2017 Conference on Implantable Auditory Prostheses

July 16-21, 2017

Granlibakken Conference Center

Lake Tahoe, CA

19 June 2017

2017 CONFERENCE ON IMPLANTABLE AUDITORY PROSTHESES

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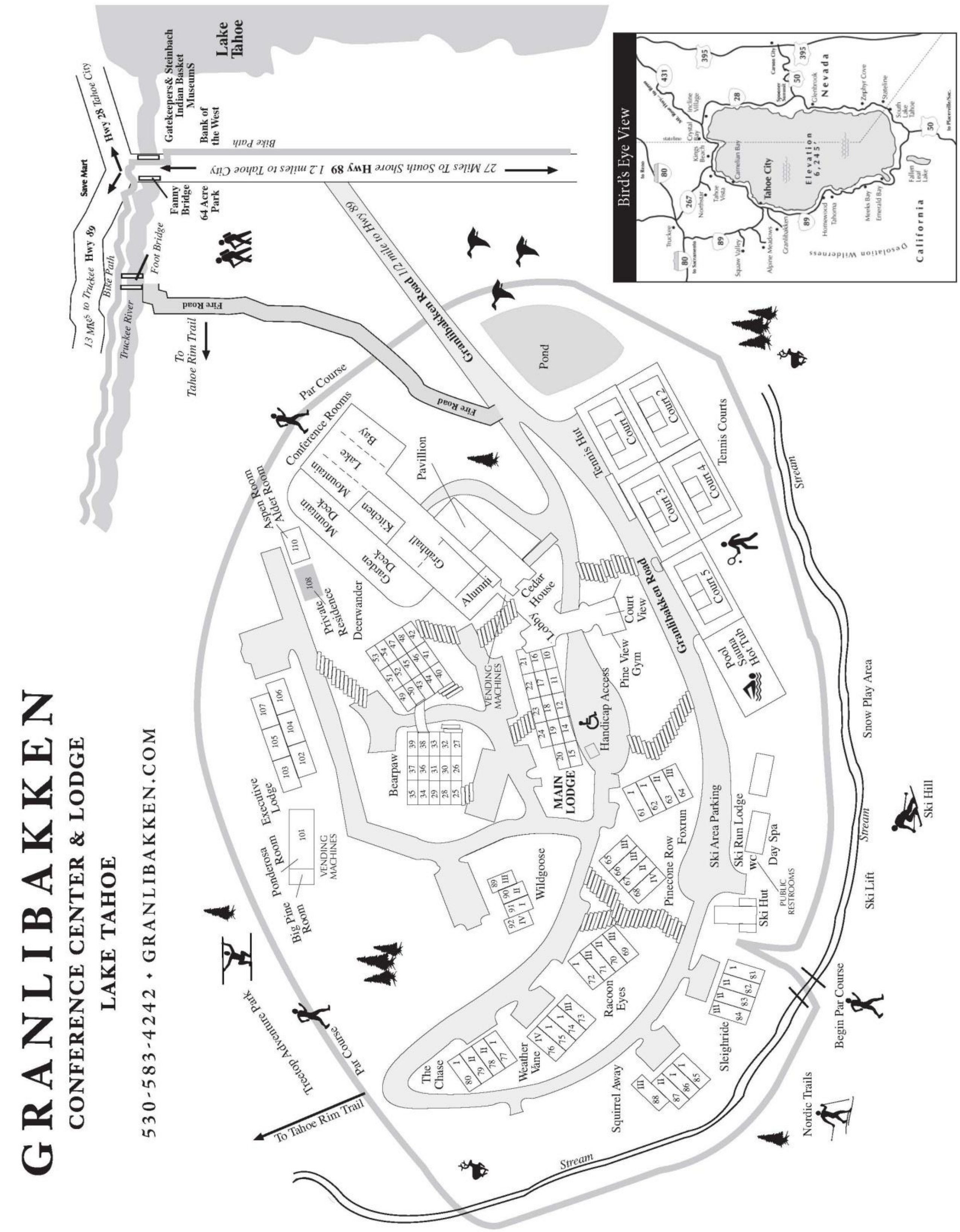

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Racoon Eyes
Weather Vane
The Chase
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Nordic Trails
Treetop Adventure Park
Par Course
To Tahoe Rim Trail

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7:00PM – Midnight	Welcome Reception
Monday July 17	
7:00AM	Breakfast opens
8:30AM – 11:5PM	CI Modeling
12:00PM- 1:00PM	Lunch
4:00PM – 6:00PM	Poster Viewing
6:00PM – 7:00PM	Dinner
7:00PM – 9:05PM	Translating to the Clinic/Consumer
9:00PM – midnight	Poster Viewing and Social
Tuesday July 18	
7:00AM	Breakfast opens
8:30AM – 12:00PM	Pediatric CIs
12:00PM- 1:00PM	Lunch
1:30PM – 4:00PM	FDA update, Company Presentations and Device workshops
4:00PM – 6:00PM	Poster Viewing
6:00PM – 7:00PM	Dinner
7:00PM – 9:00PM	Bilateral/Bimodal
9:00PM – midnight	Poster Viewing and Social
Wednesday July 19	
7:00AM	Breakfast opens
8:30AM –12:10PM	AES, Bimodal, SSD
12:00PM- 1:00PM	Lunch
1:00PM - 3:40PM	Mentoring Session
4:00PM – 6:00PM	Poster Viewing
6:00PM – 7:00PM	Dinner
7:00PM-midnight	Dance Party and Poster Viewing
Thursday July 20	
7:00AM	Breakfast opens
8:30AM – 12:00PM	Speech Perception
12:00PM- 1:00PM	Lunch
4:00PM – 6:00PM	Poster Viewing
6:00PM – 7:00PM	Dinner
7:00PM – 9:05PM	Psychophysics and TFS
9:00PM – midnight	Poster Viewing and Social
Friday July 21	
7:00AM	Breakfast opens
8:30AM – 11:30PM	Objective measures and Electrophysiology
12:00PM-1:00PM	Lunch
1:00PM	Conference End

CIAP 2017 Speaker Program

Monday July 17

8:30-11:50am CI Modeling: Moderator TBN

8:30-9:00 Laurel Carney: Aural contrast in midbrain responses to speech: Implications for Cochlear Implant
9:00-9:20 Jan Dirk Biesheuvel: Deconvolution of spread of excitation curves: Towards identification of the neural excitation area
9:20-9:40 Misagh Khayambashi: Audio re-synthesis from electrode excitations: An enhanced generic physiological approach
9:40-10:10 Ian Bruce: Advances in modeling the occurrence and timing of action potentials in response to cochlear implant stimulation

Break 10:10-10:40

10:40-11:00 Jesse Resnick: Simulated spiral ganglion demyelination alters sensitivity and temporal fidelity of responses to extracellular stimulation
11:00-11:30 Waldo Nogueira: Psychoacoustic masking models applied to sound coding strategies for cochlear implants
11:30-11:50 Mathias Voigt: Electrical stimulation of auditory cortex activates and modulates processing according to stimulated layer

12-1pm LUNCH

4-6pm Poster viewing

6-7pm DINNER

7:00-9:05pm Translating to the Clinic/Consumer: Moderator TBN

7:00-7:25 Hillary R. Perry: Health utility in unilateral verse bilateral cochlear implant recipients
7:25-7:50 Kevin Franck: Working within .edu & .com for patients
7:50-8:15 Gary Housley:TBA
8:15-8:40 Yeohash Raphael: Biological means for hearing restoration in deaf ears
8:40-9:05 Poppy Crum:TBA

9:00-midnight Poster and Social Session

Tuesday July 18

8:30-12:00am Pediatric CIs: Moderator TBN

8:30 - 9:00 David Horn: Development of auditory acuity in prelingually-deaf cochlear implant users
9:00-9:30 Laurie Eisenberg: Impact of cochlear implants on the development of spoken language: Insights from the CDACI study
9:30-9:50 Mishaela DiNino: Assessment of the electrode-neuron interface in children with cochlear implants compared to adults
9:50-10:10 Li Xu: Singing proficiency of members of a choir formed by hearing-impaired children with cochlear implants

Break 10:10-10:40

10:40-11:10 Karen Gordon: Programming the developing hearing brain: A responsibility to get it right
11:10-11:40 Lisa Davidson: The effects of early acoustic hearing on speech perception and language abilities of pediatric CI recipients
11:40-12:00 Andrej Kral: Effects of early hearing experience on activation and functional connectivity in primary and higher-order cortical field

12:00-1pm LUNCH

1:30-4:00pm FDA update, Company Presentations and Device workshops

4-6pm Poster viewing

6-7pm DINNER

7:00-9:00pm Bilateral/Bimodal: Moderator TBN

7:00-7:30 Mattias Dietz: Factors limiting spatial hearing performance with bilateral cochlear implants and first steps to reduce the shortcomings
7:30-8:00 Chen Chen: Effects of synchronizing automatic gain controls for bilateral cochlear implant users

Break, 8 to 8:15

8:15-8:35 Yoojin Chung: Neural ITD sensitivity and temporal coding with cochlear implants in an animal model of early-onset deafness

8:35-8:55	Christina Lavallee: Assessing frequency-specific effects of deafness on cortical activity in the developing human auditory system
9:00-midnight	**Poster and social session**

Wednesday July 19

8:30-11:50am	**AES, Bimodal, SSD: Moderator TBN**
8:30-9:00	David Landsberger: "Correct" electrode positions along the cochlea: Some thoughts about place coding, moveable electrodes, and rational pitch
9:00-9:20	Jeremy Marozeau: The sound sensation of electric stimulation in single-sided deafened cochlear implant recipients
9:20-9:40	Marina Imsiecke: Electric-acoustic forward masking in Cochlear Implant users with ipsilateral residual hearing
9:40-10:10	Tobias Rader: Hearing preservation and electric-acoustic stimulation: long-term results and individualized sound processing strategies
Break, 10:10-10:40	
10:40-11:00	Jeanne Clarke: Top-down repair of interrupted speech in electro-acoustic stimulation
11:00-11:30	Rene Gifford: Bimodal hearing versus bilateral implantation: speech understanding, spatial release from masking, and source location uncertainty
11:30-11:50	Maaike Van Eeckhoutte: Objective estimation of binaural loudness balance for bimodal listeners

12:00-1pm LUNCH
4-6pm Posters
6-7pm DINNER
7-8pm Posters

Wednesday 7:00pm to Midnight: Dance Night

Thursday July 20

8:30-10:00am	**Speech Perception: Moderator TBN**
8:30-9:00	Richard Wright: The importance of stimuli to intelligibility assessment
9:00-9:30	Matt Winn: Speech perception and listening effort with a cochlear implant: the rules are different
9:30-9:50	Robin Gransier: Speech perception and modulation preservation in the electrically stimulated auditory pathway
9:50-10:10	Yue Zhang: Auditory training for an optimal perceptual cue weighting strategy in CI users and its impact on speech perception and listening effort
Break 10:10-10:40	
10:40-11:10	Deniz Başkent: Voice cues and speech perception in cochlear-implant users
11:10-11:30	Mohamed Bingabr: CI electrode stimulation strategy motivated by robust intelligibility in noise of a vocoder based on the zero-crossings of the speech waveform
11:30-11:50	Olga Peskova: Speech perception performance and speech production errors in pediatric cochlear implant users
12-1pm LUNCH	
1-3:30pm	**Mentoring session: Ruth Litovsky**
4-6pm Poster viewing	
6-7pm DINNER	
7-9pm	**Psychophysics and TFS: Moderator TBN**
7:00-7:30	Brian Moore: A new method for identifying “bad” channels based on across-channel modulation masking
7:30-8:00	Josh Bernstein: Spectrotemporal modulation sensitivity and sensorineural hearing loss: Implications for cochlear-implant speech understanding in noise
Break, 8 to 8:15	
8:15-8:45	Monita Chatterjee: Complex pitch, speech prosody and lexical tone perception with cochlear implants
8:45-9:05	Maureen Shader: Age-related auditory temporal processing deficits in cochlear-implant users
9:00-midnight	**Poster and social session**

Friday July 21

8:30-10:00am	**Objective Measures and Electrophysiology: Moderator TBN**
8:30-9:00	Melissa Polonenko: Electrophysiological measures of auditory development in children using bimodal devices
9:00-9:20	Olivier Machery: Measuring eABRs to bunched-up pulses: Can this help cochlear implant programming?
9:20-9:40	Andrew Dimitrijevic: EEG alpha rhythms as a biomarker for listening effort for speech in noise perception in cochlear implant users.
9:40-10:00	Daniel Keppeler: First multichannel optical cochlear implants for optogenetic stimulation of the auditory pathway
Break, 10-10:30	
10:30-11:00	Debi Vickers: The auditory change complex as an objective measure to guide intervention
11:00-11:30	Carolyn Brown: Acoustically evoked potentials recorded from an intracochlear electrode in Nucleus hybrid CI users
12-1pm	**LUNCH**
1pm	**End of Conference**

POSTER SESSION M: MONDAY – 8AM TO MIDNIGHT

M01a: AN INTRINSIC TIME CONSTANT OF THE COCHLEAR NUCLEUS REVEALED BY ABI ELECTROPHYSIOLOGICAL MEASUREMENTS: Andreas Bahmer, Tina Kroneis, Wafaa Shehata-Dieler

M01b: TONOTOPIC NEURAL RESPONSES TO ACOUSTIC AND ELECTRIC STIMULI IN THE RAT'S PRIMARY AUDITORY CORTEX: Allison Coltisor, Taylor Myers, Guangchen Ji, Volker Neugebauer, Yang-soo Yoon

M02a: PHYSIOLOGICAL EFFECTS OF STIMULUS POLARITY AND INTERPHASE GAP AS POTENTIAL ESTIMATES OF NEURAL HEALTH: Michelle L. Hughes, Sangsook Choi, Erin E. Glickman

M02b: STIMULUS POLARITY EFFECTS ACROSS A LARGE GROUP OF COCHLEAR IMPLANT RECIPIENTS: IMPLICATIONS FOR ESTIMATING NEURAL HEALTH: Sangsook Choi, Michelle L Hughes, Joshua D Sevier

M03a: LONG-TERM SAFETY OF FOCUSED MULTIPOLAR STIMULATION: Robert K Shepherd, Andrew K Wise, Ya Lang Enke, Paul M Carter, James B Fallon

M03b: CORTICAL RESPONSES EVOKED BY COCHLEAR IMPLANT IN THE GUINEA PIG PRIMARY AUDITORY CORTEX.: Victor Adenis, Pierre Stahl, Dan Gnansia, Jean-Marc Edeline

M04a: PRELIMINARY DATA ON INTRA- AND POSTOPERATIVE ELECTROCOCHLEOGRAPHIC RECORDINGS VIA THE ADVANCED BIONICS COCHLEAR IMPLANT SYSTEM: Carolin Frohne-Buechner, Michael Bardt, Sabine Haumann, Patrick Boyle, Gunnar Geissler, Kanth Koka, Rolf Salcher, Thomas Lenarz, Andreas Buechner

M04b: AN OBJECTIVE MEASURE OF COCHLEAR HEALTH; IDENTIFYING NEURAL DEAD REGIONS: Andrew K Wise, Simone Classen, Ella Trang, Brianna Flynn, James B Fallon

M05a: USING A CUSTOMIZED MODEL OF THE AUDITORY PERIPHERY TO PREDICT INDIVIDUAL PSYCHOPHYSICAL DATA: Joshua S Stohl, Robert D Wolford, Blake S Wilson

M05b: SIGMOIDAL ECAP AMPLITUDE GROWTH FUNCTIONS: PHYSIOLOGICAL MODEL WITH BENEFITS: Konrad Schwarz, Angelika Dierker, Philipp Spitzer, Stefan Strahl, Lutz Gaertner

M06: CURRENT FOCUSING IMPROVES AUDITORY CORTICAL RESPONSES TO INTRACOCHLEAR ELECTRICAL STIMULATION IN AWAKE PRIMATE: Kai Yuen Lim, Kristin Hageman, Charles C Della Santina, Xiaoqin Wang

M07a: RECONSTRUCTION OF A HIGH-RESOLUTION COCHLEAR MODEL FOR COCHLEAR IMPLANT RESEARCH: Siwei Bai, Joerg Encke, Robin Weiss, Klaus Achterhold, Frank Boehnke, Katharina Braun, Werner Hemmert

M07b: A BIOPHYSICAL MODEL OF THE AUDITORY NERVE BASED ON HIGH-RESOLUTION MICROCT SCANS.: Joerg Encke, Siwei Bai, Niclas Baehr, Werner Hemmert

M08a: MODELLING POLARITY AND PULSE SHAPE EFFECTS ON A POPULATION OF SPIRAL GANGLION NEURON UNDER ELECTRO-STIMULATION: Matthieu Recugnat, Jaime Undurraga, David McAlpine

M08b: MODELED IMPEDANCE AND TISSUE GROWTH IN THE IMPLANTED COCHLEA: Christopher J. Buswinka, Deborah J. Colesa, Chuming Zhao, Yehoash Raphael, Karl Grosh, Bryan E. Pfingst

M09: TEMPORAL ANALYSIS OF A PURELY CONDUCTANCE BASED STOCHASTIC HUMAN AUDITORY NERVE FIBRE MODEL: Werner Badenhorst, Tania Hanekom, Johan Jurgens Hanekom

M10a: RESPONSIVENESS OF THE ELECTRICALLY STIMULATED COCHLEAR NERVE AND CORTICAL NEURAL ENCODING OF ELECTRICAL PULSE TRAINS IN CHILDREN WITH COCHLEAR NERVE DEFICIENCY: Shuman He, Nancy He, Holly F.B. Teagle

M10b: TAKING MODELS FROM THE LAB TO THE CLINIC: MODEL-BASED DIAGNOSTIC APPROACH TO A TEENAGE USER'S FACIAL NERVE STIMULATION COMPLICATIONS: Liezl Gross, Tania Hanekom, Werner Badenhorst, Johan J Hanekom

M11a: A PHENOMENOLOGICAL MODEL FOR PREDICTING RESPONSES OF ELECTRICALLY STIMULATED AUDITORY NERVE FIBER TO ONGOING PULSATILE STIMULATION: Marko Takanen, Bernhard U. Seeber

M11b: INDIVIDUAL FITTING AND PREDICTION WITH A PHENOMENOLOGICAL AUDITORY NERVE FIBER MODEL FOR CI USERS: Kaue Werner, Bernhard U. Seeber

M12a: A POLYMER-BASED INRTRACOCHLEAR ELECTRODE ARRAY FOR ANIMAL STUDY: Jin Won Kim

POSTER SESSION T: TUESDAY–8AM TO MIDNIGHT

T01a: CHARTING DEVELOPMENTAL CHANGES IN AUDITORY AND VISUAL EVOKED POTENTIALS IN CHILDREN WITH COCHLEAR IMPLANTS: Kristina C. Backer, Andrew S. Kessler, Sharon Coffey-Corina, Laurel A. Lawyer, Lee M. Miller, David P. Corina

T01b: ENVELOPE FOLLOWING RESPONSES IN COCHLEAR IMPLANTS.: Anna Samsel, Michael Hofmann, Astrid van Wieringen, Jan Wouters

T02a: ANALYZING THE CURRENT DISTRIBUTIONS OF THE MULTI-MODE GROUNDING COCHLEAR STIMULATION: Kai Dang, Pierre Stahl, Clair Vandersteen, Nicolas Guevara, Dan Gnansia, Maureen Clerc

T02b: SPEECH PERCEPTION OUTCOMES IN OLDER ADULTS WITH COCHLEAR IMPLANTS: PERIPHERAL VERSUS CENTRAL-AUDITORY CONTRIBUTIONS: Yael Henkin, Yifat Yaar-Soffer, Minka Hildesheimer, Ricky Kaplan-Neeman, Chava Muchnik

T03a: COMPARISON OF ARTIFACT SUPPRESSION METHODS FOR THE MEASUREMENT OF ELECTRICALLY EVOKED AUDITORY STEADY- STATE RESPONSES: Hanne Deprez, Robin Gransier, Michael Hofmann, Astrid van Wieringen, Marc Moonen, Jan Wouters

T03b: OBJECTIVE MEASURES TO ASSESS DIRECT ACOUSTIC COCHLEAR IMPLANT FUNCTIONING: ARTIFACT CHARACTERIZATION AND INTRA-OPERATIVE ABR AND ASSR MEASUREMENTS: Hanne Deprez, Robin Gransier, Michael Hofmann, Marc Moonen, Jan Wouters, Nicolas Verhaert

T04: MEASURING COCHLEAR IMPLANT CHANNEL INTERACTIONS WITH ELECTRICAL AUDITORY BRAINSTEM RECORDINGS (EABRS) AND THEIR RELATIONSHIP TO SPEECH PERCEPTION OUTCOMES.: Nicolas Guevara, Michel Hoen, Eric Truy, Stephane Gallego

T05: EPIDURAL RECORDINGS OF AUDITORY EVOKED POTENTIALS IN COCHLEAR IMPLANT USERS: Sabine Haumann, Guenther Bauernfeind, Magnus Johannes Teschner, Martin Georg Bleichner, Jochem Rieger, Thomas Lenarz

T06a: COMPARISON OF RESULTS BETWEEN THE BEHAVIORAL MEASURES AND OBJECTIVE MEASURES TO IDENTIFY AUDITORY TEMPORAL AND SPECTRAL RESOLUTION IN COCHLEAR IMPLANT USERS: Soojin Kang, Sung Hoon Yoon, Jihwan Woo, Sung Hwa Hong, Il Joon Moon

T06b: FREQUENCY FOLLOWING RESPONSES IN COCHLEAR IMPLANT USERS : Jana Van Canneyt, Michael Hofmann, Tom Francart, Jan Wouters

T07a: DISCRIMINATION OF LING 6 SOUNDS USING ACOUSTIC CHANGE COMPLEX (ACC): Sarah A. Klemuk, Eun Kyung Jeon, Carolyn Brown, Paul Abbas

T07b: THE ACOUSTIC CHANGE COMPLEX AND ITS RELATION TO SPEECH PERCEPTION IN NOISE IN HEARING-IMPAIRED SUBJECTS: Marc Lammers, Bernard Vonck, Wilko Grolman, Gijsbert van Zanten, Huib Versnel

T08: BRAIN ACTIVITIES DIFFER IN ACOUSTIC AND ELECTRIC HEARING ELICITED BY FREQUENCY CHANGES: Chun Liang, Fawen Zhang

T09a: MEASURING CENTRAL AUDITORY PLASTICITY IN ADULT COCHLEAR IMPLANT USERS WITH THE AUDITORY CHANGE COMPLEX: Rajeev Mathew, Jaime Undurraga, Patrick Boyle, Azhar Shaida, David Selvadurai, Dan Jiang, Deborah Vickers

T09b: USING FUNCTIONAL NEAR-INFRARED SPECTROSCOPY (FNIRS) TO UNDERSTAND, BRAIN PLASTICITY, AUDIOVISUAL INTEGRATION AND FOR AUTOMATED PROGRAMMING OF COCHLEAR IMPLANTS: Colette M McKay, Hamish Innes-Brown, Mehrnaz Shoushtarian, Xin Zhou, Stefan Weder

T10: FROM THE AUDITORY NERVE TO THE AUDITORY CORTEX IN A COCHLEAR IMPLANTED ANIMAL MODEL: HOW ARE VARIABLES OF THE ELECTRIC WAVEFORM REPRESENTED?: Charlotte Amalie Navntoft, Jeremy Marozeau, Tania Rinaldi Barkat

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T13: FUNCTIONAL CONNECTIVITY OF LISTENING NETWORKS IN EXPERIENCED BILATERAL COCHLEAR IMPLANT USERS: Daniel Alexander Smieja, Benjamin T. Dunkley, Blake K. Papsin, Karen A. Gordon

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T15a: THE EFFECTS OF INTERAURAL LEVEL DIFFERENCES ON FUSION IN ADULTS WITH NORMAL-HEARING AND BILATERAL COCHLEAR IMPLANTS: Bess Glickman, Yonghee Oh, Lina A.J. Reiss

T15b: BINAURAL PITCH FUSION IN CHILDREN WITH NORMAL-HEARING, HEARING AIDS, AND COCHLEAR IMPLANTS: Curtis Hartling, Bess Glickman, Jennifer Fowler, Gemaine Stark, Laurel Richardson, Marissa Montejano, Yonghee Oh, Lina Reiss

T16: DEVELOPMENT OF THE STRIPES TEST AS A MEASURE OF SPECTRO-TEMPORAL PROCESSING AND THE EFFECT OF STIMULATION MODE ON COCHLEAR-IMPLANT LISTENER PERFORMANCE ON SPECTRO-TEMPORAL AND SPEECH TESTS: Alan W Archer-Boyd, Wendy S Parkinson, Heather A Kreft, John M Deeks, Richard E Turner, Andrew J Oxenham, Julie A Bierer, Robert P Carlyon

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T18b: RATE MODULATION DETECTION THRESHOLDS FOR COCHLEAR IMPLANT USERS: Tim Brochier, Colette McKay, Hugh McDermott

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T39b: INTERNET-OF-THINGS AND SMART ASSISTIVE HEARING DEVICES: Hussnain Ali, John H.L. Hansen

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T42b: SPEECH DISCRIMINATION SCORE DEVELOPMENT OVER TIME AFTER COCHLEAR IMPLANTATION: Christoph Kaecker, Sebastian Hoth, Marc Praetorius

T43a: ARTIFACT REDUCTION AND LOUDNESS GROWTHS IN ELECTRICALLY EVOKED AUDITORY STEADY STATE RESPONSES: Hongmei Hu, Konrad Schwarz, Stefan Strahl, Mathias Dietz, Birger Kollmeier, Stephan D. Ewert

T43b: DOES BIMODAL HEARING PROVIDE AN ADVANTAGE TO BILATERAL BRAINSTEM DEVELOPMENT?: Melissa Polonenko, Christina Lavallee, Blake Papsin, Karen Gordon

T44a: HOW CAN WE FURTHER IMPROVE REAL-LIFE OUTCOMES FOR CHILDREN WITH EARLY COCHLEAR IMPLANTS? BILATERAL IMPLANTATION AND OTHER NEW PREDICTIVE FACTORS: Julia Sarant, David Harris, Lisa Bennet, Manasi Canagasabey, Karyn Galvin, Busby Peter

T44b: VERBAL LEARNING AND MEMORY IN ADULTS WITH COCHLEAR IMPLANTS: Aaron C. Moberly, Arthur Broadstock, Kara J. Vasil, Michael S. Harris, David B. Pisoni

T45: DEFICITS IN VOICE EMOTION PRODUCTION BY CHILDREN WITH COCHLEAR IMPLANTS: Jenni L Sis, Sara A Damm, Monita Chatterjee

T46: EFFECTS OF DEVELOPMENT ON THE ACOUSTIC CHANGE COMPLEX: A WITHIN-SUBJECT STUDY OF PEDIATRIC CI USERS: Eun Kyung Jeon, Carolyn J. Brown, Paul J. Abbas

POSTER SESSION W: WEDNESDAY –8AM TO MIDNIGHT

W01a: A MODEL BASED SOUND CODING STRATEGY FOR LASER STIMULATION IN COCHLEAR IMPLANT USERS WITH RESIDUAL HEARING: Benjamin Krueger, Torben Fiedler, Peter Baumhoff, Darshan Shah, Andrej Kral, Andreas Buechner, Hannes Maier, Waldo Nogueira

W01b: IMPROVING CHANNEL SELECTION CRITERIA IN N-OF-M STRATEGIES FOR COCHLEAR IMPLANTS: Juliana N Saba, Hussnain Ali, John HL Hansen

W02a: REAL-TIME SPECTRAL CONTRAST ENHANCEMENT APPLIED TO COCHLEAR IMPLANT CODING STRATEGIES: Federico Bolner, Bas van Dijk, Marc Moonen, Jan Wouters

W02b: FREQUENCY ADAPTATION AND SUBJECTIVE TESTING: Simon K Christiansen, Manuel S Martinez

W03a: DYNAMIC CURRENT FOCUSING: A NOVEL APPROACH TO LOUDNESS CODING IN COCHLEAR IMPLANTS.: Monique A.M. de Jong, Jeroen J.J. Briaire, Johan H.M. Frijns

W03b: CLINICAL APPROACH TO OPTIMIZE ACTIVATED COCHLEAR IMPLANT ELECTRODES AND SPECTRAL MODULATION DETECTION OUTCOMES: Sarah Warren Kennett, Samuel Atcherson, Charles Finley

W04a: IMPROVING SOUND SOURCE LOCALIZATION BY HEAD SHADOW ENHANCEMENT WITH BEAMFORMERS: Benjamin Dieudonne, Tom Francart

W04b: MEASURING THE ABILITY OF CLINICAL PROCESSORS TO ENCODE BINAURAL CUES IN THE SIGNAL ENVELOPE: Alan Kan, Jake Bergal, Zhao Ellen Peng, Keng Moua, Ruth Y Litovsky

W05a: EXTRACOCHLEAR ELECTROCOCHLEOGRAPHY DURING INSERTION OF COCHLEAR IMPLANTS: INTRAOPERATIVE RESPONSES AND POSTOPERATIVE HEARING PRESERVATION: Christopher K Giardina, Tatyana E Fontenot, Kevin D Brown, Craig A Buchman, Oliver F Adunka, Harold C Pillsbury, Douglas C Fitzpatrick

W05b: A MACHINE LEARNING APPROACH TO MITIGATING REVERBERATION IN COCHLEAR IMPLANTS: Boyla O. Mainsah, Jill M. Desmond, Leslie M. Collins, Chandra S. Throckmorton

W06: A NEURAL TIMING CODE IMPROVES SPEECH PERCEPTION IN VOCODER SIMULATIONS OF COCHLEAR IMPLANT SOUND CODING: Erik C. Johnson, Daniel H. Lee, Douglas L. Jones, Justin M. Aronoff, Rama Ratnam

W07a: PERCEPTUAL DIFFERENCES BETWEEN MONOPOLAR AND PHANTOM ELECTRODE STIMULATION IN COCHLEAR IMPLANT USERS: Silke Klawitter, David M. Landsberger, Andreas Buechner, Waldo Nogueira

W07b: PRELIMINARY STUDY OF A HARMONIC CODING STRATEGY TO IMPROVE SOUND PROCESSING IN COCHLEAR IMPLANTS: Kaibao Nie, Tyler Ganter, Les Atlas, Jay Rubinstein

W08a: EVALUATING MUSIC PERCEPTION WITH A NEUROPHYSIOLOGICALLY-BASED COCHLEAR IMPLANT CODING STRATEGY: Wai Kong Lai, Farei Timo, Norbert Dillier

W08b: DEEP NEURAL NETWORKS FOR IMPROVING SOUND SEGREGATION IN COCHLEAR IMPLANT USERS: Marianna Vatti, Lars Bramsloew, Niels Henrik Pontoppidan, Gaurav Naithani, Tuomas Virtanen, Bradford Backus

W9: LOMBARD EFFECT PERTURBATION PRE-PROCESSING STRATEGY FOR COCHLEAR IMPLANT USERS: Jaewook Lee, Hussnain Ali, John H. L. Hansen

W10a: SMILES, CHUCKLES, AND LAUGHTER: ESTABLISHING A COMPUTATIONAL SIMULATION OF COCHLEAR IMPLANT STRATEGIES FOR AMUSED SPEECH CLASSIFICATION: Payton Lin, Kevin El Haddad

W10b: MODULATED PHASE CODING STRATEGY FOR COCHLEAR IMPLANTS: Reagan Roberts, Chris Boven, Heddon Chris, Claus-Peter Richter

W11: OBJECTIVE SPEECH TRANSMISSION IMPROVEMENTS WITH A BINAURAL COCHLEAR IMPLANT SOUND-CODING STRATEGY INSPIRED BY THE CONTRALATERAL MEDIAL OLIVOCOCHLEAR REFLEX: Enrique A. Lopez-Poveda, Almudena Eustaquio-Martin

W12a: DAILY DATALOGS, NEED AND FEASIBILITY: Saji Maruthurkkara

W12b: EVALUATION OF SPECTRAL MUSIC COMPLEXITY REDUCTION METHODS FOR COCHLEAR IMPLANT LISTENERS BY MEANS OF A PERCEPTUAL MUSIC QUALITY PREDICTION MODEL: Anil Nagathil, Jan-Willem Schlattmann, Katrin Neumann, Rainer Martin

W13a: THE “TEMPORAL LIMITS ENCODER” FOR COCHLEAR IMPLANTS: ITS POTENTIAL ADVANTAGES AND AN FFT-BASED ALGORITHM: Qinglin Meng, Guangzheng Yu

W13b: LIMITING TEMPORAL INFORMATION ON MIDDLE AND BASAL CHANNELS: Joshua S Stohl, Robert D Wolford, Blake S Wilson

W14a: IMPROVING THE PERFORMANCE OF NEURAL-NETWORK BASED SPEECH ENHANCEMENT FOR NOVEL SPEAKERS: Jessica J M Monaghan, Tobias Goehring

W14b: A REAL-TIME ANDROID APP FOR MULTI-TALKER BABBLE NOISE REDUCTION.: Roozbeh Soleymani, David M Landsberger, Ivan Selesnick

W15: USING PULSE-SPECIFIC FEATURES FOR REVERBERATION MITIGATION IN COCHLEAR IMPLANT PULSE TRAINS: Lidea K Shahidi, Leslie M Collins, Chandra S Throckmorton

W16a: IMPLEMENTATION AND EVALUATION OF A SINGLE-CHANNEL NOISE REDUCTION METHOD IN COCHLEAR IMPLANTS: Ningyuan Wang, Guofang Tang, Qian-Jie Fu

W16b: COMPARE THE SPEECH INTELLIGIBILITY BENEFITS OF F0-INFORMED SPEECH ENHANCEMENT WITH COCHLEAR IMPLANT LISTENERS BETWEEN STATIONARY NOISE AND NON-STATIONARY NOISE: Dongmei Wang, John H. L. Hansen

W17a: PRESERVATION OF RESIDUAL HEARING AFTER ELECTRODE INSERTION BY TOPICAL APPLICATION OF IGF-1: Takayuki Nakagawa, Norio Yamamoto, Koji Nishimura, Kohei Yamahara, Hideaki Ogita, Juichi Ito, Koichi Omori

W17b: CAN A LATE HEARING LOSS AFTER HYBRID-L IMPLANTATION BE PREDICTED BY IMPEDANCE CHANGES?: Gerrit Paasche, Simon Konrad, Thomas Lenarz, Andreas Buechner

W18: SPATIAL RELEASE FROM MASKING IN ACTUAL AND SIMULATED BIMODAL AND SINGLE-SIDED DEAF COCHLEAR IMPLANT LISTENERS: Ben Williges, Thomas Wesarg, Lorenz Jung, Leontien Geven, Andreas Radeloff, Tim Juergens

W19: PERCEPTUAL AND NEURAL REPRESENTATION OF PULSE TRAINS DELIVERED BY ABI (AUDITORY BRAINSTEM IMPLANT) ELECTRODES: Mahan Azadpour, William H. Shapiro, Mario A. Svirsky

W20a: AUDITORY-VISUO-MOTOR TEMPORAL PROCESSING IN COCHLEAR IMPLANT USERS: Alexandre Lehmann

W20b: SOUND LOCALIZATION IN REAL-TIME VOCODER SIMULATIONS OF BILATERAL AND BIMODAL COCHLEAR-IMPLANT USERS: Sebastian Ausili, Martijn Agterberg, Emmanuel Mylanus, Bradford Backus, John van Opstal, Marc M. van Wanrooij

W21: MULTI-STUDY EVALUATION OF OBJECTIVE MEASURES THAT PREDICT COCHLEAR IMPLANT SPEECH INTELLIGIBILITY: Abigail A. Kressner, Stefan J. Mauger, Adam A. Hersbach, Torsten Dau

W22a: CCI-MOBILE PLATFORM FOR COMBINED ELECTRIC AND ACOUSTIC STIMULATION: Sandeep Ammula, Hussnain Ali, John H.L Hansen

W22b: THE COCHLEAR CATHETER FOR CELL AND DRUG DELIVERY DURING COCHLEAR IMPLANTATION: Athanasia Warnecke, Nils Prenzler, Rolf Salcher, Ariane Roemer, Melanie Leifholz, Lutz Gaertner, Anke Lesinski-Schiedat, Thomas Lenarz

W23a: TOWARDS A BIO-INSPIRED CODING STRATEGY FOR COCHLEAR IMPLANTS: Sonia Tabibi, Andrea Kegel, Wai Kong Lai, Norbert Dillier

W23b: AN ALGORITHM FOR ENHANCEMENT OF NATURALLY-OCCURRING LEVEL DIFFERENCES IN BILATERAL COCHLEAR IMPLANTS: Kostas Kokkinakis, Shadi Pirhosseinloo

W24a: IMPACT OF REVERBERATION TIME ON SPEECH PERCEPTION IN NOISE IN COCHLEAR IMPLANT USERS: Tobias Weissgerber, Anja Eichenauer, Uwe Baumann

W24b: PROSPECTIVE MULTICENTER EVALUATION OF A PARTIALLY AUTOMATED CI FITTING METHOD COMPARED TO THE CLINICALLY ESTABLISHED PROCEDURE: Joachim Mueller-Deile, Norbert Dillier, Andread Buchner, Nicole Neben, Matthias Hey

W24a: THE DESIGN, FABRICATION, AND IN VITRO EXPERIMENTS OF A MEMS THIN FILM COCHLEAR ELECTRODE ARRAY: Yuchen Xu, Chuan Luo, Fangang Zeng, Zheng You

POSTER SESSION Th: THURSDAY –8AM TO MIDNIGHT

Th01a: COMPUTER ASSISTED SELECTION OF ELECTRODE DEACTIVATION IN CI USERS: Elad Sagi, Mario Svirsky
Th01b: REDEFINING THE NUMBER OF EFFECTIVE CHANNELS FOR CONTEMPORARY COCHLEAR IMPLANT LISTENERS: Naomi B.H. Croghan, Sara I. Duran, Zachary M. Smith
Th02: EARLY IMPLANTATION IMPROVES VOCAL-TRACT LENGTH PERCEPTION FOR VOICE DISCRIMINATION IN ADULTS WITH PRE-LINGUAL DEAFNESS : Yael Zaltz, Raymond L. Goldsworthy, Liat Kishon-Rabin, Laurie S. Eisenberg
Th03a: COCHLEA-IMPLANTS IN THE ELDERLY : Mark Praetorius, Sebastian Hoth, Sara Friauf
Th03b: COCHLEAR IMPLANT USERS AND THEIR ABILITY TO RECALL SPEECH IN NOISY ENVIRONMENT: Hanna Boenitz, Dorothea Wendt, Mareike Finke, Alejandro Lopez Valdes, Bjorn Lyxell, Andreas Buechner, Thomas Lunner
Th04a: NEW PERSPECTIVES ON THE CONTRIBUTION OF MUSIC ACTIVITIES TO THE PERCEPTION OF SPEECH AND LANGUAGE DEVELOPMENT IN CHILDREN WITH CIS: Ritva Torppa, Andrew Faulkner
Th04b: INCREASED QUALITY OF THE AUDIOVISUAL SPEECH SIGNAL REDUCES SENSITIVITY TO AUDIOVISUAL ONSET ASYNCHRONY : Antoine J Shahin, Hannah Shatzer, Jess R Kerlin, Stanley Shen, Mark A Pitt
Th05: SPECTRO-TEMPORAL TRANSMISSION OF SPEECH FORMANTS IN A NEW COCHLEAR IMPLANT SOUND CODING STRATEGY – MEASUREMENTS AND PREDICTIONS OF VOWEL PERCEPTION: Anja Eichenauer, Mathias Dietz, Tim Juergens
Th06a: PROCESSING SPOKEN WORDS WITH AND WITHOUT SEMANTIC CONTEXT: EFFECTS OF SPECTRAL DEGRADATION AND COCHLEAR IMPLANTATION: Chhayakanta Patro, Lisa Lucks Mendel
Th06b: SPECTRAL RESOLUTION AND SPEECH CONTEXT EFFECTS IN COCHLEAR-IMPLANT USERS: Lei Feng, Andrew J Oxenham
Th07a: THE IMPACT OF PERCEPTUAL CUE WEIGHTING STRATEGY ON SPEECH PERCEPTION AND LISTENING EFFORT FOR CI USERS: Yue Zhang, Stuart Rosen
Th07b: EXTENDING FEATURE INFORMATION TRANSMISSION ANALYSIS (FITA): NEW APPROACHES AND APPLICATIONS: Dirk JJ Oosthuizen, Johan J Hanekom
Th08a: PREDICTING SPEECH RECOGNITION USING THE SPEECH INTELLIGIBILITY INDEX (SII) FOR COCHLEAR IMPLANT USERS AND LISTENERS WITH NORMAL HEARING: Sungmin Lee, Lisa Lucks Mendel
Th08b: A COMPARISON OF PREDICTORS OF COCHLEAR IMPLANT SPEECH INTELLIGIBILITY: Greg D Watkins, Brett A Swanson, Gregg JA Suaning
Th09a: IMPACT OF ROOM ACOUSTIC PARAMETERS ON SPEECH AN MUSIC PERCEPTION WITH COCHLEAR IMPLANTS: Bernhard Eurich, Michael Oehler, Thomas Klenzner
Th09b: EFFECT OF REVERBERATION ON SPEECH INTELLIGIBILITY IN COCHLEAR IMPLANT RECIPIENTS CONSIDERING REALISTIC SOUND ENVIRONMENTS: Javier Badajoz Davila, Jorg M. Buchholz, Richard Van Hoesel, Michael Goorevich
Th10a: THE ROLE OF SPECTRAL RESOLUTION IN COCHLEAR IMPLANT PROCESSING UNDER COCKTAIL-PARTY SCENARIOS: Nawal El Boghdady, Florian Langner, Waldo Nogueira, Deniz Baskent, Etienne Gaudrain
Th10b: COMPUTER-BASED CONNECTED TEXT TRAINING OF SPEECH PERCEPTION IN NOISE FOR COCHLEAR IMPLANT USERS: Tim Green, Stuart Rosen, Andrew Faulkner
Th11a: PERFORMANCE TESTING WITHOUT THE SOUND BOOTH: Saji Maruthurkkara
Th11b: VOWEL PERCEPTION IN A DENSELY-POPULATED SPACE: BEHAVIORAL AND EEG INDICES OF VOWEL IDENTIFICATION BY ADULT CI LISTENERS: David Jackson Morris, John Toendering, Soeren Kamaric Riis, Nicolai Pharao, Christian Stender Simonsen

Th12a: SPEECH PERFORMANCE PLATEAU IN PRELINGUALLY AND POSTLINGUALLY DEAFENED ADULT COCHLEAR IMPLANT USERS : Veronique JC Kraaijenga, Adriana L Smit, Gijsbert A van Zanten

Th12b: EARLY SENTENCE RECOGNITION IN ADULT COCHLEAR IMPLANT USERS: Chris James , Chadlia Karoui, Mathieu Marx, Marie-Laurence LABORDE, Charles-Edouard MOLINIER, Benoit LEPAGE, Olivier DEGUINE, Bernard ESCUDE, Bernard FRAYSSE

Th13a: THE DECISION BETWEEN DIRECT ACOUSTICAL COCHLEAR STIMULATION AND COCHLEAR IMPLANTATION: A RETROSPECTIVE ANALYSIS OF RESULTS: Thomas Lenarz, Eugen Kludt, Andreas Buechner, Hannes Maier

Th13b: EVALUATION OF THE LOW POWER SPEECH CODING STRATEGY MP3000™: Eugen Kludt, Pamela Dawson, Mark Schuessler, Kerrie Plant, Robert Cowan, Thomas Lenarz, Andreas Buechner

Th14a: ADVANCED TONE-VOCODER SIMULATIONS OF THE EFFECT OF CURRENT SPREAD ON COCHLEAR IMPLANT USERS' SPEECH INTELLIGIBILITY - IMPLICATIONS FOR THE CHANNEL INTERLEAVING STRATEGY: Jacques A Grange, John F Culling

Th14b: "TURN AN EAR TO HEAR": HOW A MODEST HEAD ORIENTATION AWAY FROM A TARGET TALKER CAN IMPROVE COCHLEAR IMPLANT USERS' SPEECH INTELLIGIBILITY IN NOISE, EVEN IN A HIGHLY REALISTIC RESTAURANT SIMULATION: Jacques A Grange, John F Culling

Th15: ROLE OF COGNITIVE FACTORS IN VARIABILITY OF HEARING OUTCOMES IN COCHLEAR IMPLANT USERS AND NORMAL-HEARING LISTENERS WITH SIMULATED CURRENT SPREAD: Erin R ONeill, Heather A Kreft, Andrew J Oxenham

Th16: HOW CLOSE CAN WE GET TO A REAL CI WITH ACOUSTIC SIMULATION?: Chadlia KAROUI, MATHIEU MARX, Chris JAMES, Olivier MACHEREY

Th17a: BIOINFORMATIC ANALYSIS OF THE HUMAN INNER EAR: UNDERSTANDING THE STATUS OF THE PERIPHERAL AUDITORY SYSTEM IN COCHLEAR IMPLANTATION: Hinrich Staecker, Thomas Lenarz, Sameer Alvi, Nils Prenzler, Martin Durisin

Th17b: THE BIMODAL BENEFIT ON SPEECH UNDERSTANDING IN FLUCTUATING AND STATIC NOISE: H. Christiaan Stronks, Annemarie J. Schrijver, Jeroen J. Briaire, Johan J. H. M. Frijns

Th18a: REVEALING PHONETIC UNCERTAINTY IN COCHLEAR IMPLANT LISTENERS: Steven P Gianakas, Matthew B Winn

Th18b: SEVERE DEFICITS IN PERCEPTION OF ANTICIPATORY COARTICULATION IN COCHLEAR IMPLANT LISTENERS: Steven P Gianakas, Matthew B Winn

Th19a: ADJUSTMENT TO VARIABLE VOICE ACOUSTICS BY COCHLEAR IMPLANT LISTENERS: Ashley N Moore, Matthew B Winn

Th19b: VOICE EMOTION RECOGNITION BY MANDARIN-SPEAKING PEDIATRIC COCHLEAR IMPLANT USERS: Hui-Ping Lu, Shu-Chen Peng, Mickael L.D. Deroche, Monita Chatterjee, Yung-Song Lin

Th20: REDUCING SIMULATED CHANNEL INTERACTION LEADS TO IMPROVED SPEECH PERCEPTION FOR NORMAL-HEARING CHILDREN AND ADULTS: Kelly N Jahn, Julie G Arenberg

Th21a: ACCESSIBILITY OF SPEECH INFORMATION AT VARIOUS SIGNAL-TO-NOISE RATIOS IN COCHLEAR IMPLANT PROCESSING: Smits Cas, Theo S Goverts, Lucas Stam

Th21b: SPATIAL RELEASE FROM INFORMATIONAL AND ENERGETIC MASKING IN BIMODAL AND BILATERAL CI USERS: Kristen DOnofrio, Rene Gifford

Th22a: THE RELATIONSHIP BETWEEN SPECTRAL MODULATION DETECTION AND SPEECH RECOGNITION: ADULT VERSUS PEDIATRIC IMPLANT RECIPIENTS: Rene Headrick Gifford, Jack Noble, Stephen Camarata, Linsey Sunderhaus, Robert Dwyer, Benoit Dawant, Robert Labadie

Th22b: HOW WELL DO ADOLESCENTS WITH COCHLEAR IMPLANTS LEARN A SECOND LANGUAGE IN HIGH SCHOOL?: Dorit Enja Jung, Wander M Lowie, Deniz Baskent, Anastasios Sarampalis

SPEAKER ABSTRACTS

P1: AURAL CONTRAST IN MIDBRAIN RESPONSES TO SPEECH: IMPLICATIONS FOR COCHLEAR IMPLANTS

Laurel H. Carney
University of Rochester, Rochester, NY, USA

The auditory midbrain (inferior colliculus, IC) projects to the auditory thalamus (medial geniculate body), just as the output of the retina projects to the visual thalamus (lateral geniculate body). Thus, it is interesting to consider the representation of complex sounds in the midbrain in terms of aural contrast, roughly analogous to visual contrast. In addition to a tonotopic map, responses of neurons in the auditory midbrain are strongly influenced by amplitude fluctuations at frequencies in the range of voiced pitch. Due to their sensitivity to low-frequency fluctuations, responses to complex sounds in the auditory midbrain provide a representation that is rich in contrast and that differs substantially from the stimulus spectrum. For example, voiced speech signals are characterized by strong fluctuations at the fundamental frequency (F0), with the largest amplitude fluctuations in frequency channels near spectral peaks. These envelope fluctuations are the basis for most cochlear implant stimulation strategies. However, auditory-nerve (AN) responses to voiced speech have the smallest F0 fluctuations in responses of fibers tuned near spectral peaks and the largest amplitude fluctuations for fibers tuned away from spectral peaks. In the healthy ear, the amplitudes of AN response fluctuations are strongly influenced by the interaction of saturation of the inner hair cells and cochlear amplification. The contrasts in fluctuation amplitude across frequency channels are robust across a wide range of sound levels, and are especially strong at conversational speech levels. Contrasts weaken near threshold and at high sound levels. At conversational speech levels, the majority of AN fibers (low-threshold, high spontaneous-rate fibers) have saturated average discharge rates, but instantaneous rates still fluctuate at F0, with amplitudes that depend upon proximity to spectral peaks. The varying amplitudes of F0 fluctuations set up contrasts that are ultimately represented in the rate and timing of IC responses. Background noise weakens the aural contrast, but in the healthy ear, contrast is robust down to signal-to-noise ratios near the speech reception threshold. Contrasts across the midbrain response also exist for unvoiced speech sounds, based on features such as transients and spectral slopes. Aural contrast in the responses of AN fibers and IC neurons will be illustrated using computational models. Implications for cochlear implant stimulation strategies will be discussed.

