is required. Bone-conduction hearing aids have been used successfully in children with atresia. However, their use may be complicated by the need to apply constant pressure to the skull for good coupling and adequate amplification. This may lead to deformities of the skull and patients and their families are often dissatisfied with the cosmetics. Bone-anchored hearing aids overcome those problems but may be complicated by infections. Recently, active middle ear implants have been used to augment hearing in children with congenital atresia (Frenzel et al. 2009). Subjects in the present study were 9 children with congenital aural atresia. All subjects were implanted with the Vibrant Soundbridge (VSB) active middle ear implant with the transducer located on either the oval or the round window. Functional gain, comparing VSB aided sound field thresholds with unaided thresholds, averaged approximately 30 dB across the frequency range. Speech reception thresholds in the aided condition averaged about 25 dB as compared with 60 dB unaided. Word recognition scores at 65 dB SPL(A) averaged 16% correct preoperatively and 98% correct postoperatively. Bone conduction thresholds were unchanged as a result of the treatment. There were no intra- or post- operative complications In conclusion, the use of an active middle implant may provide good hearing augmentation to children with congenital aural atresia. The use of the VSB in children is experimental only and is not approved for use in this population.

D43: PITCH MATCHING ACROSS SOUNDS AND EARS: IMPLICATIONS FOR PITCH COMPARISONS BETWEEN ACOUSTIC AND ELECTRIC STIMULI

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Several recent studies have estimated the place-pitch percepts associated with stimulation of individual electrodes of a cochlear implant ("CI"), by requiring CI users having residual hearing in the non-implanted ear to compare the pitches of acoustic and electric stimuli. We have shown that these pitch matches can be greatly affected by non-sensory range biases for both the method of adjustment and the method of constant stimuli (cf. Carlyon et al., this conference). In other words, changing the range of comparison acoustic sounds can yield very different results. A draw-back of these two methods is that the appropriate range of acoustic stimuli has to be estimated *a priori*. Here, we evaluate two other psychophysical methods - magnitude estimation and the mid-point comparison procedure (Long *et al*, 2005) - that do not make such *a priori* assumptions.

Six normal-hearing subjects took part. Pure tones were presented to their left ear and narrow-band noises (1/3rd of an octave) to their right ear. For the method of magnitude estimation, 16 sounds (eight pure tones ranging from 375 to 3000 Hz and eight noises) were presented randomly and the subject was asked to estimate the pitch of each them using a number between 0 and 100. For the mid-point comparison procedure, subjects were asked to make direct pitch comparisons between pairs of sounds chosen within the same 16 sounds, which led to a pitch rank order of the sounds. On different days, the center frequencies of the noise bands ranged either from 1000 to 8000 Hz, or from 125 to 1000 Hz. The matches between tones and noises showed a shift that could reach almost two octaves when changing the range of noises. This range effect was present for both methods and was very consistent over time. Furthermore, the method of pitch scaling was contaminated by additional non-sensory biases (e.g. contraction and centering biases) that affected the pitch matches. It is concluded that both procedures are susceptible to range effects, and that these effects are likely to contaminate electro-acoustic matches obtained with CI users.

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