P2: DECONVOLUTION OF SPREAD OF EXCITATION CURVES: TOWARDS IDENTIFICATION OF THE NEURAL EXCITATION AREA

Jan Dirk Biesheuvel, Randy K. Kalkman, Jeroen J. Briaire, Johan H.M. Frijns
ENT-department, Leiden, NLD

Monopolar stimulation of cochlear implants causes relatively large current spread through the cochlea. Consequently, electrode contacts do not have distinct excitation areas, but various contacts excite the same neural fibres. The spread of excitation (SOE) can be estimated with the electrically evoked compound action potential (eCAP), measured by forward masking (FM) with a fixed probe and roving masker stimulus. Plotting the eCAPs as function of the masker electrode contact results in a SOE curve showing the interaction between the probe contact and the other contacts. SOE curves obtained in this manner have long been used as a direct measure of SOE. However, from a mathematical point of view, the SOE curve is a convolution of masker and probe, and recently we have shown that the SOE curve must be deconvolved to retrieve the real excitation areas attributable to either masker or probe [1].

Currently, we are working on the improvement and (clinical) validation of our deconvolution method. In the absence of exact information on real neural excitation patterns, we use a computational model of the implanted human cochlea [2] to improve the parameters for estimating the excitation density profiles (EDPs) in the deconvolution method. In addition to the previous set of parameters [1], allowing some off-centre excitation and variation in the density decay along the electrode array improves the fit between estimated EDP and simulated excitation pattern by 60% (in terms of RMS-error).

Using the new set of parameters to estimate the EDP, we investigated the relationship between stimulus intensity and excitation area. SOE curves were measured in 38 patients (30 intra- and 8 post-operatively), all implanted with a HiRes90K device (Advanced Bionics). The stimulus intensity was equal for masker and probe at all electrode contacts. The curves were deconvolved into 16 EDPs, one for each electrode contact. Subsequently, at three electrodes (3, 9 and 15) a new set of SOE curves was measured with equal masker, but varying probe stimulus intensity. Using the previously determined EDPs for the masker contacts, these recordings can be deconvolved, providing the EDPs for the different probe stimuli. Preliminary results show that lower probe intensities lead to a decrease of the amplitude in the raw SOE curves, while the width of the curve does not change noticeably. In contrast, the EDPs reveal that -in line with expectations- lower stimulus intensities induce more restricted excitation areas.

From the modelling study it is concluded that extending the deconvolution method with a minimal amount of EDP parameters increases the reliability of the deconvolution and EDPs considerably. This improved deconvolution method demonstrates that lower stimulus intensities do indeed cause smaller, more selective, excitation areas, which was not directly visible in the traditional raw SOE curves.

References

[1] Biesheuvel J D, Briaire J J and Frijns J H M 2016 A Novel Algorithm to Derive Spread of Excitation Based on Deconvolution. Ear Hear. 37 572–81
[2] Kalkman R K, Briaire J J and Frijns J H M 2015 Current focussing in cochlear implants: an analysis of neural recruitment in a computational model. Hear. Res. 322 89–98

P3: AUDIO RE-SYNTHESIS FROM ELECTRODE EXCITATIONS: AN ENHANCED GENERIC PHYSIOLOGICAL APPROACH

Misagh Khayambashi, Daniel Alfsmann, Leonid Litvak
Advanced Bionics, Valencia, CA, USA

The principal driver of cochlear implant (CI) development is to improve patients' hearing experience. Currently, patient tests are the main-stream and most reliable method of testing development outcomes. Unfortunately, patient tests require an extensive setup and long preparation time, making it very hard to get quick, reliable feedback on new stimulation strategies. To circumvent this problem, contributors have been using computer tools, typically called Vocoder, to re-synthesize the audio that patients hear, taking as input different signals along the hearing device. The accuracy of such a framework may be verified by feeding the re-synthesized audio to a normal hearing (NH) subject, and comparing the perception results with that delivered to patients by the actual implant system. Outputs of current Vocoder implementations are of poor quality, hardly perceptible, and rarely coincide accurately with patients' experience. Therefore, they have little value as reliable feedback tools.

In this work, we present a refined Vocoder implementation with significant improvement in both output audio quality and correlation with patient test outcomes. Since the ultimate physical interface between device and patient is electrode signals, the proposed Vocoder processes raw electrode signals, rather than other upstream signals, captured from actual or simulated systems. This also has the added benefit of masking higher-level implementation details from the voice re-synthesis framework. Most importantly, the vocoder tries to mimic the very initial stages of auditory path by considering the physics of electrode-neuron interactions and the physiology and audio-encoding of auditory nerves. Considering higher level processing blocks in auditory path is a promising future improvement. For the first time, the proposed Vocoder also takes care of significant subtleties required for meaningful signal reconstruction (energy-conversion in log-to-linear domain transfer) and also accurate patient-vs-normal perception comparisons (compensation of pre-emphasis). Last, but not least, the framework has been tested and verified against various patient test results and has been able to provide accurate feedback in various design scenarios.

P4: ADVANCES IN MODELING THE OCCURRENCE AND TIMING OF ACTION POTENTIALS IN RESPONSE TO COCHLEAR IMPLANT STIMULATION

Ian C. Bruce
McMaster University, Hamilton, CAN

Having an accurate description of the patterns of action potentials (APs) generated in auditory nerve (AN) fibers by cochlear implant (CI) stimulation is a crucial component to relating stimulation strategies to perceptual outcomes. Generalizing the results of individual physiological experiments and synthesizing the results of many disparate studies can be fraught with difficulty. This prompts the development of computational models that allow for formal description and prediction of physiological data and provide a tool for further exploring stimulation strategies.

While a number of models of CI stimulation of AN fibers that are able to capture the most basic response characteristics have existed for many years, there are a range of important physiological phenomena that have been more elusive to describe accurately. These include, strong adaptation and/or accommodation to high-rate stimulation, very long relative-refractoriness in a large subset of AN fibers, strong facilitation (temporal summation) even for biphasic pulses, systematic shifts and variability in the node at which APs are initiated, and strong effects of the current waveform shape and polarity. In this talk I will review recent progress made in both phenomenological and biophysical AN models to better explain and predict these physiological characteristics of CI stimulation. I will also discuss physiological details that remain to be fully addressed by computational models and highlight implications of the modeling results for CI stimulation strategies.

[Funded by NSERC Discovery Grant #261736.]

P5: SIMULATED SPIRAL GANGLION DEMYELINATION ALTERS SENSITIVITY AND TEMPORAL FIDELITY OF RESPONSES TO EXTRACELLULAR STIMULATION

Jesse Midgley Resnick, Jay T Rubinstein
University of Washington, Seattle, WA, USA

Since cochlear implant function involves direct depolarization of spiral ganglion neurons (SGNs) by injected current, it is presumed SGN physiological health is an important factor in cochlear implant (CI) outcomes. This expected relationship has, however, been difficult to confirm in implant recipients. Suggestively, animal studies have demonstrated both acute and progressive SGN ultrastructural changes (notably axon demyelination), even in the absence of soma death, and corresponding altered physiology following sensorineural deafening. Whether such demyelination occurs in humans and how such changes might impact CI function remains unknown. To approach this problem, we incorporated SGN demyelination into a biophysical model of extracellular stimulation of SGN fibers.

We have previously presented this biophysical model of axons represented as segmented wires including purely passive internode segments and voltage-dependent, stochastic nodal segments. Calculation of the dynamic membrane potentials within each segment at each time step of stimulation via a finite differencing method enables analysis of fiber response properties. Here we introduce a modification to this model in which, by varying only the membrane capacitance for subsets of internode segments while keeping all other parameters fixed, variable amounts of axonal demyelination were simulated. This approach enabled exploration of the entire parameter space corresponding to simulated myelin thickness and extent of fiber affected. All simulated fibers were stimulated distally with anodic monophasic, cathodic monophasic, anode-phase-first (AF) biphasic, and cathode-phase-first (CF) biphasic pulses from an extracellular disc electrode and monitored for spikes centrally.

Unsurprisingly, axon sensitivity generally decreased with demyelination in response to all stimulation paradigms, resulting in elevated thresholds, however, this effect was strongly non-uniform. Fibers with severe demyelination affecting only the most peripheral nodes responded nearly identically to normally myelinated fibers. Additionally, partial demyelination (<50%) yielded minimal increases in threshold compared to more severe demyelination given similar lengths of affected axon. The temporal effects of demyelination were more unexpected. Both latency and jitter of responses demonstrated resilience to modest changes but exhibited strongly non-monotonic and stimulus-dependent relationships to more profound demyelination. Normal, and modestly demyelinated fibers, were more sensitive to cathodic and CF pulses than anodic or AF pulses. However, when demyelination becomes more severe and affects more than the most peripheral nodes, anodic and AF pulses become more effective. Comparison of threshold crossing between nodal segments demonstrated stimulus-dependent shifts in action potential initiation site with different fiber demyelination statuses. For some particular demyelination scenarios, both phases of biphasic pulses could initiate action potentials at threshold resulting in bimodal latency and initiation site distributions and dramatically increased jitter.

In summary, simulated demyelination leads to complex changes in fiber sensitivity and spike timing, suggesting the possibility of dramatic impacts in CI recipients on spread of excitation and temporal cue encoding; alterations in action potential initiation site due to non-uniformities in the electrical properties of axons underlie these observed dependencies. These simulation results highlight the importance of exploring the SGN ultrastructural changes caused by an etiology of hearing loss to accurately predict cochlear implantation outcomes.

This work was funded, in part, by a generous education gift from Advanced Bionics. It was facilitated through the use of advanced computational, storage, and networking infrastructure provided by the Hyak supercomputer system and funded by the Student Technology Fee at the University of Washington.

P6: PSYCHOACOUSTIC MASKING MODELS APPLIED TO SOUND CODING STRATEGIES FOR COCHLEAR IMPLANTS

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Psychoacoustic masking models have been incorporated in sound coding strategies to optimize the tradeoff between power consumption and performance in cochlear implants (CI). Psychoacoustic masking models estimate masking effects generally occurring in the auditory system during the normal process of hearing and have been successfully used in audio coding algorithms (i.e. mp3) to significantly reduce the bitrate required to store or transmit audio signals without compromising sound quality. This work presents a psychoacoustic masking model for CI sound coding strategies and particularly discusses its extension towards electric acoustic stimulation.

Several years ago, we incorporated a psychoacoustic masking model derived from normal hearing listeners into the ACE strategy (Psychoacoustic Advanced Combinational Encoder, PACE). The model considered simultaneous masking with the goal to only select perceptually relevant signal components for stimulation in CIs. The rationale was to account for masking effects between different electrodes to reduce the number of intra-cochlear stimuli reducing channel interaction in NofM sound coding strategies. The perceptual model was extended to next generation CI coding strategies providing an increased number of stimulation sites synthesized through current steering. In recent years, CIs have been implanted in patients with hearing loss in the high frequencies but residual hearing in the same ear (electric acoustic stimulation; EAS). This work investigated the mutual interaction between electric and acoustic stimulation to extend the masking model and optimize the sound coding strategies for EAS.

Psychophysical experiments investigated hearing threshold elevation of a probe stimulus in the presence of a masker stimulus in 5 EAS users. To determine the amount of electric masking, the probe stimulus consisted of an acoustic pure tone while the masker stimulus consisted of an electric pulse train. Acoustic masking was determined by reversing the probe and the masker stimulus. Results from this study demonstrate significant masking effects between electric and acoustic stimulation. For the electric masking experiment, threshold elevations of acoustic tones increased exponentially with smaller distance between the electric and acoustic stimulation sites. In contrast, for the acoustic masking experiment, the threshold elevation of electric pulse trains was broader across stimulation sites.

Based on these findings, we can conclude that there is an asymmetry in masking between the electric and the acoustic modalities. These observations may have implications not only for the design of masking models for EAS but also to improve the general understanding of masking and the design of masking models such as those used in audio coding algorithms.

This work was supported by the DFG Cluster of Excellence EXC 1077/1 "Hearing4all"

P7: ELECTRICAL STIMULATION OF AUDITORY CORTEX ACTIVATES AND MODULATES PROCESSING ACCORDING TO STIMULATED LAYER

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The processing of auditory information in the primary and secondary auditory cortices is a complex procedure involving the coordinated activation of the separate cortical layers. Previous work has shown that missing hearing experience during development leads to a deterioration of the functional connection between these intricately linked layers, even when hearing is restored later in life through implantable auditory prostheses (Kral and Sharma, 2012, TINS). To improve hearing outcome in these cases, ways have to be found to restore the natural sequence of processing in the auditory cortices. One method to directly activate specific cortical areas is intracortical microstimulation (ICMS). By combining ICMS and extracellular recordings in the primary auditory cortex of an animal model, we can show that given the right parameters (e.g. stimulation intensity and depth) ICMS is indeed able to activate the cortex in a focused, layer-specific fashion. These experiments were done on ketamine/xylazine anaesthetized guinea pigs using one shank of a Michigan type, linear multi-electrode array implanted in the primary auditory cortex. Population level responses (local field potentials, multi-unit activity) to single current pulses of low intensity showed distinct cortical activation patterns according to the depth of stimulation. Comparing these responses to physiological, auditory evoked responses using cross-correlation analyses showed best matching patterns when stimulating the thalamo-recipient granular layer. Furthermore, focused current pulses also showed the ability to layer-specifically modulate physiological cortical processing, when presented in conjunction with auditory evoked activity. Analyzing time-frequency representations of responses to combined acoustic and electric stimulation showed that focused ICMS leads to supra-additive broadband oscillations several hundred milliseconds after the stimulation. These late (non-phase-locked) induced responses were dependent on the stimulated layer, as well as the time delay between the acoustic and the electric stimulation. Together our results show that focused intracortical microstimulation may be used to activate and also modulate ongoing cortical processing in a layer-specific manner. Therefore, ICMS may be a valuable tool in trying to develop ways to restore or improve the natural sequence of processing of auditory information in the auditory cortices. Ultimately this technique may lead to a new kind of centrally implantable prosthesis for those patients with very poor hearing outcomes due to prolonged deafness, especially during critical phases of development.

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P8: HEALTH UTILITY IN UNILATERAL VERSE BILATERAL COCHLEAR IMPLANT RECIPIENTS

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Purpose: Binaural hearing provides multiple advantages over monaural hearing in difficult listening situations. These advantages include improved understanding of speech in noise and improvements in localization abilities (Dillon, 2001). To quantify advantages and improvements from health interventions, a health utility value of 0 (death) to 1 (perfect health) is measured. There are significant quality of life improvements for unilateral cochlear implant (CI) users pre- and post-implant (Kuthubutheen et al, 2014; Loeffler et al, 2010; Noble 2010; Noble et al, 2008; Sparreboom et al, 2012). However, health utility benefits from the addition of a second cochlear implant are more difficult to access due to lack of sensitivity of available metrics to aspects of bilateral hearing. The purpose of this study was to examine the extent to which health utility improves with a second cochlear implant. A secondary aim was to determine if any questions on the hearing specific Speech Spatial and Qualities of Hearing (SSQ) might be related to health utility. The SSQ is a hearing specific patient-reported outcome measure which assesses a patient's subjective benefits with speech understanding, spatial hearing abilities, and the quality of speech (Gatehouse & Noble, 2004).

Research Design: Participants in this study were adult unilateral or bilateral cochlear implant recipients who have had their most recent implant active for a minimum of six months. Participants were recruited from University of Washington research pool. The participants were divided into two groups: Unilateral Cochlear Implant (UCI) recipients (N=9) and Bilateral Cochlear Implant recipients (BiCI) (N=9). The measures used in this study included Health Utility Index Mark 3 (HUI3) (HUInc), Speech, Spatial, and Qualities of Hearing (SSQ) (Gatehouse & Noble, 2004), Time Trade Off (TTO), and Visual Analog Scale (VAS) All participants completed the HUI3, SSQ, and VAS in pen and paper format in person with an interviewer (the first author) to give instructions. The VAS asked participants to label overall quality of life from 0 (death, no quality of life) to 100 (perfect quality of life). The TTO was administered using a computer program. The TTO is a health utility measure which asks participants to indicate how many years of their life they would be willing to "give up" for perfect health, in this example, normal hearing. Users were asked which scenario was most desirable; normal hearing with only x years of remaining life verses their current hearing with a standard 30 years remaining life. The computer program then continued through a series of these scenarios until a thresholds for years of life willing to trade was reached and a health utility value generated.

Results: TTO showed a significant difference between the UCI and BiCI group's health utility values of 0.1 (p=0.0376). The UCI group was on average willing to trade 6 years of life for normal hearing, while the BiCI group was only willing to trade 1 year. The health utility increase suggests the quality of life of a bilateral user is, on average, 10% better than that of a unilateral user. A significant difference was found between groups on the spatial hearing subsection of the SSQ (p=0.006). The qualities of hearing and speech hearing (p=0.3676) were not significantly different. A correlation was ran between TTO results and the SSQ questions which showed the greatest significant differences between groups. No significant correlation was found. The VAS and HUI3 did not show a significant difference.

Conclusions: The results suggest that a second cochlear implant can provide a substantial improvement in health related quality of life as measured by the TTO. These results are consistent with findings by Kuthubutheen et al. (2014) which explored a similar question.

This study supports substantial benefits in terms of spatial hearing capabilities of a second side implant. It also suggests a perceived quality of life benefit as reported by the TTO. This underscores the need for a quality of life (QoL) metric that captures substantial health utility benefits of a second cochlear implant and bilateral hearing. Based on interview and conversation with participants, improvements in feelings of safety due to improved spatial hearing abilities might greatly impact improvements in quality of life for bilateral implant recipients. A metric highlighting these may provide greater sensitivity to bilateral benefits on health utility. Such a metric could be utilized in conjunction with a generic QoL metric with a health utility value and potentially provide a strong basis for evaluation of the health economic benefits of a second side implant, supporting routine use of bilateral CIs.

P9: WORKING WITHIN .EDU & .COM FOR PATIENTS

Kevin Franck
Varied, Concord, MA, USA

This talk will discuss translational research - taking ideas from the academic context into point-of-care patient applications with examples from the presenter's experience. The talk will incorporate broad themes around generalizing research and clinical experience into novel ideas, protecting these ideas, translating the ideas into a context that can attract resources, and then seeing them through to affecting patient care.

P10: Gary Housley

P11: BIOLOGICAL MEANS FOR HEARING RESTORATION IN DEAF EARS

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Improving speech performance and broader hearing capabilities of cochlear implants (CIs) relative to current state of the art could be substantially aided by better understanding and improving the biology of the implanted ear. One goal is to enhance the neural substrate in the ear that receives CI stimulation. Specifically, we aim to reverse regression of peripheral auditory fibers from the sensory epithelium, increase SGN soma survival and improve the physiological state of the neurons. This has been accomplished in guinea pigs with CIs using viral-mediated neurotrophin over-expression, which resulted in improved psychophysical and electrophysiological measures. Furthermore, some of the measures improved by this gene therapy have been shown to be predictive of speech recognition in human implant users.

Side effects of neurotrophin therapy also should be considered. We determined that the presence of elevated levels of the neurotrophin NT-3 in the cochlear fluids disrupts the neural networks in the normal mouse ear (Lee et al., 2016), suggesting that impaired human ears with residual hearing may also experience unwanted degradation. To express neurotrophin genes in an area restricted to the proximity of the surviving inner hair cells, it is necessary to use viral vectors in which the transgene is driven by a cell-specific promoter. Such selective expression might mitigate these side effects and could also enhance survival of the inner hair cells.

We have also developed a new animal model for CI studies using the diphtheria toxin receptor (DTR) mouse (Golub et al., 2012), where diphtheria toxin (DT) leads to a complete hair cell loss (Golub et al., 2012; Tong et al., 2015; Kurioka et al., 2016). Because the neuronal components of the cochlea survive in these mice for at least several months after DT deafening, the DTR mice provide a better model than the neomycin-deafened guinea pig for determining the functional effects of a good neural substrate in the absence of hair cells. Pilot studies show the feasibility of inserting the implant and recording from it for over a month. The latter is critical because several studies in non-human primates and guinea pigs have shown that responses to electrical stimulation are not stable in the first weeks or months after implantation.

Finally, the CI provides less than ideal hearing, involves a complex surgery, and an expensive set of electrical components. We propose a novel and purely biological approach for providing hearing to deaf ears, based on reengineering auditory nerve cells to become mechano-electrical transducer cells. Thus, akin to olfactory neurons, the auditory neuron would serve as both transducer and primary neuron. The auditory neurons would be infected with a gene construct for expression of a mechanically-gated ion channel similar to those transduced by pain or touch. The peripheral process would then be induced to grow into the vibrating portion of the basilar membrane where sound would vibrate the nerve ending, causing the neurons to depolarize and send signals up the auditory pathway, eliciting hearing. Preliminary data demonstrate (a) the ability to attract the auditory fibers to grow back into the vibrating part of the deaf basilar membrane (Budenz et al., 2015) and (b) the ability of AAV vectors to infect auditory neurons (Kilpatrick et al., 2011). This novel approach for hearing restoration would bypass the need for inner hair cells and could provide a foundation for useful biological hearing without CIs.

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P12: Poppy Crum

P13: DEVELOPMENT OF AUDITORY ACUITY IN PRELINGUALLY-DEAF COCHLEAR IMPLANT USERS

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Measures of acoustic spectral and temporal processing have been used to characterize auditory acuity in post-lingually deaf adults who use cochlear implants (CI). Relative to normal hearing listeners, post-lingually deaf adults demonstrate markedly reduced spectral resolution and moderately reduced temporal resolution, both of which are related to speech understanding with a CI. In contrast to post-lingually deaf adults, pre-lingually deaf children receive this impoverished auditory acuity during spoken language development. In order to develop methods to maximize auditory outcomes in this population it is necessary to understand how development of spectral and temporal processing is impacted by CI use early in life.

Development of spectral and temporal processing will be related to the maturation of the auditory mechanisms underlying each domain. Spectral processing depends on resolution of spatial location across the elecrode array (frequency resolution) as well as sensitivity to across-channel intensity differences. Temporal processing depends on the rate limit for encoding intensity changes (temporal resolution) as well as sensitivity to intensity modulation (within-channel intensity resolution). Based on developmental studies in normal hearing infants and children, the above mechanisms are hypothesized to have different developmental trajectories. It is hypothesized that frequency resolution will mature by 6 months after CI activation whereas across-channel intensity resolution will mature through school-age. In addition, it is hypothesized that temporal resolution will mature during the first year of CI use but within-channel intensity resolution will develop more slowly over years.

A series of completed and ongoing experiments have been designed to examine these hypotheses. Spectral processing has been measured using spectral ripple discrimination whereas temporal processing has been measured using amplitude modulation detection. Performance of prelingually-deaf children on these measures has been examined from infancy to school-age and compared to post-lingually deaf adult CI users' performance. Control groups of normal hearing children and adults have also been tested. Results across studies support the hypotheses above. These results suggest that temporal and frequency resolution could be used to assess device efficacy in young children with CIs who have immature sensitivity to intensity changes.

P14: IMPACT OF COCHLEAR IMPLANTS ON THE DEVELOPMENT OF SPOKEN LANGUAGE: INSIGHTS FROM THE CDACI STUDY

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The first child to undergo cochlear implant (CI) surgery received a single-channel system in 1980. During the intervening 37 years, systematic improvements in speech recognition and spoken language skills have been associated with advancements in multichannel technology and younger ages at implantation. From a multitude of studies, we have learned that substantial variability in performance remains the hallmark of this technology across a number of developmental domains. We also have learned that specific child, family, and intervention factors help explain why some pediatric CI users excel while others continue to lag behind.

The majority of findings come from large-scale investigations that track development through longitudinal data collection. The Childhood Development after Cochlear Implantation (CDaCI) study is one such prospective multicenter investigation that strives to identify variables that may explain spoken language development in young children with CIs compared to their hearing peers. Additional aims explore the impact of language-related outcomes in the developmental domains of speech recognition, speech production, cognition, psychosocial functioning, scholastic performance, and quality of life.

Initial enrollment into the CDaCI study occurred between 2002 and 2004 across six large CI centers around the US. Total enrollment consists of 188 children with severe to profound hearing loss and 97 hearing peers. The children are assessed annually until they reach the 156-month post-activation time point. Results indicate that about half of the CI sample has performed on par with their hearing peers on standardized language assessment measures by 8 years post CI. However, findings from a series of CDaCI-related papers indicate that spoken language gaps persist for many children. Factors that contribute to higher levels of performance include earlier age at implantation, access to sound with hearing aids prior to CI surgery, longer duration of auditory experience, parent-child interactions that facilitate language development (including maternal sensitivity), high socioeconomic status (income and maternal education), and early language input via oral communication. The strengths of the CDaCI study lie in its diverse national sample and longitudinal data collection on a number of age-appropriate measures.

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P15: ASSESSMENT OF THE ELECTRODE-NEURON INTERFACE IN CHILDREN WITH COCHLEAR IMPLANTS COMPARED TO ADULTS

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Increasing numbers of prelingually-deafened children receive cochlear implants (CIs) early in life and develop with electric stimulation as their exclusive auditory input. In contrast, most adults with CIs were born with acoustic hearing, and lost their hearing and were implanted later in life. Presently, children and adults are provided with similar CI programs and processing strategies. This study seeks to better understand how acoustic or electric input to the developing auditory system may differentially affect perception through a CI. Focused and monopolar auditory detection threshold profiles of early-implanted children and later-implanted adults were compared to investigate potential differences in the electrode-neuron interface of these groups. Elevated detection thresholds with focused stimulation suggest poor electrode-neuron interfaces due to either poor neuronal survival or electrodes distant from spiral ganglion neurons.

Thirteen children (mean age = 14.0) and fourteen adults (mean age = 57.9) with Advanced Bionics CIs participated in this study. All but one child received their first CI prior to five years of age (mean = 2.85 years). Adults were perilingually (n = 2) or postlingually (n = 12) deafened and all received CIs later in life. Eleven pediatric and one adult participant were bilaterally-implanted and were tested with each CI separately. Auditory detection thresholds were obtained using focused ($\sigma = 0.9$) and monopolar ($\sigma = 0$) electrode configurations via a sweep procedure. Channel-to-channel variability (standard deviation of the signed differences between thresholds of adjacent electrodes) was calculated for both configurations. A multivariate mixed-model analysis of variance (ANOVA) with “subject” as a random intercept was performed to compare thresholds and channel-to-channel variability between electrode configurations, child and adult CI users, and 1st- and 2nd- implanted ears of bilateral participants.

Consistent with previous studies, focused thresholds were higher and more variable than monopolar thresholds. The analysis revealed significantly lower focused thresholds in children (mean = 42.0) compared to adults (mean = 44.9). Monopolar thresholds were also significantly lower in children (mean = 31.2) than adults (mean = 33.2) but this difference between the groups was smaller, likely due to the higher sensitivity of focused stimulation to the electrode-neuron interface. These results suggest greater neural health and/or better placement of electrodes relative to target auditory neurons in early-implanted children compared to later-implanted adults. No significant differences between children and adults were found in channel-to-channel variability, indicating that higher average detection thresholds of adults are not simply a result of increased variability in thresholds across the electrode array. For bilaterally-implanted participants, thresholds and channel-to-channel variability were disparate between the two CIs of each subject. These results suggest that outcomes of these measures are driven primarily by CI physiology and not by cognitive or global perceptual factors.

The findings from this study illustrate perceptual differences related to the electrode-neuron interface of prelingually-deafened, early-implanted children compared to later-implanted adults with CIs. These results and accompanying future investigations will lay the groundwork for development of CI speech processing program strategies specifically for children.

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P16: SINGING PROFICIENCY OF MEMBERS OF A CHOIR FORMED BY HEARING-IMPAIRED CHILDREN WITH COCHLEAR IMPLANTS

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Previous research has shown that most children with cochlear implants can't carry a tune when asked to sing children's songs. However, this view may be challenged due to the fact that children with cochlear implants can sing in a choir and perform on stages. In 2014, a children's choir, called "Little Dolphins", was founded in Tianjin, China. All 10 members (7 girls and 3 boys, aged 5 – 10 years old) were prelingually deafened children who received cochlear implantation at the age of 1.0 – 6.5 years old. All members have taken part in weekly singing training for the past two years. In July, 2016, the choir participated in the Ninth World Choir Games in Sochi, Russia and won a Silver Diploma of the Category of Scenic Folklore.

The present study is designed to evaluate the singing proficiency of the members of the children's choir. Individual singing samples without instrument companion were recorded from 9 of the 10 members. The singing proficiency of each individual was appraised by a professional musician. The singing samples were further subject to acoustic analysis in which the fundamental frequency (F0) of each sung note was extracted and the duration of each note was measured.

Results showed that the singing proficiency varied among all members. A majority of them demonstrated high accuracy with few errors in melody while a few demonstrated more or less monotonic singing with inconsistent melody contours. All members did sing with excellent tempo accuracy. Acoustic analysis of the singing samples was based on five metrics in order to quantify the singing proficiency. The metrics were: (1) percent correct of F0 contour direction of the adjacent notes, (2) F0 compression ratio of the entire song, (3) mean deviation of the normalized F0 across the notes, (4) mean deviation of the pitch intervals, and (5) mean deviation of duration ratio between notes. The metrics (1) through (4) represented the pitch-related accuracy of singing from four different aspects whereas metric (5) measured the accuracy of tempo of the singing. Results of the acoustic analysis confirmed the subjective appraisal by the professional musician. For all the four pitch-based metrics and the one tempo-based metric, a majority of the choir members performed at highly accurate levels that exceeded the performance observed in the normal-hearing children who were casual singers.

Our results demonstrated that rigorous music training could facilitate high singing proficiency in prelingually deafened children with cochlear implants. Findings of the present study highlight the accomplishment of the hearing-impaired children with cochlear implants as well as the challenges they are facing when they receive limited pitch information through the auditory prostheses.

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P17: PROGRAMMING THE DEVELOPING HEARING BRAIN: A RESPONSIBILITY TO GET IT RIGHT

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Clinicians have a great responsibility to provide the best input available to children with hearing loss as soon as possible. The goal is that, with time and therapy, children will make optimal use of what they hear for spoken communication as they play, learn, and grow. The developing brain is remarkably plastic, first responding to compensate for the auditory deprivation, and then reorganizing in response to the input provided through auditory devices. To date, clinical targets have reasonably concentrated on providing audibility of sound to children with hearing loss in an effort to reduce delays in speech and language development. We have also tried to improve audibility by emphasizing one sound over others. Although impressive outcomes have been realized in this way for children with hearing loss, these have come at the expense of considerable neural compensation, effort, and deficits in working memory. Bilateral device fitting attempts to restore binaural/spatial hearing so that children can distinguish between sounds around them and make their own decisions about what to listen to. In our attempts to restore this essential hearing function, we have found that the timing of bilateral input in childhood is key and restores some degree of expected neurodevelopment. Despite these advances, bilateral auditory devices fail to promote expected cortical processing of binaural cues or normal binaural hearing. Although children continue to impress us with their abilities to gain benefits from their bilateral hearing devices, efforts to match bilateral or bimodal input provide potential for children with hearing loss to gain better spatial hearing. If we can accomplish this, we might be closer to improving children's ability to develop with hearing loss.

P18: THE EFFECTS OF EARLY ACOUSTIC HEARING ON SPEECH PERCEPTION AND LANGUAGE ABILITIES OF PEDIATRIC CI RECIPIENTS

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The primary aim of our current project is to determine the degree to which a period of hearing aid (HA) use facilitates language development in children following the receipt of their first cochlear implant (CI). Specifically, we seek to determine critical threshold levels and duration of HA use that should be applied before proceeding to bilateral CIs (BCI). Although CIs support high levels of phoneme perception (segmental) necessary for word recognition, the contribution of suprasegmental perception (i.e. stress, pitch and timing) that bootstraps language development may be lacking, partly due to reduced frequency resolution of current CIs. We hypothesize that early exposure to some suprasegmental cues via a HA may facilitate more rapid language acquisition for children with CIs.

We tested 117 pediatric cochlear implant recipients ranging in age from 5-8 years (mean age 7 years, SD 1.25 years) on tests of speech perception, receptive vocabulary and receptive language. The speech perception test battery includes word recognition in quiet and noise (segmental perception), and talker and stress discrimination as well as emotion identification (suprasegmental perception). Standardized tests of receptive vocabulary and language are the Peabody Picture Vocabulary test (PPVT) and Children’s Evaluation of Language Fundamentals (CELF). We also tested 42 age mates (mean age 6.75 years, SD 1.28) with normal hearing sensitivity as controls on all measures. A continuum of residual hearing levels and length of HA use are represented: some children have bimodal devices (CI+HA; N=29), better acoustic hearing and longer periods of HA use while others received their second CI (2CIs) either simultaneously (N=23) or sequentially (N=65) at varying time intervals since their first CI (CI interval mean 13.5 months; SD 11.4 months) and had some prior acoustic hearing experience. The mean age at first (or only) CI was 2.1 years (range from 8 months to 4.6 years). Pre-implant hearing data were collected on all participants and analyses are under way to quantify early acoustic experience using unaided thresholds and duration of HA use. These data have been analyzed in a multiple regression analysis to determine the effects of early acoustic experience on speech perception (both suprasegmental and segmental), and ultimately on vocabulary and language. The results of these analyses and their clinical implications will be discussed.

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P19: EFFECTS OF EARLY HEARING EXPERIENCE ON ACTIVATION AND FUNCTIONAL CONNECTIVITY IN PRIMARY AND HIGHER-ORDER CORTICAL FIELD

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Neuronal activations are manifested as oscillations in local field potentials (LFP) recorded extracellularly. Cochlear stimulation activates both primary and secondary auditory fields through thalamic input, while the auditory fields subsequently interact via corticocortical connections. The thalamic input is more represented in evoked (time- and phase-locked) cortical responses, corticocortical interactions are better represented in induced (non-phased-locked) responses. Here we have investigated an effect of auditory developmental experience on the representation of thalamocortical and corticocortical interactions in the primary and secondary auditory cortex.

We have evaluated time-frequency representations (TFR) of local field potentials recorded simultaneously from the primary auditory cortex (A1) and posterior auditory field (PAF) in hearing and congenitally deaf cats. Responses elicited by acoustic (through loudspeakers) in hearing animals and electric stimuli (through cochlear implants) in hearing and deaf animals were compared to investigate the effect of stimulation mode (acoustic vs electric stimulation) and effect of developmental experience (hearing vs deaf animals). LFP signals were recorded using two 16-channel multi-electrode arrays inserted in the auditory fields A1 and PAF simultaneously. Total, evoked and induced TFR power, and inter-trial phase locking factor (PLF) were calculated from bipolar derivation signal between neighbouring channels using wavelet analysis using Morlet wavelets. The Debiased weighted phase-lag index was used to estimate coupling between different channels in each recording site in both auditory fields.

The TFR grand means showed that evoked (phase locked) responses appeared mainly at early latency (<100ms) while induced (non-phase locked) responses appeared at both early and long latencies (>100ms) corresponding to their assumed role in thalamocortical vs. corticocortical processing, respectively. Electric stimulation resulted in reduced (weaker and shorter) induced activity compared to acoustic stimulation in hearing cats indicating that the mode of stimulation affects oscillatory responses. The comparisons between animal groups demonstrated no significant effect of deafness on evoked responses in A1, but a near loss of induced responses in both investigated fields in the deaf cats, particularly at longer latencies. Furthermore, when comparing the primary and secondary fields, hearing experience affected the activity in the secondary field PAF to a greater extent than in A1. The brief and weak induced responses in the deaf group resulted in correspondingly weaker couplings between two recorded fields compared to the hearing animals. This finding support the concept that developmental hearing experience is essential for corticocortical A1-PAF interactions.

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P20: A NEW U.S. STANDARD FOR COCHLEAR IMPLANTS WITH REQUIREMENTS FOR SAFETY, FUNCTIONAL VERIFICATION, LABELING AND RELIABILITY REPORTING

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U.S. Food and Drug Administration, Silver Spring, MD, USA

Introduction: A U.S. standard for cochlear implant systems, AAMI CI86 Cochlear Implant Systems: Requirements for Safety, Functional Verification, Labeling and Reliability Reporting has been developed by the American Association for Medical Instrumentation (AAMI). The standard applies to both implantable and external components, including electrodes, stimulators, sound processors, batteries, system accessories and supporting software. In addition to establishing acceptable design and testing requirements for both internal and external components, this standard requires public reporting of device reliability to aid clinics in patient management and inform the cochlear implant user community.

Objective: The aim of AAMI CI86 is to codify in a single document requirements for uniform public reporting of device reliability and specifications; device design parameters relating to electrical, mechanical, and environmental safety; bench verification and validation testing; and regulatory submission content. To our knowledge, these areas have been unaddressed, addressed in less detail, or addressed separately by existing national/international standards for medical devices.

Methods: The AAMI Cochlear Implant Committee was formed in 2010 following submission of a work item proposal by the U.S. Food and Drug Administration (FDA). This committee includes representatives of four cochlear implant manufacturers, FDA representatives, surgeons, audiologists, academicians, and members from professional organizations. AAMI CI86 was developed by the Committee between 2010 and 2016 during numerous collaborative face-to-face meetings and teleconferences.

Results: Based on the Committee's collective experience, AAMI CI86 specifies a set of requirements for cochlear implants to help ensure that a device will operate as intended over its lifetime. Publication of AAMI CI86 is expected in 2017. Following publication, manufacturers who choose to comply will submit high-quality, scientifically-supported marketing applications to regulatory bodies. Also, more uniform and transparent public reporting on device reliability will result in terms of device explantation rate, stratified by explant type (i.e., medical related, device failure, or inconclusive failure analysis) and patient age. A complying manufacturer will also report on its website a consensus set of device system specifications.

Conclusion: Clinicians and users are expected to make better informed decisions about devices through uniform and transparent public reporting of reliability information and device specifications. The accumulation of device reliability data, together with advances in cochlear implant hardware, software, and psychophysics/hearing science, is expected to lead to the innovation of future generations of safe, reliable and effective devices that reach market sooner.

P21: FACTORS LIMITING SPATIAL HEARING PERFORMANCE WITH BILATERAL COCHLEAR IMPLANTS AND FIRST STEPS TO REDUCE THE SHORTCOMINGS

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A wealth of bilateral CI experimental studies over the past 20 years have demonstrated that careful matching and balancing of left and right stimulation in controlled laboratory settings typically results in a fair sensitivity to interaural level differences (ILDs) and in some sensitivity to interaural time differences (ITDs) at least for most post-lingually deaf users. However, with their own processors in typical listening conditions, many factors can work against an optimal exploitation of the interaural differences. Today's device technology and fitting procedures are mostly ear specific, and multiple open questions remain about the optimal stimulation strategy and fitting for bilateral CI users. More open questions arise with respect to novel speech coding strategies which operate at pulse rates < 300 pps such as the Cochlear research strategy FAST and the MED-EL strategy FS4 (most apical electrodes only). Such low rates allow bilateral users – at least in theory – to exploit interaural pulse time differences as a spatial hearing cue that cannot be exploited at rates > 400 pps.

Over the past years, we have identified and addressed several new aspects that are relevant for improving bilateral stimulation. The ILD-based aspects are relevant for all speech coding strategies. In contrast, most of our ITD studies only address pulse time cues, applicable to FAST or FS4.

The talk will provide a summarizing overview of five recently published studies: (1) ITD-based lateralization: 700 µs ITDs are often not enough to elicit maximum lateralization and the rate limit is lower than for ITD discrimination. (2) Temporal course of ITD sensitivity: While normal hearing listeners are most sensitive to fine-structure ITDs at the beginning of a modulation cycle, CI users are most sensitive near the peak, which may be a disadvantage regarding localization in reverberation. (3) Identifying tonotopically matched L/R electrode pairs: A discrepancy between pitch matching and optimizing binaural interaction in the brainstem. (4) Simulation of N-of-M selection: Negative ILDs in apical channels and corrupted ITD cues. (5) Adaptive binaural beamformers: Substantially larger benefits in CI listeners as compared to hearing aid users.

Inspired by these insights, a binaural CI stimulation strategy was developed. Acute testing reveals that the optimization of ILD cues brings an immediate benefit, while ITD cues fall short of the improvement predicted by our simulations. Nevertheless, we will report from two subjects that were able to reliably lateralize a speech sound solely based on ITD cues.

P22: EFFECTS OF SYNCHRONIZING AUTOMATIC GAIN CONTROLS FOR BILATERAL COCHLEAR IMPLANT USERS

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In recent years, bilateral implantation has become common and has enhanced hearing performance for the CI population. Bilateral CI users can hear better because of input to both ears; however, binaural benefit can be limited in complex listening situations compared to normal hearing listeners. One reason for this difference could be that signal processing algorithms in the two CIs currently operate independently. As a result, temporal- and level-dependent, binaural hearing cues are not well preserved.

Automatic Gain Control (AGC), which is primarily used to better utilize the input signal dynamic range, currently works independently and applies gain separately on each of the two sound processors for bilateral CI recipients. This unsynchronized operation results in a loss of binaural information, especially interaural-level difference (ILD) cues. In the present study, we created a binaural CI research platform in which the separate processor AGCs are synchronized via a wireless transmission link. Resultantly, the same forward-path AGC gain is applied to both processors, thus maintaining the same input signal ratio between the two sides and thereby preserving binaural ILD cues. We examined the effect of independent and synchronized AGC settings on localization capability and speech intelligibility for adult, bilateral recipients of the Advanced Bionics CI system. Speech performance was evaluated with spatially-separated sources of speech and single or multi-talker noise. Localization capabilities were examined for a variety of sounds located at fixed or non-fixed positions on the horizontal plane.

Results show improved localization ability and speech intelligibility when the AGCs were synchronized between the two processors. Synchronizing the AGCs and other front-end processing features may allow bilateral CI users to benefit from preservation of ILD cues and hear better in complex listening environments where there are various noise sources and multiple talkers.

P23: NEURAL ITD SENSITIVITY AND TEMPORAL CODING WITH COCHLEAR IMPLANTS IN AN ANIMAL MODEL OF EARLY-ONSET DEAFNESS

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Bilateral cochlear implants provide benefits in sound localization and speech perception in noise over unilateral CIs. However, bilateral CI users' sensitivity to interaural time differences (ITD), a major cue for sound localization, is still poorer than normal. As a result, bilateral CI users still face challenges in everyday situations, such as understanding conversations in noise. The degradation in ITD sensitivity is especially acute at the high stimulation rates used in clinical CI processors and in those who lost hearing in early childhood. Here, we characterize temporal coding and ITD sensitivity of single neurons in the auditory midbrain of unanesthetized rabbits that were deafened as neonates.

Three Dutch-belted rabbits were deafened as neonates with daily injection of neomycin and then bilaterally implanted at 2-3 months of age. Beginning at adult age (6 months), their cochleas were electrically stimulated in the laboratory during single-unit recording sessions from the inferior colliculus (IC). Stimuli were periodic trains of biphasic electric pulses with varying pulse rates (20 – 640 pps) and ITDs (-2000 to +2000 µs). The results are compared to measurements from adult-deafened rabbits (Chung et al., J Neurosci. 36:5520) to understand the effect of early-onset deafness on neural temporal coding and ITD sensitivity.

IC neurons in early-deafened rabbits showed decreased sustained responses to pulse-train stimulation. Fewer neurons showed synchronized responses to pulse train stimuli at any rate in the early-deaf group (66%) compared to the adult-deaf group (83%). However, the maximum pulse rates that could elicit synchronized responses were similar between the two groups when the analysis was limited to synchronized neurons (early-deaf: median = 202 pps, adult-deaf: median = 182 pps). Fewer neurons showed significant ITD sensitivity in their overall firing rate (62%) in the early-deaf group compared to adult-deaf animals (76%). ITD sensitivity was lower for pulse rates above 80 pps in early-deaf animals compared to adult-deaf animals. Neural ITD discrimination thresholds in the early-deaf group were poorer than thresholds in adult-deaf group for all pulse-rates tested.

In summary, fewer neurons show synchronized responses and ITD sensitivity to pulse train stimuli in rabbits that experienced early-onset, long-term deafness. The degradation in ITD sensitivity in early-deaf animals is most acute at high pulse rates. The overall degradation of neural ITD sensitivity is consistent with difficulties encountered by human CI users who lost hearing early in life.

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P24: ASSESSING FREQUENCY-SPECIFIC EFFECTS OF DEAFNESS ON CORTICAL ACTIVITY IN THE DEVELOPING HUMAN AUDITORY SYSTEM

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The objective of the present study was to use a novel approach to identify effects of deafness on cortical function in toddlers. These children were deprived of access to sound from infancy but had received bilateral cochlear implants at ages 2.13 to 3.13 years to electrically stimulate auditory development. Measurement of cortical activity evoked by acute cochlear implant use (in the first week of device activation) provides a unique opportunity to define effects of deafness on the immature brain. This is important as we seek to define phenotypes associated with the multiple genetic and acquired causes of childhood deafness and to explain the high degree of variability in outcomes of cochlear implantation. Electroencephalography was recorded across 64 cephalic recording sites in 10 toddlers recently provided with bilateral cochlear implants and 8 peers with normal hearing. Stimuli were trains of electrical cochlear implant pulses (CI users) or clicks (Normal hearing toddlers). Standard methods involving dipole source modeling were expanded upon to assess brainwave activity across 4 specific bands of frequency (theta (4-8 Hz), alpha (8-12 Hz), beta (13-30 Hz), gamma (30-60 Hz)) in a novel approach which left the post-stimulus time window open. Toddlers with normal hearing demonstrated increased activity across all frequency bands in auditory cortices contralateral to the side of stimulation during earlier time windows. Thereafter, activity spread to other cortical regions. On the other hand, toddlers with bilateral deafness demonstrated increased alpha and theta activity in the initial 200 ms after electrical cochlear implant stimulation with diffuse patterns of high frequency activity (beta, gamma) thereafter. Additionally, the naïve contralateral auditory cortex demonstrates delayed responses to cochlear implant stimulation in the low frequency theta band, when compared to responses in the normal hearing toddlers. These results suggest a disordered pattern of auditory response with increases in activity typically associated with attention in toddlers with little prior auditory experience.

P25: "CORRECT" ELECTRODE POSITIONS ALONG THE COCHLEA: SOME THOUGHTS ABOUT PLACE CODING, MOVEABLE ELECTRODES, AND RATIONAL PITCH

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There is typically a mismatch between the frequency expected at a given cochlear angle and the frequency presented at that angle by a cochlear implant. The frequency mismatch may be particularly important for the population of cochlear implant users who are combining electric hearing with acoustic hearing in either the ipsilateral or contralateral ear. If the place coding provided by the cochlear implant is misaligned with the place coding from acoustic input, then the listener may be provided with inconsistent or even conflicting auditory cues. Due to plasticity, the auditory system may be able to compensate for these misalignments. However, data suggests that the ability of some listeners to fully adapt to the distorted or conflicting place maps is limited.

The frequency mismatch can be adjusted by changing the electrode length, insertion depth, and frequency allocation. Additionally, changing these variables effect the relationship between a change in input frequency and the corresponding change in place pitch. If the relationship between a change in input frequency and corresponding change in place pitch is distorted, then melodies, chords, or harmonic structures will be distorted. We define rational pitch as pitch coding such that a doubling in frequency is perceived as an octave shift. It is therefore expected that a careful manipulation of electrode length, depth, and frequency allocation is required to maintain rational pitch.

Using current shaping techniques "moveable electrodes" can be placed anywhere along the array. Such moveable electrodes could be placed to optimize electrode discriminability, the delivery of rational pitch, or a combination of the two. This approach is constrained by the location of the physical electrodes (phantom stimulation notwithstanding). Thus, a long electrode array covering the entire cochlea might be required for a post-hoc determination of the optimal locations for electrodes within the cochlea. Furthermore, an array that can provide stimulation in the apex may provide improved delivery of temporal information and sound quality.

P26: THE SOUND SENSATION OF ELECTRIC STIMULATION IN SINGLE-SIDED DEAFENED COCHLEAR IMPLANT RECIPIENTS

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In a previous study, the sensation evoked by the most apical electrode was characterized in cochlear implant (CI) recipients with contralateral residual hearing. Psychoacoustic evaluation of the percept involved fundamental frequency (F0), filter characteristics and harmonicity factor using an original multidimensional sound quality judgment task. This experiment was extended to CI users with single-sided deafeness (SSD) and to an apical (e20) and a medial (e14) electrode.

Ten unilateral CI users with SSD were asked to vary the parameters of an acoustic sound played to the normal-hearing ear, in order to match its perception with that of the electric sensation of e20 and e14. The experiment was divided in three consecutive conditions in which the nature of the acoustic sound and the controlled parameters varied. In the first condition the subject had to vary the frequency of a pure tone. In the second condition, the subject varied the center frequency and the bandwidth of a filter applied to a harmonic complex sound which F0 was determined by the result of the first condition. In the last condition, the subject had to vary F0 and the harmonicity factor of a complex sound processed through the bandpass filter determined during the second condition.

Six subjects performed the experiment at three and twelve months after activation to evidence a possible effect of brain plasticity. One subject performed the three-month session only, and three additional subjects performed the twelve-month session only.
Results were compared using a mixed-linear model.

Averaged F0 of the pure tones matching e20's and e14's pitch were significantly different ($p=0.02$, 506 Hz and 901 Hz respectively). In the second condition, the average center frequencies of the band-pass filters were 864 and 2.85 kHz for e20 and e14, respectively ($p<0.005$); the Q-Factors, respectively 6.2 and 6, were not significantly different ($p>0.05$). In the third condition, the average F0s were 307.5 Hz and 433 Hz for e20 and e14; the harmonicity factor was 1.7 for both electrodes. In this latter condition no significant effect of electrode place was found ($p>0.05$). A significant effect of session was observed between three and twelve months only in the third condition for F0.

The results of the first condition confirmed that the pitch sensation induced by a pulse train follows the tonotopy of the basilar membrane when matched with a pure tone. However, this frequency cannot be solely predicted by the Greenwood function nor by the manufacturer frequency allocation map. This may be explained by the mismatch between the cochlear tonotopy and the placement of the electrode-array, the spread of excitation that stimulates several nerve fibers at the same time, and a fixed stimulation rate lacking temporal coding consideration. In the second condition, the results indicated a significant difference in filter center frequency between e20 and 14. As this parameter is known to relate to sound brightness, e14 seems to evoke a brighter sound than e20. In the third condition, no significant difference (F0, inharmonicity rate) was found between the two electrodes. Although this last result must be interpreted with care – as F0 of an inharmonic sound cannot reliably predict its pitch -, the present study suggests that the sound sensation of different electrodes is more linked to a difference in timbre (brightness) than to a difference in pitch, and is more similar to an inharmonic complex sound than to a pure tone. Finally, a one-year follow up was not sufficient to show any plasticity. No consistent shift of the psychoacoustic parameters were observed over time.

P27: ELECTRIC-ACOUSTIC FORWARD MASKING IN COCHLEAR IMPLANT USERS WITH IPSILATERAL RESIDUAL HEARING

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Introduction. Users of electric-acoustic systems (EAS/AES) combine in one ear the stimulation through a Cochlear Implant (CI, electric stimulation) with their natural but impaired residual hearing (acoustic stimulation), which is enhanced by an acoustic component/hearing aid. The benefit of the residual hearing on speech reception is most pronounced in adverse listening conditions. However, initial studies show that the two stimulation modes interact and that simultaneous masking, meaning the obscuring of an acoustic tone by electrical stimulation and vice versa, is occurring. If electric-acoustic stimulation also shows non-simultaneous masking, this could have a significant impact on the temporal information and the perceived fine structure of the combined signal. This study investigates the temporal interaction effects between electric and acoustic stimulation in a forward masking paradigm.

Methods. Eight MED-EL Flex electrode users with ipsilateral residual hearing participated in both a simultaneous and a forward masking experiment. Psychoacoustic methods (a 3I-AFC paradigm) were used with both electric and acoustic maskers to measure the change in threshold on an acoustic or electric probe, respectively. Subjects were stimulated electrically directly through a research interface with unmodulated pulse trains and acoustically through a headphone delivering pure tones. For the simultaneous condition different combinations of acoustic frequencies and electrodes were tested. For each subject a forward masking paradigm, where the probe was shifted in time with respect to the masker, was conducted for the combination of electrode and frequency that delivered maximum simultaneous masking.

Results. The simultaneous masking experiment showed a significant (Wilcoxon rank test; $p<0.01$) threshold elevation, both for acoustic probe tones in the presence of electric maskers (mean elevation: 2.9 dB) and for electric probes in the presence of acoustic maskers (mean elevation: 1.4 dB). Individual results showed significant threshold elevations for only five out of eight subjects. A tendency was observed towards increasing masking effects with better residual hearing.

For the non-simultaneous masking experiment, two subjects showed a significant threshold elevation, with decay times of 80 to 100 ms. This lower number of subjects showing masking effects may be explained by the shorter probe durations used in comparison to the simultaneous masking experiment. The two subjects for whom non-simultaneous masking was observed were the ones having best residual hearing.

Conclusions. From these results in can be concluded that both acoustic and electric stimulation mask each other, not only when presented simultaneously but also up to 100 ms afterwards. These results may have implications for the fitting of EAS systems especially with respect to temporal modulations that may be affected by these masking effects.

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P28: HEARING PRESERVATION AND ELECTRIC-ACOUSTIC STIMULATION: LONG-TERM RESULTS AND INDIVIDUALIZED SOUND PROCESSING STRATEGIES

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Combined electric-acoustic stimulation (EAS) in the same ear is treatment for subjects with profound ski-slope hearing loss accepted worldwide by local approval bodies. EAS was first described by von Ilberg et al. (1999) where the surgical approach for hearing preservation (HP) was outlined and thus triggered the development of electrode designs dedicated to HP.

Audiological outcomes of HP surgery was reviewed in 103 ears of cochlear implant (CI) patient population with clinical follow-up up to 11 years after implantation. Long-term HP was feasible in a subset of patients. Sufficient long-term residual hearing was a prerequisite to benefit from additional acoustic stimulation. In case of delayed loss of residual hearing, reprogramming the CI processor to transfer the full frequency range of speech could maintain sufficient monosyllable test scores. Consequently, revision surgery with longer CI electrode was only necessary in a small number of cases.

EAS users with a contralateral hearing aid showed very good results in complex noise situations and demonstrated improved speech perception performance when compared with bilateral CI users. Average speech reception thresholds in the EAS group were significantly lower (better) than those for the bilateral CI group in all test conditions. A comparable effect was observed in simulated and modeled EAS data.

The benefits observed with EAS are mainly attributed to acoustic transmission of low-frequency information. In cases where residual hearing is lost, beneficial low-frequency pitch information could possibly be maintained: Reconciling place and temporal pitch in CI was studied using place-dependent stimulation rates to improve the “electric” pitch perception information in the electric-acoustic transition zone and to minimize mismatch between frequency and place. Individual electrode locations were determined by analysis of cochlear radiographic images obtained after surgery and place-dependent stimulation rates were calculated according to models of the normal tonotopic function. The electrically evoked pitch was evaluated by eleven subjects with late-onset single-sided deafness and almost normal hearing in the unaffected ear. Pitch matching results show that place dependent stimulation rates allow thus far unparalleled restoration of tonotopic pitch perception. Sound processing strategies incorporating place dependent stimulation rates are expected to improve pitch perception in CI and EAS users.

The presentation will underline the beneficial impact of hearing preservation on perception. A discussion of long-term effects and an individualized CI coding strategy will be presented.

P29: TOP-DOWN REPAIR OF INTERRUPTED SPEECH IN ELECTRO-ACOUSTIC STIMULATION

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Cochlear implant (CI) users benefit differently from top-down repair of interrupted speech than normal-hearing (NH) listeners [Bhargava et al., 2014, Hear. Res., 309, 113-123]. The poor pitch perception commonly reported in CI listeners might contribute to this difference, because voice pitch (F0) is a primary grouping cue that may be involved in repair mechanisms. F0 cues can be available to bimodal CI users with low-frequency (LF) acoustic residual hearing. We thus investigated the effect of residual hearing on top-down repair mechanisms for bimodal CI users. Previous studies showed that simulating electro-acoustic stimulation (EAS) yielded better intelligibility of interrupted speech than simulating electrical stimulation alone [Başkent, 2012, JARO, 13, 683-692] and the addition of F0 to CI simulation improved top-down repair in the spectral resolution range of CI users [Clarke et al., 2016, JASA, 139, 395-405]. We thus expected to observe similar improvement in benefits with bimodal CI users wearing a hearing aid (HA) in the contralateral ear where low frequency information, rich in F0 cues, can be transmitted.

We tested twelve bimodal users in two hearing modes, CI only, and CI and HA together, to measure bimodal benefit. The top-down repair of speech was assessed with the phonemic restoration (PR) paradigm. The PR benefit was measured by the increase in intelligibility of interrupted sentences when the periodic silent interruptions were filled with noise. As CI users show PR benefit for different interruption parameters than NH listeners, we used a range of gap duration for the interruptions.

Not confirming our expectation, groups results showed no bimodal benefit from adding the HA to the CI, and also no PR benefit, even for conditions where it was previously shown that CI users benefited from PR. However, subjective reports showed a general preference for wearing the HA along the CI, and suggesting that the additional HA provides better sound quality. Despite the lack of bimodal benefit at the group level, individual analysis showed that some bimodal users could benefit from the addition of the LF acoustic residual hearing to trigger top-down repair mechanisms. In addition, more participants could benefit from the acoustic cues delivered by their HA along their CI for top-down restoration of interrupted speech as the gaps were shortened (for longer speech segments). That is, some participants showed a bimodal benefit on PR, and more participants showed this benefit as the gaps were shortened. This suggests that every improvement in quality of bottom-up cues (in frequency and in duration) may contribute with an additive effect to better top-down restoration, showing a powerful interaction between bottom-up cues and top-down repair mechanisms.

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P30: BIMODAL HEARING VERSUS BILATERAL IMPLANTATION: SPEECH UNDERSTANDING, SPATIAL RELEASE FROM MASKING, AND SOURCE LOCATION UNCERTAINTY

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The decision whether to continue use of a hearing aid (HA) in the non-implanted ear or to pursue a second cochlear implant (CI) can be a difficult decision. This decision is complicated by a lack of a data-driven criterion for determining bilateral implant candidacy. We will contrast speech understanding and discuss underlying mechanism for a group of adult bimodal listeners and bilateral CI recipients. Experiments include investigation of 1) spatial release from masking (SRM) with symmetric maskers, 2) investigation of energetic and informational masking, 3) effect of randomly roving target speech in the front hemifield, and 4) effect of source location certainty on speech understanding. Results were as follows:
1) Neither bimodal nor bilateral CI users exhibited SRM with symmetric noise maskers; bimodal listeners exhibited negative SRM in conditions for which target and distracter fundamental frequencies were similar;
2) Bimodal listeners exhibited significantly greater release from informational masking than bilateral CI users;
3) Bilateral CI users exhibited similar levels of speech understanding regardless of source azimuth whereas bimodal listeners exhibited higher performance for speech directed to the better hearing ear even in the bimodal condition, and;
4) Source location certainty did not affect speech understanding performance.
In symmetric noise conditions, listeners must rely on binaural timing cues, which are not generally available to either bimodal or bilateral CI users. Bimodal listeners, however, may have been able to combine segregation and/or glimpsing—via fine structure in the non-CI ear—thereby increasing susceptibility to informational masking with the speech distracters. In conditions of roving signal location, bilateral CI users overcame the deleterious ear and source/azimuth effects observed for the bimodal listeners. The likely reason is that bilateral CI users have access to high-frequency level cues, whereas bimodal listeners generally have interaural asymmetry in both speech understanding and audible bandwidth. In summary, bimodal and bilateral CI users exhibited similar speech understanding in various conditions. Bimodal hearing was superior to bilateral CI in conditions without informational masking. Bilateral CI performance was superior to bimodal hearing in conditions with source location uncertainty.

P31: OBJECTIVE ESTIMATION OF BINAURAL LOUDNESS BALANCE FOR BIMODAL LISTENERS

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Listeners with bimodal hearing, who have a cochlear implant in one ear and wear a hearing aid in the other ear, do usually not perceive a perfectly balanced binaural loudness. They have difficulties in localizing sound sources and in perceiving a natural sound quality.

While loudness growth is highly patient and electrode dependent, behavioral measures are time-consuming and require an active cooperation of the patient. In previous studies we demonstrated that the amplitude of the 40-Hz auditory steady-state response (ASSR), an auditory evoked potential that can be measured in the EEG, grows similarly with intensity as behavioral loudness, measured monaurally for normal-hearing, hearing-impaired, and cochlear implant listeners.

The aim of this study was to objectively find balanced binaural loudness in case of bimodal hearing. We investigated whether the 40-Hz ASSR amplitude growth functions, monaurally measured in both ears, can be used to objectively estimate at which intensities or current levels the loudness is balanced across both ears.

We tested normal hearing listeners, listeners with an asymmetric hearing loss, and bimodal listeners. All stimuli had a modulation frequency of 40 Hz. For acoustical stimulation, a carrier frequency of 500, 1000 and 2000 Hz was used. For electrical stimulation, we used direct computer controlled bipolar stimulation (BP+2) consisting of 900-pps biphasic pulse trains. Apical CI electrodes were chosen. EEG was recorded with a Biosemi 64-channel ActiveTwo EEG recording system to the stimuli presented monaurally to both ears at different intensities or current levels encompassing the listeners' dynamic ranges in order to obtain ASSR amplitude growth functions of the left and right ear. Linear interpolation (blanking) was used to remove CI stimulation artifacts. Behavioral binaural loudness balancing was performed using an adjustment and adaptive procedure.

For NH listeners, who have equal loudness growth functions across the ears, the difference between the left and right ear 40-Hz ASSR amplitude growth function was small. For listeners with an asymmetric hearing loss and bimodal listeners, similar ASSR amplitudes were found corresponding to the loudness as measured behaviorally. This demonstrates the potential of using 40-Hz ASSRs to objectively find the balanced binaural loudness in case of asymmetric and bimodal hearing. Such an objective measure can contribute to a more automatic and objective fitting of hearing aids and cochlear implants.

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P32: THE IMPORTANCE OF STIMULI TO INTELLIGIBILITY ASSESSMENT

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Speech-based stimuli are critical tools for evaluating individual outcomes post-implantation and for understanding how human auditory perception interacts with cochlear implants. These stimuli, used in an effort to estimate conditions that a patient may experience in conversational settings, are typically drawn from standardized test materials. Indeed, the strict limitations on administering clinical tests and methodological limitations in perception experiments often necessitate standardization. While attention is paid to norming the materials, control of signal levels, and to test-retest reliability, there is less understanding about how stimulus-specific factors, and practices in the laboratory or clinic, can interact with perceptual tests. One issue is the materials themselves. Lexical factors (usage frequency, confusability for word-based tests) contribute to list-dependent variability. With longer stimuli, stimulus structure can have even greater effects. Finally, individual talker intelligibility traits can introduce significant stimulus-specific effects. These effects can be amplified in detrimental ways through practices in the laboratory or clinic. For example, demographic norming (such as dialect matching) is rarely applied in stimulus choice, thereby introducing stimulus-goodness effects that modulate the intrinsic intelligibility of a stimulus set and underestimate or overestimate intelligibility on the part of the hearer. On the other hand, recycling specific wordlist recordings or even stimulus structures can result in the patient or subject overlearning the stimulus-specific details, thereby inflating intelligibility scores and even unintentionally changing the nature of the task. In the end, using a fixed set of testing materials can present significant issues in interpreting the results of tests. For example, CNC wordlists are often recycled in a fixed order, training the hearer to memorize word orders and to attend to the specifics of individual talker's vocal traits rather than attending to the speech materials themselves. Similarly, matrix sentences provide ways of automating testing and are therefore widely employed; however, they lead to overlearning of material which results in the testing of pattern recognition rather than speech reception. Even IEEE sentences, which vary dramatically in their content and structure, are often sub-sampled and presented with a single talker in a way that can overestimate the hearer's speech understanding.

In this talk I will discuss strategies for mitigating negative effects of using fixed stimuli such as interleaving stimulus structures and tasks, dialect norming, using multiple talkers, and list rotation.

P33: SPEECH PERCEPTION AND LISTENING EFFORT WITH A COCHLEAR IMPLANT: THE RULES ARE DIFFERENT

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A large body of evidence from psycholinguistics suggests that speech perception in people with normal hearing is largely predictive in nature. Using only small portions of the signal, listeners rapidly generate expectations about what will be heard next, from low-level phonetic properties to higher-level aspects of a talker's intention. Predictive processing is a common and well understood aspect of normal speech perception and cognition in general. For listeners with cochlear implants (CIs), performance can suffer from inaccuracies, but more critically, the process of speech perception appears to be qualitatively different in nature. A sequence of studies shows that rather than rapidly accumulating evidence from the signal and forming expectations, we observe responses that are not merely erroneous, but delayed in critical ways that suggests retroactive rather than predictive processing.

To assess the time course of speech perception, we have measured pupil dilation to gauge the degree of cognitive activity as it occurs over time, in cases where listeners can "restore" previously heard words. Pupillometry reveals that sustained cognitive activity needed to restore a recently heard utterance can compete with perception of ongoing speech or noise, as would occur in a normal conversation. Furthermore, we show evidence of reallocation of effort over time in cases where that disruption is expected. This underscores a largely underappreciated challenge in auditory perception, which is not focused on the signal itself, but post-stimulus processing. This phenomenon might underlie individuals' difficulty in real-life scenarios where a single mistake cascades forward to disrupt perception of later utterances.

In this talk, we will discuss how explicitly acknowledging retroactive processing has implications for our ability to assess speech perception in people with CIs. If performance is driven primarily by competence in linguistic / cognitive restoration, then perception of smaller units (e.g. phonemes) will not predict perception of larger units. In other words, conversational performance cannot be predicted by sentence recognition, which cannot be predicted by word recognition, which cannot be predicted by phoneme recognition. However, out of this unseemly deduction rises the possibility that by understanding and deliberately disrupting post-stimulus restorative processing, we might be better able to assess the auditory challenges for people with CIs, and better understand the limitations of behavioral auditory testing when trying to predict intelligibility.

P34: SPEECH PERCEPTION AND MODULATION PRESERVATION IN THE ELECTRICALLY STIMULATED AUDITORY PATHWAY

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Cochlear implant (CI) users have relatively good speech intelligibility in quiet environments. In difficult listening environments [e.g., speech-in-noise (SPIN)], however, their performance deteriorates and the variability in performance across users increases. CI users predominantly perceive speech based on the temporal modulations within a speech signal. Here we hypothesize that the strength of the temporal modulations, across stimulation channels, must be preserved equally throughout the tonotopically allocated neural assemblies across the electrode array in order to allow good SPIN intelligibility.

In order to test this hypothesis we measured the differences in the 40-Hz electrically evoked auditory steady-state response (EASSR) across stimulation channels in nine adult Nucleus® CI users. The 40-Hz EASSR is an evoked phase-locked response to a 40-Hz modulated pulse train that originates from subcortical regions of the auditory pathway, is present in most CI subjects [Gransier et al. (2016) Hear Res, 335, 149-160], and its strength is related to modulation detection [Luke et al. (2015) Hear Res, 324,37-45]. The participating CI users were selected based on their SPIN performance, speech reception thresholds ranged from ~0 to ~20 dB SNR. 40-Hz EASSRs were evoked at the maximum comfortable loudness level with a 40-Hz modulated 500 pulses-per-second pulse train from each stimulation electrode (in monopolar mode), and were measured by means of EEG.

Our results revealed strongly subject and electrode dependent 40-Hz EASSR patterns across the array, indicating differences in modulation preservation across tonotopically allocated neural assemblies. In addition, we found that the number of stimulation electrodes resulting in significant 40-Hz EASSRs and a low variability in response strength across the array is related to good SPIN performance, whereas poor SPIN performance is related to a reduction in the number of stimulation electrodes resulting in significant 40-Hz EASSRs and widely varying response strengths across the array.

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P35: THE IMPACT OF PERCEPTUAL CUE WEIGHTING STRATEGY ON SPEECH PERCEPTION AND LISTENING EFFORT FOR CI USERS

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This ongoing study investigates the impact of acoustic cue weighting strategies for cochlear implant (CI) users on their sentence recognition and listening effort. Previous studies suggest that CI users who weight the spectral cues more than the temporal cues have better word recognition. Our recent study testing normal hearing (NH) listeners using CI acoustic simulations also shows that listeners with more weighting on the spectral cue are more efficient in using cognitive effort for speech recognition than listeners weighting more on the temporal cue. Therefore, it is hypothesized that heavier perceptual weighting of the spectral cue in CI users would predict better sentence recognition performance and less listening effort.

7 CI users were recruited. They were first tested with sentences in quiet in order to determine their maximum performance level. Following that, adaptive procedures were used to determine Speech Reception Thresholds (SRTs) for sentences in speech-shaped noise, to obtain 50% of their performance level in quiet. They were then tested with sentences fixed at this signal-to-noise ratio (SNR) and both their cognitive load (assessed through pupillometry) and performance measured. Listeners' relative perceptual weighting on duration and spectral cues were measured with a tense and lax vowel categorization task in quiet. Their auditory sensitivity to spectral and duration cues was measured using a three-alternative forced-choice (3AFC) test procedure. To look at how much between-individual variance in sentence recognition and listening effort could be explained by individual differences in acoustic cue weighting strategy and auditory sensitivity, a mixed effect logistic regression model will be fitted in order to predict performance level in the fixed SNR test, with listeners' pupil responses, acoustic cue weighting strategies and auditory sensitivities as predictors.

Findings from the current experiment will extend the line of studies investigating factors contributing to the great variability in speech perception and listening effort among CI users. It will also highlight the importance of looking at the efficiency of using cognitive resources for speech perception.

P36: VOICE CUES AND SPEECH PERCEPTION IN COCHLEAR-IMPLANT USERS

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Two main components of speech are voice (who said it) and linguistic content (what they said). Voice information can directly inform about the speaker, such as their sex, age, socio-economic background. Voice cues can also significantly contribute to communication, in conveying vocal emotions and enhancing speech segregation and comprehension in cocktail-party listening. These are situations where CI listeners have most difficulties, yet most clinical tools used in patient care are based on assessment of linguistic content with simple speech materials, such as words and sentences, where voice plays no or little role.

The two voice cues, voice pitch (related to fundamental frequency, F0) and vocal-tract length (VTL; related to the height of the speaker and formant frequencies), are particularly effective for voice discrimination, and seem to be related to voice advantages observed for speech-on-speech perception. The reduced sound quality due to impoverished spectro-temporal details of the speech signal would also affect perception of the voice cues. Confirming this, a significant amount of past research on voice perception by CI users has shown perception of F0 to be poor. In contrast, minimal research has been done on perception of VTL.

Recently, we manipulated F0 and VTL separately on the recordings from the same talker and assessed gender categorization of the manipulated voices by CI users [Fuller et al. 2014 JARO 15:1037-1048]. This way, we were able to assess perception of F0 and VTL per se and in a systematic manner. Since the manipulation was applied on the recordings from the same speaker, listeners could not rely on other speaker-related characteristics, such as accent, pace, intonation, that may additionally help in identifying speakers and their genders. Only with such systematic approach, we observed that, while perception of F0 was poor, as was reported before, this was still the main voice cue that CI users relied on. They were not able to make use of VTL cues, however, which lead to abnormal patterns in recognizing speaker's gender, compared to normal hearing where both F0 and VTL are used to achieve this task. This finding implied that voice perception in CI users is more complex than what was previously shown.
In our follow-up research, we now focus on perception of VTL to explore whether the deficit comes from VTL-related cues not being delivered by the CI, or if these are delivered in a distorted way and therefore ignored by the CI user [Gaudrain et al. 2015 JASA 137:1298-1308]. If it is the latter, CI users may be able to learn to make use of these distorted cues with focused training. We further explore perception of these cues and their connection to speech perception in various populations, such as persons implanted early as children or later after a long duration of auditory deprivation. Since VTL perception relies on spectral resolution, we explore new signal-processing techniques that may help improving perception of this voice cue. With such a comprehensive approach, we aim to fully explore the limitations in voice perception in CI users, and what potential solutions we can offer to overcome these limitations.

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P37: CI ELECTRODE STIMULATION STRATEGY MOTIVATED BY ROBUST INTELLIGIBILITY IN NOISE OF A VOCODER BASED ON THE ZERO-CROSSINGS OF THE SPEECH WAVEFORM

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Current cochlear-implant Speech Coding Strategies (SCS), represent the speech spectral bands in terms of the spatial arrangement of the intracochlear electrodes. This paper describes a novel cochlear-implant SCS that takes into account the time interval between the zero-crossings of the speech time waveform. To a degree, these time intervals (or speech segment durations) convey information about the instantaneous spectral information of the speech waveform, longer segments corresponding to low frequencies and shorter segments to high frequencies. Simulation of the zero-crossing vocoder consists of breaking down the temporal speech waveform into segments and quantizing all possible segment durations into 8 possible duration bins. The speech waveform between adjacent zero crossings is approximated by half a sine wave that matches in amplitude the maximum of the speech segment. Eight normal-hearing participants evaluated the intelligibility of two sets of HINT sentences vocoded by two eight-channel vocoders that simulated the contemporary SCS and the zero-crossing coding proposed herein. In a quiet environment, much the same speech intelligibility was achieved with both vocoders, but in noisy environments, the intelligibility was higher with the zero-crossing than the contemporary vocoder. As the SNR decreases, the intelligibility difference between the two vocoders increases to 14% in favor of the zero-crossing coding. Based on this experiment, we propose a SCS that maps the segment duration to the spatial arrangement of the intracochlear electrodes. The segment duration specifies the location of the active electrode along the longitudinal extent of the basilar membrane. Longer segments activate electrodes near the apex of the cochlea and shorter segments activate electrodes near the base. The distance between the active and reference electrodes is proportional to the segment duration. The maximum amplitude of the waveform segment determines the amplitude of the current delivered to the active electrode. Due to charge spread, the current amplitude decreases starting from the apical active electrode to the basal reference electrode to mimic the basilar-membrane mechanical stimulation of the hair cells. The electrodes pulse rates are inversely proportional to the segment durations to provide a further cue about the instantaneous frequency of the speech waveform.

P38: SPEECH PERCEPTION PERFORMANCE AND SPEECH PRODUCTION ERRORS IN PEDIATRIC COCHLEAR IMPLANT USERS

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Introduction: Cochlear implants (CI) allow most children with profound hearing losses (HL) to achieve open-set speech perception and speech production understandable to normal hearing (NH) listeners. However, these outcomes are represented by a wide variability of scores. We examined the pattern of speech production errors and identified the sounds most affected by speech errors. We also investigated the effects of duration of CI use, age of implantation, generation of CI technology, length of auditory deprivation prior to implantation and speech perception performance on speech production errors.

Methods: A subset of 58 orally-educated children who received a CI during the 1990s were drawn from Geers & Brenner, 2003. These children were implanted between the ages of 2 and 4 years and tested at 8-9 years of age. More recently implanted participants included a group of 60 orally-educated children reported by Geers & Nicholas, 2013 who were implanted in the 2000s between the ages 1 and 3 years (±2 months) and tested at 9-12 years of age. In both samples, speech perception was evaluated using the Lexical Neighborhood Test (LNT) (Kirk et al., 1995), an open-set measure of speech perception of words. The number of phonological errors was evaluated using McGarr sentences (McGarr, 1983). Sentences produced by CI users, were transcribed by four speech language pathologists and analyzed using Computer Aided Speech and Language Analyses (CASALA) software (Serry et al., 1997) to determine the accuracy scores for each consonant and percentage of omission and substitution errors.

Results: Significant negative correlations between speech perception scores and omission/substitution errors for both groups were evident. Children implanted at younger ages with more recent CI technology had significantly fewer omission/substitution errors but the error patterns were similar across groups.

Conclusion: Significant reductions in the number of errors were observed for children implanted at younger ages relative to children implanted at later ages. Performance was influenced by speech perception, as well as demographic factors including early implantation, longer duration of CI use and use of newer speech processing strategies.

P39: A NEW METHOD FOR IDENTIFYING "BAD" CHANNELS BASED ON ACROSS-CHANNEL MODULATION MASKING

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The large variability in performance across cochlear implant (CI) users may be partly explained by variability in the number and distribution of surviving auditory neurons. There is considerable interest in identifying "bad" channels in CIs, i.e. channels whose electrodes fall at places in the cochlea where there are few or no surviving neural processes (dead regions), and which produce neural excitation only via the spread of electric current to remote places. Deactivating those channels can lead to improved performance. We describe here a new method for identifying bad channels with the following desirable characteristics: (1) The method does not require "direct" electrical stimulation; (2) The method is based on assessment of the ability to discriminate the primary form of information conveyed by CIs, namely discrimination of the amplitude modulation (AM) pattern applied to one electrode when there is a different pattern of AM on adjacent electrodes; (3) The method is reasonably quick.

The stimuli are amplitude modulated sinusoidal carriers delivered via the auxiliary input of the sound processor. The "target" sound has a carrier frequency centered on channel N of the processor. AM is applied to this carrier with 50% depth. A two-interval forced-choice task is used with an AM rate of 4 Hz in one interval and 8 Hz in the other. The task is to indicate the interval with the "faster" AM. These AM rates were chosen because they are within the range that is important for speech perception. This task is easy when no other sounds are present. The target sound is presented together with interfering sounds with carriers centered on channel N-1, N+1, or both N-1 and N+1. The mean level of each carrier is selected to match the level of the speech falling within the given channel for speech at 65 dB SPL. The AM applied to each interfering sound is an independent sample of the envelope of speech, lowpass filtered at 16 Hz. The envelope is scaled by a factor S. An adaptive procedure is used to determine the value of S giving 71% correct discrimination of the target. A "good" target channel is indicated by a high value of S at threshold and a "bad" target channel is indicated by a low value of S at threshold.

Pilot data using this new method, and the consequences for speech perception of deactivating "bad" channels will be presented.

P40: SPECTROTEMPORAL MODULATION SENSITIVITY AND SENSORINEURAL HEARING LOSS: IMPLICATIONS FOR COCHLEAR-IMPLANT SPEECH UNDERSTANDING IN NOISE

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Cochlear-implant (CI) recipients show an extraordinarily large distribution of outcomes, with speech understanding in quiet ranging from 0 to 100%. A number of studies have found that speech-reception scores are correlated with spectral-ripple sensitivity, suggesting that CI listeners with relatively good frequency selectivity demonstrate relatively good speech understanding, especially in quiet. Speech perception in noise represents an even larger challenge for CI listeners. While many CI listeners perform as well for speech perception in quiet as hearing-aid users, performance in noise is relatively poor for CI listeners. Measures of spectral-ripple sensitivity do not correlate nearly as well to speech-understanding scores in noise as they do for speech in quiet.

In an attempt to shed light on the limitations of CIs for facilitating speech understanding in noise, this presentation will summarize a series of studies that have examined the relationship between speech understanding in noise and spectrotemporal modulation (STM) detection for hearing-impaired (HI) listeners. STM stimuli are spectrally rippled noises with spectral-peak frequencies that shift over time, similar to modulations that exist in speech signals. The results show that STM sensitivity correlates to speech-reception performance in noise after accounting for audibility differences, including when HI listeners are properly fit with individualized frequency-dependent gain. Critically, the correlation with speech scores is ascribed mainly to the low-frequency portion of the STM stimulus (<2 kHz), and hearing loss has the largest impact on STM sensitivity for low temporal rates and low carrier frequencies. These results suggest that HI listeners have trouble understanding speech in noise because they have a reduced ability to use temporal fine-structure information to detect slow-moving spectral peaks.

The fact that CI listeners with better ripple sensitivity have better speech scores is a promising sign that if we can improve frequency selectivity, we can improve speech understanding, especially in quiet. At the same time, our findings for HI listeners suggest that spread of excitation along the cochlea is not the whole story. At low frequencies, acoustically stimulated auditory-nerve fibers relay temporal fine-structure information that may further enhance the ability to identify critical speech features in a noisy environment. CI listeners will likely not achieve better speech understanding in noise until this critical aspect of auditory processing can be successfully mimicked through electrical stimulation.

[The views expressed in this abstract are those of the author and do not reflect the official policy of the Department of Army/Navy/Air Force, Department of Defense, or U.S. Government.]

P41: COMPLEX PITCH, SPEECH PROSODY AND LEXICAL TONE PERCEPTION WITH COCHLEAR IMPLANTS

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Complex harmonic structure is richly encoded by the normal auditory system. The perceived fundamental frequency pitch (F0) extracted from the harmonic structure of voice plays multiple roles in speech perception. In cochlear implants (CIs), key acoustic cues to complex pitch are lost or degraded, and listeners must rely on F0-related-periodicity remaining in the temporal envelope of the electric signal for F0 information. As this form of pitch is perceptually weak, CI listeners show significant deficits in their sensitivity to aspects of speech in which F0 is important, such as voice emotion or speech intonation recognition, speaker identification and lexical-tone recognition. In a number of studies in our lab, we have investigated CI listeners' sensitivity to complex pitch in relation to their perception of speech prosody and lexical tones.

Our results show significant correlations between this sensitivity and CI listeners' processing of voice emotion, speech intonation and lexical tones, indicating that the perceptually-weak pitch conveyed by the temporal envelope does contribute to speech communication in this population. Age can also have an impact on sensitivity to this temporal envelope periodicity pitch: in children with CIs, we find significant beneficial effects of age, while older adults show significant deficits in envelope-pitch sensitivity. Linguistic environment may play a further role: results of our ongoing studies suggest that children in Taiwan have an advantage over children in the US in an F0-sweep-direction identification task, but not in static-F0 or dynamic-F0 discrimination tasks. In this talk, I will summarize these findings, and discuss their implications for speech perception by children and adults with CIs.

P42: AGE-RELATED AUDITORY TEMPORAL PROCESSING DEFICITS IN COCHLEAR-IMPLANT USERS

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Cochlear-implant (CI) users must rely primarily on the temporal characteristics of a signal to understand speech. Therefore, it may be that older CI users (over 65 years of age) with age-related auditory temporal processing deficits may experience relatively large disadvantages in using their CI. Aging can produce negative effects on multiple levels of auditory processing, which are broadly categorized as peripheral, central, and cognitive. Previous studies have shown that older CI users tend to perform more poorly than expected based on variables such as age at onset and duration of hearing loss, suggesting an important role for peripheral neural survival on auditory temporal processing. However, assessment of central temporal processing and cognitive processing in CI users has yet to be extensively studied. The purpose of this study was to determine the contributions of peripheral, central, and cognitive processing on age-related temporal processing deficits in CI users.

Gap detection thresholds (GDTs) and amplitude-modulation (AM) detection thresholds (MDTs) were measured in three younger (YCI: 18-45 yrs), two middle-aged (MCI: 46-64 yrs), and eight older (OCI: 65+ yrs) post-lingually deafened CI users. Thresholds were obtained via direct stimulation of single electrodes at stimulation rates of 100, 500, 1000, and 4000 pulses per second (pps). The contribution of peripheral neural survival to temporal processing ability was estimated using the slope of electrically evoked compound action potential (ECAP) amplitude growth functions. The contribution of cognitive factors was also estimated using non-auditory speed of processing and working memory tasks. All listeners passed a cognitive screening for dementia.

Results for GDTs and MDTs both showed aging and stimulation rate effects. Average GDTs were 3.6 ms in YCIs, 8.1 ms in MCIs, and 6.2 ms in OCIs. No differences in GDTs between groups were observed for the 100-pps rate condition, but OCI listeners had poorer performance compared to YCI listeners at faster stimulation rates, suggesting a rate × age interaction. Steeper ECAP growth function slopes (>5μV/CL), which indicated better neural survival, were associated with better GDTs in all groups. The steepness of individuals' ECAP slopes were negatively correlated with their duration of deafness, and not with age. MDTs (percent modulation depth) using stimulation rates of 500 and 4000 pps for detection of a 100-Hz AM pulse train were 1.03% in YCIs, 3.05% in MCIs, and 6.03% in OCIs. MDTs were not affected by stimulation rate for the YCI group. The MCI and OCI subjects showed poorer MDTs overall, with markedly poorer detection at 4000 pps compared to 500 pps. Cognitive variables did not correlate with listeners' temporal processing ability, suggesting that temporal processing was primarily determined by peripheral and central auditory processing components.

The results indicate that age-related central auditory temporal processing deficits occur in CI users, similar to the same age-related deficits that occur in acoustic-hearing individuals. Peripheral function (i.e., neural survival) also contributed because electrodes with steeper ECAP amplitude growth functions showed better thresholds compared to electrode locations with shallow slopes, both within and across subjects. These results initiate the development of a profile of auditory temporal processing and cognitive processing deficits in older CI users, with an important component being that higher-rate carriers appear to amplify age-related temporal processing deficits. This information may be useful in developing age-specific programming techniques to help mitigate the performance-limiting effects of temporal processing deficits for understanding speech with a CI. [Research was supported by the National Institute On Aging of the National Institutes of Health under Award Number R01AG051603.]

P43: ELECTROPHYSIOLOGICAL MEASURES OF AUDITORY DEVELOPMENT IN CHILDREN USING BIMODAL DEVICES

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Cochlear implantation criteria are expanding to include children with various degrees of asymmetric hearing loss in order to provide early access to bilateral sound by treating each ear with the most appropriate device. Children with asymmetric hearing loss may be fit with a cochlear implant in one ear and a hearing aid in the other (bimodal devices). However, it is unclear whether these two very different inputs support neurodevelopment and/or promote binaural hearing. To answer these questions, electrophysiological and behavioural outcomes can measure benefits of bimodal fittings to each ear and assess how the electric and acoustic signals are used together in this significantly diverse population of children.

We have measured both early and late latency evoked potentials in children who use bimodal devices. Auditory brainstem responses help to quantify asymmetric timing that comes from bimodal input. An acoustic delay is expected but some children experience additional delays due to poor development. The delays are always associated with the acoustically hearing ear indicating that electrical stimulation is very effective in promoting development in the brainstem. Late latency responses help to: 1) quantify the extent and time course of abnormal cortical changes to asymmetric input during development which promote a preference for the better hearing ear and 2) assess whether bimodal input can prevent or reverse this reorganization. These cortical responses have shown that bimodal input can provide an effective form of bilateral input when delay to implant is minimized and the child has sufficient residual hearing in the un-implanted ear. Comparisons to the same measures collected in children receiving bilateral cochlear implants identified a remarkably similar time course for reorganization in response to unilateral hearing, indicating that cortical measures are sensitive to the timing that bilateral input is provided in development irrespective of stimulation mode to each ear.

The remarkable changes in auditory development and function revealed by electrophysiological measures can be combined with behavioural outcomes to better understand the effectiveness of bimodal stimulation in children.

P44: MEASURING EABRS TO BUNCHED-UP PULSES: CAN THIS HELP COCHLEAR MPLANT PROGRAMMING?

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While eCAP and eABR thresholds for low-rate pulse trains correlate well with behavioral thresholds measured at the same rate, the correlation is much weaker with behavioral thresholds measured at higher rates, such as used clinically. This implies that eCAPs and eABRs cannot be reliably used for objective programming of threshold levels in CI users. This weak correlation is probably due to the fact that short-time constant temporal processes influence the auditory nerve response when stimulating at high rates while they do not at lower rates. Here, we investigate if the use of bunched-up pulses (BUPS) which consist of groups of pulses separated by silences may better reflect these processes and be used as an alternative for objective programming of cochlear implants (CIs) based on eABRs.

Experiment 1 measured behavioral detection thresholds for several 500-ms stimuli having a repetition rate of 31 Hz in nine CI subjects implanted with a Med-EL device. The stimuli differed in the number of pulses present in each period (from 1 to 32), the inter-pulse interval (IPI) within each period (either 0 ms called BUPS or 1 ms) and the electrode location (apical or basal). For the 32-pulses condition with an IPI of 1 ms, the stimulus was equivalent to a regular 1000-pps pulse train, similar to the stimulus used clinically. We show that the correlation between behavioral thresholds obtained for this clinical stimulus and for the BUPS stimuli increased as the number of pulses per period present in the BUPS increased from 1 to 32. This first psychophysical experiment suggests that the short-time constant processes influencing the threshold of clinical stimuli are also active for BUPS stimuli having a high number of pulses per period.

Experiment 2 measured eABRs on the apical electrode of eight CI subjects for BUPS having 1, 2, 4, 8, 16 or 32 pulses per period. For all subjects, Wave V was visible for BUPS having up to 16 pulses per period. However, only 4 subjects showed a measurable response for the 32-pulses condition. The latency of Wave V at threshold increased as a function of the number of pulses per period, suggesting that the eABR reflects the integration of multiple pulses at such low levels. At comfortably loud level, however, the response latency was similar for the different BUPS, suggesting that in this case, the response is elicited by the first few pulses of the stimuli. Interestingly, there was a strong within-subject correlation between electrophysiological and behavioral thresholds for the different BUPS stimuli. This demonstrates that the drop in behavioral threshold obtained when increasing the number of pulses per period in BUPS stimuli can be measured electrophysiologically using eABRs.

Overall, these two experiments suggest that BUPS may be a promising alternative to predict behavioral thresholds for clinical stimuli based on eABR measurements and be used as a tool for objective programming of threshold levels in CIs.

P45: EEG ALPHA RHYTHMS AS A BIOMARKER FOR LISTENING EFFORT FOR SPEECH IN NOISE PERCEPTION IN COCHLEAR IMPLANT USERS.

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Background: Cochlear implant (CI) users often struggle while listening to a conversation in adverse listening environments such as a noisy room and often report that they feel exhausted after a day of listening. In order to follow conversations, especially in the presence of noise, attention and effort must be exerted and may be related to listening effort (LE). The physiological mechanisms of LE are not well understood. This study relates LE rating to physiological processes as measured by the electroencephalogram (EEG) in CI users while performing a speech perception in noise task. We have previously shown that EEG alpha power is related to speech perception in noise in normal hearing adults and children. We therefore hypothesized that alpha power would show a similar relationship in CI users and would additionally be related to LE.

Methods: Ten adult CI users were tested in free field using their everyday CI setting while performing the Digit Triplet Test (DTT). The DTT presents trials of three digits in speech-shaped noise. In an initial behavioral task, the signal to noise ratio (SNR) was varied adaptively until 50% of digits were identified correctly, the Speech Reception Threshold (SRT). Afterwards, 64 channel EEG recordings were made during DTT listening at individualized suprathreshold levels. After each recording block, participants were asked to rank the difficulty of performing the DTT task (i.e, LE).

Results: Listening to speech in noise was associated with increased alpha power, in both normal hearing individuals and CI users. CI users had greater alpha power compared to normal hearing individuals. Significant correlations were observed between left frontal alpha power and LE in CI users using brain source analysis.

Conclusions: CI users and normal hearing have similar cortical oscillation patterns while listening to speech in noise. Given that alpha power was significantly correlated to LE and that CI users had greater alpha power compared to normal hearing individuals, alpha may represent an objective measure of LE in CI users.

P46: FIRST MULTICHANNEL OPTICAL COCHLEAR IMPLANTS FOR OPTOGENETIC STIMULATION OF THE AUDITORY PATHWAY

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In case of sensorineural hearing loss, cochlear implants (CIs) partially restore hearing and provide missing auditory information to the brain. Electrical stimulation of the spiral ganglion neurons (SGNs) enables speech understanding in the majority of the approximately 500,000 users. However, current clinical CIs are limited from their wide current spread resulting in a limited coding of spectral information. As light can be better confined in space, optical CIs (oCIs) promise lower spread of excitation in the cochlea which might enable better speech comprehension in noisy background and music appreciation. In this study we established multichannel oCIs based on microfabricated light-emitting diode (LED) arrays. The probes were thin-film passivated and encapsulated with a layer of silicone resulting in stable oCIs over weeks. We characterized them for optical stimulation of channelrhodopsin-2 (ChR2)-expressing SGNs in transgenic rats using optical auditory brainstem responses (oABR) stimulated by individual or multiple LEDs. X-ray tomography revealed correct positioning of oCIs in the scala tympani to cover the basal cochlear turn which corresponds to about three octaves of the rats hearing range. Taken together, our experiments demonstrate the feasibility of optogenetic cochlea stimulation by LED-based multichannel oCIs.

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P47: THE AUDITORY CHANGE COMPLEX AS AN OBJECTIVE MEASURE TO GUIDE INTERVENTION

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The spatial auditory change complex (ACC) is a cortical response to a change in an ongoing stimulus, indicating a difference in place of stimulation. It can be measured in cochlear implant (CI) users soon after activation and the ACC response to changes in adjacent electrode stimulation has been shown to be related to behavioural electrode discrimination scores. There is evidence that poor electrode discrimination is associated with poor speech perception abilities particular in the apical and mid array region and that re-mapping or auditory training to improve electrode discrimination could lead to improvements in speech understanding. Research with adult CI users (pre-lingual and post-lingual onset of deafness) looking at speech perception (vowels and sentences), behavioural electrode discrimination and spatial ACC measures for the five most apical electrode pairs demonstrated that the ACC could be used to understand discrimination and potentially inform clinical practice. A wide range of performance across the participant group was observed, with all but one participant showing an improvement in speech perception in the 6 months post CI activation period. There was an associated improvement in the ACC and the behavioural electrode discrimination with the ACC pass rate being strongly associated with the behavioural electrode discrimination scores. Interestingly for the adults with pre-lingual onset there were electrode pairs where the ACC response passed but the behavioural electrode discrimination did not. The findings suggest that the ACC may provide an objective measure of electrode discrimination that is associated with speech perception and has the potential to inform training programmes or fitting paradigms that could lead to improvements in outcomes.

P48: ACOUSTICALLY EVOKED POTENTIALS RECORDED FROM AN INTRACOCHLEAR ELECTRODE IN NUCLEUS HYBRID CI USERS

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Recent changes in cochlear implant (CI) candidacy, coupled with changes both in the design of the intracochlear electrode array of the Nucleus CI and surgical techniques, have allowed many CI users to retain acoustic hearing in their implanted ear. In those individuals, a recording electrode placed on the round window can be used to record a composite response from the cochlea that is often referred to as an electrocochleogram (ECoG). Recent research shows intraoperative ECoG recordings correlate with post-implant outcomes (Fitzpatrick et al., 2014; Formeister et al., 2015).

Our recent work has focused on using the neural response telemetry (NRT) system of the Nucleus CI to obtain ECoG recordings from an intracochlear electrode (Abbas et al., 2017; Kim et al., 2017). A series of low frequency tone bursts are presented in both positive and negative leading polarities. We use CustomSound EP software to record changes in intracochlear voltage over time. The recordings that result include a combination of cochlear microphonic (CM), auditory neurophonic (ANN) and in some cases the compound action potential (CAP). In order to segregate responses from the cochlear hair cells and responses from the auditory nerve, we add recordings obtained using opposite polarity tone bursts. This creates an evoked response we refer to as the SUM response. We contend that this SUM component primarily reflects contributions to the ECoG from the auditory nerve. We subtract the two opposite polarity recordings and refer to the resulting waveform as the DIFF response. Contributions from the cochlear hair cells (primarily the CM) are emphasized in the DIFF component. We recognize that the separation of the neural and hair cell components is imperfect, however, we argue that this method provides a more detailed measure of the status of the peripheral auditory system than has previously been possible. This talk will focus on describing preliminary results from a series of studies ongoing in our lab geared toward identifying clinical applications where differentiation of responses from the cochlear hair cells and the auditory nerve may prove informative.

The first study compares DIFF and SUM recordings with audiometric thresholds and post-implant speech perception data. Recordings obtained from individuals with stable acoustic hearing thresholds post-implant are contrasted with similar measures obtained from Hybrid CI users who experienced a delayed onset loss of acoustic hearing in the implanted ear. Changes in the SUM and DIFF components of the ECoG are shown to parallel changes in acoustic hearing.

In a second study we identified eight Nucleus Hybrid CI users who had a confirmed genetic diagnosis and residual acoustic hearing in their implanted ear. Five of these CI users were found to have deleterious variations of genes expressed primarily in the hair cells (TMC1, KCNQ4, MYO15A, MYO6, and LOXHD1). Three subjects were found to have deleterious variants in the TMPRSS3 gene, which is thought to be primarily expressed in spiral ganglion cells. We reasoned that if the SUM component reflected the response of the auditory nerve, the amplitude of this response as well as the ratio of the amplitude of the SUM and DIFF components should be reduced for the three subjects with the TMPRSS3 gene. We interpret this clearly preliminary finding as evidence that the intracochlear electrophysiologic recordings may serve as a more refined measure of phenotype than has previously been available for use in genetic studies.

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MONDAY POSTER ABSTRACTS

M01a: AN INTRINSIC TIME CONSTANT OF THE COCHLEAR NUCLEUS REVEALED BY ABI ELECTROPHYSIOLOGICAL MEASUREMENTS

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The placing of ABIs on the surface of the cochlear nucleus is a delicate step in an ABI operation. In order to find the proper place for the ABI, electrophysiological responses are recorded. The “right” placing of the ABI is determined by emerging of electrically evoked auditory brainstem responses (eABR) and by their amplitude. We have analyzed the first peak (related to responses of cochlear nucleus neurons) and found a constant latency after electrical stimulation. This time constant is also present in other electrophysiological measurements (Bahmer and Langner 2006 I). Simulations of a network model of the cochlear nucleus neurons can explain the inherent time constant (Bahmer und Langner 2006 II, Bahmer und Langer II, Bahmer und Langner 2009, Bahmer and Langner 2010).

M01b: TONOTOPIC NEURAL RESPONSES TO ACOUSTIC AND ELECTRIC STIMULI IN THE RAT'S PRIMARY AUDITORY CORTEX

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Despite the improvements in performance gained from cochlear implants (CIs) and auditory brainstem implants (ABIs), patients still face considerable difficulty understanding speech in noise due to spectral mismatch, which is an incongruence between auditory information received and the neurons actually stimulated. In addition to the reduced benefit caused by spectral mismatch, current auditory devices are unable to provide benefit to patients with injury or disease processes at or above the brainstem. In order to (1) overcome spectral mismatch and (2) provide salient auditory information to patients who are ineligible for current devices, a new device must be developed. The long-term goal of the project is to develop an auditory cortex implant that provides superior fidelity of spectro-temporal information to the primary auditory cortex (A1) by directly stimulating specific tonotopic points on A1 with electric signals processed by a CI speech processor. The distinct tonotopic organization within the A1 allows for significantly more precise electrode placement than CIs and ABIs, which will result in significant reduction of spectral mismatch. As an initial step, in this project, we compared tonotopic neural responses to electric and acoustic stimulation of the A1 area in an intact animal auditory system by measuring characteristic frequency responses. Electric and acoustic stimulation may be differently processed in a normal auditory system. However, data do not exist for electric stimulation of A1 at this time. These baseline frequency mappings within A1 are an essential part of our study as we must understand how the tonotopicity within the A1 area is changed and the extent of the tonotopic changes within the stimuli specific (i.e., electric vs acoustic) mappings of A1. The full comparative frequency mapping, recorded by responding to electric and acoustic stimuli data will be presented.

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M02a: PHYSIOLOGICAL EFFECTS OF STIMULUS POLARITY AND INTERPHASE GAP AS POTENTIAL ESTIMATES OF NEURAL HEALTH

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Modeling studies of the human auditory nerve suggest that anodic pulses more effectively elicit action potentials than cathodic pulses in the deafened ear, whereas cathodic pulses tend to yield lower thresholds when peripheral processes are intact. Thus, differences in neural responses between polarities might provide insight about neural survival patterns within the cochlea. Another parameter that has been shown to relate to neural survival in animal models is the interphase gap (IPG). For regions of better neural survival, a given current level yields larger neural responses and lower thresholds for increasing IPG durations. For regions of poorer neural survival, these amplitude and threshold shifts are less apparent. The primary goal of this study was to examine the combined effects of polarity and IPG on the electrically evoked compound action potential (ECAP) to elucidate whether both measures reflect similar underlying patterns of neural health, as suggested by animal studies. ECAP amplitude-growth functions (AGFs) were obtained for four electrodes in each of 12 Cochlear Ltd. recipients. For each electrode, AGFs were obtained using cathodic-leading and anodic-leading symmetrical biphasic pulses with IPGs of 7, 25, and 58 microseconds. Threshold, average amplitude (across a common range of current levels), and AGF slope were compared across polarity and IPG conditions. For threshold, results showed no effect of polarity and a significant effect of IPG, as expected. Longer IPGs yielded lower thresholds. There was a significant interaction between polarity and IPG, where polarity had a larger effect on threshold at shorter IPGs than at longer IPGs. There was a significant positive correlation between IPG effect (threshold for IPG-7 minus threshold for IPG-58) and polarity effect (cathodic minus anodic), suggesting both IPG and polarity share some common underlying mechanisms for threshold. Second, AGF slopes were steeper for the anodic polarity and for longer IPGs, as expected. There was no significant correlation between IPG effect and polarity effect, which suggests different underlying mechanisms contributing to slope. Last, average amplitudes were larger for the anodic polarity and for longer IPGs, as expected. There was a significant correlation between IPG effect and polarity effect, suggesting some common underlying mechanisms contributing to average amplitude.

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M02b: STIMULUS POLARITY EFFECTS ACROSS A LARGE GROUP OF COCHLEAR IMPLANT RECIPIENTS: IMPLICATIONS FOR ESTIMATING NEURAL HEALTH

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Cochlear implant (CI) devices use a train of electric pulses to stimulate the auditory nerve (AN). Research has shown that the excitability of the AN is dependent on the polarity of electric pulses (anodic vs. cathodic). Specifically, anodic pulses are more efficient in exciting the AN in CI recipients. Initial studies that showed higher sensitivity to anodic polarity in CI recipients used non-clinical pulse shapes (e.g., asymmetric or pseudo-monophasic pulses). More recently, our lab demonstrated polarity effects for electrically evoked compound action potentials (ECAPs) using clinically available pulses (i.e., symmetric biphasic pulses) in a group of Cochlear and Advanced Bionics (AB) recipients. Both groups demonstrated shorter N1 latencies for anodic-leading pulses vs. cathodic-leading pulses, but only Cochlear users demonstrated larger amplitudes and steeper slopes for anodic-leading polarity. Motivated by this finding, the current study tested a large group of CI recipients (N=62) with Cochlear and AB devices to (1) further investigate the difference in outcomes between devices by using the same stimuli for both manufacturers; and (2) investigate the relation between polarity effects and duration of hearing loss as a proxy measure for neural health. ECAP amplitude growth functions were obtained for both cathodic-leading and anodic-leading symmetrical biphasic pulses using monopolar stimulation. The dependent measures were mean amplitude, threshold, and slope. Slopes were estimated using linear regression (as is used in the clinical software) and a sigmoid fit (more commonly used in animal studies) to determine which method yielded the best fit to the data. Polarity effects were derived by subtracting the cathodic result from the anodic result, and then duration of hearing loss was correlated with polarity effects for amplitude and slope. The results were as follows:
(1) Anodic-leading pulses yielded significantly larger mean amplitudes and steeper slopes compared to cathodic-leading pulses, with no effect of polarity on threshold. This finding was consistent across Cochlear and AB recipients.
(2) For slope, no significant difference was observed in the total amount of variance explained (r^2) between the linear regression and sigmoid fit models. However, the sigmoid-fit slopes were significantly steeper than the linear-regression fit slopes.
(3) No correlation was found between polarity effects and duration of hearing loss.
The current study demonstrated polarity effects in a large group of CI recipients using clinically available biphasic pulses. Greater efficiency with anodic polarity is consistent with the previous findings; however, in contrast to our earlier study, AB recipients also showed polarity effects. No correlation between polarity effects and duration of hearing loss suggests that polarity sensitivity may be independent of or not very sensitive to AN survival. Further work is needed to better understand the underlying mechanisms for polarity sensitivity in the deafened human auditory system.

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M03a: LONG-TERM SAFETY OF FOCUSED MULTIPOLAR STIMULATION

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Cochlear Implants (CIs) have a limited number of independent stimulation channels due to the highly conductive nature of the fluid-filled cochlea. Focused multipolar (FMP) stimulation uses simultaneous stimulation via multiple current sources to reduce interaction between stimulating channels. FMP also allows the use of more complex stimuli, than conventional biphasic current pulses, that includes extended periods of stimulation before charge recovery is achieved, raising questions on whether chronic stimulation with this strategy is safe.

The present study evaluated the long-term safety of intracochlear stimulation using FMP in a preclinical animal model of profound deafness. Six cats were bilaterally implanted with scala tympani electrode arrays two months after deafening, and received continuous unilateral FMP stimulation at levels that evoked a behavioural response for periods of up to 182 days. Electrode impedance, electrically evoked compound action potentials (ECAPs) and auditory brainstem responses (EABRs) were monitored periodically over the course of the stimulation program from both the stimulated and contralateral unstimulated control cochleae. On completion of the stimulation program cochleae were examined histologically and the electrode arrays were evaluated for evidence of platinum (Pt) corrosion.

There was no significant difference between ECAP and EABR thresholds evoked from control or stimulated cochleae at either the onset of stimulation or at completion of the stimulation program. Chronic FMP stimulation had no effect on spiral ganglion neuron (SGN) survival when compared with unstimulated control cochleae. Long-term implantation typically evoked a mild foreign body reaction proximal to the electrode array. Interestingly, stimulated cochleae exhibited a small but statistically significant increase in the tissue response. However, there was no significant difference in electrode impedance between control and chronically stimulated electrodes following long-term FMP stimulation. Finally, there was no evidence of Pt corrosion following long-term FMP stimulation.

In summary, chronic intracochlear FMP stimulation at levels used in the present study did not adversely affect electrically-evoked neural thresholds or SGN survival but evoked a small, benign increase in inflammatory response compared to control ears. Moreover, chronic FMP stimulation does not affect the surface of Pt electrodes at suprathreshold stimulus levels. These findings support the safe clinical application of an FMP stimulation strategy.

M03b: CORTICAL RESPONSES EVOKED BY COCHLEAR IMPLANT IN THE GUINEA PIG PRIMARY AUDITORY CORTEX.

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Improving the coding strategies in cochlear implants (CI) is still the subject of intense investigations: the stimulation mode, the pulse shape and grounding schemes may lead to drastic consequences on the electrical spreading, electrode discriminability and nerve excitability. All those changes can impact the subject’s perception in multiple ways. For example, several strategies can be used to code loudness such as modifying the pulse amplitude, the pulse duration or the pulse rate. This study aims at better understanding the physiological effects of changing electrical stimulation parameters by comparing the responses obtained from auditory cortex neurons to stimulations delivered through a cochlear implant using pulses modified in amplitude, in duration and in asymmetrical ratio (pseudo-monophasics).

Experiments were performed in urethane anesthetized guinea pigs (6-18months old). A map of the primary auditory cortex (AI) was first established by inserting a matrix of 16 cortical electrodes (2 rows of 8 electrodes separated by 1mm and 350µm within a row) and quantifying the tonotopic gradient in AI based on multiunit recordings. A dedicated stimulation-array (300µm) was then inserted in the cochlea (4 electrodes inserted in the 1st basal turn) and its connector was secured on the skull. The cortical electrodes were placed back in the auditory cortex at the exact same location. The eight nerve fibers were then stimulated with 20 levels of pulse amplitudes or 20 levels of pulse duration generating similar charges through a dedicated stimulation platform. For a given injected charge, the ratio between the pulses phases increased from 1/1 to 1/10 where the cathodic phase amplitude is one tenth of the anodic phase.

The cortical responses evoked by electrical stimulations were often of shorter duration than the acoustic responses; the firing rate evoked by both the pulse duration and pulse amplitude strategies was usually lower than the one evoked by pure tones. Overall, only small differences were observed between the cortical responses corresponding to increases in pulse duration vs. increases in pulse amplitude. These data suggest that, at the level of the primary auditory cortex, equivalent cortical activation can be achieved by coding sound intensity either with pulse amplitude or with pulse duration. Analyzing the effect of asymmetrical pulses indicates that evoked activities and spatial activation tend to decrease as the ratio increased.

M04a: PRELIMINARY DATA ON INTRA- AND POSTOPERATIVE ELECTROCOCHLEOGRAPHIC RECORDINGS VIA THE ADVANCED BIONICS COCHLEAR IMPLANT SYSTEM

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Electrocochleography (ECochG) is an electrophysiologic measurement technique which represents the response of the inner ear to an acoustic stimulus. For decades, the method is well established in the audiologic clinical routine. With the expansion of cochlear implant (CI) indication criteria towards more residual hearing the method also becomes interesting for objective monitoring of residual hearing. Even though the telemetric system of the Advanced Bionics CI system was delevoped to measure electrode contact impedances as well as the neural response to an electric stimulus it also enables EcochG recordings from the inner ear. The group around Adunka and Fitzpatrick showed the feasibility of telemetric ECochG recordings in CI users with residual hearing. For this purpose the CI system is controlled by research software and the acoustic stimulus is presented via an insertion phone. During the surgery the measurement can already be taken during the electrode insertion process. This way the ECochG response can be monitored during the insertion. This may help to better understand causes for intra-operative degradation of residual hearing.

As part of a clinical study intraoperative ECochG recordings were performed during the insertion process, typically with a tone burst at 110dB SPL and 500Hz. At the end of the surgery ECochG was measured for 125, 250, 500, 1000 and 2000Hz. This measurement was repeated one or two days after surgery, as well as two weeks, one, two, three and four months after surgery. Pure tone audiogram was measured prior surgery and at the same appointments as the postoperative ECochG recordings. So far 16 subjects were recruited and passed the four weeks appointment.

Postoperative recordings so far showed a good correlation with the pure tone threshold at the same appointment. Measurements one or two days after surgery showed a lower correlation than those obtained later. Probably swelling, middle ear fluids or healing processes interfere with the acoustic stimulation. Intra-operative recordings can only be compared to the pure tone threshold prior surgery or one/two days after surgery. Changes during the electrode insertion process as well as during the early healing phase have to be taken into account for the interpretation of the results. Some subjects had a good agreement with the pure tone threshold prior surgery, others with the threshold one or two days after surgery. Inappropriate measurement conditions one or two days after surgery add a further variable. By the time of the presentation data from more subjects will be available. Analysis of results in a bigger group will help to better understand the value of the intraoperative ECochG recordings for prediction of the post-operative pure tone threshold.

Our results indicate the feasibility of intra- as well as postoperative ECochG recordings. ECochG results correlate with the pure tone threshold obtained on the same day.

M04b: AN OBJECTIVE MEASURE OF COCHLEAR HEALTH; IDENTIFYING NEURAL DEAD REGIONS

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Background
Current focusing strategies are designed to improve cochlear implant performance by reducing current spread in the cochlea. However, clinical trials have not resulted in the expected improvements. It is thought that regions of relatively greater neural loss (known as neural dead regions) have a significant effect on the efficacy of focused stimulation strategies. This study used an animal model with well-defined neural dead regions to determine the relationship between the neural electrical thresholds and neural survival. We examined the hypothesis that differences in neural thresholds using focused and unfocused electrical stimulation strategies could be used to identify neural dead regions.

Methods
Normal hearing adult guinea pigs were noise deafened using 10 kHz 130 dB SPL for two hrs. After 28 days the left cochlea was acutely deafened with local perfusion of neomycin and implanted with an intra-cochlear electrode array. The contralateral inferior colliculus (IC) was exposed and a multichannel silicone probe inserted along the tonotopic axis of the central nucleus of the IC. Neural activity was measured in response to electrical stimulation using focused and unfocused (monopolar) stimulation strategies. Cochleae were collected and the density of the auditory neurons measured.

Results
The deafening technique resulted in a significant notch-like loss of auditory neurons in the basal cochlear turn (ANOVA $p<0.001$). There was a significant correlation (Pearson correlation, $p<0.02$) between electrodes with high thresholds for focused stimulation (compared to monopolar thresholds) and the regions of the cochlea that exhibited greater neural loss.

Conclusion
The results from this study have shown that threshold differences between focused and unfocused stimulation strategies could provide an objective method of determining the ‘neural health’ of the cochlea by identification of neural dead regions.

M05a: USING A CUSTOMIZED MODEL OF THE AUDITORY PERIPHERY TO PREDICT INDIVIDUAL PSYCHOPHYSICAL DATA

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Variability in outcomes with cochlear implants may be due at least in part to the numbers and health of neural structures in the implanted ears. In an effort to characterize the peripheral status of cochlear implant users, we recorded evoked compound action potentials for fixed-amplitude bursts of biphasic pulses with 14 different pulse rates to quantify the temporal response properties of individual ears (Wilson et al., 1997, Otol & Neurotol 18(6): S30-S34). Using a global optimization search algorithm (particle swarm optimization), we then configured our phenomenological, computational model of the electrically-stimulated auditory periphery (Wilson and Stohl, 2014, Bernstein Sparks Workshop on Modeling and Signal Processing for Auditory Implants, Munich, Germany) to reproduce individual patterns of evoked responses across the same 14 pulse rates (median coefficient of determination, $r^2 = 0.97$).

The cochlear implant users for which we generated customized models also performed loudness scaling experiments using pure tone stimuli presented through laboratory sound processors implemented with various bandpass filter types in the frequency decomposition (filter bank) stage of the coding strategy. Stimuli identical to those used for the behavioral measures were presented at the input to generic and to the customized computational models, and predictions of the scaling data were obtained from processor and model outputs.

Model outputs provided significantly better predictions of loudness scaling data compared to direct analysis of the processor outputs ($F(1,160) = 4.11$, $p = 0.044$), and using a personalized configuration of the model produced further improvements in the predictive power of the model with respect to individual psychophysical data (generic model: $r^2 = 0.32$; custom model: $r^2 = 0.58$).

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M05b: SIGMOIDAL ECAP AMPLITUDE GROWTH FUNCTIONS: PHYSIOLOGICAL MODEL WITH BENEFITS

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Intra-cochlear measures of electrically evoked compound action potentials (ECAPs) are routinely performed for cochlear implant (CI) users. Besides the detection limit (ECAP threshold), the slope of an amplitude growth function (AGF) can be determined. Whereas ECAP thresholds are used for fitting CIs [1], the slope of AGFs can improve automatic fitting [2] and be used to monitor neural health [3]. Determination of the slope is biased by the used fitting function, but a sigmoidal function [4] reflects the expected physiologic shape of the ECAP amplitude growth very well.

The presented sigmoidal fitting function is based on basic processes of auditory nerve neurons like firing rates and synaptic potentials [5]. Firing rates within a population of fibers are related to the number of released action potentials. Those represent the dominating influence for AGFs [6], but especially synaptic potentials and corresponding facilitation respectively inhibition effects [5] potentially distort the sigmoidal shape.

This study regards physiologic properties of the auditory nerve in details, and single parameters of the sigmoidal fitting function for AGFs are assigned to parameters describing synaptic potentials, spontaneous neural activity and population firing rates.

Especially limitations of the sigmoidal function regarding the stimulation intensity are quantified. Using traditional estimation techniques, parameters remain stable only if the inflection point of the sigmoid is reached. The presented approach allows accurate estimation of the parameters at a lower limit, which was tested in 11 MED-EL CIs (10 subjects) on all 12 electrodes.

AGFs reflect patient-dependent anatomies, and clinical applications based on AGFs gain benefit if sigmoidal functions instead of e.g. linear fitting functions are used.

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M06: CURRENT FOCUSING IMPROVES AUDITORY CORTICAL RESPONSES TO INTRACOCHLEAR ELECTRICAL STIMULATION IN AWAKE PRIMATE

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Electrical stimulation of the cochlear nerve via a cochlear implant (CI) is successful in restoring auditory sensation to individuals with profound hearing loss. Despite successes, CI users still face limitations in such situations as music appreciation and hearing in a noisy environment. How CI devices engage the brain at the single neuron level has remained largely unknown, in particular in the primate brain. To this end, our lab has established a non-human primate CI model using the common marmosets (Callithrix Jacchus). Using a preparation in which one ear was deafened and implanted with an intracochlear electrode array and the other ear remains intact, our recent studies have shown that conventional intracochlear electrical stimulation (ICES) strategies using monopolar (MP) and bipolar (BP) configurations were inefficient in activating many neurons in primary auditory cortex (A1). In some cases, MP stimulation was found to suppress the spontaneous activity of A1 neurons. Further analysis revealed that a particular group of A1 neurons narrowly tuned to both frequency and sound level, termed the “O-shaped” neurons, were poorly driven by the ICES due to its broad cochlear excitation patterns (Johnson et al 2016). Current focusing techniques have been proposed to sharpen the electrical field generated within the cochlea, and have been proven successful in reducing current spread in neurophysiological studies (George et al 2014; Snyder et al 2008; Bierer et al 2002; Kral et al 1998). In the present study, we tested the hypothesis that current focusing can improve the efficiency of ICES in activating A1 neurons. Our data showed that current focusing techniques using tripolar (TP) and partial tripolar (pTP) configurations indeed increased A1 neurons’ responsiveness to ICES in comparison to MP stimulation. In particular, many O-shaped neurons that could not be driven by MP stimulation were responsive to TP and pTP stimulation. Furthermore, using forward masking and channel spread paradigms, it was revealed that the current spread was in fact lower for the TP than the MP configuration. Together, these findings suggest a promising potential of applying current focusing technique in engaging A1 neurons, especially those highly selective to frequency and sound level. These neurons are likely to play a role in perceptual behaviors requiring fine frequency and level discrimination, such as music appreciation and speech recognition in noise.

M07a: RECONSTRUCTION OF A HIGH-RESOLUTION COCHLEAR MODEL FOR COCHLEAR IMPLANT RESEARCH

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Computer models of the cochlea have been used in cochlear implant (CI) research as a tool to facilitate the CI development (Hanekom and Hanekom, 2016; Kalkman et al., 2016), but most existing models adopt only an idealised representation of the geometry due to limitations in structural image resolution or in computational expenses. We therefore developed a finite element (FE) model of the cochlea with an anatomically-accurate geometry and high-resolution detail of the auditory nerve as the first step of a project devoted to an advanced computational model of the cochlea.

X-ray microtomography (µCT) scans of a human cadaveric temporal bone were acquired at a spatial resolution of 5.9 µm. The bone, cochlea, cochlear nerve and CI electrode were segmented from the µCT scans in 3D Slicer, and the reconstructed surface mesh was then smoothed and postprocessed in Geomagic Wrap. This composite was then embedded within the temporal bone of a pre-segmented head model in Blender. The tetrahedral elements of the volumetric mesh were later constructed from the surface mesh in ICEM CFD. Moreover, over 400 cochlear nerve fibres were constructed inside the FE cochlear nerve model. Each individual nerve fibre ran from the distal end of a dendrite through a Rosenthal's canal to the distal end of an axon, based on Dijkstra's shortest path algorithm. An additional constraint of a 45° spiral pathway around the modiolus axis was included in the shortest path algorithm to realistically reflect the spiral feature of the auditory nerve fibre bundles (Arnesen and Osen, 1978; Middlebrooks and Snyder, 2007).

Our work generates a three-dimensional model of the cochlear implant electrode and individual cochlear nerve fibres, which provides a visualisation of the anatomical details in the cochlea. The convergence of the dendrites of cochlear ganglion cells in Rosenthal's canals is clearly visible. Due to the difficulty in differentiating various soft tissues in the µCT scans, blood vessels are included in the geometry of the cochlear nerve. The electrical potential along each constructed auditory nerve fibre as a response to an electrical stimulation of the CI electrodes was simulated with the FE solver COMSOL Multiphysics. In our next step, firing patterns of individual spiral ganglion neurons to the electrical excitation will be calculated with a multi-compartment model.

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M07b: A BIOPHYSICAL MODEL OF THE AUDITORY NERVE BASED ON HIGH-RESOLUTION MICROCT SCANS.

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Modeling the electrically stimulated cochlea has a long history. It has come a long way from early lumped-parameter models to highly-detailed models based on microCT data. Most of these models either relied on an artificial geometry of the neuronal structure or failed to include biophysical models of the auditory nerve fibers (ANFs). The activation of ANFs critically depends not only on the distribution of the electrical potential but also on the exact trajectory of single fibres. A more realistic reconstruction of the naturally occurring variations would therefore help to better understand the strong variations in performance and sound perception seen in today’s cochlear implant users.

Using a novel reconstruction method (detailed in the abstract of Bai et al.) on a high-resolution microCT scan of an implanted human cadaveric cochlea, we were able to reconstruct realistic pathways for 480 auditory nerve fibers. The nerve fibers were evenly spaced along the length of the cochlear duct providing a good sample of their tonotopic arrangement. Using the finite element method, we calculated the potentials along the ANFs in response to the stimulation at each of the 12 electrode contacts. Cable models of the ANFs were coupled to evaluate the activation of the nerves in response to the electrical stimulation. This model is based on the segmentation of a real implanted electrode array and not an artificial, idealized location of the electrodes. Together with the detailed segmentation of bone and nerve tissue, we found a strong variation in the thresholds and activation patterns created by the different electrodes. This is in agreement with the variations in thresholds and dynamic range observed in cochlear implant users. We will use the model to further investigate the influence of stimulation strength, electrode positioning and polarity on the activation pattern of the neurons.

M08a: MODELLING POLARITY AND PULSE SHAPE EFFECTS ON A POPULATION OF SPIRAL GANGLION NEURON UNDER ELECTRO-STIMULATION

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The efficacy of electrical stimulation in cochlear implantation (CI) depends critically on the electrode-neuron interface. Factors such as electrode-neuron distance, spread of excitation along the cochlea, and the status of the auditory nerve fibres determine the number of effective independent neural channels representing sounds in the form of neural action potentials. Current research focuses on improving that interface; biologically through increased 'bio-mimicking' of electrical stimulation strategies, pharmacologically with neuro-trophic or –protective drug coatings applied to the electrode array, or through parallel advances in signal processing.

Models of populations of Spiral Ganglion Neurons (SGNs) are often employed for CI modeling and provide an environment to evaluate how stimulation strategies impact the recruitment of nerve fibers. Here, using cable-equation methods, we focus on the effects of polarity and the shape of electrical pulse on the electrically stimulated auditory nerve by means of a physiologically inspired model of a single SGN,. This study investigates the effect of electrical stimulation in a realistic SGN model in order to evaluate stimulation strategies and determine the efficacy of other proposed improvements in CI devices.

The model incorporates relevant physiological characteristics that generate action potential and result in refractoriness, facilitation, accommodation and spike-rate adaptation. The model also allows for parameterization of ionic channels dynamics as well as geometry characterization. Specifically, we study the effects of polarity and pulse shape on the firing pattern of a population of SGNs undergoing several degrees of degeneration – from partial (decrease of peripheral myelination) to total peripheral degeneration. Results are compared with published data from animal and computational models.

M08b: MODELED IMPEDANCE AND TISSUE GROWTH IN THE IMPLANTED COCHLEA

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Introduction: Fibrotic tissue development in the scala tympani after cochlear implantation is a well-reported phenomenon. This tissue growth has been hypothesized to be the cause of increased electrode impedance resulting in increased power requirements for implant function. High impedance may also negatively affect recordings of the auditory nerve's compound action potentials. However, details of the functional effects of tissue on impedance are poorly understood. The objective of this study was to investigate changes in a fitted physical circuit model of electrochemical impedance during rapid-onset fibrotic growth in the scala tympani caused by AAV.TGF-β1 inoculation in the scala tympani.

Methods: In this study ten adult, male, guinea pigs (400-700g) were implanted in the left ear with two-channel, ball electrode, cochlear implants. Five animals were inoculated with 2 μL AAV.TGF-β1 at a rate of 1 μL per minute, 20 minutes prior to implantation, while the remaining five were left untreated as a control. AAV.TGF-β1 inoculation has been shown to cause rapid onset fibrotic growth in the scala tympani. Complex impedance measurements were recorded, twice daily for 14 days post implantation. Impedances were recorded over the range 100 Hz-100 kHz using a controlled current at 10μA. Sinusoidal stimuli and various electrode configurations were used. The recorded impedance data were then fit to a physical circuit model using a custom MATLAB script. Animals were euthanized 14 days after implantation.

Results: Previously developed physical circuit models of electrochemical impedance of cochlear implant electrodes were found to poorly fit the recorded data of this study, and as such a new model was developed. This new physical circuit model was found to more significantly fit the frequency domain impedance in 96% of all recordings than a more general electrochemical model for neural implants. For all electrode configurations, AAV.TGF-β1 treatment was found to slow impedance growth when compared to implant only animals. In addition, based on the physical circuit impedance parameters, over all electrode configurations, the magnitude of impedance representing the electrochemical interface of the implant electrode, at 1 kHz, grew at a faster rate than fitted impedance representing tissue.

Conclusion: AAV.TGF-β1 treatment seems to have a dampening effect on impedance change over time after implantation. One possibility is that the AAV.TGF-β1 treatment might cause cells to quickly adhere to the electrode surface, changing the properties of the electrochemical interface and thus stabilizing impedance. An additional study would be needed to address this hypothesis.

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M09: TEMPORAL ANALYSIS OF A PURELY CONDUCTANCE BASED STOCHASTIC HUMAN AUDITORY NERVE FIBRE MODEL

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Variance in threshold stimulus intensity is one of the important properties of a nerve fibre that has an impact on its temporal characteristics. Contained within the cochlear implant's (CI) electrically stimulated neural response (ESNR) is temporally encoded information that influences the speech perception of CI users as well as pitch perception of complex tones and pure-tone frequency discrimination. Therefore, since the temporally encoded information is affected by the high frequency pulsatile stimulation of CI speech processors via the ESNR, the desired auditory nerve fibre (ANF) models not only need to estimate the neural excitation threshold or stimulus intensity value through deterministic ANF models, but also the ANF temporal characteristics through stochastic ANF models. Though numerous approaches are followed to create stochastic ANF model through mostly phenomenological stochastic models and a recent hybrid stochastic model (Van Gendt et al, Hear. Res. 2016; 341: 130-143), the present study applies a purely conductance based stochastic model (Badenhorst et al, Biol. Cybern. 2016; 110(6): 403-416) based on the Hodgkin-Huxley (HH) and Rattay compartmental model (Rattay et al, Hear. Res. 2001; 153(1-2):43-63) since only these models provide biophysically meaningful results (Izhikevich, IEEE Trans. Neural Netw. 2004; 15(5):1063-1070) as required in the study and modelling of CIs.

The study presents the application of a purely conductance-based stochastic model of a human ANF within a finite element volume conduction model of a semi-generic head and user-specific cochleae. The stochastic, threshold and temporal characteristics of the human model are compared and successfully validated against physiological feline results with the application of a mono-polar, bi-phasic, cathodic first stimulus. Stochastic characteristics validated include: (i) the log(Relative Spread) vs log(fibre diameter) distribution for the discharge probability vs stimulus intensity plots and (ii) the required exponential membrane noise versus transmembrane voltage distribution. Threshold and dynamic range are compared among users at short and long pulse widths for single full vs degenerate fibres and for a population of degenerate fibres of a single user having equal and varying diameters. Temporal characteristics validated through application of different stimulus pulse rates and different stimulus intensities include: (i) discharge rate, latency and latency standard deviation vs stimulus intensity, (ii) period histograms and (iii) inter-spike-interval histograms. The model is shown to correctly and accurately simulate the physiological stochastic and temporal characteristics required to model user-specific temporally encoded information, which influences the speech perception of CI users.

M10a: RESPONSIVENESS OF THE ELECTRICALLY STIMULATED COCHLEAR NERVE AND CORTICAL NEURAL ENCODING OF ELECTRICAL PULSE TRAINS IN CHILDREN WITH COCHLEAR NERVE DEFICIENCY

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Background: The overall goal of this study is to better understand auditory neural encoding of electrical stimulus delivered by the cochlear implant (CI) in children with cochlear nerve deficiency (CND). The first project evaluates responsiveness of the electrically stimulated cochlear nerve (CN) in children with CND. The second project investigates the effect of the CN responsiveness on cortical neural encoding of electrical pulse trains in these patients.
Methods: All subjects tested in this study used Cochlear® Nucleus devices in their test ears. Subjects recruited in the first project included 23 children with CND and 18 children with normal-size CNs. The CN responsiveness was evaluated using the input/output (I/O) function and the refractory recovery function measured with the electrically evoked compound action potential (eCAP) at multiple electrode sites across the electrode array. Dependent variables included the slope of the I/O function, and time constants derived from the refractory recovery function (i.e. the absolute and the relative refractory recovery periods).

In the follow up project, electrically evoked auditory event-related potentials (eERPs), including the onset response and the auditory change complex (eACC), were measured in a subgroup of children with CND. For each subject, the eERP was recorded for at least two stimulating electrodes with different CN responsiveness. The stimulus was an 800-ms electrical pulse train. Two stimulation conditions were tested: (1) In the standard condition, an 800-ms pulse train was presented without any interruption; (2) In the gap condition, a temporal gap was inserted after 400 ms of stimulation. Gap duration tested ranged from 2 to 128 ms. The shortest gap that could evoke the eACC was defined as the gap detection threshold (GDT).

Results: The eCAP was recorded at all test electrodes in children with normal-size CNs. In contrast, the eCAP could not be recorded at any electrode site in four children with CND. For all other children with CND, the percentage of electrodes with measurable eCAPs decreased as the stimulating site moved in a basal-to-apical direction. Children with CND had significantly flatter slopes of I/O functions, and longer absolute refractory periods than children with normal-size CNs. There was no significant difference in the relative refractory period measured in these two subject groups. Preliminary results showed that prolonged GDTs were recorded for stimulating electrodes where the CN showed prolonged recovery from refractoriness.

Conclusions: In children with CND, the functional status of the CN varied along the length of the cochlea. Compared to children with normal-size CNs, children with CND showed reduced CN responsiveness to electrical stimuli. The prolonged absolute refractory period in children with CND might account for, at least partially, the observed benefit of using relatively slow pulse rate in these patients. Temporal responsiveness of the CN seems to have an important effect on cortical encoding of temporal gaps in these patients.

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M10b: TAKING MODELS FROM THE LAB TO THE CLINIC: MODEL-BASED DIAGNOSTIC APPROACH TO A TEENAGE USER'S FACIAL NERVE STIMULATION COMPLICATIONS

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Three-dimensional (3D) cochlear implant (CI) modelling has in recent years led to the evolution of generic models into user-specific models with one of the intentions being to re-apply these models clinically as a diagnostic tool. This translational application of user-specific 3D CI models was validated in a collaborative effort between BioEng@UP and an ENT surgeon who implanted and cared for a user that presented as a complicated case of facial nerve stimulation (FNS). The user suffered severe hearing loss after she contracted meningitis at the age of 21 months. She received a CI in the right ear at age 4 years and 4 months and in the left ear at age 7 years and 3 months. She experienced several complications after implantation, which eventually culminated in wide-spread bilateral FNS by age 16 years. None of the traditional interventions alleviated the FNS and the surgeon resorted to injecting Botox (Botulinum Toxin) in the vicinity of the FN to block neuromuscular excitation. While the treatment effectively inhibits the FNS, a serious visible side-effect is that the user has little or no facial expression, rendering the treatment a short-term solution.

Facial nerve stimulation is a common side-effect of cochlear implantation that can result in considerable discomfort for the user and essentially limits the optimal use of the implant. While literature suggests that there is no definite etiology for FNS, some mechanisms have been identified as possible causes. These include insertion trauma, cochlear ossification due to meningitis and lowered impedance of the bone surrounding the cochlea. Qualitative assessment of the structures surrounding the cochlea is often carried out to assess the degree of ossification in meningitis-related cases as well as to assess the severity of bone demineralisation in cases of otosclerosis. For the specific case, however, a quantitative analysis of the user's cochlear environment and the underlying causes of the FNS was required to consider treatment options and evaluate the potential benefit of re-implantation with an alternative device.

A 3D volume conduction model that contained user-specific bilateral descriptions of the cochleae (right and left) and a semi user-specific description of the head volume was created from computed tomography imaging data employing BioEng@UP's user-specific modelling approach. The model was expanded to include the facial nerve on both sides and was then used to probe mechanisms of FNS such as ossification of the cochlear ducts and lowered temporal bone density. An excitation model for the facial nerve was developed so that auditory- and facial nerve fibre thresholds could be predicted. Predicted trends in neural excitation were similar to those observed in user data. Possible custom treatment options that included alternative stimulation strategies with the current implants as well as re-implantation with alternative devices were explored. The models predict that the user's FNS may deteriorate over time and that the potential benefit of re-implantation with an alternative device is marginal. However, an alternative stimulation strategy using the current implants may provide some relief of the FNS.

The study demonstrated the utility of model-based diagnostics in a clinical setting. It showed that complication mechanisms may be explored in a computational model tailored for a specific user and that customised treatment options may be evaluated. The findings of the study may also inform implant decisions and treatment options for other users suffering from similar complications.

M11a: A PHENOMENOLOGICAL MODEL FOR PREDICTING RESPONSES OF ELECTRICALLY STIMULATED AUDITORY NERVE FIBER TO ONGOING PULSATILE STIMULATION

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The ability of cochlear implants (CIs) to restore hearing for profoundly deaf people is based on electrical stimulation of auditory nerve fibers (ANFs). Several characteristics of the electrical stimulus and of the ANF affect how the ANF responds to a particular stimulus. Such information is vital for development of new coding strategies for CIs, but can be obtained only via neurophysiological measurements. Computational models of the electrically-stimulated ANF could provide a useful tool for the developers, giving estimates of the peripheral responses that different stimulations evoke.

Here, we present a functional model for the ANF response to pulse-train sequences. It builds on the phenomenological biphasic leaky integrate-and-fire (BLIF) model by Horne et al. (2016), in which the ANF is thought to integrate incoming electrical current and to release an action potential if the membrane voltage exceeds a stochastic threshold and if the neuron is not hyperpolarized before it is ready to spike. Moreover, the latency and jitter of the modeled ANF neuron depend on how greatly the threshold is exceeded. Their model can reproduce neurophysiological data from single pulse stimulations with various pulse shapes.

We have developed that model further by adding elements that simulate refractoriness and facilitation and accommodation by affecting the threshold value of the model momentarily after supra- and subthreshold stimulation, respectively. We have also extended the model to consist of two independent BLIF units that are sensitive to different polarities in biphasic pulses and able to generate action potentials at different time instants, emulating the neurophysiological finding that the ANF can be excited both at its peripheral and central parts (see, e.g. Miller et al., 1999).

We show that the revised model can reproduce neurophysiological data from single neuron recordings considering temporal phenomena related to inter-pulse interactions. These phenomena affect the responsiveness of the ANF to pulsatile stimulation and continue to provide challenges for computational models (Takanen et al., 2016). Specifically, data for refractoriness, facilitation, accommodation and spike-rate adaptation are shown to be reproduced. In addition, the model is shown to account for effects of pulse rate on the synchrony between the pulsatile input and the spike-train output. Consequently, the model offers a versatile instrumental tool for testing new coding strategies employing, e.g. pseudo-monophasic pulses or variable pulse timing. Due to the limited parameter space, the model can also be conveniently tuned to individual CI users to predict their hearing percepts (Werner and Seeber, 2017).

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M11b: INDIVIDUAL FITTING AND PREDICTION WITH A PHENOMENOLOGICAL AUDITORY NERVE FIBER MODEL FOR CI USERS

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The development of models fitted to individual cochlear implant (CI) patients may lead to individually optimized stimulation strategies that can improve speech perception. Cochlea's geometric information and electric conduction parameters play an important role in individual models, although the neural elements should also be part of the fitting procedure. Interesting neural parameters for fitting are the status of degeneration of the nerve, all the way to knowing the location and extent of dead regions. Several studies have investigated the potential of electrical compound action potentials (ECAPs) measured in the cochlea via neural response telemetry to be used for estimating thresholds and dead regions [1, 2]. The neural survival density distribution along the spiral ganglion (SG), which varies substantially among patients [3], can then be taken into account to model an individual electrode-nerve interface.

In this work, the SG cells were modeled as a one-dimensional array of nerve fibers positioned along the cochlear longitudinal length, where the total population was divided into a number of sections with local neural survival density. The evoked neural activity of each fiber to electrical stimulation was modeled using a phenomenological model (extension of the biphasic leaky integrate and fire model) for pulse train stimulation, taking into account the effects of refractoriness and facilitation [4, 5]. The current spread distribution was approximated with a weight function varying with the distance between source electrode and nerve fiber.

All parameters were fitted to individual CI patient's psychophysical and electrophysiological data following the assumptions of the practical model description proposed by Cohen [2]. The following patient data was used for the fitting procedure: threshold and maximum comfort stimulation levels; electrode configuration and pulse shape; electrode position along the cochlea; loudness growth; ECAP growth, refractory recovery and spread of excitation. The ECAP was assumed to be proportional to the difference between the total number of spikes for single probe and masker-probe stimulations. The ECAP spread of excitation data of three source electrodes (basal, middle and apical regions) were used as objective functions, and the parameters for dead regions and lower density sections were then optimized among the local populations to obtain the neural survival distribution that provides the best fit.

The proposed approach can model the spatial and temporal behavior of an individual CI patient's auditory nerve in respect to electrical stimulation parameters used in electrophysiological measurements. Based on the assumptions about the relation between loudness and ECAP, the method can also be extended to predict psychophysical percepts. The obtained results show also how neural survival local densities can be used to model the individual overall auditory nerve response to different stimulation sites with a fixed set of parameters. Overall, this study provides methods towards individual model fitting using neural density functions and has the potential to evaluate benefits of individual stimulation parameters with the aim to improve CI strategies.

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M12a: A POLYMER-BASED INRTRACOCHLEAR ELECTRODE ARRAY FOR ANIMAL STUDY

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There have repeatedly been demands on low-cost cochlear implant because the cost of conventional cochlear implant is more than $20,000. The main reason that makes cost high is manual process in cochlear electrode array fabrication.

We developed a manufacturable intracochlear electrode array based on liquid crystal polymer(LCP) substrate for animal study. Its width is varied from 0.3 mm (tip) to 0.4 mm (base). And the final length is 28 mm for small animals as well as large animals. In this study, we introduce the fabrication method and assess the feasibility of the LCP-based cochlear electrode array.

M12b: DEVELOPING A FLEXIBLE COCHLEAR IMPLANT RESEARCH STIMULATION INTERFACE FOR ANIMAL: STIMULATOR AND DEDICATED ELECTRODE ARRAYS

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Introduction: Cochlear implants (CIs) are designed to produce hearing sensations in people suffering from severe to profound deafness. Besides their medical utility in directly stimulating the auditory nerve fibers, CIs are now considered by the research community as a formidable opportunity to better understand the hearing system. The possibilities are however technically limited by the CI systems already available. By design, most manufacturer's stimulator chips are restricted so that the battery consumption is limited during a clinical use. The generation of multiple different electrical waveforms and stimulation modes can be therefore extremely limited.

Portable CI stimulator: The Animal Stimulation Platform (ASP) is a portable research interface that contains an unleashed version of the Oticon Medical stimulation chip. Contrary to its clinical version, the ASP chip is controlled both by a microcontroller and a field programmable gate array (FPGA) to ensure enough data power transfer. This enables the generation of a large possibility of pulse waveforms (from monophasic to multiple-phases, pseudomonophasic to ramped, on a monopolar or multipolar version) while keeping accessible clinical functionalities such as backward telemetries (Impedance and eCAPs). The ASP can be plugged directly via a USB connection that provides both energy and data to the platform. The user is then able to drive complex stimulations using a dedicated software from any computer. This software was designed to automatically drive pre-programmed stimulation patterns, and is able to synchronize with an external storing system to record eCAPs and/or eABRs.

Dedicated electrodes: Standard clinical electrode arrays are compatible with the ASP. In addition of those Oticon Medical collaborates with researchers to realize dedicated electrode arrays for specifics animals - array lengths and electrode diameters being configurable – and for research in-vivo, chronic or acute experiments.

This work aims to present both the ASP functionalities and the electrode portfolio. This include a description of the electrodes and electrode connectors that can be adapted to the ASP, and examples of studies that used this platform.

766: MODEL EVALUATION OF A NOVEL DYNAMIC CURRENT FOCUSING SPEECH CODING STRATEGY

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Cochlear implants are able to provide reasonably good speech understanding in quiet situations. In noisy (real life) situations however, the performance is much reduced. Other limitations are found in the encoding of music, and pitch accents in tonal languages. New speech coding strategies are commonly evaluated by means of psychophysical experiments and clinical trials. In this study an alternative approach through computational modelling is used. The newly developed coding strategy that will be evaluated in this study uses focused TP stimulation near threshold and gradually broadens the excitation (by decreasing the compensation coefficient σ) to increase loudness without the need to increase overall current.

The hypothesized benefits of this dynamic current focusing (DCF) strategy, which are subject of this study, are: increased spatial selectivity, especially at lower loudness levels, while maintaining maximum selectivity at higher loudness levels, without reaching compliance limits. The model used is a combination of both a 3D human geometric model of the implanted cochlea, an active nerve model of the human auditory nerve and a phenomenological neural model. This combination of models allows for the study of temporal and structural aspects from the 3D volume conduction model, while the final phenomenological modelling step introduces threshold adjustments according to previous-spike and current-related effects such as refractoriness, adaptation and accommodation. Stochasticity and spike jitter and spike delay are added to the model in order to have realistic spiking predictions. Both a normal cochlear nerve and one suffering from neural degeneration were modeled.

Electrical interaction and spread of excitation in the cochlea was evaluated for all partial tripoles (from σ=1 to σ =0) and for all 14 tripolar contacts in a model equivalent of a HiFocus1J electrode array. In addition, spectral ripple experiments were replicated using the complete model and the resulting spike patterns were compared to a normal monopolar CIS strategy. To enable comparison with data from clinical trials with the DCF strategy, exactly the same strategy was used for this model evaluation, requiring parameter adaptations in the phenomenological model to allow implementation of the newly introduced loudness scaling parameter (σ).
In line with expectations for the DCF strategy, the model outcomes show limited current spread at low levels, which is increasing towards MCL. In some model configurations, the threshold current levels (with the highest currents on the flanking electrodes) at σ=0.8 were too low to reach MCL level before the σ=0 value was reached. Neural degeneration can explain some of the differences found between subject tested with the DCF strategy, as simulations with degenerated peripheral processes resulted in a larger excitation area with decreasing sigma than in a healthy nerve. Evaluation of spike patterns of the complete nerve shows improvement of expected performance on the spectral ripple test when compared to a monopolar strategy.

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M14a: EFFECTS OF THE ELECTRODE POSITION AND FIBER DIAMETER ON SPECTRAL RIPPLE DISCRIMINATION IN COCHLEAR IMPLANT USERS: A COMPUTER MODEL STUDY

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The spectral ripple discrimination (SRD) test has been widely used to evaluate spectral resolution of cochlear implants (CIs). Previous studies have shown the variability in SRD performance across CI users. Such performance variability is quite large even among the subjects implanted with the same implants and sound processors, generating a hypothesis that the differences in the electro-neural interface may be one of the critical factors affecting SRD performance for CI users. While behavioral psychoacoustic studies are helpful to characterize SRD performance, it is not feasible to evaluate the effects of the electro-neural interface on SRD performance for CI users. In this study, we used a computational model to systematically evaluate the effects of the electrode positions and the auditory nerve fiber (ANF) diameters on SRD performance. The model data are then compared to the behavioral SRD data collected from human CI subjects.

For the model study, the biophysical computational model of the ANF was used to simulate the neural responses to electric stimulations coded by the ACE strategy. Electric potentials at each node of ANF were computed by modeling the Nucleus CI24 implants. To investigate the effects of electrode-to-fiber distance and ANF diameter, three different fiber diameters (1.2, 2.3, and 4.6 μm) and three different electrode-to-nerve distances (0.235, 0.245, and 0.525 mm) were tested, producing a total of 9 model conditions. The SRD thresholds were predicted by calculating the similarity of two neurograms in response to standard and inverted ripple stimuli. Finally, the model data are compared to the psychometric functions collected from 15 CI subjects implanted with the Nucleus CI24 implants. Results showed that as the ripple density increased, the discriminability of the model decreased, consistent with human CI subjects. The range of the subject variability observed in the human CI users was accounted for by the model predictions, suggesting that the electrode positions and the ANF diameters have significant impacts on SRD performance. The current study suggests that the computational model study combined with the human psychoacoustic experiment may provide a useful tool to understand the underlying factors affecting CI outcomes that cannot be evaluated by the behavioral study alone.

M14b: THE EFFECTS OF BILATERAL COCHLEAR IMPLANTS ON VOCAL CONTROL

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Speakers with normal hearing (NH) listen to their own vocal production to maintain control over their vocal pitch (i.e. F0), a mechanism referred to as the perception-production loop. By using this loop, they are able to correct F0 perturbations, allowing for a more stable F0. As with NH speakers, cochlear implant (CI) users also constantly monitor their own vocal productions and make adjustments using a perception-production loop, although they still have difficulty maintaining a stable F0.

While much of the research investigating vocal control has focused on individuals with unilateral CIs, bilateral CI users may have unique issues with vocal control. First, given that bilateral CI users often have a better and worse ear across a number of tasks, vocal control may differ when using either their left or right CI, raising the possibility that, when using both CIs together, they could do as well as the better ear, the worse ear, or an average of the two. Additionally, because the two ears often yield different pitch percepts with current clinical fitting methods, potentially providing conflicting information for the perception-production loop, there may even be a detrimental effect when the two ears are combined.

To test these hypotheses, sixteen bilateral cochlear implant users produced a sustained /a/ vowel while wearing no cochlear implants, either the right or left cochlear implant alone, or two cochlear implants. When using their cochlear implants, participants used their clinical programs.

Consistent with previous literature, the results indicated that a cochlear implant can help improve vocal control, resulting in a more stable F0. However, there were substantial differences in participants' vocal control when using one cochlear implant versus the other. Most participants demonstrated a clear better ear effect, often only demonstrating a benefit with one of their two CIs. Additionally, when two CIs were used together, the participants' voice was less stable than it was when using their better ear. However, their voice was more stable when using two CIs than it was when using their worse ear alone. This suggests that bilateral CI users do not gain the full benefits of their better ear regarding their ability to control F0. In addition, although the likely mismatch between ears in bilateral CI users may degrade performance, it does not result in a significantly less stable F0 than with their worse ear alone.

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M15a: EFFECT OF STIMULUS FOCUSING ON THE MAGNITUDE OF NEURAL RESPONSES IN HUMAN SUBJECTS

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This study investigates Electrically-Evoked Compound Action Potentials (ECAPs) obtained in response to Focused Multipolar (FMP) stimuli in deaf subjects treated with a cochlear implant (CI). Focused stimuli have been proposed as a way to improve channel independence and evaluate site-by-site cochlear health. An objective measure would provide information for fitting and diagnostics without the need for subject input. While there is much ECAP data with monopolar stimuli there is little with tripolar or multipolar stimuli.

Here we obtained ECAP responses from 5 subjects on all available electrodes with a percutaneous implant and a Contour Advance electrode array using a laboratory based multipolar stimulator/recorder. Amplitude growth functions (AGFs) were measured using a forward masking paradigm with the masker having the same configuration as the probe, but at a level 10CL higher. Focus was varied from strongly-focused stimuli (e.g., van den Honert and Kelsall, 2007) to unfocused, nearly monopolar, stimuli with 4 intermediate steps. We used a 12-electrode multipolar stimulus with the 3rd electrode from the center as the recording electrode.

The correlation between psychophysical threshold and ECAP threshold was significant ($r = 0.79$; $p < 0.0001$) overall. With increased focus, ECAP threshold increased ($r = 0.53$; $p < 0.0001$) and AGF slope decreased ($r = -0.55$; $p < 0.0001$). With increased focus, loud-but-comfortable (LBC) perceptual levels were obtained with fewer electrodes ($r = -0.86$; $p < 0.0001$), but when obtainable, ECAP magnitudes for a given site were similar across the range of stimulus focusing tested. That is, the effect of the change in focus on ECAP magnitude was small (12uV) relative to other effects, like changing subject (124uV) or changing electrode (134uV) in a generalized linear model of the data collected at LBC. This is consistent with a model in which loudness is determined by the number of neurons firing synchronously and in which that number is influenced by current level, degree of focus, and the fidelity of the electro-neural interface.

These results have implications for models of the neural representation of monopolar and multipolar stimuli, models of loudness encoding, and measures of cochlear health.

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M15b: RELATING ECAP MEASURES WITH SPEECH PERCEPTION IN ADULT CI LISTENERS

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Most individuals with cochlear implants report substantial benefit with their devices, but large individual differences in performance are universally reported. These individual differences in outcome and benefit result from a combination of sources, including the electrode-neuron interface and how well an individual listener can make use of degraded information. As candidacy criteria expands and technology continues to improve, better clinical methods for assessing cochlear implant function are also needed. Physiologic methods are especially beneficial, as they can be performed regardless of the patient's age, attention, or cognitive ability. Recent work suggests that ECAP measures may provide insight into the electrode-neuron interface, which is thought to reflect both the distance from the electrodes to the neural elements and the presence of neural pathology. The ECAP threshold (Long et al., 2015) and the ECAP channel interaction function (DeVries et al., 2016) have been related to electrode-to-modiolus distance in adult cochlear implant users. Slopes of ECAP amplitude growth functions have been related spiral ganglion survival in guinea pigs (Pfingst et al., 2015) as well as speech perception in adult cochlear implant listeners (Kim et al., 2014).

The first objective of this pilot study was to characterize the relations among single channel ECAP thresholds and amplitude growth function slopes with speech perception in quiet and in noise. We hypothesized that these two ECAP measures would be predictive of performance on speech understanding. Our second objective was to evaluate the influence of cognitive abilities on speech understanding and quality of life measures. We hypothesized that individuals with better cognitive abilities may be able to compensate in the face of poorer peripheral encoding, whereby cognitive abilities would be related to better speech understanding and higher self-reported quality of life. For each participant, forward masked ECAP responses were measured for nine electrodes spaced along the array. Word and sentence recognition was assessed using CNC words/phonemes and AzBio sentences in quiet and +5 dB signal-to-noise ratio (SNR). Vowel perception (syllables and segments) was measured using the concurrent vowel perception test (Hedrick and Madix, 2009). Cognitive abilities were assessed with auditory running memory span and the Montreal Cognitive Assessment (MoCA). Self-reported listening difficulty/quality of life was assessed with the Speech, Spatial, and Qualities of Hearing questionnaire (Gatehouse and Noble, 2004).

Preliminary analyses with four post-lingually deafened adults (n=4) reveal substantial within- and across-subject variability in ECAP thresholds and ECAP amplitude growth function slopes across individual electrode sites. Small but significant correlations were noted for the slopes of the ECAP growth functions with speech perception as well as the speech subscale of the SSQ. Emerging research suggests that cognitive skills likely provide additional benefit for speech understanding in noise, regardless of the physiologic signal. It is important to evaluate the way the sounds are encoded peripherally, as well as the influences of higher-order processing to speech understanding in noise. Relationships between speech perception scores, cognitive abilities, and self-reported scores on the SSQ Questionnaire will be discussed. ECAP growth functions may be a clinically feasible method that could bridge the gap between research and clinical practice and provide site-specific information to guide cochlear implant mapping.

M16: RESIDUAL HAIR CELL AND NEURAL RESPONSES TO SOUND IN COCHLEAR IMPLANT SUBJECTS

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Pre-implant audiograms and other behavioral responses to sound reflect only those elements that retain functional connections between hair cells and auditory nerve fibers. Such measures have shown little relation to speech perception outcomes. Over the past few years, we have shown that the overall magnitude of sound-evoked responses vary over a >60 dB range among implant subjects and that a single measure acquired intraoperatively, called the total response (TR), can account for ~45% of the variance in percent correct on monosyllabic word score tests in adults (Fitzpatrick et al., 2014, Otol Neurotol, 35:64-71; McClellan et al., 2014, Otol. Neurotol 35:e245-52). The TR is measured from the ongoing, or steady-state portion of the responses to tones of different frequencies. To low frequencies, it reflects the summed activity of a hair cell potential, the cochlear microphonic (CM), and a neural potential, the auditory nerve neurophonic (ANN). In addition to this complexity, the TR does not include other potentials including the compound action potential (CAP), from auditory nerve fibers, and the summating potential (SP), whose sources have remained enigmatic. We have obtained ECochG recordings to tones from >300 CI subjects of all ages. In addition, we have performed parallel recordings in gerbils while pharmacologically manipulating the proportions of inner and outer hair cells and neural elements. From these data we have been able to identify subjective and objective attributes of the ECochG responses that reflect the individual sources. In particular, the ANN contributes patterns of distortions that can be distinguished from those seen from the CM, despite their both being phase-locked to the same stimulus tone. The CAP is highly variable in CI subjects and when present the SP is small, while when the CAP is absent the SP is often large. The experiments in gerbils indicate that inner hair cells and the auditory nerve contribute the same polarity to the SP, which is opposed by the polarity derived from the outer hair cells, leading to the result seen in CI subjects when the CAP is absent. By careful identification of the sources contributing to responses in each individual, it is hoped that the proportion of variance in speech perception outcomes can be increased over that using the TR alone.

M17: MODELING CURRENT SPREAD IN A DYNAMICALLY FOCUSED COCHLEAR IMPLANT STRATEGY

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Focused current strategies such as tripolar stimulation are designed to reduce the spread of current to distant spiral ganglion neurons and increase the independence of stimulating channels on the cochlear implant. Focused strategies have previously been shown to improve behavioral measures of spectral resolution. Modeling studies have also suggested that for electrodes far from the inner wall of the cochlea, such strategies can narrow the spread of excitation, although side lobes of excitation may result at high stimulation levels. However, results of speech tests with tripolar stimulation have been mixed. It remains unclear why there is not a more marked benefit, and hypotheses include the existence of neural dead regions or deleterious effects of side lobes. Recently, cochlear implant listener performance with a novel focusing strategy called dynamic tripolar was examined. In this strategy, the amount of current focusing is varied as a function of stimulus level. There was a significant improvement in performance on a speech task using dynamic tripolar over the traditional monopolar strategy, but curiously, many listeners who benefited from their dynamic tripolar map did not show the same effect with the original tripolar strategy. In the present study, we use a computational model of current spread within the implanted cochlea, followed by a model of spiral ganglion excitation, to predict how the activation pattern of neurons may differ for tripolar and dynamic tripolar strategies. Loudness growth curves are predicted that demonstrate how the width of excitation changes as a function of the number of neurons excited over threshold. We model how electrode position, near or far from the inner cochlear wall, affects the spatial pattern of excitation for both strategies. We hypothesize that dynamic tripolar and tripolar strategies may be qualitatively similar for electrodes close to their neural targets, but at moderate distances effects may become apparent. Finally, we consider how dynamic focusing may accentuate the neural representation of changes in level, both as it pertains to detection of amplitude modulation in a single channel and in the context of a speech stimulus delivered on many channels.

M18a: LOW-THRESHOLD POTASSIUM CHANNELS AND THEIR EFFECT ON POLARITY SENSITIVITY OF THE ELECTRICALLY STIMULATED AUDITORY NERVE

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Populations of voltage-gated ion channels regulate information encoding and processing in neural membranes. Their function is crucial also for success of cochlear implants, which inject an electrical charge in the cochlea to trigger a set of reactions among the voltage-gated ion channels to generate spikes on auditory-nerve fibers (ANF). It is generally assumed that injection of a cathodic (-ve) charge leads to movement of sodium and potassium ions that depolarizes the neural membrane and generates a spike, whereas anodic charge hyperpolarizes the neural membrane and is required mainly to neutralize the charge gradient in the cochlea. However, several studies recording ANF responses to electrical stimulation have demonstrated that charges of both polarities can depolarize the ANF membrane and generate a spike. Recordings from the root of the ANF show that monophasic anodic stimuli result in shorter spike latencies and monophasic cathodic stimuli result in longer spike latencies. Based on ANF latency differences, it has been suggested that cathodic charge depolarizes the peripheral process of the ANF, whereas anodic charge depolarizes the central process (van den Honert and Stypulkowski, 1984). The 'two-site' theory has been supported by computational models based on cable theory which include the properties of sodium and potassium ion channels (Rattay et al, 2001). Although widely accepted, this explanation lacks definitive empirical evidence. In this study, an alternative explanation for the spike time differences is proposed. Recent biophysical studies of ANFs have demonstrated the presence of a population of potassium ion channels, commonly referred to as the 'low-threshold potassium channels' (e.g. Mo & Davis, 2002; Kim and Rutherford, 2016). It was shown that that sodium and LTK ion channels are present at sites along the peripheral process (heminode and nodes) and the central process (soma and axonal initial segment) where spikes may be generated. The dynamics and voltage-sensitivity of these channels result in a sensitivity to the rising slope of membrane potentials, especially after a period of hyperpolarization. For example, the dynamics of LTK channels depolarize the neural membrane at the end of a hyperpolarizing stimulus that can result in a spike. Thus the LTK channel allows a neuron to generate spikes in response to both depolarizing and hyperpolarizing currents. A Hodgkin-Huxley type conductance-based model of the neural membrane was used to test the effect of the LTK channels on polarity sensitivity to different pulse types used for CI stimulation. Initial results show that a neural model with LTK and other ion channels (Rothman and Manis, 2003) can generate a spike in response to both anodic and cathodic pulses simulating electrical stimulation. Furthermore, this model has shorter spike latencies for anodic than for cathodic pulses. A further evaluation of this model will be presented in terms of its ability to predict the responses to various pulse shapes, including symmetric and asymmetric biphasic pulses and pulses with varying inter-phase gaps.

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M18b: MODELING POLARITY SENSITIVITY OF ELECTRICALLY STIMULATED AUDITORY NERVE FIBERS IN HUMANS

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Cochlear implants (CIs) stimulate the auditory nerve fibers (ANF) with trains of symmetric biphasic pulses. While the charges of two opposite polarities are used for safety and charge-balancing, animal and human studies have demonstrated that the electrically stimulated ANF responds differently to each polarity. For example, recordings from the ANFs of cat show higher sensitivity to cathodic than anodic polarity for stimulation with monophasic pulses. Conversely, the thresholds for asymmetric pulse shapes in many human CI users show the opposite, i.e. a higher sensitivity to the anodic than the cathodic polarity. A recently proposed model of the electrically stimulated ANFs suggested that consideration regarding sensitivity to both the polarities is necessary to account for the ANF responses to various symmetric and asymmetric pulse shapes and dynamic pulse trains of different pulse rates (Joshi et al. 2017). Additionally, analysis of model responses to modulated and unmodulated pulse trains showed that an increase in number of spikes generated by anodic charge resulted in worsening of representation of the envelope in the ANF responses; a robust encoding of the envelope was observed when the spikes were generated mainly in response to the cathodic charge. These results indicated that polarity interactions can reduce the neural representation of speech-related envelope information in the ANF and may degrade speech understanding in CI users. The model was developed using the ANF responses measured in cats and therefore predicts higher sensitivity to cathodic pulse. The model must first account for the polarity sensitivity as observed in human data in order to be able to quantify the effect of interaction between the charges two polarities in human CI listeners. This report explores various factors, such as electrode-neuron distance, charge-integration properties of the neural membrane and demyelination of the ANFs, which have been proposed to affect the polarity sensitivity in human listeners. A ‘humanized’ model of the ANF responses to electrical stimulation will provide a useful tool to quantify the degradation of the envelope related information in the ANF responses and to design novel stimuli that will facilitate robust encoding of the cues useful for speech understanding.

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M19a: LOW-FREQUENCY ELECTROCOCHLEOGRAPHY IN A GUINEA PIG MODEL OF COCHLEAR IMPLANTATION WITH HEARING PRESERVATION

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Introduction: Patients with severely impaired high-frequency hearing and residual low-frequency hearing cannot be sufficiently accommodated with conventional hearing aids. Using hearing preservation (HP) electrode designs and surgical techniques, these cases can be provided with cochlear implants (CIs), thereby facilitating ipsilateral electric and acoustic stimulation. Still, HP is usually partial and long-term degradation was observed. Possibilities of surgical monitoring and clinical follow-up using electrocochleography (ECochG) in CI patients have been recently studied, specifically using cochlear microphonics (CM). However, interpreting the complex ECochG signal with respect to “cochlear health” has proven to be a difficult task. We present an experimental setup to further investigate low-frequency ECochG in a guinea pig model of cochlear implantation.

Methods: The guinea pig model (Dunkin Hartley, n = 4) was implanted with MED-EL custom-built four-contact CI electrode carrier at max. 4 mm insertion depth. Extracochlear ECochG via gold-wire electrode placed at the round window niche was used to assess HP. Intracochlear ECochG via CI electrode contacts was compared for direct and telemetric recording via the CI hardware, which was previously validated in vitro. Stimuli were 100 µs click and 10 ms sinusoidal tone bursts from 250 Hz to 64 kHz for direct recordings, and from 250 Hz to 4 kHz for telemetric recordings.

Results: Extracochlear ECochG confirmed comprehensive HP in 3 out of 4 guinea pigs. Intracochlear ECochG was comparable between direct and telemetric recordings in the difference response typically showing CMs, while limitations were found for telemetric recordings when looking at the sum response. Comparing ECochG transient potentials with spectral components of ongoing potentials showed dissimilar sensitivity with respect to HP assessment. Furthermore, second harmonic of the sum response showed more low-frequency selectivity than the first harmonic of the difference response, i.e., the spectral component of CM may not be sufficient as an outcome measure for low frequencies.

Conclusion: Our experimental setup validated telemetric recording of ongoing low-frequency ECochG responses in an implanted guinea pig model. Spectral analysis of different harmonic components constitute a potentially feasible measure of “cochlear health” in the apex, while considering isolated components such as CMs showed limitations.

M19b: DETECTION OF NEURAL RESPONSES IN SINGLE ECAP RECORDINGS USING AN AUDITORY NERVE MODEL

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The electrically evoked compound action potential (eCAP) is a routinely performed measure of the auditory nerve in cochlear implant users. Besides commonly used parameters like the eCAP threshold, a convolution model of the eCAP response can be used to obtain additional information about the auditory nerve firing properties. The derived compound discharge latency distribution (CDLD) can be used to indicate neural health of the auditory nerve [1], but also allows for an automatic detection of auditory nerve responses in a recording.

In this study, over 20.000 single eCAP recordings from 20 cochlear implants were obtained using a fine-grain amplitude growth sequence [2] with alternating polarity and zero template artifact reduction. The amplitude growth functions were analyzed by 5 human experts, i.e. the presence of a neural response was determined and the eCAP threshold if applicable. For the automatic classification of an eCAP presence in a single recording, its CDLD was derived and compared with human physiological values [1], achieving a hit rate of 93.3% and 84.8% correct rejection rate.

Analysis of the 15.2% of cases that led to a false alarm showed that these recordings mainly contained remaining stimulus artifacts which could not be compensated for by the applied artifact reduction. The remaining artifact signal had a morphology that resembled an eCAP response. This indicates that an eCAP classification system that is based only on single recordings is susceptible to wrong decisions due to residual stimulation artifacts. Any automatic eCAP detection system, especially for clinical applications, should therefore include additional information sources, for example the shape of the amplitude growth function.

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M20: MECHANISMS ASSOCIATED WITH OPTOGENETIC CONTROL OF SPIRAL GANGLION NEURONS

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Recently, optogenetic stimulation has shown promise in the improvement of frequency resolution in a multichannel auditory prosthesis (Fernandez 2014). However, the mechanisms accounting for optogenetic activation of spiral ganglion neurons (SGNs) remain unclear.
In an attempt to better understand optogenetic excitation, we examined the activation of voltage gated ion channels by electrical stimulation, and excitation thresholds activated by electrical current or light pulses in individual SGNs. We found that optogenetic stimulation relies on photosensitive ion channels (ChR2, Chronos) and generic voltage gated channels (Nav, Kv, and HCN) to modify membrane potential and elicit action potential. A positive correlation between optogenetic depolarization and firing thresholds was observed and will be pursued in the design of the next generation of auditory prostheses. The requirement for intrinsic and optogenetic excitability in SGNs, expressing transgenic channel rhodopsins, suggests the possibility of using a combination of optogenetic and electrical stimulation in future multichannel cochlear implants. Preliminary data from whole cell recording showed a significant shift of electrical threshold in SGN with the blue light facilitation.

Our data provide insights into optogenetic activation of SGNs and suggest that alternative modes of stimulation may be incorporated into novel optogenetics based auditory prostheses.

M21a: ACROSS-ELECTRODE SENSITIVITY TO DIFFERENCES IN THE ENVELOPE AND ITS RELATION TO THE ELECTRODE-NEURON INTERFACE

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In complex acoustic environments, if listeners have access to source segregation cues, they can extract information from a target in noise. Access to segregation cues can be limited in bilateral cochlear implant (CI) users due to poor signal transduction at the interface between the auditory nerve fibers and electrodes, which changes between sites along the cochlear array. One example of a source segregation cue preserved in CI processing that may vary depending on the integrity of electrode-neuron interface is the rate of envelope fluctuations that occur in speech.

This study measured threshold for detecting differences in the rate of envelope fluctuations, or amplitude modulation (AM) rate, across-electrodes. The experiment occurred in two phases: (1) AM rate sensitivity at individual electrodes was measured to make inferences about the integrity of the electrode-neuron interface; (2) subjects compared AM rate information presented simultaneously across two electrodes. It was hypothesized that if one of the electrodes in a stimulus pair had poorer AM rate sensitivity (in phase 1), then the threshold for differences in AM rate across electrodes in the pair would increase (in phase 2).

Participants were bilateral CI users, and normal-hearing (NH) listeners presented with stimuli that simulated good and poor electrode-neuron interface. For CI users, stimuli were sinusoidally amplitude-modulated (SAM) pulse trains (3000 pulses per second) at electrodes 4 or 16, with 50% AM depth. For NH listeners, stimuli were SAM tones with carriers of 4000 or 7260 Hz, and AM depths of 20% or 50%. Poor electrode-neuron interface was simulated in NH listeners by reducing AM depth. The first phase of the experiment featured a three-interval, two-alternative forced choice (3I-2AFC) discrimination task, where the subject chose the interval with the faster AM rate on a single electrode. Elevated AM rate difference thresholds in the 3I-2AFC task suggested poorer electrode-neuron interface integrity.

In the second phase of the experiment, thresholds for detecting differences in AM rate across electrodes were measured using a one-interval, two-alternative forced choice task. Listeners indicated whether they heard AM rates presented to two electrodes as the same or different. AM rates were tested in pairs, within- or across-ears. AM rate thresholds from each electrode in the first task were used to predict performance of the pair of electrodes in the second task.

Results were similar in CI users and NH listeners: Performance in the 3I-2AFC task was dependent on electrode site (for CI users) or AM depth (for NH listeners). In the second task, detecting differences between two sites of simulation required listeners to use larger differences in AM rate when one channel had poorer AM rate sensitivity.

Results from this study suggest that poor signal transduction at one cochlear place worsens the ability to compare AM rate across place and ears. This has implications for real world listening, where listeners have to compare the AM rate across the ears and cochlear place to segregate between sound sources. Thus, the inability to compare the AM rate across electrodes due to site-specific decrements in the electrode-neuron interface is one potential mechanism contributing to difficulty listening in noisy environments for CI users.

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M21b: BINAURAL SENSITIVITY IN BILATERALLY IMPLANTED CHILDREN: MECHANISMS INVOLVED IN DISCRIMINATION VS. IDENTIFICATION TASKS

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In a typically-developed binaural system, the brain learns to associate spatial cues, including interaural differences, with the location of sounds. Interaural differences can also aid in detecting a signal in noise. In the laboratory, sensitivity to interaural time and level differences (ITD and ILD) is typically measured by finding the smallest detectable change in direction. The ability to use interaural differences to detect a signal in noise is usually measured via the binaural masking level difference (BMLD), which is defined as the difference in signal-to-noise ratio needed to detect a tone when presented dichotically vs. diotically.

In recent years, we have been investigating the sensitivity of children who listen with bilateral cochlear implants (BiCIs) to interaural differences using direct electrical stimulation. In a series of experiments (Ehlers et al., 2017 JASA in press), we found that all children who listen with BiCIs had ILD sensitivity, but less than half had ITD sensitivity. However, in a different study (Todd et al., 2016 JASA 140(1):59), some of the children who had no measurable ITD sensitivity in the Ehlers study had measureable BMLDs. This is surprising because ITD sensitivity and BMLD are typically assumed to be mediated by similar binaural mechanisms in the brain.

One explanation for this discrepancy is that the tasks used to measure ITD sensitivity vs. BMLD may require that the listener use binaural cues differently. On the ITD task, children had to correctly identify and report the direction of a second sound relative to a preceding sound that had the opposite ITD value. On the BMLD task children only had to discriminate which interval was different, which may be an easier task. Hence, we hypothesized that if children are able to discriminate interaural differences but had no measurable ITD sensitivity in the Ehlers study, this would be due to a task difficulty, i.e. correct identification of sound direction.

To test this hypothesis, ITD and ILD just noticeable differences (JNDs) were measured using a two-interval, two-alternative forced-choice (2I-2AFC) right vs. left identification task and a three-interval, two-alternative forced-choice (3I-2AFC) oddball discrimination task. In both tasks, stimuli were 100 pulses per second, electrical pulse trains with either an ITD or ILD cue. Results to date show that lack of measurable ITD sensitivity is independent of task. However, for children who had ITD sensitivity, the 3I-2AFC task proved to be much more difficult than the 2I-2AFC task. Children showed elevated JNDs in the 3I-2AFC task in both ITD and ILD conditions which was contrary to expectations. Results suggest that mechanisms involved in mediating BMLD ability are different than those needed for ITD discrimination, such as the ability to use interaural decorrelation (Goupell and Litovsky, 2014 JARO, 15(1):115-29).

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M22a: USING THE ACOUSTIC SIGNAL TO TIME-LOCK THE PULSES IN THE LEFT AND RIGHT COCHLEAR IMPLANT

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Although bilateral cochlear implants (CIs) have led to a significant improvement in performance compared to unilateral CIs, bilateral CI users still do not receive the same benefits from having two ears that normal hearing listeners do. One of the main limitations is that bilateral CI users are generally not sensitive to interaural time difference (ITD) cues when using their clinical processors. Work with research interfaces suggests that it is possible for CI users to perceive ITDs. However delivering precise ITDs may require synchronized processors. An alternative to physically synchronizing the left and right processors is to use the acoustic signal, which is already naturally time-locked at the two ears, to synchronize the processors. By delivering stimulation at each zero-crossing of a signal, it is possible to time-lock the pulses in the two ears. However, the accuracy of this time-lock depends on the sampling rate used to detect the zero-crossings. The goal of this experiment was to determine a) if ITD sensitivity can be improved by using the acoustic signal to time-lock the pulse trains, and b) how that improvement is affected by the zero-crossing sampling rate.

ITD sensitivity was measured for six bilateral CI users using a four interval, two alternative forced-choice task. Participants were presented with four stimuli, where the first and last stimuli always had an ITD of 0 microseconds. One of the middle two stimuli had a non-zero ITD. Participants were asked to indicate which stimulus was different. ITD was varied adaptively.

Participants were tested in six conditions. In the synchronized conditions, a 117 pulse per second pulse train was delivered to both ears using a single clock. This resulted in a precise ITD cue with no interaural temporal jitter. In the remaining five conditions, a front-end processor was implemented that determined the zero-crossings of a 117 Hz sine wave using a fixed zero-crossing sampling rate but with a random starting time across ears to simulate independent processor clocks. This resulted in random interaural temporal jitter added to the ITD. However, by using increasingly fast zero-crossing sampling rates, the magnitude of the jitter was effectively decreased. The zero-crossing sampling rates used were 1 kHz, 4 kHz, 8 kHz, 16 kHz, and 44 kHz.

ITD sensitivity was best when the pulses in the two ears were manually time-locked. However, when the sampling rate was 4 kHz or above, using the acoustic stimulus to time-lock the two ears produced comparable results as the physically time-locked stimuli. Performance was poorer with a 1 kHz sampling rate.

The results indicate that it is possible to use the acoustic signal to time-lock the pulses in the two ears and yield good ITD sensitivity. However, high zero-crossing sampling rates may be needed to yield good performance.

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M22b: BILATERAL PITCH MATCHES ADAPT BASED ON THE PROCESSOR FREQUENCY ALLOCATION FOR BILATERAL COCHLEAR IMPLANT USERS

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Even after extended experience with bilateral cochlear implants (CIs), electrodes that receive the same frequency allocation do not necessarily yield the same pitch. However, some CI users have been shown to partially adapt to these frequency allocation differences after extended use. Like bilateral CI users with large insertion depth differences due to different length arrays and bimodal users, bilateral CI users with two full length arrays exhibit an ongoing mismatch between pitch percepts and frequency allocations. This indicates either a lack of adaptation to these mismatches, or insufficient adaptation. To determine if bilateral pitch matches do adapt for bilateral CI users with two full length arrays, pitch matches were obtained for five bilateral CI users over a one year period directly post-activation.

Participants were tested within the first month post-activation, six months post-activation, and one year post-activation using a pitch-matching task. For this task, an electrode was stimulated first in one ear (reference ear) and then in the second ear (target ear). Participants were presented with a dial that allowed them to move the stimulation location to different locations along the array in the target ear. The process of listener-directed change in the stimulation location in the target ear followed by stimulus presentation was repeated until the participant indicated that the stimulation in both ears yielded the same pitch.

For all five participants, the difference between the interaural electrode pairs that yielded the same pitch and those that received the same frequency allocation in the participants' clinical maps diminished between initial post-activation testing and one year post-activation testing. These results indicate that bilateral CI users with two full length arrays adapt to pitch mismatches, although the amount of adaptation is insufficient to completely overcome the mismatches.

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M23a: FACTORS THAT INFLUENCE INTERAURAL TIMING SENSITIVITY IN BILATERAL COCHLEAR IMPLANT USERS

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Sound localization in the horizontal plane is primarily mediated by interaural level and timing differences. Presently, bilateral cochlear implant (CI) users exhibit poor interaural timing difference (ITD) sensitivity. There are several stimulation parameters that could affect ITD sensitivity in CI users. In the present study, we investigated the effects of interaural pitch-matching, cochlear place of stimulation, stimulation mode, and stimulation rate on ITD sensitivity. Middlebrooks and Snyder (2010) found that more selective electrical stimulation of the auditory nerve created more effective channels for the transmission of fine structure information as measured by the degree of phase-locking of neurons in the inferior colliculus to stimulus periodicity. For NH listeners, ITD cues found in the TFS typically provide the strongest cue for localization in the horizontal place. We hypothesized that bipolar stimulation mode would provide better ITD sensitivity at higher rates than monopolar mode. We also tested electrode pairs at different cochlear regions (basal, middle, apical locations) to determine whether place of stimulation may also influence ITD sensitivity. Subjects were adult bilateral CI users who wore Nucleus devices. . All stimulation was provided using a pair of USC Cochlear Implant Research Interfaces in bilateral configuration. Prior to testing, subjects were mapped in both monopolar and bipolar modes in order to determine T and C levels. ITD discrimination was measured using a two-interval two-alternative forced choice procedure on the selected electrode pairs. One of the two intervals contained a stimulus with either a left or right leading pulse train. The stimuli consisted of biphasic pulse trains (with 50 µs phase duration and 8 µs phase gap) presented at 200, 400, 600, and 800 pulses per second at constant amplitude with a duration of 500 ms and presented at a comfortable listening level. Subjects clicked on two buttons to indicate whether the sound moved from left to right or right to left across the two intervals. Adaptive procedures were used to converge on the 75% discrimination threshold. Subjects were also tested with at-home training exercises to determine how much the existing signal processing in clinical processors may degrade ITD sensitivity. Preliminary results indicate a steeper increase in ITD thresholds as rate was increased for monopolar mode as compared to bipolar mode at select electrode pairs. There was no clear effect of cochlear place of stimulation across subjects. Findings from this study will have important implications for the development of effective binaural sound coding strategies.

References

Middlebrooks, J. C., and R. L. Snyder. 2010. Selective electrical stimulation of the auditory nerve activates a pathway specialized for high temporal acuity. J. Neurosci. 30:1937– 1946.

M23b: THE INTERAURAL PHASE MODULATION FOLLOWING RESPONSE: TOWARDS AN OBJECTIVE MEASURE OF INTERAURAL ELECTRODE MISMATCHES IN BILATERAL COCHLEAR IMPLANT USERS

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Binaural hearing, particularly the ability to detect interaural time differences (ITDs), is essential to effective listening in complex acoustic environments. Despite its importance, however, the neural mechanisms underlying ITD processing in humans remain poorly understood. To gain insight into specific neural mechanisms, we developed an objective measure of ITD sensitivity – the interaural-phase modulation following-response (IPM-FR; Haywood et al. 2015, Undurraga et al. 2016) – an EEG-response evoked by periodic transitions of interaural phase differences (IPDs). IPM-FRs have been recorded to IPDs in the temporal fine-structure of low-frequency sounds, as well as in the envelope of high-frequency sounds using transposed tones (McAlpine et al. 2014).

Here, we investigate the IPM-FR to IPDs in the envelope of high-frequency sounds, employing band-pass filtered click trains. One advantage of band-pass filtered click trains is that they have been used to simulate electrical hearing. They also seem to provide better ITD discrimination performance than the commonly employed transposed tones (Majdak and Laback 2009), suggesting that better EEG responses may be obtained. Here, we assess how interaural offsets in the carrier affect the IPM-FR to filtered click trains with envelope IPDs in normal listeners, providing a means of exploring the effect of interaural electrode mismatches in bilateral cochlear implant users.

M24a: SPATIAL HEARING BY BILATERAL COCHLEAR IMPLANT USERS WITH FINE-STRUCTURE PROCESSING

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INTRODUCTION. Several studies demonstrated the advantage of bilateral cochlear implantation over unilateral implantation. However, it remains unclear to what extend bilateral implanted subjects can process binaural cues. For processing of binaural cues, accurate processing of ITDs for low-frequencies (<1.5 kHz) and ILDs for high-frequencies (>3 kHz) is needed. In this study, we tested 30 patients bilaterally implanted with a MEDEL cochlear implant system with fine structure processing as they standard coding strategy. In order to assess the spatial hearing performance in this population, localization, psychophysical ILD and ITD experiments and a speech in noise task were evaluated.

MEDTHODS. Localization: Subjects were asked to localize different noise bursts (150 ms, varying bandwidth) by pointing with a natural rapid head movement to the stimuli presented in a dark, anechoic room. Absolute sound localization performance was tested for broadband, high-pass and low-pass stimuli. With low-pass stimuli only the first 4 apical channels (fine structure processing) were stimulated. Sound levels were roved over a 20dB range in order to avoid the use of the head-shadow as a potential localization cue. Stimuli were presented from random selected locations between ±75 degrees in azimuth.
Psychophysics: Using low-pass and high-pass stimuli as in the localization task (150ms burst), a 2AFC task was performed for ILD and ITD perception. Subject were asked to imagine a point in the middle of their head and indicate whether stimuli were perceived at the right or left side from this imagined central spot by pressing the arrows on a keyboard.
Speech in noise: The OSLA MATRIX test in an open format and a single-talker noise was used as the masker. The noise was adapted to understand 50% of the words while the target sentences were always presented from the front. Speech was tested in 3 spatial configurations: noise from the front (S0N0), from the right (S0N90) and from the left (S0N-90).

RESULTS. Psychometric results show that subjects are able to use ILD differences but they present an ITD sensitivity out from the normal physiological range. Surprisingly, some subjects demonstrated localization abilities in free field which were almost similar to normal hearing performance. Nevertheless, saccade’s reaction times are longer than in normal hearing listeners. The benefit of having bilateral input was found for speech understanding in noise in all subjects. Head shadow effect, summation and squelch effect indicate the spatial hearing abilities to avoid the masker by using the ear with the better signal to noise ratio.

CONCLUSION AND DISCUSSION. For at least a sub-population of bilaterally implanted adults, sound localization might be based on processing of binaural cues. Others, possible because the lack binaural fusion, typically lateralize sounds. All subjects are sensitive to ILDs and benefit from bilateral input to segregate the masker from the speech. The bias estimated from the ILD psychophysical task, is a strong tool to verify the balance between ears and, therefore, predict the bias in free field localization. The clinical fitting of the device can profit from this simple psychophysical left/right task as a step towards a better outcome in the bilateral fitting.

M24b: EVALUATION OF ITD BASED LATERALIZATION SKILLS OF COCHLEA IMPLANT USERS WITH A FINE STRUCTURE CODING STRATEGY

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Background: Normal hearing listeners localize sound in the horizontal plane by utilizing two different kinds of cues, interaural level differences (ILD) and interaural time differences (ITD). With an ear-to-ear distance in humans of about 22 cm, the maximum ITD for sound can be 0.64 ms, which means that phase differences between the ears will occur at frequencies up to 1600 Hz providing localization cues for the auditory system. Above 1600 Hz, ILDs become increasingly relevant for localization, although temporal aspects can even play a role at higher frequencies, i.e. the delay of the sound arrival between the two ears for a newly started auditory event. With standard coding strategies like CIS, Cochlea implant (CI) users have access to ILDs and ITDs from the signal envelope, but not from detailed fine structure information (FS), which is needed for perceiving phase differences between the ears. With fine structure coding strategies, additional low frequency cues are presented to the CI user, which could help to improve the ITD perception. The aim of our study is to evaluate the ITD perception with a standard CIS coding strategy and a fine structure coding strategy, as well as making a comparison between the two.

Methods: To evaluate ITD sensitivity, a lateralization experiment has been set up, where two successive acoustic signals are presented to the two unsynchronized speech processors of the subject, each of them again consisting of two slightly delayed acoustic signals (delay between 50 and 600 µs, signal duration: 500ms). The task for the subject is to report, which of the two sounds comes further from the left. These signals are generated on a computer and administered through the direct audio input of the two speech processors, electrically coupled to the stereo-output of the soundcard. The method of constant stimuli is used, with seven fixed ITDs in the range of 50 to 600 µs, which are repeatedly presented. Two different sound stimuli are being investigated: pink noise as well as simple sinusoids. To further investigate any effect of crosstalk between intracochlear electrodes on the perception of ITDs, the experiment is being conducted in 3 different electrode configurations: one, four and ten active electrodes on each side, always selecting the most apical electrodes for each condition. Eleven bilaterally implanted subjects with MedEl cochlear implant systems (Pulsar or later model) could be recruited for the study.

Results: Of the eleven subjects, seven showed sensitivity for ITDs at all, meaning they could perceive ITDs in a range < 600 µs. These seven achieved a median value of 80% correct (ITD value of 300 µs) with the fine structure strategy in the sinusoidal condition (150 Hz / one active electrode pair). With the CIS strategy however, they only reached ITDs in the range of chance level. With the much broader pink noise signal, even with the CIS strategy a moderate ITD perception was observed, probably caused by ITD cues in the envelope of the processed signal. However, the performance with the fine structure strategy still was better than with CIS in five of seven cases (ITD value of 400 µs / four active electrode pairs). With an increasing number of active electrodes we also observed that in general the ITD sensitivity decreased.

Conclusions: In those patients, who were able to perceive ITD cues (<600µs), results with the fine structure strategy were superior compared to the CIS strategy. However, our preliminary results also suggest that channel interaction between intra cochlear electrodes might hamper ITD perception in CI subjects.

M25a: A NEW METHOD FOR DELIVERING BINAURAL CUES FROM MULTIPLE SOURCES TO CI USERS

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Normal hearing listeners use binaural cues such as interaural time differences (ITDs) and interaural level differences (ILDs) as part of an auditory scene analysis to separate acoustic objects in space. This enables them to attend to objects of interest while ignoring competing objects—an ability termed 'spatial release from masking' that can be measured and quantified. CI users, although they do have access to an ILD cue, cannot generally un-mix acoustic objects using this cue.

Here we describe a method that uses interleaved simulations to present ILD and ITD cues from multiple sources to a CI user. The method was tested with the ITD cue on 7 normal hearing subjects. We used the Oticon Medical research platform (OMRP) to produce vocoded simulations of a target speech signal from the front (ITD = 0) within competing noise at various ITDs. A statistically significant spatial release from masking was observed from the ITD cue alone. This clears the way for testing this method on bilateral CI users.

M25b: ENHANCING BEHAVIORAL ITD SENSITIVITY WITH SHORT INTER-PULSE INTERVALS IN AMPLITUDE MODULATED PULSE TRAINS

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In normal hearing, interaural time differences (ITDs) at low frequencies are considered important for sound localization and spatial speech unmasking in the lateral dimension. These fine structure ITD cues are not encoded in commonly used envelope based stimulation strategies for cochlear implants (CI) at high pulse rates. In an earlier study we showed that introducing short interpulse intervals (SIPI) pulses in high-rate pulse trains improved behavioral ITD sensitivity. The magnitude of improvement depended on the rate at which the SIPI pulses were introduced (SIPI rate) and their relative position within the high-rate pulse train (SIPI width). For application with more realistic stimuli with amplitude modulation (AM), an important question is to what extent SIPI pulses further enhance ITD sensitivity when the AM itself provides envelope ITD cues. Further, it is unclear at which temporal position within the envelope period SIPI pulses should be placed, to be most effective.

In this study we measured the sensitivity of bilateral CI listeners to ITD cues when presented with amplitude modulated high-rate (1000 pulses/s) periodic pulse trains with inserted SIPI pulses. 600-ms pulse-train stimuli with vowel-like temporal envelopes were presented binaurally via a research interface. Using SIPI parameters fixed at best improvement in ITD sensitivity (SIPI width = 10% and SIPI rate = 62.5 Hz), we systematically varied the temporal position of SIPI pulses within the envelope period (SIPI phase), the fundamental frequency (F0, 125 and 250 Hz), and the AM depth (from 0.1 to 0.9). Participants performed a left/right discrimination task with a centralized reference stimulus. We tested these AM pulse trains as well as unmodulated high-rate pulse trains with and without inserted SIPIs.

Our results show improved ITD sensitivity with the introduction of SIPI pulses in AM pulse trains compared to without SIPI pulses. Introducing SIPI pulses at and around the peaks of the envelope resulted in greater improvements than at other off-peak portions of the envelope. These results are promising with respect to the idea of enhancing behavioral ITD sensitivity in speech stimuli with future bilateral CIs. In particular, the results suggest that it is possible to maintain high ITD sensitivity with bilateral CIs even at high pulse rates required for speech coding.

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M26: CORRECTIVE BINAURAL PROCESSING IMPROVES LOCALIZATION PERFORMANCE BY BILATERAL COCHLEAR IMPLANT

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Bilateral cochlear implant (BCI) users have shown significantly poorer horizontal-plane localization abilities than listeners with normal hearing (NH). This is likely due to the fact that, of the two binaural cues available to NH listeners, interaural time differences (ITDs) are less well encoded than interaural level differences. A possible solution to this limitation was examined in which instantaneous ITDs are measured within frequency bands, and converted to ILDs. This general approach has been shown to improve speech intelligibility in the presence of a spatially-separated masker (Brown, 2014). In that study, linear ILD functions were used, wherein the applied ILD increased linearly as the measured ITD increased. In the current study, individualized corrective ILD functions were generated in each frequency band, derived from the difference between ideal localization performance, and the psychometric function generated by each subject to bandpass noise. These functions were then used in a real-time implementation of the algorithm, while participants localized broadband noise. Six BCI patients participated. The noise was presented from one of thirteen locations in the front hemifield, from -90 to +90 degrees (15-degrees separation), in an acoustically-treated room. In one condition ('Processed'), localization performance was measured with the approach described, implemented on a smartphone with 1/4" condenser microphones mounted on ear hooks capturing sound and direct-connect cables delivering processed sound to the user's devices. In the other condition ('Unprocessed'), each user performed the localization task with their devices. No modifications were made to device settings or clinical maps, except to disable device microphones in the 'Processed' condition. Root-mean-square (RMS) error was computed for each participant in each condition. Results showed significantly lower mean RMS in the Processed condition. Mean error was 31 degrees in the Unprocessed condition, which is on par with that reported in the literature, and 13.4 degrees in the processed condition, which is approaching the performance range of NH listeners. Two of the six participants exhibited localization performance in the Processed condition that was equivalent to typical NH performance. (Work supported by grant R01-008329 from the NIDCD).

M27: OPTIMIZING PITCH MATCHING FOR BILATERAL COCHLEAR IMPLANT USERS

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Interaural place-of-stimulation mismatch might be one important factor in preventing some bilateral cochlear implant (BICI) users from receiving binaural advantage. While pitch-based tasks have been used in the literature as a perceptual way to assess relative places of stimulation in the two ears, no previous investigation has critically evaluated the efficacy of these approaches for BICI. The goal of the current study was to evaluate three different approaches to assess bilateral pitch comparisons for BICI listeners: pitch discrimination, pitch ranking and pitch matching. Experiments were designed to evaluate the susceptibility of pitch judgments to range biases, transfer biases, and pitch-stimulus ambiguities.

Experiment 1 examined pitch discrimination, where listeners judged relative pitches of sequential stimuli using a two-interval forced-choice paradigm in a method of constant stimuli (300-ms pulse trains, 1000-pps stimulation rate, monopolar stimulation). The reference stimulus was presented on electrode 4, 12, or 20. On each trial, the test stimulus was chosen randomly from one of three possible ranges: basal (electrodes 2-12), full (2-22), or apical (12-22). Reference-stimulus conditions were presented in a blocked or randomized order to test for transfer bias. Experiment 2 examined a pitch-ranking procedure termed “midpoint comparison”, whereby successive pairs of electrodes were chosen so to minimize the total number of pitch discrimination judgments necessary to rank all electrodes. Experiment 3 examined pitch matching where listeners used a dial to adjust the stimulus in one ear to match the stimulus in the other ear. The electrodes in the dial were either arranged according to their position in the array (i.e., 1 to 22) or according to their pitch ranks obtained from the unilateral midpoint comparison task in Experiment 2.

Combined over the three experiments, several instances of mismatch were observed where electrodes paired for frequency allocation elicited different pitch percepts. Results from Experiment 1 revealed a significant effect of non-sensory range bias, but not one due to transfer bias. For bilateral pitch discrimination, we describe a post-analysis approach where the range bias is modelled explicitly and subtracted from the response. Preliminary results from Experiments 2 and 3 suggest that bilateral pitch matching and pitch ranking were less affected by the range effect and were substantially faster to measure.

Overall, the task of comparing pitch across the two ears is not easy for BICI, which makes assessing place-of-stimulation using pitch-based psychophysical tasks sensitive to non-sensory biases.

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M28: FACTORS UNDERLYING THE BINAURAL SPEECH UNMASKING AND INTERFERENCE FOR BILATERAL COCHLEAR-IMPLANT USERS

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One of the main benefits provided by bilateral (BI) and single-sided-deafness (SSD) cochlear implants (CIs) is improved speech perception in noise. For these listeners, the most well-documented advantage of having two ears is the head-shadow benefit derived from having access to the ear with the better target-to-masker ratio (TMR). We recently demonstrated that BI-CI and SSD-CI listeners can also benefit from binaural unmasking, using their two ears in concert to perceptually separate concurrent talkers in an auditory scene. In this “binaural unmasking” paradigm, the target speech was always presented monaurally, while the interfering speech was either presented monaurally to the same ear or binaurally to both ears. On average, BI-CI and SSD-CI listeners showed a 4-5 dB improvement in performance in the binaural condition. This benefit occurred only at negative TMRs, suggesting that adding masking energy to the second ear helped in in the most demanding conditions. However, binaural unmasking benefits do not always occur in these populations. Some BI-CI listeners who were deafened early in life or had an asymmetrical hearing history, and some SSD-CI listeners attending to target speech in their CI ear, experienced as much as 10 dB of interference, instead of binaural unmasking. The interference occurred at positive TMRs, suggesting a different mechanism than the binaural-unmasking phenomenon.

The current study was designed to understand the cause the interference effect observed for some listeners. Critically, it is presently unclear if interference occurs for any input stimulus, only modulated stimuli, or only speech stimuli. The same “binaural unmasking” paradigm was used to evaluate speech understanding as a function of target-to-masker ratio (TMR) using the Coordinate Response Measure corpus. Several masker types were tested: 1, 2, 3, or 4 same-sex talkers, a speech-modulated noise from a single talker, and a speech-shaped stationary noise. Control measurements of open-set sentence understanding for IEEE sentences were also made in each ear.

Preliminary data were taken for six BI-CI listeners who previously showed interference in one or both ears. The largest amounts of interference were observed with a single interfering talker or speech-modulated noise. For most listeners, the amount of interference decreased with increasing number of interfering talkers, toward the level often observed for the steady-state noise, which was small. In some cases, interference was observed for every masker condition. The magnitude of the interference was negatively correlated to speech understanding in the ear ipsilateral to the target and positively correlated to speech understanding in the contralateral ear.

The results suggest that interference occurs for both speech and speech-modulated noise maskers; therefore, interference does not solely occur for speech signals, ruling out language-specific processing centers as the cause. For most of the BI-CI listeners in the study, maskers with reduced speech-envelope modulations (steady-state noise or multi-talker babble), produced small amounts of interference. However for some individuals, even the steady-state noise maskers caused interference, suggesting a possible central cortical processing bias for one ear over the other (as what occurs with the visual system with amblyopia). These listeners tended to have asymmetric speech understanding in quiet, which was strongly related to differences in duration of deafness across the ears. Taken as a whole, the results of this series of studies suggests that interference for BI-CI listeners might be avoided by minimizing duration of deafness in both ears or through auditory training and rehabilitation to produce more equal speech understanding between the ears.

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M29a: SIMULTANEOUS VERSUS SEQUENTIAL BILATERAL COCHLEAR IMPLANTATION IN ADULTS: A RANDOMIZED CONTROLLED TRIAL ON OBJECTIVE AND SUBJECTIVE MEASURES

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Importance: To date no randomized controlled trial on the comparison between simultaneous and sequential bilateral cochlear implantation (BiCI) have been performed.

Objectives: To investigate hearing capabilities and self-reported benefits of simultaneous BiCI compared with sequential BiCI.

Design: Multicenter randomized controlled trial.

Setting: Five tertiary referral centers.

Participants: Forty participants were eligible for BiCI. Main inclusion criteria were postlingual hearing loss, age of 18 to 70 years and a maximum duration of hearing loss of 20 years.
Intervention: The simultaneous BiCI group received 2 cochlear implants during 1 surgery. The sequential BiCI group received 2 cochlear implants with an inter-implant interval of 2 years.

Main outcomes and measures: First, we compared the results 1 year after simultaneous BiCI with the results 1 year after sequential BiCI. Second, we compared the results of 3 years of follow-up for both groups separately. Our primary outcome measure was speech intelligibility-in-noise from straight ahead. Secondary outcome measures were speech intelligibility-in-noise from spatially separated sources, speech intelligibility-in-silence, localization capabilities and self-reported benefits assessed with various hearing and quality of life questionnaires.

Results: Nineteen participants were randomized to undergo simultaneous BiCI and 19 to undergo sequential BiCI. Three patients did not receive a second cochlear implant and were lost to follow-up. We found comparable results 1 year after simultaneous or sequential BiCI for speech intelligibility-in-noise from straight ahead: difference 0.9 dB (95% CI: -3.1 – 4.4) and all secondary outcome measures except for localization with a 30° angle between loudspeakers: difference -10% (95% CI: -20.1 – 0.0). In the sequential BiCI group, all participants performed significantly better after BiCI on speech intelligibility-in-noise from spatially separated sources and on all localization tests, which was consistent with most of the participants' self-reported hearing capabilities. Speech intelligibility-in-noise results improved in the simultaneous BiCI group up to 3 years following BiCI.

Conclusion: This study shows comparable objective and subjective hearing results 1 year after simultaneous and sequential BiCI with an inter-implant interval of 2 years. It also shows a significant benefit of sequential BiCI over unilateral cochlear implantation. Until three years after simultaneous BiCI, speech intelligibility-in-noise significantly improved compared to previous years.

Key Words: cochlear implants, bilateral cochlear implantation, speech intelligibility-in-noise, localization, spatial hearing, quality of life, benefit
Trial Registration: Dutch Trial Register NTR1722
Level of evidence: 1b
Funding: This study is sponsored by Advanced Bionics ®.

M29b: CORRELATION BETWEEN SUBJECTIVE AND OBJECTIVE HEARING TESTS AFTER UNILATERAL AND BILATERAL COCHLEAR IMPLANTATION

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Objective: The aim of the current study was to investigate the correlation between subjective and objective hearing tests in both unilateral and bilateral adult cochlear implant patients.

Design: Data for this study were prospectively collected as part of a multicentre randomised controlled trial (RCT).

Study sample: Thirty-eight postlingually deafened adult patients were randomly allocated to receive either unilateral or bilateral cochlear implantation. The correlation between the 1-year results on the related domains of the Speech, Spatial and Qualities of Hearing Scale (SSQ) and Nijmegen Cochlear Implant Questionnaire (NCIQ) on the one hand, and objectively measured speech perception and localisation skills on the other hand, were investigated.

Results: Significant weak to moderate negative correlations were found between the subjective tests (speech domain of the SSQ and the advanced speech perception domain of the NCIQ) and the related objective speech perception in noise tests (r=-0.33 to -0.48). A significant moderate correlation was found between the subjective test (spatial domain of the SSQ) and the related objective localisation test (r=0.58).

Conclusions: Current objective tests do not fully reflect subjective everyday listening situations. This study elucidates the importance and necessity of questionnaires in the evaluation of cochlear implantation. Therefore, it is advised to evaluate both objective and subjective tests in cochlear implant patients on a regular basis.

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For this study, all centers received the second cochlear implant from Advanced Bionics®. Advanced Bionics® in part sponsored this study. This company did not have any influence on the data collection, data analysis, data interpretation or study design.

M30a: ELECTRICALLY EVOKED AUDITORY BRAINSTEM RESPONSES AND ACOUSTIC CHANGE COMPLEXES IN ADOLESCENT COCHLEAR IMPLANT USERS WITH LONG INTER-IMPLANT INTERVALS

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Background

A prolonged interval between the first and the second cochlear implant (CI) in children is known to negatively affect auditory performance with the second CI. The rel¬atively poor performance with the second implant (CI2) might be due to an impaired maturation of the auditory pathway of the later implanted ear caused by unilateral hearing with the first CI (CI1). To study possible mat-urational differences, we compared electrically evoked auditory brainstem responses (eABR) and acoustic change complexes (ACC) in children with long inter-im¬plant intervals.

Methods

In 14 sequentially implanted adolescents (age 10-19) with varying inter-implant intervals (range 4 to 15 years), eABRs and ACCs were obtained 12 months after the first activation of CI2. ACCs are cortical auditory evoked potentials in response to change within an ongoing sound;, in the current study frequency changes were used. ACC stimuli consisted of three components: A) pure tone in the center frequency of a middle electrode B) a frequency modulation sweep C) a pure tone in the center frequency of a more basal electrode, accounting for a higher frequency. eABR stimuli consisted of an electrical biphasic pulse on a middle electrode.

Results

The consonant vowel consonant (CVC) phoneme scores were significantly lower in CI2 compared to CI1 (means 56% vs 91%, $P < 0.01$). Latencies of eABR waves III and wave V were significantly longer for CI2 than for CI1 (means 2.01 vs 1.91 ms and 3.88 vs 3.68 ms respec¬tively, $P < 0.05$). There were no significant differences in ACC N1 and P2 latencies between CI2 and CI1. ACC N1-P2 amplitudes were significantly smaller for CI2 than for CI1 (means 5.8 vs 8.2 μV, $P < 0.05$). These various differences in eABRs and ACCs between CI2 and CI1 did not correlate with the inter-implant interval.

Conclusion

The longer eABR latencies and the smaller ACC amplitudes found for the CI2 ear indicate an impaired maturation of the auditory pathway of the CI2 ear, explaining the inferior hearing with CI2. One year of using a second CI does not restore deficiencies.

M30b: SEQUENTIAL BILATERAL IMPLANTATION IN OLDER CHILDREN: INTER IMPLANT MAP DIFFERENCES AND THEIR EFFECTS ON FUNCTIONAL OUTCOMES

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It is established that sequential bilateral implantation offers functional benefits to children with bilateral hearing loss, mainly in spatial and speech in noise discriminations. Despite these functional advantages, getting long term unilateral users to adapt to a second implant can be challenging and requires some effort from both patients and clinical teams, especially in older users with long inter implant delays (IID). Although it has been reported that the second implant (CI2) tends to stabilise significantly sooner than first implant (CI1) (Domville-Lewis et al. 2005), Myhrum and colleagues (2016) propose a longer follow-up period post second implant (CI2) to encourage long term bilateral CI.

The main objective of this study is to look at different factors that can affect long term use of the second implant in an older group of sequentially implanted children in Ireland. In particular we were interested in exploring the effect of map differences between the two devices on CI2 usage and on speech and spatial discrimination.

Spatial discrimination ability was assessed using a novel portable virtual reality tool (Sechler et al, 2016). This innovative tool uses Head Related Transfer Functions (HRTF) to replicate 3D sounds which are delivered to the users via a direct connect audio cable. The auditory stimuli consisted of 1-sec white noise bursts presented in 3 different conditions: CI1, CI2 and bilateral mode. Users wearing the VR headset were instructed to turn their head and face one of the 13 possible virtual sound sources separated by 15 degrees in a semi-circle array, while information such as accuracy and head velocity were measured via the VR headset.

This study looks at a cohort of twenty-three older children (current age > 10) who received sequential implants in Ireland (age at CI1: 1.6 – 6.6 years; age at CI2: 3 – 18.5 years; gap: 1-16yrs). All children included in this study had at least 1 year experience with CI2. Depending on the IID, children were categorised in small gap (n=12; mean age = 12 years; mean IID = 4.1 years; range: 1 - 7) and big gap (n=11; mean IID = 12.6 years; range: 8- 16).

Preliminary results show that, for the big gap group, dynamic range (DR) was on average 25% smaller for CI2 than CI1 ($p<0.01$). This difference was driven by significant smaller C-levels (24 CU; $P<0.01$) on CI2 compared with CI1. No such difference in DR was observed for the small gap group. There was a trend for children with balanced DRs to be more consistent users of the two implants while children with significant DR differences tend to use their CI2 less and become non-users.

Children with big IID exhibit poor performance during the spatial discrimination task compared to the children in the small gap group (rms= 68 deg Vs rms= 55 deg, $p<0.05$). Furthermore, their performance in the bilateral condition mirrors the CI1 alone mode, implying that CI2 has a minor impact on their spatial discrimination abilities. This contrasts with the small gap group, whose spatial ability rely on both implants use with spatial discrimination greatly diminished in the CI1 mode.

Finally, the small gap group show better speech discrimination scores in noise in bilateral mode than with CI1 alone, as opposed with the big gap who exhibit no benefit from CI2.

Overall, older sequential implanted children show some functional benefits with the second implant, although this functional advantage seems to be greatly determined both by a smaller IID and balanced DRs between the two implants. Further analysis will expand on the current results and explore correlation between these different measures.

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M31: EXPLAINING VARIABILITY IN SPEECH AND LANGUAGE OUTCOMES FOR CHILDREN WITH BILATERAL COCHLEAR IMPLANTS: A LONGITUDINAL STUDY

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Children with bilateral severe to profound sensorineural hearing loss receive cochlear implants (CIs) at a young age to promote early development of speech and language. Moreover, bilateral cochlear implants (BiCIs) have become the standard of care for children, in part, to promote better spatial hearing abilities. Many of these children rely primarily on auditory-oral modes of communication to learn and interact with their normal-hearing peers in mainstreamed educational environments. However, not much is known about acquisition of speech and language in this growing population of children.

The present study investigated the relationship between speech and language development and multiple demographic and CI-related factors in 22 children with BiCIs who are functioning in mainstreamed educational settings. The factors of interest included: sex, age at the time of the first CI, maternal education level, hearing age (defined as the amount of time exposed to sound), and bilateral experience. The 22 children, ages 4-9 years, were tested annually for 2-4 years (2 visits (n=3), 3 visits (n=15), 4 visits (n=4)). At each visit, participants were administered the Test of Language Development-Primary (4th Edition) which included subtests that yield standardized receptive and expressive language scores, as well as an overall composite core language score. To control for general intelligence and memory, nonverbal IQ and memory were evaluated using the Leiter International Performance Scale-Revised.

On average, all 22 children with BiCIs scored within the normal range on the nonverbal IQ (mean ± SD=115±12.5) and memory tests (mean ± SD=107.5±11). These scores remained stable across annual visits. Standardized scores for expressive, receptive, and core language improved over time. Preliminary multi-level analyses revealed that (1) a higher maternal education level, and (2) a lower hearing age at the first testing interval were both significant predictors of a faster growth (i.e. improvement) over time in the areas of expressive and core language. In addition, it was found that an earlier implantation of the first CI predicted faster growth in expressive language. No significant predictors were found for the receptive language outcome measure. Previous work from our lab did not show a significant correlation between length of use of the first CI and expressive language (Hess et al., 2014); however, the aforementioned work investigated only one time point. Together results from the current study, along with further investigation of individual growth-curve analyses, are essential to help establish potential benefits for the acquisition of speech and language in children with BiCIs. In addition, results may help in clinical habilitation decision making for families who are considering bilateral cochlear implantation for their child.

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M32: VOICE GENDER RELEASE FROM MASKING IN COCHLEAR IMPLANT USERS IS CORRELATED WITH BINAURAL PITCH FUSION

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Spatial and voice gender separation of target from competing speech leads to substantial release from masking in normal-hearing listeners. However, binaural pitch fusion is often broad in cochlear implant (CI) listeners, such that dichotic stimuli with pitches differing by up to 3-4 octaves are fused (Reiss et al., 2014, JARO 15:235-248). We hypothesized that broad binaural fusion could reduce a listener's ability to separate competing speech streams with different voice pitches, and thus reduce the voice gender as well as spatial benefit. The purpose of this study was to investigate the relationship between binaural pitch fusion and binaural benefits in speech perception in the presence of competing background talkers for CI listeners.

Ten bimodal CI (CI worn with hearing aid in contralateral ear) and eleven bilateral CI adults were recruited for the study. All subjects completed a dichotic fusion range measurement task, in which a reference stimulus (electrode) was presented simultaneously in one ear with a comparison stimulus (tone or electrode) in the contralateral ear, and the comparison stimulus varied to find the frequency/electrode range that fused with the reference stimulus. Speech recognition thresholds (SRTs) in competing speech were measured with stimuli drawn from the Coordinate Response Measure (Bolia et al., 2000, JASA 107:1065-1066), using same or different genders (male or female) of targets and maskers. Two spatial configurations were used: co-location and 60-degrees of target-masker separation.

Overall, SRTs improved with different genders compared to same genders of target and maskers in bimodal CI users, but not in bilateral CI users. No spatial separation benefit was seen in either CI group. As hypothesized, voice gender masking release was strongly correlated with binaural fusion range in bimodal CI users. In other words, listeners with narrow fusion showed greater voice gender masking release than listeners with broad fusion. These results suggest that sharp binaural fusion is necessary for maximal speech perception in concurrent speech sounds in bimodal CI users, but does not benefit bilateral CI users.

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M33: BINAURAL OPTIMIZATION OF COCHLEAR IMPLANTS: DISCARDING FREQUENCY CONTENT WITHOUT SACRIFICING HEAD-SHADOW BENEFIT

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Background. Mismatched place of stimulation between ears can reduce binaural-hearing sensitivity. This is one possible reason that individuals with bilateral (BI) cochlear implants (CIs) or single-sided deafness (SSD) and a CI gain limited binaural benefits (e.g., binaural squelch) compared to normal-hearing (NH) adult listeners. While standard audiological practice is to program each ear individually to maximize monaural CI performance, BI-CI and SSD-CI patients might benefit from a binaural fitting that reallocates frequencies to reduce interaural spectral mismatch. However, such an approach could have a negative side effect by excluding low- or high-frequency information from one ear, thereby reducing head-shadow benefit, the largest and most reliable speech-perception benefit that BI-CIs and SSD-CIs provide. This study examined how much low- or high-frequency information can be excluded from a CI signal in the poorer ear without reducing head-shadow benefits for speech recognition in noise.

Methods. Speech-reception thresholds were measured for fourteen BI-CI and four SSD-CI adult listeners performing sentence recognition in speech-shaped noise. Stimuli were presented using non-individualized in-the-ear or behind-the-ear head-related transfer-function (HRTF) simulations of a maximal head-shadow spatial configuration (speech at 70º on the poorer-ear side, noise at 70º on the better-ear side). For the BI-CI listeners, low- and high-pass filtering were systematically applied to the poorer ear. For the SSD-CI listeners, only high-pass filtering was applied, since the CI frequency allocation would never need to be adjusted downward to frequency-match the ears. Nine normal-hearing adults were also tested using vocoder simulations of BI-CI and SSD-CI listening, with two levels of performance in the poorer ear simulated by adjusting the synthesis-filter slopes (5 or 20 dB/oct). Results were compared to predictions from an existing model of spatial release from masking that uses frequency-specific signal-to-noise ratios, the speech intelligibility index, and a measure of speech-recognition asymmetry between ears.

Results. Head-shadow benefit in all groups decreased in a concave-downward curve with little to no decrease (< 2 dB) from broadband to the 1000-Hz high-pass cutoff and from broadband to the 5000-Hz low-pass filter cutoff. For the CI listeners, model predictions closely matched group-average performance or predicted that slightly more frequency content could be removed without sacrificing head-shadow benefit. Mean broadband head-shadow benefit was greater for the BI-CI group (~14 dB) than the SSD-CI group (~7 dB). CI performance for both BI-CI and SSD-CI groups closely matched the vocoder simulations that included more current spread (5 dB/oct) in the poorer ear.

Discussion. Together, the data and model simulations demonstrate that 1) frequencies below 1000 Hz can be excluded from the poorer ear because with minimal head shadow in this region, the better ear contributes as much or more to speech recognition and 2) frequencies above 5000 Hz can be excluded because of their low importance in the speech intelligibility index. Thus for many BI-CI and SSD-CI listeners, the CI in the poorer ear can be reprogrammed to minimize interaural frequency mismatch without losing the largest and most reliable benefit that the CI provides. Considering the two ears together as a single system, rather than treating each ear individually, can allow for a more optimal bilateral programming solution by discarding redundant frequency content in one ear.

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M34a: COMPARING METHODS FOR PAIRING ELECTRODES ACROSS EARS WITH COCHLEAR IMPLANTS

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Clinically bilateral cochlear implant maps are created by pairing electrodes in the two ears based on the relative distance from the end of the electrode array (i.e., based on electrode number). Better performance may result from pairing electrodes chosen to optimize performance on a binaural task. However, it is unclear if different binaural tasks will yield different optimal bilateral electrode pairs. The goal of this study was to determine if pairing electrodes based on interaural time difference (ITD) sensitivity, interaural level difference (ILD) sensitivity, or pitch matching would yield the same bilateral pairs.

Six bilateral Nucleus users were tested. ITD and ILD sensitivity were measured using a four interval, 2 alternative forced choice paradigm. Participants were presented with four stimuli, where the first and last stimuli always had a zero ITD and ILD. One of the middle two stimuli had a non-zero ITD or ILD. Participants were asked to indicate which stimulus was different. The magnitude of the ITD or ILD was varied adaptively.

For the pitch matching task, an electrode was stimulated first in one ear (reference ear) and then in the second ear (target ear). Participants were presented with a dial that allowed them to move the stimulation location to different locations on the array in the target ear. The process of listener-directed change in the stimulation location in the target ear followed by stimulus presentation was repeated until the participant indicated that the stimulation in both ears yielded the same pitch.

All three measures were acquired with the same 5 reference electrodes spanning the length of the electrode array and multiple comparison electrodes. For each reference electrode, the optimal bilateral pair for ITD and ILD sensitivity was the pair that yielded the lowest threshold. The preliminary results suggest that optimizing for ITD sensitivity, ILD sensitivity, and pitch matching do not result in the same bilateral electrode pairings.

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M34b: INFLUENCE OF BILATERAL FITTING PARAMETERS ON BINAURAL UNMASKING IN BICI USERS

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The ability to detect a target signal masked by noise is improved in normal-hearing listeners when interaural phase differences (IPDs) between the ear signals exist either in the masker or in the signal. To improve binaural hearing in bilaterally implanted cochlear implant (BiCI) users, a coding strategy providing the best possible access to IPDs is highly desirable. Outcomes of a previous study (Zirn, Arndt et al. 2016) revealed that a subset of BiCI users showed improved IPD detection thresholds with the fine structure processing strategy FS4 compared to the constant rate strategy HDCIS using narrowband stimuli. In contrast, little differences between the coding strategies were found for broadband stimuli with regard to binaural speech intelligibility level differences (BILD) as an estimate of binaural unmasking. Compared to normal-hearing listeners (7.5 ± 1.2 dB) BILD were small in BiCI users (around 0.5 dB with both coding strategies).

In the present work, we investigated the influence of binaural fitting parameters on BILD. In our cohort of BiCI users many were implanted with electrode arrays differing in length left versus right. Because this length difference typically corresponded to the distance of two electrode contacts the first modification of bilateral fitting was a tonotopic adjustment by deactivation of the most apical electrode contact on the side with the deeper inserted array (tonotopic approach). The second modification was the isolation of the residual, most apical electrode contacts by deactivation of the basally adjacent electrode contact on each side (tonotopic sparse approach). Applying these modifications, BILD improved by up to 1.5 dB.

Zirn, S., S. Arndt, A. Aschendorff, R. Laszig and T. Wesarg (2016). "Perception of Interaural Phase Differences With Envelope and Fine Structure Coding Strategies in Bilateral Cochlear Implant Users." Trends Hear 20.

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M35: MULTI-ELECTRODE LATERALIZATION USING REALISTIC INTERAURAL LEVEL DIFFERENCES IN BILATERAL COCHLEAR-IMPLANT LISTENERS

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Bilateral cochlear-implant (BICI) listeners rely mostly on interaural level differences (ILDs) to localize sounds. Conventional cochlear-implant (CI) mapping does not take into account possible binaural consequences that can affect the accuracy of ILDs as a cue to sound location, especially for the real world sounds that are broadband stimuli that will activate multiple electrodes. Unlike interaural time differences, processing of ILDs have additional levels of complexity to consider because ILDs produced by the head are not well-behaved functions of azimuth. Namely, these functions are frequency-dependent and non-monotonic. The purpose of this study was to better understand and refine an across-frequency ILD processing model in BICI listeners using ILDs that are naturally produced by the head from free-field sources.

Five bilateral CI listeners using Cochlear-brand devices were tested in a lateralization experiment using direct stimulation. Stimuli were monopolar, 1000-pulses/second, 300-ms, constant-amplitude pulse trains. Thresholds and most-comfortable levels were obtained for five electrode pairs (4, 8, 12, 16, and 20) in each ear using a conventional mapping procedure. Then bilateral stimulation was centered in single-electrode-pair stimulation at 70-80% of the dynamic range. The frequency-dependent ILDs were derived from behind-the-ear (BTE) microphones head related transfer functions from the Oldenburg head-related transfer function (HRTF) library using the bandwidths from a standard frequency-to-electrode allocation table. The ILDs for sources at 0, ±30, ±45, ±60, ±80, ±90° azimuth were converted to current units at the five electrode pairs. The stimuli were presented using combinations of one to five electrode pairs. Twenty trials per condition were measured. The subjects reported the intracranial image lateralization for the single- and multi-electrode-pair stimulation.

An analysis of the stimuli showed that BTE HRTFs produced smaller ILDs than those taken from ear canal measurements. In addition, the BTE HRTFs produced ILDs as a function of azimuth with relatively large non-monotonicities, including a very small ILD at 80° azimuth at all frequencies. When these ILDs were presented to the BICI listeners, the lateralization range was affected by frequency-dependent ILDs, with a trend to increasing lateralization for increasing frequency for the single-electrode-pair stimulation. Non-monotonicities in the single-electrode-pair lateralization functions were also observed. For the multi-electrical stimulation, a centered image at 0° azimuth was preserved for some BICI listeners, while other listeners showed a significant lateralization offset. The multi-electrode-pair lateralization generally followed a linear summation of the single-electrode-pair lateralization. A previously developed numerical model that successful predicts frequency-specific contributions to across-channel ILD processing in BICI listeners will be refined based on these data.

These results suggest that naturally occurring frequency-specific ILDs from BTE microphones produce lateralization percepts in BICI listeners that vary across electrode pairs, and can produce non-centered auditory images for 0° azimuth even after centering of the individual electrode pairs. The reduced lateralization ranges in multi-channel stimulation caused by the inclusion of the small ILDs that naturally occur at low frequencies might explain the variability in localization abilities and speech understanding in background noise in BICI listeners compared to the normal-hearing listeners. Nonetheless, corrective action to these limitations, in terms of novel sound processing strategies and clinical mapping approaches, can be developed based on these results. [Research reported in this publication was supported by the National Institute On Deafness And Other Communication Disorders of the National Institutes of Health under Award Number R01DC014948.]

M36a: AN UPDATED ALGORITHM FOR IMPROVING ITD-BASED LOCALIZATION OF BILATERAL CI USERS USING ENVELOPE ONSET ENHANCEMENT

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Interaural time differences (ITDs) can often assist normal hearing (NH) listeners perceive, locate and understand sounds in noisy and reverberant conditions. While ITD cues were previously shown to help bilateral cochlear implant (BiCI) users localize sounds in reverberant space (Kerber & Seeber, 2013), BiCI users do not enjoy the same degree of benefit as NH listeners and are less sensitive to ITDs. BiCI users can detect ITDs in the temporal envelope of a signal, particularly if that envelope is characterized by deep modulations and sharp onsets. Both characteristics are, however, disrupted by reverberation (Monaghan et al., 2013). Monaghan & Seeber (2016) therefore developed an onset enhancement (OE) algorithm that selectively sharpens and deepens modulations at onsets of peaks in the signal envelope. The algorithm was shown to improve envelope ITD sensitivity for NH individuals listening through a tone vocoder, and for BiCI users (Wijetillake & Seeber, 2015). The algorithm uses knowledge of the short-term direct-to-reverberant ratio (DRR) to select peaks that are dominated by the direct sound rather than reflections and applies enhancements at times derived from the timings of envelope peaks. However, extensive analysis revealed that envelope peak timings do not robustly convey the ITD of a source in reverberant rooms. Therefore, despite showing perceptual benefits, the algorithm itself was not coding ITDs optimally.

Presented here is an updated version of the OE algorithm that additionally estimates the short-term ITD from the signal TFS and adjusts the enhancement timings to encode that ITD. Furthermore, the new algorithm enhances envelope peaks based on the short-term interaural coherence (IC), which, unlike the DRR, requires no a-priori knowledge. The new algorithm was evaluated against the old algorithm and unenhanced processing with regards to the impact on sensitivity to the ITDs of the direct sound in (simulated) reverberation and on speech understanding. The former was assessed with an intracranial lateralization test, the latter with an Oldenburg sentence test. Both tests employed speech stimuli convolved with binaural room impulse responses (BRIR) that simulated conditions in a reverberant rectangular gypsum-walled room. The simulated source-receiver distances of the BRIRs were varied to generate DRRs of 2, -3 and -8.5 dB. The ITD of the direct signal was adjusted, and the interaural level difference (ILD) set to 0 dB, without altering the reflected signals. This ensured that outcomes are not confounded by ILD cues in the direct signal or by shifts in the perceived position of reflections.

Results of the evaluations revealed that the new algorithm significantly improved ITD sensitivity, for all DRRs examined, relative to the old algorithm and unenhanced case, without significantly degrading speech understanding. This provides promise that BiCI users may also gain benefits from the algorithm, and we aim to present results from the ongoing evaluation.

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M36b: VERIFICATION OF THE VIRTUAL SOUND LOCALIZATION SYSTEM FOR HEARING IMPAIRED

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For hearing impaired, cochlear implants or hearing aids have contributed to improving their speech perception. However, especially for those who have sequential bilateral cochlear implants or bimodal hearing aids, there is an increasing demand for assessment of their localization ability. How to set up a simple sound reproduction platform to test their localization ability conveniently and accurately is worthy of investigation. In this study, five sound source reproduction systems have been applied to test localization ability of both normal hearing listeners and hearing impaired listeners. The reproduction systems include a 4-channel speaker array system by vector-based amplitude panning (VBAP) and first-order Ambisonics (FOA), an 8-channel speaker array system by VBAP and FOA, and a 24-channel speaker array system with physical source reproduction. Results show that VBAP have significant superiority over FOA. The 8-channel VBAP system was proved competent to substitute the 24-channel speaker array, providing accurate sound source positioning, less cost, as well as lower complexity.

M37: QUANTIFYING CONNECTIVITY TO AUDITORY CORTEX: IMPLICATIONS FOR CROSSMODAL PLASTICITY AND HEARING RESTORATION

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When one sensory modality is lost, compensatory advantages are observed in the remaining senses. There is evidence to suggest these advantages reflect recruitment of cortical areas that normally process sound. In the cat, crossmodal reorganization of auditory cortex appears to be field specific. While little or no activity is evoked in primary cortical regions by visual and somatosensory stimulation, higher-level fields confer increased peripheral acuity and improved visual motion detection. In order to better understand the changes in neural connections that underscore these functional adaptations, we have undertaken a series of detailed anatomical studies aimed at quantifying and comparing the patterns of connectivity in hearing and deaf cats. A retrograde neuronal tracer was deposited into auditory cortical areas, coronal sections were taken, and neurons showing positive retrograde labeling were counted and assigned to cortical and thalamic areas. Projections within and between sensory modalities were quantified; while some small-scale differences emerge, patterns of connectivity are overwhelmingly preserved across experimental groups within each cortical field examined. This structural preservation has implications for our understanding of the mechanisms that underlie crossmodal reorganization; moreover, it suggests that the connectivity necessary for resumption of auditory function may withstand even lengthy periods of deprivation.

M38: EFFECT OF CHRONIC STIMULATION AND LEVEL ON TEMPORAL PITCH PERCEPTION BY COCHLEAR-IMPLANT LISTENERS

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Presenting a pulse train to one cochlear-implant (CI) electrode produces a pitch that usually increases with pulse rate only up to up to an “upper limit” that is about 300 pps and varies markedly across subjects and electrodes. Animal experiments suggest that the limitation arises at or prior to the inferior colliculus (IC), where neurons entrain to pulse trains up to a certain rate, above which they show only an onset response. This physiological upper limit is sensitive to auditory deprivation, and can be restored (increased) by periods of chronic stimulation (e.g. Vollmer et al, J. Neurophysiol., 2005). We investigated whether the psychophysical upper limit increased in adult-deafened human CI patients following activation of their implant. We therefore tested 9 users of the Cochlear Nucleus CI522 straight array device on the day of activation (“switch on”) and two months later, using 400-ms pulse trains presented in monopolar mode to electrode 16. We used an optimally-efficient pitch-ranking procedure and eight pulse rates logarithmically spaced between 120-980 pps to measure the upper limit of pitch. Two measures controlled for potential practice effects: (i) we included a task – rate discrimination measured using an adaptive procedure and with standard and signal rates centred on 120 pps – that we expected to be less sensitive to chronic stimulation, (ii) each task was tested twice during each session; the reasoning was that practice effects would be at least as large within than between sessions. At the start of each session the levels of each pulse train were set to the listener’s Most Comfortable Level (MCL), and these levels were used for the rate discrimination and pitch-ranking tasks. The upper limit increased significantly between but not within sessions. Performance on the low-rate discrimination task improved significantly between sessions, but the effect size was significantly less than for the upper limit. Both of these findings are consistent with an effect of neural plasticity on temporal coding at high rates. However, subjects set the pulse trains to a higher MCL in the second session, which might explain the increase in upper limit. Indeed, we found that, for a separate set of subjects, performance on both tasks improved with increasing level. Two findings provide tentative evidence against the level-difference explanation: (i) the increase in upper limit did not correlate, across subjects, with the change in MCL between sessions, (ii) a group of seven listeners re-tested after 6 months showed further increases in MCL from 2-6 months that were not consistently accompanied by changes in the upper limit. In addition, we re-tested six subjects after 9 months, using levels similar to those at switch-on. Here, the upper limit did not differ significantly from switch-on, but two listeners still showed improved discrimination despite the softer loudness of the stimuli.

M39a: DEVELOPMENT AND EVALUATION OF AUDITORY NEURAL STIMULATOR FOR ANIMAL RESEARCH

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Restoration of auditory sensory function is allowed via auditory prosthesis like cochlear implant. Some researchers use a neural stimulator try to find out plastic change of auditory nervous system. We designed a fully implantable and cost-effective auditory neural stimulator with 4channels and evaluated its effectiveness and safety.

The device can deliver electrical pulses with given pulse rate, width, and amplitude. It consists of a body and electrode module. The body includes Li-ion battery and memory for stand-alone operation. Users simply turn the implanted device on and off with magnets transcutaneously. A LED, bright enough that light goes through the animal skin, was mounted to indicate operating mode and status. Various types of electrode modules are available. In this study, we adopt electrodes for cochlear implant. The effectiveness and safety of the device were validated after cochlear implantation via EABR measuring and wound observation.

The body size of the device was 3.0 x 2.5 x 5 mm size including an electronic circuit, battery, and package, small enough to be implanted in laboratory rats, rabbits or guinea pigs. There are 4 memory slots for specific configuration storage. The configuration includes the specific pulse rate (20~230 Hz), width (0~630 microsecond/phase), and amplitude (0~2 mA). The activation of auditory brain stem after stimulation was observed. We also assessed the lifetime of it where 150mAh capacity of the battery was included, resulting in 25 days (8 hr/day) when four channels were fully operated, spending up to 700uA current. There was no inflammation or device extraction during the experiment.

The fully implantable neural stimulator was developed and evaluated successfully. The auditory nervous system activated effectively and the device worked reliably about 1 month after implantation. It can be useful for neural stimulation or neuromodulation study.

M39b: AAV-MEDIATED NEUROTROPHIN GENE THERAPY PROMOTES IMPROVED SURVIVAL OF COCHLEAR SPIRAL GANGLION NEURONS IN NEONATALLY DEAFENED CATS

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The efficacy of cochlear implants (CI) likely depends partly upon the survival and health of the cochlear spiral ganglion (SG) neurons, which degenerate progressively following deafness. In early-deafened cats, electrical stimulation from a CI partly prevents SG degeneration, and intracochlear infusion of brain-derived neurotrophic factor (BDNF) via an osmotic pump further improves neural survival. However, high concentrations of BDNF also elicit disorganized, ectopic sprouting of radial nerve fibers, which could be detrimental to optimum CI function due to loss of precise tonotopicity. Further, use of osmotic pumps is not ideal for clinical application. The current study explores the potential use of adeno-associated viral vectors (AAV) to elicit targeted neurotrophic factor expression in the cochlea of normal and deafened cats.

Kittens were deafened prior to the onset of hearing by systemic injections of neomycin sulfate with ABRs showing profound hearing loss by 16-18 days postnatal. At ~4 weeks of age, a unilateral injection of 10μl of AAV2-GFP (green fluorescent protein), AAV5-GFP, AAV2-BDNF or AAV5-GDNF (glial-derived neurotrophic factor) was made through the round window into the scala tympani. For GFP immunofluorescence, animals were studied ~4 weeks post-injection; after AAV-neurotrophic factor injections, animals were studied at 14 or 24 weeks post-injection to evaluate SG and radial nerve fiber survival.

Following AAV2-GFP injections, immunofluorescence showed strong expression of the GFP reporter gene in inner (IHCs), outer hair cells (OHCs), inner pillar cells, and some SG neurons throughout the cochlea. AAV5-GFP elicited robust transduction of IHCs and some SG neurons, but few OHCs and supporting cells were transfected. Data from deafened cats examined 14 weeks after AAV2-BDNF injections showed significant but modest neurotrophic effects, with ~6% higher SG densities (63% of normal after AAV2-BDNF vs 57% contralateral; n=5) and also significantly improved radial nerve fiber survival vs. contralateral controls. Importantly, no ectopic sprouting of radial nerve fibers was observed with AAV2-BDNF. Similar neurotrophic effects on SG survival were elicited by AAV5-GDNF (55% of normal SG density with AAV2-BDNF vs 49% contralateral; n=5), but disorganized, ectopic fiber sprouting into scala tympani also observed in all ears injected with the AAV5-GDNF virus. A further study was then conducted to assess the neurotrophic effects of AAV2- BDNF would persist over a longer post-injection survival periods. Data from cochleae examined 24 weeks after virus injections showed a more substantial effect of AAV2-BDNF on neural survival, with SG density averaging ~14% higher in injected cochleae than in controls (53% of normal vs. 39% contralateral; n=4) and the extended survival time resulting in more severe degeneration in the control ears.

In conclusion, AAV-GFP (both serotypes 2 and 5) elicits GFP expression in IHCs and SG neurons; AAV2-GFP additionally transduced OHCs and some inner pillar cells. A single injection of AAV2-BDNF can elicit sufficient expression of BDNF in the deafened cat cochlea over ~3 months to promote modestly improved SG neuron and radial nerve fiber survival. Further, neurotrophic effects persisted over 6 months and appeared more robust due to progressive contralateral SG degeneration. Similar neurotrophic effects were observed with AAV5-GDNF in deafened cats, but potentially deleterious ectopic radial nerve fiber sprouting also occurred.

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M40a: TEMPORAL INPUT CHARACTERISTICS FROM COCHLEAR IMPLANTS SELECTIVELY DRIVE TEMPORAL PLASTICITY IN THE INFERIOR COLLICULUS

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The temporal patterns of sound in the acoustic environment are critically important for the development of neuronal temporal processing in the immature auditory system, as well as for modifications in temporal processing in the adult system. The present study investigates whether the specific temporal properties of intracochlear electric stimulation (ICES) delivered by a cochlear implant can modify neuronal temporal processing and plasticity in the deaf auditory midbrain.

Kittens were neonatally deafened by systemic injections of ototoxic drugs. Between 6-8 wks of age, animals were implanted with a feline prosthesis in the left scala tympani, and a regimen of continuous, passive ICES was initiated (~4 h/day, 5 day/wk). The temporal fine structure (TFS) rates of passive ICES were selected to be either 1) low (30 or 80 pps, unmodulated); 2) intermediate (300 pps); or 3) high (500-800 pps) relative to the upper range (~300 pps) of temporal following capacity of neurons in the inferior colliculus. Intermediate and high rate carriers (300-800 pps) were 100% amplitude modulated by sinusoids at 30-60 Hz. After several weeks of stimulation, the responses of single neurons in the contralateral central (ICC) and external (ICX) nuclei of the inferior colliculus to unmodulated pulse trains of increasing rates were recorded with metal microelectrodes in anesthetized animals. The principal temporal response parameters of interest were: best repetition rate (BRR), i.e., the stimulus rate that produced the maximum number of phase-locked spikes; cutoff rate (CR) at which the number of phase-locked spikes was 50% of the number at BRR; minimum neuronal response latency and response jitter. Adult animals with prior normal hearing experience served as controls.

In the ICC, passive stimulation with an intermediate TFS rate of 300 pps significantly enhanced neuronal temporal processing as compared to controls, whereas stimulation with both low and high carrier rates had no significant effect on ICC temporal processing. In the multisensory ICX, temporal processing was not affected by the temporal characteristics of the applied signals.

Our findings indicate that the temporal characteristics of ICES can modulate auditory temporal processing in the deaf cat ICC. The observed potential for differential plasticity suggests that, within a clinical setting, passive stimulation in humans with appropriate stimulus repetition rates could provide a means of overcoming temporal processing deficits and perhaps improving outcomes in individuals with poor speech discrimination abilities.

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M40b. EFFECT OF ELECTRODE POSITION ON ELECTROPHYSIOLOGICAL AND PSYCHOPHYSICAL PARAMETERS IN COCHLEAR IMPLANT PATIENTS WITH LATERAL AND PERIMODIOLAR ELECTRODE ARRAYS

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Hypothesis: Electrophysiological and psychophysical parameters are significantly different depending on the distance between the electrode contacts and the modiolus. Using precurved electrode arrays for closer positioning of electrode contacts to the medial wall leads to lower thresholds and a decreased spread of excitation.

Background: The electrode position within the cochlea plays an important role for the interaction between electrode contacts and spiral ganglion cells. It is determined by the form of the electrode carrier. Straight electrode arrays (Nucleus™ 522 „SRA“) are pressed against the lateral wall of the cochlea, while precurved arrays (Nucleus™ 532 „SMA“ and 512 „Contour“) curl around the modiolus and ideally have no contact to the lateral wall. Recent improvements in postoperative CBCT (cone beam computational tomography) imaging resolution now allow accurate determination of the space between each electrode contact and the medial wall of the cochlea and to observe correlations between this distance and electrophysiological and psychophysical measurement values.

Methods: Postoperative high resolution CBCT-images of 30 patients with Cochlear® Nucleus™ 532, 522 and 512 implants were evaluated using the Comet (Cochlea Measurement Tool) program to determine the distance between the 22 individual electrode contacts and the medial wall. During the adjustment week after the initial activation ECAPs, T- and C-levels were measured. The neural spread of excitation (SOE) was determined using spatial masking (SM) with ECAPs and electric field imaging (EFI) was performed to measure the voltage spread.

Results: Novel tools can be used in the evaluation of high resolution CBCT-images to determine individual electrode-modiolus-distances after cochlear implantation. ECAP thresholds, T-Levels, C-Levels and SOE widths are larger with increased distance to the modiolus. These parameters are therefore overall lower and more uniform in perimodiolar arrays compared to straight arrays.

Conclusion: Our results show that the electrode position has a significant effect on both electrophysiological and psychophysical parameters. Low psychophysical thresholds are among other aspects relevant for prolonging battery life. The data gained in this study may be useful in the development of imaging-based cochlear implant fitting strategies.

M41a: INVESTIGATING A MODEL FOR MUSIC COMPLEXITY APPLIED TO MUSIC PREPROCESSING FOR COCHLEAR IMPLANTS

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Music appreciation in cochlear implant (CI) users is generally poor. A strong negative correlation between music complexity and music appreciation was found for CI subjects, i.e. music that was rated less complex, was appreciated more. The effect of complexity reduction on music appreciation was studied with a music preprocessing scheme in which the vocal melody was extracted together with bass/drums, whereas the other instruments were removed or attenuated with an adjustable attenuation parameter (Buyens et al, 2015). In the evaluation of the music preprocessing scheme with CI subjects, a positive correlation was found between the (subjective) music complexity and the preferred attenuation parameter, i.e. with more complex music, the preferred attenuation applied to the other instruments was larger. Based on these findings, it was anticipated that a model for music complexity might give an indication for the preferred attenuation parameter setting. The investigation of music complexity is divided in three parts.

First, a complexity rating experiment with pop/rock music excerpts is summarized and discussed. Fifty song excerpts were played in random order and normal hearing (NH) test subjects were asked to rate the music complexity of the song on a scale from 1 to 100 with a slider in a graphical user interface on a laptop.

Second, different music features are extracted from the pop/rock song excerpts to describe the characteristics of the songs. A linear regression model is developed to describe the (subjective) music complexity by combining the different music features with the results from the complexity rating experiment in the first part.

Finally, the evaluation of the music preprocessing scheme with CI subjects is discussed. The complexity reduction with music preprocessing is validated objectively based on the music complexity model, and an indication for the preferred adjustable parameter setting is proposed.

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M41b: EFFECTS OF COMPRESSION ON MUSICAL SOUND QUALITY IN COCHLEAR IMPLANT USERS

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Cochlear implant (CI) users frequently report poor sound quality while listening to music, although the specific parameters responsible for this loss of sound quality remain poorly understood. Audio compression, which reduces the dynamic range for a given sound, is a ubiquitous component of signal processing employed by both CI and hearing aid technology. However, the relative impact of compression for acoustic and electric hearing on music perception have not been well studied, an important consideration especially given that most compression algorithms in CIs were developed to optimize speech perception.

The CI-MUSHRA is a tool that can be used to assess relative changes in the perceived sound quality of music across increasingly degraded listening conditions, in both CI and normal hearing controls. Previous experiments tested the effect of low-pass and high-pass filter manipulations on music perception. In these studies, CI users had greater difficulty making overall sound quality discriminations than normal hearing controls (Roy et al., 2012). The present study utilizes the CI-MUSHRA to evaluate listener sensitivity to increasing levels of compression applied to music stimuli. In this study, we applied multiple iterations of an aggressive compression algorithm to the music clips in the CI-MUSHRA test using Adobe Audition. Compression was applied with an input to output ratio of 10:1, attack time of 40ms, release time of 150ms and look-ahead of 3ms. The test conditions included 1 iteration, 3 iterations, 5 iterations and 20 iterations sound tokens, with the 20-iteration samples serving as "anchor" stimuli. The compressed excerpts were 5 seconds in length, with 5 clips for each of five common musical genres (i.e., classical, jazz, country, rock, and hip hop). Subjects were also presented with a hidden reference excerpt, which was the original music clip without any additional compression applied. Cochlear implant (CI) recipients (n=7, 11 ears) and normal hearing (NH) listeners (n=10) were asked to rate the sound quality of additionally compressed music as compared to the reference.

Preliminary results indicate that NH subjects were better able to identify the reference, detect the differences between the levels of compression, and rank the "anchor" condition as "much worse" than the reference, as expected. CI subjects had greater variability in their responses and were unable to consistently detect the differences between the various levels of compression. On average, the CI group also rated the "anchor" condition only as "slightly worse" than the reference. Collectively, these preliminary results indicate that CI listeners exhibit less sensitivity to sound quality changes attributable to high levels of compression. These experimental findings may ultimately allow researchers to optimize compression settings and programming parameters responsible for the generally poor music perception observed among CI users.

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M42a: PERCEPTION OF MUSICAL EMOTIONS IN CI RECIPIENTS WITH CONTRALATERAL ACOUSTIC HEARING

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Background:
Cochlear implants (CI) have become very successful in improving hearing performance of patients suffering from severe-to-profound hearing loss or even deafness, in particular regarding speech understanding in quiet. More difficult listening tasks, like perception of emotions in music, however, remain challenging for most CI recipients. Emotion in music is mainly carried by tempo and modality. Due to insufficient pitch discrimination, many CI users are not able to discriminate minor and major chords, and thus, to detect sad and happy emotions via modality. CI recipients with contralateral acoustic hearing, however, might have access to temporal and spectral fine-structure cues and thus, be able to better detect musical emotions.

Materials and methods:
To allow efficient behavioral testing of emotional perception, a new procedure with dedicated stimuli has been developed to assess the benefit of bimodal fitting on emotion perception in music. Stimuli consisted of short melodies (seven tones), chords (three chords) and combinations thereof with different tempi and modality, but same arrangement (violin and piano). Subjects were instructed to listen to pairs of stimuli and indicate which sample sounded happier. A group of normal listeners was used to generate reference data. Normal-hearing listeners had a correct identification rate of almost 100% when non-ambiguous pairs were presented. In order to investigate whether emotional perception of music can be improved by contralateral hearing aids, ten experienced adult CI recipients were fitted with the same hearing aid (Naida Q90 UP) and participated in two acute appointments and a chronic trial between the visits. After an acclimatization phase of least four weeks emotional perception of music was examined when listening with the CI only or together with hearing aid. Individual ratings were compared to reference ratings of normal-hearing listeners and the percentage of correct emotion perception calculated.

Results:
While some subjects had no difficulties at all to rate perceived emotions in this paired-comparison task, others did not hear any differences at all or were not able to make consistent ratings. On a group level, emotional perception of music was significantly improved in the bimodal condition when only modality cues (minor vs. major third) were available.

Conclusion:
The use of a contralateral hearing seems to improve the emotional perception of music in CI recipients by providing additional cues to identify modality of music.

M42b: MUSICAL PITCH DISCRIMINATION WITH A NEW INTERLACED CI CODING STRATEGY

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The Nucleus Implant (Cochlear Corporation) has the possibility to be driven with various coding strategies, e.g. Spectral Peak Coding (SPEAK), Advanced Combinational Encoder (ACE) and Continuous Interleaved Sampling (CIS). N-of-M coding strategies such as SPEAK or ACE do not preserve the full acoustic signal as only a limited number of channels with the highest amplitudes are selected for presentation, often resulting in missing spectral components. This does not appear to be a major problem for speech input because of its relatively low complexity. However, musical tones are comprised of a larger number of spectral components compared to speech, and missing components will lead to misrepresentation and possibly a wrong pitch percept.

A new interlaced coding strategy allows the selection of a larger number of spectral components, thereby better preserving the information of the original input signal, while maintaining the same overall stimulation rate as ACE. The interlaced coding selects stimuli in alternating frames from maximally 11 even or odd numbered channels, representing all 22 channels over time. ACE, in contrast, selects stimuli from a limited number of possible selectable channels out of all 22 channels. As a result, the interlaced coding strategy is potentially able to represent a larger range of input frequency channels and thus preserve important spectral components.

Another aspect of the new coding strategy is that interlacing the even or odd channel stimuli in time could help to reduce interactions from immediately adjacent channels. This differs from ACE, which tends to select its stimuli in clusters of adjacent channels.

The new interlaced coding strategy has been implemented with MATLAB using the Nucleus Implant Communicator (NIC) software library, which also includes an implementation of ACE. The output stimulus sequences are sent to and processed by a neural based CI simulation vocoder (El Boghdady et al., 2016) for presentation to normal hearing listeners. The enhanced signal representation with the new interlaced coding strategy was tested and compared to ACE with pitch discrimination involving musical tones in a just-noticeable difference (JND) task (Sek et al., 1995). Results will be presented at the conference.

It is expected that interlaced coding will improve the ability to perceive pitch changes to yield smaller JNDs due to less misrepresentations of spectral components. Further investigations are planned with the same pitch discrimination task for CI patients by direct streaming of the NIC/MATLAB sequences.

M43: MUSIC TRAINING AND ITS EFFECT ON SPEECH PERCEPTION FOR CHILDREN WITH COCHLEAR IMPLANTS

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Introduction: Cochlear implant (CI) recipients have difficulties in a range of auditory tasks including: speech-in-noise (SIN), prosody (inferring emotional content and linguistic distinctions such as questions or statements), and music perception. As such, formal auditory training has been proposed as a means of providing effective (re)habilitation, and recent attention has been focused on music training. This has been driven largely by numerous normal-hearing musician studies indicating a wide range of benefits to cognitive abilities, SIN, and prosody. The number of studies investigating the benefits of music training for adult CI recipients are modest; and minimal for paediatric CI recipients, though there have been significant results indicating music training improves some elements of speech perception—most notably prosody.

The aim of this study is to evaluate the effect of music training on music perception and speech perception for paediatric CI recipients.

Methods: The design is a pseudo-randomised, longitudinal study with a delayed control group. The duration of music training is 12 weeks, consisting of weekly music therapy sessions and interactive music apps 3 times a week. Testing occurs at pre (double-baseline), mid, post-training, and follow-up.

Participants are pseudo-randomly assigned to one of two groups (families can opt for the alternate group if they have planned commitments that would disrupt their attendance). When Group 1 begins their training, Group 2 acts as a delayed control during this time, before commencing their own music training program. This design allows for a between-subject and within-subject comparison of music training, providing a baseline of developmental changes in Group 2 (delayed control group) compared against training changes in Group 1.

The test battery includes: the Clinical Assessment of Music Perception (CAMP) (pitch and timbre perception), Australian Sentences Test in Noise (AusTIN), Spectral-temporally modulated ripple test (SMRT), and prosody tests of emotion (happy/sad, and angry/scared) and reception (question/statement). All tests were presented in random order.

Results: Presently the study is at the initial phase, and double-baseline data from six paediatric CI recipients aged between 6 and 9 years old from Group 1 has been collected. One-way repeated measures ANOVA of double-baseline data indicate no significant difference between any test item, indicating good test-retest reliability and minimal practice effects. Correlations between all test items indicated that only timbre perception and SIN ($r = -8.12$, $p = 0.05$) was near significance, and timbre perception and prosody perception ($r = 0.869$, $p = 0.03$) was statistically significant.

Conclusion: While previous studies have indicated that pitch perception would be the musical percept most relevant to speech perception, our preliminary data suggests that timbre perception is a more robust predictor of speech perception abilities for children with CIs. More participants are currently undergoing training and testing, and an up to date dataset will be presented at this meeting.

M44: MULTIPLE PITCH PERCEPTION WITH LIMITED SPECTRAL RESOLUTION: IMPLICATIONS FOR COCHLEAR IMPLANTS

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Cochlear-implant (CI) listeners typically perform poorly in complex pitch perception tasks. This limitation in performance is thought to be mainly due to the restricted number of active channels and the broad current spread that leads to channel interactions and subsequent loss of precise spectral and temporal information. We previously carried out a series of experiments using a noise vocoded melody perception task where we systematically varied the number of channels as well as the spread of excitation by varying the slope of the vocoder filter bands. Our results indicated that the number of channels required to extract complex spectral pitch is much greater than found in previous studies. For conditions with non-overlapping channels, a minimum of 32 channels was required to accurately perceive spectral pitch. However, the factor of greatest importance is the amount of spectral overlap between channels (equivalent to current spread in CI). For symmetric vocoder filters, even with 64 channels, melodic pitch perception was not achieved with filter slopes of 72 dB/octave or less.

Our melody perception task had single tones played in a sequence; hence listeners were required to only perceive a single pitch at any given point in time. In music, however, one often is exposed to multiple pitches simultaneously. It is unknown whether greater spectral resolution is required to perceive more than one pitch simultaneously. To answer this question we presented listeners with a sequence of repeating single tones, with the final tone either increasing or decreasing in frequency (or F0). The final tone was combined simultaneously with two interfering tones, selected from within the same octave as the target tone. The task was carried out for both pure and complex tones. All the tones were noise vocoded with either 32, 48 or 64 non-overlapping channels.

Our preliminary results show that the resolution required for perceiving multiple pitches is comparable to our previous results found for single tone pitch perception. Given that the perception of multiple pitches is fundamental to the perception of music, these results further suggest that spectrally based pitch for music is unlikely to be generated in CI users without a substantial change in technology or and/or site of stimulation. The results highlight the limitations of pitch perception in current CIs, in addition to shedding light on the cues that the normal (acoustic) auditory system uses to perceive multiple complex pitches.

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M45: MUSICAL EMOTION RECOGNITION WITH NORMAL HEARING AND COCHLEAR IMPLANTS

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Music is powerful in evoking emotions. This study investigated the recognition of emotions in music by normal-hearing (NH) listeners and cochlear implant (CI) users. The following questions were asked: 1. how is musical emotion recognition affected by musicianship in NH listeners? 2. Does bimodal fitting (i.e., the use of a hearing aid in the non-implanted ear) improve musical emotion recognition for CI users? 3. What is the contribution of tempo and mode cues to musical emotion recognition? 4. Is musical emotion recognition affected by instrument timbre? 5. How is musical emotion recognition related to pitch ranking, tempo ranking, and vocal emotion recognition?

To answer these questions, musical emotion recognition, vocal emotion recognition, pitch ranking, and tempo ranking were tested in NH listeners (both musicians and non-musicians) and CI users (both with and without a hearing aid in the non-implanted ear). In the vocal emotion recognition test, a male and a female talker each produced ten semantically neutral sentences in angry, happy, sad, and anxious emotions (Luo et al., 2007). Similar to the vocal emotion recognition test, the musical emotion recognition test (Hailstone et al., 2009) had ten melodies composed to express each of the four emotions (angry, happy, sad, and fearful). These melodies were played with piano, violin, trumpet, and organ. In the tempo-normalized condition, all the melodies were normalized to have the same tempo, while in the mode-changed condition, all the melodies were changed to their opposite modes (major to minor and vice versa). Pitch ranking was tested for harmonic complex tones with a nominal fundamental frequency of 174.6 Hz. Tempo ranking was tested for a standard tempo of 150 beats per minute.

It was found that musicians had significantly better pitch ranking, tempo ranking, and musical (but not vocal) emotion recognition than non-musicians. In addition, musicians were more sensitive to the mode changes in melodies than non-musicians. Both musicians and non-musicians recognized happy and sad emotions better than angry and fearful emotions in music. Different instruments did not make a significant difference in musical emotion recognition for musicians and non-musicians. Musical emotion recognition scores were significantly correlated with pitch-ranking thresholds for non-musicians. CI users had significantly poorer musical emotion recognition, vocal emotion recognition, and pitch (but not tempo) ranking than NH listeners. Bimodal fitting did not significantly improve CI performance in any of the tests. CI users were not significantly affected by the manipulations of tempo and mode cues when recognizing musical emotions, possibly due to the floor effects. They recognized sad emotion significantly better than angry, happy, and fearful emotions in music, similar to the pattern in their vocal emotion recognition. CI users' musical emotion recognition was significantly better with piano and trumpet than with violin and organ. This was in strong contrast to the effect of instrument timbre on melodic contour identification with CIs (Galvin et al., 2008). Finally, for CI users with bimodal fitting, musical emotion recognition scores were significantly correlated with tempo-ranking thresholds and vocal emotion recognition scores.

M46a: CONGRUENT TIMBRE CUES IMPROVE MELODIC CONTOUR IDENTIFICATION WITH COCHLEAR IMPLANTS

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Melodic contours (or the pitch change directions between successive musical notes) contribute to the perception, appreciation, and memory of melodies. Cochlear implant (CI) users' deficits in music perception are partially due to their poor melodic contour identification (MCI). Musical notes elicit both pitch perception associated with the fundamental frequency (F0) and timbre perception such as sharpness associated with the spectral slope. Our previous study showed that CI users' pitch ranking sensitivity was significantly affected by the congruency of simultaneous sharpness (spectral slope) changes with similar perceptual salience. This observation led to the hypothesis of this study, i.e., MCI with CIs may improve with congruent spectral slope changes than with no spectral slope changes, and in turn, than with incongruent spectral slope changes.

CI users were tested with their clinical CI devices in one ear. F0 difference limens (DLs) for nominal F0s of 220, 440, and 880 Hz (i.e., the middle F0s of melodic contours, see below), and spectral slope DLs for a nominal slope of -8 dB/octave (i.e. the middle spectral slope of melodic contours) were measured using a 2-alternative, forced-choice (2AFC) task with a 2-down/1-up adaptive procedure. MCI was then tested using a 9AFC task (Galvin et al., 2007). Each melodic contour had five notes with one of nine contour patterns (e.g., rising, rising-flat, rising-falling, etc.). Each note was a 500-ms harmonic complex tone up to 4 kHz with 20-ms onset and offset ramps. The intensity of each note was either fixed at 65 dBA or roved by ±10 dB. The middle note of each contour had an F0 of 220, 440, or 880 Hz. The pitch interval between successive notes was 1, 3, or 5 semitones. Thus, there was a total of 81 melodic contours (3 middle F0s × 3 pitch intervals × 9 contour patterns). In the condition with no slope changes, each note had the same spectral slope of -8 dB/octave. In the condition with congruent slope changes, the spectral slope changed in the same direction as the F0 from note to note, while in the condition with incongruent slope changes, the spectral slope changed in the opposite direction as the F0. The middle note of each contour always had a slope of -8 dB/octave. The spectral slope change between successive notes had the same multiple of individual DLs as the pitch interval, so that the sharpness and pitch changes were similarly salient. Different cue conditions were tested in random order.

Results showed that the MCI scores of CI users were significantly affected by both intensity roving and spectral slope changes. There was also a significant interaction between intensity roving and spectral slope changes. MCI significantly degraded with than without intensity roving. When there was no intensity roving, congruent spectral slope changes significantly improved MCI, while incongruent spectral slope changes significantly worsened MCI, as compared to no spectral slope changes. When there was intensity roving, MCI was only significantly better with congruent than with incongruent spectral slope changes. MCI improved with larger pitch intervals and the pattern across the spectral slope conditions was similar with the different pitch intervals.

M46b: EFFECTS OF A NOVEL SOUND PROCESSING STRATEGY ON MUSIC PERCEPTION AND ENJOYMENT IN COCHLEAR IMPLANT USERS

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Introduction. With the considerable advances made in cochlear implant (CI) technology with regard to speech perception, it is natural that many CI-users and -candidates express hopes of achieving music enjoyment. However, due to limitations in the sound transmission, music listening with a CI is challenging, leading to reduced music perception and enjoyment for CI users.

A crucial element in a CI is the sound processing strategy which usually integrates automatic gain control (AGC) with the purpose of adaptively reducing input dynamic range (IDR) at the front-end. However, this input compression approach may result in losses in soft sounds and distortions in loud sounds which eventually could lead to lost information. A new back-end output compression system (VoiceGuard) from Oticon Medical (OM) operates with a continuously wide IDR which has previously been proven beneficial for CI users. Thus, this strategy could provide a better listening experience, and possibly augment music enjoyment for CI users.

Aims. This study aims to test whether a CI-sound processing strategy based on back-end multi-channel output compression (VoiceGuard) significantly augments music appreciation and enhances accuracy in discrimination of details in music compared to an input compression method, as measured electrophysiologically with EEG and behaviourally with a discrimination test. The tests will be performed shortly after switch on and again following three months of CI experience to study the auditory development.

Methods. Using electroencephalography and an adapted no-standards musical multifeature paradigm, we will record the mismatch negativity (MMN) response to four different deviants (pitch, intensity, timbre, rhythm) presented in four levels of deviation magnitude. As an additional measurement, EEG-recordings will be performed using a free-listening paradigm with entire pieces of music, with and without lyrics. A complimentary multifeature music discrimination test will be presented to investigate the participants' ability to perceive the deviants when attention is directed towards the stimuli. Sound will be presented through an audio cable, and all tests will be carried out twice using the input and output compression strategy, respectively. Preprocessed audio files will be used for the input compression condition.

Furthermore, participants are required to complete a Danish version of the IOWA Musical Background Questionnaire to survey music habits, experience and enjoyment.

Participants include OM implant users as well as users of Cochlear, Advanced Bionics and Med-EL brands. The comparison between input and output compression will be assessed only in OM patients, whereas the auditory development can be studied in all participants. Normally hearing controls will provide reference data. In addition to the primary target group, a group of experienced CI-users will be included in the study to validate the newly developed paradigms and tests.

Results. Preliminary results from all target groups are expected to be available for presentation at the conference.

Perspectives. This study offers the capacity to guide the development of novel sound processing strategies in CIs, which may improve perception of music in CI recipients and, as positive side-effects, even their perception of details in speech and quality of life. In a wide perspective, the results may represent a substantial step forward in the development of CI outcome, impacting daily life of CI users worldwide.

TUESDAY POSTER ABSTRACTS

T01a: CHARTING DEVELOPMENTAL CHANGES IN AUDITORY AND VISUAL EVOKED POTENTIALS IN CHILDREN WITH COCHLEAR IMPLANTS

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Cochlear implant (CI) technology has made great strides over the past thirty years and has enabled deaf children to acquire spoken language skills. However, there remains a large amount of variability in language outcomes. Current research has questioned whether differential weighting of auditory and visual processing may underlie inter-individual variability in language development. We have begun a longitudinal study to address this question. A novel electroencephalography (EEG) approach allows us to rapidly and simultaneously record auditory and visual evoked potentials in children. We present results from our first year of data collection, involving normal hearing (NH) children (n=26) and children with CIs (n=18), who ranged in age from 21 months to 8 years. In response to a continuous speech stimulus, the NH children showed significantly larger auditory evoked potentials (i.e., P1 and N1) than the children with CIs. Developmental changes in the P1 as a function of age and time in sound were observed for NH children, but not in children with CIs. In contrast, developmental changes in the N1 were observed in the CI group, but not in NH children. Visual evoked responses to high-contrast visual checkerboard stimuli showed no significant group differences. We discuss the implications of these findings in relation to the expression of cortical cross-modal plasticity and spoken language development. Funding from NIH-NIDCD supported this research (R01DC014767).

T01b: ENVELOPE FOLLOWING RESPONSES IN COCHLEAR IMPLANTS.

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Introduction: Neural processing of the envelope of sounds is important for speech understanding. Auditory steady state responses (ASSRs) or envelope following responses (EFRs) are electrophysiological methodologies to quantify the sensitivity to amplitude modulations, the response amplitude as a function of the frequency of the fluctuation. This is the temporal modulation transfer function (TMTF), which can be considered a building block for the speech and music envelope.

By measuring ASSRs for many discrete modulation frequencies, the TMTF can be approximated. However, determining the TMTF with ASSR is time-consuming, because it demands measuring a response for many discrete frequency values. Therefore, the use of continuous sweeps, for which amplitude modulation frequency varies over time, is more appropriate. This provides more detailed insight into the TMTF, while preserving time-efficiency. Brain potentials evoked with this type of stimuli can be identified as envelope following responses (Artieda et al., 2003; Purcell and John, 2004; Dimitrijevic, John, Picton, 2004). Investigation of EFRs allows to trace the maturation of the auditory pathway in the brain. Moreover, the nature of measured responses can be linked to brain oscillations and speech perception.

Gransier et al. (2015) recently obtained TMTFs in cochlear implant users by measuring ASSR. This study revealed individual-specific fine structure in the TMTF r frequencies in the 1- 20 Hz range and decrease in responses for high modulation rates (80-100 Hz).

Objective: The objective of this study is to investigate envelope following responses to continuous stimuli with changing amplitude modulation frequency, in a range of frequencies relevant for speech and music. Results for cochlear implant users are compared with those of normal hearing subjects. The EFR at specific modulation frequencies (phoneme rate, syllable rate) will be used as an objective measure to assess the progress of rehabilitation, and will allow to monitor the process of the auditory maturation in cochlear implant users.

Methods and results: Electrically evoked envelope following responses were measured in EEG (electroencephalography) recordings. At the conference, results obtained for 2 cochlear implant users will be compared with data from five normal hearing subjects that participated in this study

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T02a: ANALYZING THE CURRENT DISTRIBUTIONS OF THE MULTI-MODE GROUNDING COCHLEAR STIMULATION

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Introduction: Modern cochlear implants can adopt different stimulation modes in order to achieve the predicted current distribution in the inner ear. While the Monopolar mode forces the current to return to a reference electrode placed between the skull and scalp in order to reduce the energy consumption, the common ground mode allows the current to return to all non-stimulating electrodes of the array in order to achieve better focusing.

The Multi-Mode Grounding (MMG) is provided by Oticon Medical. This mode combines both Monopolar and common ground modes with the assumption that MMG leads to an optimized balance between efficiency and focus. However, the current distribution of this stimulation mode has not yet been studied.

Objectives and methods: The present study uses both experimental measures and simulations to estimate the current flow into a 3D cochlear model. This procedure was more specifically used to evaluate current spread with MMG stimulation. The proportion of returning current on each pathway during MMG stimulation was acquired through a XP implant produced by Oticon Medical implanted in a dead human specimen . During each stimulation, the current waveform on all non-stimulating electrodes was recorded, resulting in a map of the returning current distribution in relation to the place of stimulation in the cochlea. The measured current distribution was finally used as an input parameter in a 3D cochlear model to simulate the current field across the inner ear, especially at the position of the auditory nerve fibers. This model was previously used to estimate the current pathways of the Monopolar and bipolar stimulations.

Results: This combination of experimental measurements and simulations provided a powerful and easy tool to estimate the current pathway into a 3D modeled cochlea. While the Monopolar and the bipolar lead respectively to the largest and smallest current patterns, the MMG current spread was shown to be in between.

T02b: SPEECH PERCEPTION OUTCOMES IN OLDER ADULTS WITH COCHLEAR IMPLANTS: PERIPHERAL VERSUS CENTRAL-AUDITORY CONTRIBUTIONS

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A growing body of literature indicates that older adults gain significant benefits from cochlear implants (CI), however, controversy exists as to whether speech perception performance of older adults is comparable or poorer than that of young adults. Analysis of speech perception data obtained from 32 older (60-80 years) and 31 young (29-59 years) CI recipients implanted at the Sheba Medical Center and matched for duration of deafness, revealed significantly poorer performance in older recipients in monosyllabic, two-syllable, and sentence tests in quiet. In the current study, we sought to explore peripheral and central-auditory and cognitive factors that may explain this difference in outcomes between older and young CI recipients. Peripheral function was assessed by means of MAP variables including behavioral thresholds, comfortable levels, dynamic range, and electrical compound action potentials (ECAP) thresholds. Central-auditory and cognitive function was explored by means of event-related potentials elicited during a high-load auditory Stroop task. Results indicated comparable thresholds, comfortable levels, and ECAP thresholds between the groups. A trend for wider dynamic range in young CI recipients was evident, however, correlation between dynamic range and speech perception performance was weak and not significant. In contrast, aberrations in auditory-cognitive processing were evident in older compared to young CI recipients and manifested in prolonged perceptual and post-perceptual processing (prolonged P3 latency and reaction time), decreased ability to inhibit processing of irrelevant stimuli (reduced prevalence of N4), and a differential conflict processing strategy. Taken together, aberrant auditory-cognitive processing in older adults contributes to the significant differences in speech perception outcomes between older and young CI recipients.

T03a: COMPARISON OF ARTIFACT SUPPRESSION METHODS FOR THE MEASUREMENT OF ELECTRICALLY EVOKED AUDITORY STEADY- STATE RESPONSES

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Electrically evoked auditory steady-state responses (EASSRs) are currently being investigated for objective cochlear implant (CI) fitting, the development of stimulation strategies, and studying auditory maturation and plasticity in CI subjects. EASSRs can be detected in the electro-encephalogram (EEG) in response to periodic (modulated) pulse trains presented through the CI. However, the EEG is obscured by electrical artifacts, that may also be present at the response frequency and that are caused by (1) the implant's radiofrequency link, and (2) the electrical stimulation pulses. Their characteristics are subject and stimulus dependent, and vary depending on the stimulation mode.

A number of CI artifact suppression methods have been developed in our lab, with the aim of suppressing CI artifacts in all recording channels for clinically used high-rate stimulation in monopolar mode. The first method is based on a linear interpolation over the CI artifact duration. The underlying assumption is that the CI artifact is short enough such that for each stimulation pulse two samples free of CI artifact can be found. The second method is based on independent component analysis. It is assumed that CI artifacts and EASSRs are statistically independent, such that they can be separated by minimizing the mutual information. The third method is based on template subtraction: templates are constructed for each subject in every recording channel, based on a response-free measurement. The constructed templates are subsequently subtracted from the recording of interest. This single-channel method has the potential of suppressing CI artifacts in EASSR measurements, without imposing many assumptions on the CI artifact morphology, and only assuming that CI artifacts are stationary within one recording session.

The three CI artifact suppression methods have been applied to the same dataset, consisting of EASSRs with high-rate stimulation in monopolar mode at comfort level for various modulation frequencies in the 30-50 Hz range. The performance of each method and trade-offs will be discussed. As expected, the linear interpolation method cannot sufficiently suppress CI artifacts in ipsilateral recording channels for high-rate stimulation. The second method, based on independent component analysis, can reliably suppress CI artifacts in ipsi- and contralateral channels in case the contralateral hemisphere is response dominated. However, a multichannel EEG acquisition system is needed. The third method, based on template subtraction, reliably suppresses CI artifacts in ipsi- and contralateral channels for high-rate stimulation at comfort level in monopolar mode.

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T03b: OBJECTIVE MEASURES TO ASSESS DIRECT ACOUSTIC COCHLEAR IMPLANT FUNCTIONING: ARTIFACT CHARACTERIZATION AND INTRA-OPERATIVE ABR AND ASSR MEASUREMENTS

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Direct Acoustic Cochlear Implants (DACIs) are used to treat severe to profound mixed hearing loss. An actuator in the middle ear is coupled via a stapes prosthesis to the inner ear, and directly vibrates the cochlear fluid. Confirming proper DACI coupling, crucial for its functioning, is challenging for ENT surgeons. Currently, the movement of the actuator is verified intra-operatively using laser doppler vibrometry (LDV), requiring specific technical skills. Furthermore, LDV movement measures at the actuator rod do not confirm correct DACI coupling or adequate auditory processing.

In [1], it was shown that auditory brainstem responses (ABR) and steady-state responses (ASSRs) can be obtained post-operatively from DACI subjects. ABRs and ASSRs could possibly be used intra-operatively, to verify correct DACI functioning and coupling. If ABRs and ASSRs can be recorded, the DACI is effectively stimulating the cochlear fluid, and auditory processing beyond the periphery is confirmed. However, the radiofrequency (RF) link between the DACI's external and internal parts causes electrical artifacts, obscuring the ABR and ASSR. The actuator possibly also causes electrical artifacts, obscuring the EEG, although it was shown in [1] that the actuator did not cause visible artifacts in a simple bench set-up.

The aim of the current study is to characterize the DACI artifacts, and to use ABRs and ASSRs intra-operatively to confirm correct DACI coupling and evaluate auditory processing beyond the periphery.

In this study, the electrical artifacts resulting from DACI stimulation were measured on a fresh-frozen cadaver head, with the aim of better characterizing, modeling and removing DACI artifacts. In this realistic set-up, it was possible to disentangle RF and actuator artifacts, and no background brain noise or evoked responses were present. Measurements show that both the RF and the actuator cause electrical artifacts, although actuator artifacts are of negligible size for intermediate stimulation levels.

Furthermore, ABRs and ASSRs were measured in three subjects under general anesthesia, immediately after DACI implantation. Click stimuli were presented directly to the implant with stimulation frequencies in the 40Hz and 90Hz range at various stimulation levels. For stimulation in both frequency ranges, clear ABR peaks V were observed and ABR thresholds could be estimated. Significant steady-state responses were measured for 33Hz stimulation and for 90Hz stimulation, allowing electrophysiological threshold estimation.

In this study, we obtained reliable electrophysiological responses beyond the periphery intra-operatively to confirm DACI coupling.

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T04: MEASURING COCHLEAR IMPLANT CHANNEL INTERACTIONS WITH ELECTRICAL AUDITORY BRAINSTEM RECORDINGS (EABRS) AND THEIR RELATIONSHIP TO SPEECH PERCEPTION OUTCOMES.

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Introduction: Electrical interactions across electrodes of cochlear implant (CI) are limiting the number of independent spectral channels actually available to users and could explain a large amount of the interindividual variability of outcomes observed. The distribution and efficiency of individual spectral channels could be improved by using dedicated mapping or stimulation strategies if these interactions could be well quantified.

Objective: This work aimed to test the hypothesis that electrical Brainstem Responses (eABRs) could be used to estimate the electrical crosstalk. EABR measurements were then used as a metric and compared to individual speech perception outcomes to ensure that this method could be used as a prognostic tool relating speech intelligibility to channel interactions.
Methods: In this series of experiments, we measured the monaural interaction component (MIC), defined as the ratio observed in Wave-V amplitudes obtained either: 1) from the addition of wave-V amplitudes acquired by stimulating individually different electrodes (individual condition), or 2) from the wave-V amplitude triggered by the simultaneous stimulation of the same electrodes (simultaneous condition). 16 post-lingual deaf adults took part in two eABR recording sessions. In the first experiment, we studied the pattern of eABRs obtained by stimulating three adjacent electrodes. The individual condition was compared to a simultaneous condition in which the stimulation amplitude of the middle electrode was varied from 0 to 100% of its electrical dynamic range. In a second experiment, eABRs were derived from individual or simultaneous stimulations from four distant electrodes at 70% of their individual dynamic. The MIC obtained from each participant in this condition was then compared to individual performances of speech recognition, evaluated using a logatome recognition test (64 vowel-consonant-vowel items, forced choice among 16 responses).

Results: In experiment 1, increasing the amplitude of the stimulation applied on the middle electrode in a group of three progressively reduced the composite ABR relatively to the sum of the three independent ABRs, confirming that proximal channel interactions could be directly quantified by the MIC. In experiment 2, a significant correlation was found between speech recognition performance and the MIC values (Pearson’s linear regression model, parametric correlation: $R2=0.33$, $p<.05$; $n=16$; non-linear regression model: $R2=0.47$, $p<.05$).

Conclusion: Results from these experiments demonstrate that electrical cross-talk across cochlear implant electrodes can be quantified using eABR measurements and that this metric can partially explain speech outcomes.

T05: EPIDURAL RECORDINGS OF AUDITORY EVOKED POTENTIALS IN COCHLEAR IMPLANT USERS

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Introduction: On the long term it is desirable for cochlear implant (CI) users to control their device in a closed loop via brain signals. A possible application is the active or passive selection of speech coding strategies or preprocessing algorithms. A promising approach is the use of auditory evoked potentials (AEP) and previous studies have shown the possible suitability of auditory paradigms [1]. However, these investigations are based on non-invasive signal acquisition which requires the use of additional EEG electrodes mounted on the users scalp [2]. For CI users in an everyday life application it is more convenient to use implanted electrodes for recording the signals. Further it is to be expected that invasively recorded signals are of higher quality and are less affected by movement artefacts. Permanently implanted electrodes would also allow for a monitoring of maturation of the auditory system following the CI implantation. First invasive recordings within CI surgeries were already done in the early years of CIs [3]. However, under the influence of anesthesia cortical potentials cannot be recorded reliably.

Method: In this project, we investigate the feasibility of implanting epidural electrodes temporally during the CI surgery and the possibility to record AEPs in the course of several days when the patient is awake again. Intraoperatively E-ABR and E-MLR are recorded, postoperatively different kinds of AEP (ABR, MLR, CERA, MMN, P300). After a few days the epidural electrodes are removed.

Results: First data sets of eight patients were obtained which show promising results. The recorded potentials were compared to the clinical standard recordings using adhesive electrodes. Especially cortical evoked response audiometry (CERA) depicted clearer N100 waves which were also visible at lower stimulation intensities. Furthermore the signal was less disturbed by artefacts [4].

Conclusion: Altogether the approach is feasible, safe and well tolerated by the patients, and the AEP waves are clearly recognizable.

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T06a: COMPARISON OF RESULTS BETWEEN THE BEHAVIORAL MEASURES AND OBJECTIVE MEASURES TO IDENTIFY AUDITORY TEMPORAL AND SPECTRAL RESOLUTION IN COCHLEAR IMPLANT USERS

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This study examines an objective method using the electrically acoustic change complex (eACC) response to evaluate the performance of auditory temporal and spectral resolution in cochlear implant users. The purpose of this study was to compare the relationship of between objective measure and behavioral psychoacoustic measure.

Five cochlear implant users participated in the study. All subjects involved in both behavioral psychoacoustic and objective measures to evaluate the performance of auditory spectral and temporal resolutions. The behavioral psychoacoustic measures consist of spectral modulation detection test and temporal modulation detection test. The objective measures separate to two sessions. The first session is to measure the threshold of eACC response to a change in the temporal gap duration after onset. The second session is to measure the threshold of eACC response using a change in the stimulating electrode. The stimulus for the objective measure has 'change' in the stimulus at 400ms after onset. The eACC was recorded using surface electrode located Cz. Two to five recordings of 50 sweeps were acquired for each stimulus condition and averaged waveforms were analyzed.

The eACC responses were successfully recorded from all participants with stimulus via Nucleus Implant Communicator (NIC) streaming. The relationship between behaviorally and electrophysiologically obtained thresholds was analyzed. The correlations between the two measures for each auditory resolution were 0.72 and 0.9, respectively, but, there are no significant relationships ($P>0.05$). Further studies are necessary to determine and confirm this idea. Preliminary results of this study demonstrate that it is possible to discriminate the auditory resolution in CI users using an electrophysiological method.

T06b: FREQUENCY FOLLOWING RESPONSES IN COCHLEAR IMPLANT USERS

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For acoustic stimulation, auditory processing at brain stem level can be investigated through frequency following responses (FFRs). FFRs are auditory evoked electroencephalogram (EEG) potentials, generated by the brain stem, that literally follow the frequency of the evoking stimulus. Measuring FFRs for cochlear implant (CI) users is challenging, as the electrical stimulation of the CI causes large artifacts in the registered EEG signal. These artifacts obscure the neural response and moreover, can be mistaken for a response. Previously, our lab has developed a method to reliably measure cortically dominated auditory evoked potentials in CI users, i.e., electrically evoked auditory steady-state responses (EASSRs). There, the same problem was solved through a number of artifact reduction techniques (a.o. based on blanking and interpolation ([1], [2]□)). We investigate (adaptations of) these techniques to allow the measurement of electrically evoked frequency following responses (EFFRs) as well.

A first attempt to measure EFFRs was part of a previous study in our lab, which investigated the effect of modulation frequency (1-100 Hz) on auditory evoked EEG potentials [3]□. Cortical areas of the auditory system do not phase-lock to modulation frequencies as high as 80-100 Hz. As a result, auditory responses to these fast modulations are strongly dominated by activity at brain stem level. In this study very few significant responses were found for modulation frequencies between 80 and 100 Hz, but measuring EFFRs was not the focus of the research.

The goal of the current study was to verify the feasibility of measuring EFFRs with high-rate amplitude modulated pulse trains (modulation frequencies of 80 and 100 Hz) and unmodulated low-rate pulse trains (pulse rates of 80 pps and 100 pps). In contrast with the previous study, results show that significant EFFRs can be measured in response to both the amplitude modulated and low-rate electrical pulse trains for stimulus frequencies of 80 Hz and 100 Hz (and even up to 500 Hz in pilot studies). Moreover, low-rate pulse trains seem to cause responses with higher amplitudes and signal-to-noise-ratios than amplitude modulated pulse trains, confirming expectations based on pilot studies in normal hearing subjects. Final results and conclusions will be presented at the conference.

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T07a: DISCRIMINATION OF LING 6 SOUNDS USING ACOUSTIC CHANGE COMPLEX (ACC)

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LING 6 sounds have been widely used to validate cochlear implant programming and hearing aid fittings. They are used with hearing impaired children both for detection or discrimination tasks. Testing is quick, flexible, requires minimal training to administer and has strong face validity. However, for some individuals behavioral testing is not possible. The goal of the present study was to test the feasibility of using LING 6 sounds to elicit the acoustic change complex (ACC). This is a cortical auditory evoked response that can be elicited from both children and adults in a passive listening paradigm. In the present study we opted to use stimulation and recording paradigms that could be used in clinical settings. Toward that end, we used a limited set of recording electrodes and a stimulus that consisted of a string of LING 6 sounds that were presented in the sound field at a normal conversational level. We hypothesized that if the listener could discriminate the six Ling sounds, we should record a series of 6 ACC responses. This report describes the morphology of the responses we collected, the effect that the order in which the LING 6 sounds were presented had on the ACC recordings and the repeatability of these recordings.

A total of 10 normal hearing young adults participated in the study. Six 500 msec phoneme segments were combined to form a single auditory sequence that was 3 seconds in duration. Varying the order in which the LING 6 sounds were presented generated four separate stimuli. A total of 200 sweeps was recorded for each of the four LING 6 combinations. No inter-stimulus interval was used. The order of testing was randomized in blocks of 50 sweeps across the four auditory sequences. Test time for each block of 50 sweeps was under 3 minutes. ACC responses were recorded via surface electrodes in a two-channel Cz-A1-A2 montage, with an additional eye channel used to eliminate eye blink artifact. Subjects were tested while watching captioned videos and seated in a sound treated booth. Artifact rejection was used to eliminate responses with high noise in the unaveraged EEG.

ACC responses that exceeded the noise floor of our recording system were detected for each stimulus change in all four stimulus sequences. For a given phoneme contrast, response morphology varied substantially across subjects. We opted, therefore, to use RMS amplitude rather than traditional peak picking to evaluate these responses. While morphology of the evoked responses varied across subjects, they were highly reproducible, even for individual subjects who were tested one year apart (correlation=0.948 ±0.01(SD), N=4). While more research is needed in pediatric populations, these preliminary results support the use of this objective measure in clinical settings.

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T07b: THE ACOUSTIC CHANGE COMPLEX AND ITS RELATION TO SPEECH PERCEPTION IN NOISE IN HEARING-IMPAIRED SUBJECTS

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Background
Cortical auditory evoked potentials (CAEPs) in re¬sponse to changes within sounds (e.g., vowel transi-tions, or changes in level or frequency) may be suitable for assessing suprathreshold neural processes related to speech perception. These CAEPs evoked by sound changes are also referred to as acoustic change com¬plexes (ACCs) and are composed of a typical P1-N1-P2 waveform morphology. Since frequency changes are a fundamental part in speech sounds, ACCs elicited by frequency changes may be related to speech percep¬tion. This study's objective was to investigate whether the ACC was related to psychophysical outcomes as frequency discrimination and speech reception in noise.

Methods
In 13 patients with sensorineural hearing loss and 12 normal hearing controls we recorded ACCs in response to frequency increases within stimuli. Stimuli were tones of 3300 ms with three components: a) a reference tone of 1000 Hz with a duration of 3000 ms, b) an FM sweep with a frequency change Δf, c) a tone with a frequency 1000-Δf or 1000+Δf Hz and a duration of 300 ms. First ACCs were recorded in response to 12% Δf with respect to reference tones of 500, 1000, 2000 and 4000 Hz. Then the size of Δf was reduced in order to determine an ACC threshold. In addition, frequency discrimination thresh¬olds were assessed using pure tones with reference fre¬quencies of 500, 1000, 2000 and 4000 Hz in a 3-interval 2-alternative forced choice paradigm. Speech reception thresholds (SRTs) were measured in free-field speech-in-noise tests using Dutch standardized sentences.

Results
The ACCs of the hearing-impaired group showed high¬er thresholds, smaller N1-P2 amplitudes and longer N1 latencies compared to the normal-hearing controls. As expected, the hearing impaired group performed more poorly on the frequency discrimination and speech per¬ception tasks than the normal-hearing controls. Unex¬pectedly, none of the ACC measures including ACC threshold were correlated to frequency discrimination. However, interestingly, subjects with better speech per¬ception results showed shorter N1 latencies. Multiple re¬gression analyses revealed that after hearing loss, ACC latency was a secondary predictor for speech percep¬tion.

Conclusion
ACC thresholds are poor indicators for hearing perfor¬mance. Instead the suprathreshold ACC latency, in ad¬dition to hearing loss, appeared to be an indicator for speech perception in noise. The ACC might therefore hold clinical value as an objective measure to assess hearing performance in hearing-impaired subjects.

T08: BRAIN ACTIVITIES DIFFER IN ACOUSTIC AND ELECTRIC HEARING ELICITED BY FREQUENCY CHANGES

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Background
The capability to detect fine frequency differences in acoustic stimuli plays a significant role in speech perception in cochlear implant (CI) users (Kenway et al., 2015). However, little is known about how the auditory cortex processes frequency change information in electronic hearing provided by the cochlear implant. Acoustic change complex (ACC) is a type of cortical auditory evoked potential (CAEP) elicited by acoustic changes embedded in ongoing stimuli. The scalp-recorded ACC evoked by acoustic changes and the typical CAEP evoked by stimulus onset showed differences and similarities in waveforms (Liang et al., 2016). The purpose of this study is to determine the neural substrates that may underlie the N1 peak of the onset CAEP and the N1 peak of the ACC evoked by frequency changes using standardized Low Resolution Electromagnetic Tomography (sLORETA).

Methods
Twelve CI users and 12 normal-hearing (NH) listeners participated in this study. Stimuli were tones (base frequency 160 Hz and 1200 Hz) containing different magnitudes of upward frequency change (0%, 5%, and 50%) for each frequency. The frequency change occurred for an integer number of cycles of the base frequency and the change occurred at 0 phase (zero crossing) and thus there were no audible transients when the frequency change occurred (Dimitrijevic et al., 2008). Tones were approximately 1 s in duration and presented in the sound field with an inter-stimulus-interval of 800 ms. sLORETA comparisons were performed between current source density (CSD) values for the N1 peak of the onset CAEP and N1 peak of the ACC response.

Results
In NH listeners, the sLORETA comparison map between the N1 of the onset CAEP and the N1 of the ACC displayed significant activation in brain regions outside of the temporal lobe (e.g. frontal and parietal lobes). This pattern was different from that in NH listeners.

Conclusion
In acoustic hearing, the auditory brain processes stimulus onset and acoustic changes embedded in ongoing stimuli differently, although the corresponding waveforms of the scalp-recorded responses (onset CAEP and ACC) share similarities in morphologies. While the N1 of the onset CAEP reflects the obligatory representation of sound, the N1 of the ACC reflects a discrimination process that involves the activation of cognitive neural resources. Such neurological dissociation between the N1 of the onset CAEP and the N1 of the ACC in NH listeners was not observed in CI users, possibly due to the combination of their neural deficits and the limitation of electric hearing.

T09a: MEASURING CENTRAL AUDITORY PLASTICITY IN ADULT COCHLEAR IMPLANT USERS WITH THE AUDITORY CHANGE COMPLEX

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Background: The spatial auditory change complex (ACC) is a cortical response elicited by a change in place of stimulation. We have previously shown that the spatial ACC can be measured in different cochlear implant (CI) devices and as early as 1-week after switch-on. The aim of this study was to determine A) how the spatial ACC develops in the first 6 months after switch-on and B) whether changes in the ACC could be explained by the development of loudness tolerance.

Method and Results: A) Ten adult CI users (age 27-80 years), including 3 pre-lingually deafened adults took part in the study. Apical electrode pairs were tested at 1 week, 3 months and 6 months after switch-on. For 2 participants, data were also collected at 12 months. Electrode pairs were loudness balanced at the maximum comfort level. EEG was recorded with the Biosemi Active 2 system. CI artefact was removed with filtering and denoising source separation (DSS). Behavioural electrode discrimination was measured with a 3-interval 2-alternative forced choice task. Group average data showed that there was a significant increase in amplitude of the spatial ACC between 1 week and 3 months. At the individual electrode level, changes in the spatial ACC were associated with changes in behavioural discrimination and could continue up to 12 months after switch-on. Of note, in certain individuals the spatial ACC could be measured prior to the development of accurate behavioural discrimination.

B) Changes in cortical responses that occur over time could be confounded by changes in loudness perception and stimulation levels. We therefore conducted an experiment on the effect of stimulus intensity on the spatial ACC in 8 adult CI users (age 42-68). Apical electrode pairs were loudness balanced and presented at 40, 50, 60, 70, and 80% of the dynamic range. EEG and behavioural performance were measured as in part A. We found that stimulus intensity has an effect on both the spatial ACC amplitude and behavioural discrimination performance. Stimulus intensity has a smaller effect on the ACC than the cortical onset response and only partly explain ACC changes that occur over time in CI users.

Conclusion: These data provide evidence of central auditory plasticity in adult cochlear implant users. Furthermore, they show that there is a strong relationship between the spatial ACC and behavioural performance. We suggest that it may be useful to measure the spatial ACC to guide auditory rehabilitation and improve hearing performance in CI users.

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T09b: USING FUNCTIONAL NEAR-INFRARED SPECTROSCOPY (FNIRS) TO UNDERSTAND, BRAIN PLASTICITY, AUDIOVISUAL INTEGRATION AND FOR AUTOMATED PROGRAMMING OF COCHLEAR IMPLANTS

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fNIRS is a recently developed brain imaging technique that uses near-infrared light to detect changes in oxygenated and de-oxygenated haemoglobin (HbO and HbR, respectively) in the outer layers of the cortex. Compared to fMRI, it has better temporal resolution and poorer spatial resolution, and compared to EEG is has better spatial resolution and poor temporal resolution. The major advantages of fNIRS over fMRI and PET imaging are that it is non-invasive, is patient and user friendly, is portable, is compatible with implanted devices such as cochlear implants, and is not affected by electrical artefacts. The major disadvantage of fNIRS is that it can only image activity in the outer layers of the cortex. At the Bionics Institute, fNIRS is being used by the Hearing Research Group to investigate the effect of deafness and cochlear implant use on brain plasticity and brain connectivity in adults who use, or are planning to receive, a cochlear implant (CI). We are also investigating the use of fNIRS for automated programming, or validation of hearing aids or cochlear implants. Our results so far have shown that a) the cortical response to visual and auditory speech differs between experienced CI users and normal hearing listeners, b) the response in some parts of the language network is negatively correlated with speech understanding, c) the occipital cortex is involved in audiovisual integration in CI users more than in normal hearing listeners, and d) fNIRS shows strong promise for automated fitting. In summary, the work of our lab shows that fNIRS has the potential to be a useful diagnostic and prognostic tool to guide clinical management, and optimize individual outcomes for the CI.

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T10: FROM THE AUDITORY NERVE TO THE AUDITORY CORTEX IN A COCHLEAR IMPLANTED ANIMAL MODEL: HOW ARE VARIABLES OF THE ELECTRIC WAVEFORM REPRESENTED?

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Cochlear implants (CIs) can restore the sense of hearing in deaf people by electrically stimulating the auditory nerve. Current commercial CI sound processors extract slow temporal changes in the envelope of the sound input and transmit them as amplitude-modulated electrical pulse trains to intracochlear electrodes. The standard electric stimulation is a series of symmetric, biphasic pulses designed to prevent damage from charge accumulation. Such a pulse shape makes it hard to determine which aspects of the electric stimuli most efficiently excite the auditory nerve.

Despite the ubiquity of its use, little is know how precisely the CI electrical stimulation activates neural circuits and how it relates to acoustic inputs. This study aimed to better understand the transmission chain of the electric waveform from the auditory nerve to the auditory cortex using a cochlear implanted animal model.

In the first phase of the project, we have implemented an anaesthetized CI mouse model (4-channel electrode array: 0.2 mm diameter, 0.2 mm contact width, inserted into the 1st basal turn) and have successfully recorded electrically-evoked auditory brainstem response (eABR) with biphasic and monophasic pulses of different intensities and durations (biphasic: 80 μs/phase, 10us interphase gap; monophasic: 100-1000 μs cathodic/anodic phase duration). The pulses were generated by a stimulation platform developed by Neurolec/Oticon and delivered in both monopolar and bipolar configuration mode. In parallel, we have performed population imaging of acoustic-evoked signals in the auditory cortex in anaesthetized, normal-hearing mice to establish a tonotopic map (voltage sensitive dye imaging with RH1691, protocol of 50 ms-duration pure tones ranging 0.5-48 kHz with 8 frequencies/octaves). The following experiments will combine the CI-model and cortical imaging to investigate how the cortical network representation is affected by different pulse shapes, polarities, and amplitude modulations.
Our findings will help us to better understand the electro-neural interface and in general how electric stimulation is represented in the cortex. The outcome has the potential to guide future pulse shape design that might lead to more efficient CI.

T11a: DOES CYTOMEGALOVIRUS IN EARLY DEVELOPMENT AFFECT CORTICAL BRAIN OSCILLATIONS EVOKED BY COCHLEAR IMPLANTS?

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Objectives: (1) To identify abnormalities in cochlear implant evoked cortical activity in children whose deafness is associated with congenital cytomegalovirus (CMV) and (2) To evaluate potential relationships between functional changes in cortical activity and intracranial structural anomalies.

Background: Congenital CMV is one of the leading infectious causes of perinatal sensorineural hearing loss (SNHL) and neurologic disabilities in children born in North America and Europe. Infants with congenital CMV will either present as symptomatic or asymptomatic at birth. Of the infants who present with symptomatic CMV, many (~40%) develop SNHL. Of those with asymptomatic CMV, up to 7% develop SNHL. These hearing impairments can affect one or both ears, can be fluctuating or progressive, and can range from mild to profound loss. Cerebral white matter abnormalities and delayed myelination in children with CMV and SNHL may put these children at an increased risk for abnormal cortical development relative to their peers whose SNHL is associated with oto-genetic abnormalities. Reduced power at specific frequencies of oscillating cortical activity can be used to identify functional abnormalities in children which could be related to known white matter lesions and other structural abnormalities associated with CMV. We hypothesized that children with CMV exhibit slowing of cortical responses measured by increased power in lower frequency bands of cortical activity. The extent of this widespread spectral slowing are hypothesized to increase with structural changes to white matter, as indicated on magnetic resonance imaging (MRI).

Method: Electroencepaholography was used to record cortical responses across 64 channels while children sat in a sound-treated booth and passively listened to monaurally presented sound. A total of 9 children with SNHL ages 1-5 years old were included. Six were children with CMV and cochlear implant(s) (bilateral simultaneous n=2, bimodal n=1, single-sided deafness n=3). The other 3 children were matched for age at testing, duration of deafness, age of implantation and hearing modality. Acoustic clicks were presented to non-implanted ears and electric pulses were presented through the cochlear implant. Responses were wavelet-transformed to obtain spectral power across time from 2 to 60 Hz. Time-frequency analyses were created for the right, left, frontal, central and posterior hemispheres. Scalp topographic maps of common average referenced distribution for the first peak of the cortical response were also created for each of the four frequency bands: theta (4-8 Hz), alpha (8-14 Hz), beta (14-30 Hz) and gamma (30-50 Hz). Magnetic resonance imaging (MRI) scans of the brain were reviewed, and the findings were classified by degree and location of white matter change.

Results: Preliminary results in children with CMV indicate elevated levels of slow oscillatory activity (e.g., theta). A step-wise increase in power from frontal to posterior regions was also observed. These patterns occur regardless of the ear of stimulation. Further analyses will investigate whether children with CMV show differences in brain activity from normal and whether these differences are associated with the location of structural changes in the brain white matter.

Conclusions: These data have the potential to identify cortical effects of CMV in children with cochlear implants.

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T11b: A COCHLEAR IMPLANT BASED PER-OPERATIVE AUDITORY NERVE MONITORING PROTOTYPE FOR SURGICAL MANAGEMENT OF ACOUSTIC NEUROMA: PRELIMINARY DATA FROM CLINICAL TRIAL

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Patient with auditory nerve tumors (i.e. NF2 syndrome, acoustic neuroma, meningioma, etc.) can experience progressive hearing loss related to the tumor expansion and auditory nerve compression. Such tumors are benign and can undergo surgical removal with anatomic preservation of auditory nerve, depending on tumor size and location. Per-operative monitoring technique may demonstrate improvements in functional preservation of auditory nerve during the surgery. Several per-operative techniques have been developed and evaluated with particular focus on nerve preservation. Among these methods, the most frequently used are ECochG, direct eCAP or ABR. These methods are using a single extra-cochlear stimulating electrode unable to provide detailed information about specific section of the cochlea or provide later latencies related to far-field stimulation. Direct intracochlear electrical stimulation is an interesting option to measure an electrically-evoked functional response of the auditory nerve.

In the present study, a prototype device (Neuristim) is used for auditory nerve monitoring. It is composed of a sterile disposable 10-contacts electrode-array used per-operatively, connected to a reusable stimulator. This device allows to stimulate the entire cochlea and to record eABR responses in the same manner as the standard practice in cochlear implantation. The Neuristim is a cost-effective diagnosis medical device based on cochlear implant technology, used here to determine the auditory nerve integrity. This device is not approved for routine clinical practice (not CE approved, not FDA approved), it is an investigational device for which ethical approval and specific Ministry of Health approval was required for study conduction.

This goal of the present study is to evaluate auditory nerve functionality after neuroma surgery, in order to guide the surgeon in its medical decision. Indeed, with non-functional auditory nerve, an auditory brainstem implant may be indicated.

17 participants are planned, so far 3 were included. The device was used successfully, and it allowed for all participants to measure eABR responses to electric stimulation on several electrodes. Regular cochlear implantation was therefore chosen in all these cases, postoperative outcomes were not yet measured at this point in time.

Cochlear implant technology has been used here as a monitoring tool. Cochlear implant cost is however too high to consider a single use as in this application, a lower cost solution is proposed here with successful outcomes.

T12: AUTOMATED SEGMENTATION OF COCHLEAR WALLS FROM CLINICAL CT SCANS

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Most clinics acquire a computed tomography (CT) scan for preoperative planning of cochlear implant surgery. These scans consist of multiple 2D images. Unfortunately, stacking and scrolling through these images only provides limited 3D information to the surgeon. Measurements of cochlear characteristics (e.g., diameter, height and area of the cochlear cross section) are tedious when performed manually on the image stack. Therefore, in order to reduce analysis time, inconsistencies and bias resulting from manual analysis, our aim is to develop an automated segmentation method to obtain the 3D surface of the cochlear walls for individual patients from a clinical CT scan.

The cochlear walls approximately follow a logarithmic spiral. Commonly, a cylindrical coordinate system is used which is defined around the modiolus - the central axis of the cochlea - and parallel to the basal turn. Using this coordinate system instead of a Cartesian system, we can parameterize the cochlea such that both the centre of the cochlear duct and the cochlear walls only change gradually, when moving from base to apex. Using small angular steps (e.g., 1 degree), the position of the cochlear walls will be approximately the same on consecutive midmodiolar slices (i.e., radial cross sections with the modiolus as the central axis), and following the cochlear walls from the round window towards the apex becomes easier.

The first part of our methodology is the preparation of the input to the automated segmentation routine. Following clinical routine, CT scans are rotated, cropped and stacked to obtain multi-planar reconstructions of the cochlea. As a manual preparatory step the round window and apex location are identified using custom written MATLAB software previously developed in our lab. These data are then loaded into the automated segmentation routine, programmed in MATLAB.

In order to assess the precision of our segmentation method to determine the position of the cochlear walls in the noisy clinical CT scans, we tested it on down-sampled micro-CT scans with added noise. These down-sampled micro-CT scans visually resembled the quality of clinical CT scans. We then superimposed the segmentation results onto the original high resolution micro-CT scan and found good agreement between the segmented cochlear walls and the cochlear walls clearly visible in the micro-CT scan.

We successfully extracted the 3D surface of the cochlear lumen from clinical CT scans. This allowed us to consistently measure important cochlear features like the diameter, height and area of the cochlear cross section as well as the length of the first turn. Additionally, the shape of the cochlea could be seen better from the 3D reconstruction compared to the original 2D stack of CT images. Features like the ascending profile became visible, which describes the progression of elevation of the cochlea from the round window towards the apex.. It is impossible to infer this directly by scrolling through the 2D CT stack.

The MATLAB routine completed the segmentation for two hundred CT stacks, yielding two hundred 3D surfaces of the first cochlear turn. In these 200 cochleae we analysed the average ascending profile and found that it did not increase monotonously but rather peaked after half a turn and then descended for 90 degrees before it started to rise again. This local peak in the ascending profile at approximately 180 degrees is in line with the previously described ‘roller-coaster’ profile and might explain the concentration of intra-operative trauma occurring at this site.

With the current algorithm the reliability of the segmentation deteriorated after the first turn as a result of the poor contrast between the cochlear walls. We are planning to make the algorithm more robust and include MRI scans in order to extend the range of the segmentation until 540 degrees (1.5 turns) to cover the range of insertion of most cochlear implant electrodes.

T13: FUNCTIONAL CONNECTIVITY OF LISTENING NETWORKS IN EXPERIENCED BILATERAL COCHLEAR IMPLANT USERS

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Objectives
The present research aims to define cortical auditory networks involved when children who are deaf listen through bilateral cochlear implants (received simultaneously).

Background and Rationale
We asked: Are listening networks impaired as measured by functional connectivity between specific cortical sources in children using bilateral implants?

Despite the success of cochlear implants, many users of bilateral cochlear implants still have difficulty with spatial localization and hearing in noise. These difficulties may be linked to crude frequency representation and insufficient integration of binaural cues from two independent implants. Recent evidence from our laboratory indicates that these impoverished auditory cues cannot restore normal binaural processing in immature auditory areas located in the temporal cortical lobes. Yet, the brain is made up of distinct networks that extend beyond the temporal areas to support higher-level processes such as listening. Our hypothesis in the present study is that cortical activity in children receiving bilateral cochlear implants simultaneously will be largely generated from the same cortical locations as in children with normal hearing but will show atypical strength and timing of functional connectivity in certain frequency bands.

Methods
Functional connectivity of the auditory system and cortex is evaluated using 64-channel electroencephalography (EEG) recorded from children who use bilateral cochlear implants and an age-matched control group. The responses are evoked using current pulse-train stimuli and click stimuli for the children with implants and normal hearing, respectively. Cortical activity is considered within canonical frequency bands associated with specific cognitive functions: Theta (4-8Hz), Alpha (8-13Hz), Beta (13-30Hz), and Gamma (30-70Hz). A spatial filtering method is used to attribute the EEG data recorded from the scalp to 90 atlas-guided anatomical sources within the brain. Correlational analyses are performed between the source estimates pairwise, within each frequency band, to show functional relationships involved in listening.

Results
Preliminary data reveal expected frequency content and cortical sources in children with bilateral cochlear implants. Assessment of timing and strength of functional connectivity in each frequency band is ongoing.

Significance
Analyses of functional connectivity could help define the unique hearing network in children using bilateral cochlear implants.

T14a: NEURAL ENTRAINMENT TO THE SPEECH ENVELOPE WITH A COCHLEAR IMPLANT

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The temporal envelope of speech is encoded in the oscillating patterns of the listener's brain. Recent studies with normal hearing participants have shown that this neural representation of the envelope can be decoded from EEG measurements, and that it is related to speech intelligibility. In this study, neural entrainment to the speech envelope is demonstrated for the first time in cochlear implant (CI) users.

EEG was measured from CI users while they listened to natural running speech. Because electrical stimulation artifacts hamper EEG recordings in CI users, a novel technique to suppress the electrical artifacts is applied. A part of the artifact-free EEG is used to train a linear decoder, which reconstructs the speech envelope from the EEG by optimally combining the time signals from multiple channels. The decoder is then used to reconstruct the envelope from the remaining part of the EEG. The strength of neural entrainment to the envelope is measured by correlating the reconstructed envelope with the real envelope. To validate that the EEG is free of components related to the electrical stimulation, the same decoder is applied to EEG measured while the subject is stimulated below the threshold level. EEG obtained during sub-threshold stimulation still contains electrical artifacts, but is free of neural responses to the stimulus.

The correlation between reconstructed and real speech envelope was significant above chance level, indicating that there is neural entrainment to the speech envelope. The envelope reconstructed from sub-threshold stimulation did not correlate with the real envelope, indicating that the electrical artifacts, if at all, only have a minor contribution to the significant responses.

In conclusion, this study demonstrates that neural entrainment to the speech envelope can be measured as a response to electrical stimulation. Reliable EEG recordings for experimental purposes were obtained using a novel CI artifact suppression technique. It was verified that the responses to the speech envelope are of neural origin and that the electrical artifacts do not affect the envelope reconstruction. The demonstrated measure for the neural encoding of speech may support future automatic fitting methods and other objective measures of hearing with a CI.

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T14b: THE RELATIONSHIP BETWEEN INTENSITY MODULATION FOLLOWING RESPONSES AND BEHAVIORAL THRESHOLDS

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When fitting cochlear implant (CI) devices, determining reliable thresholds is critical for diagnostic and therapeutic purposes; in cochlear implantation, sounds are processed to convey the maximum amount of information within a limited level range that lies between the estimated threshold and the maximum comfortable level resulting from the fitting of the device. Although electroencephalography (EEG) measures have proven to be useful to estimate behavioral thresholds in normal and hearing-impaired listeners, these evoked responses are usually contaminated with large electrical artifacts that obstruct the biological response in CI users. Ideally, an improved objective measure could be achieved by evoking neural responses at a frequency range with little or none influence of electrical artifacts. We recently demonstrated that periodic, abrupt modulations of the interaural phase difference of a sound generate a following response – the so-called interaural phase modulation following-response (IPM-FR). Latency analyses suggest that the generators of this steady-state response are the same involved in acoustic complex change (ACC) responses, namely, P1-N1-P2 waveforms likely generated at the level of the midbrain and the auditory cortex. This suggests that steady-state following responses could be generated by any stimulus change presented periodically. Here, we investigate if periodic abrupt intensity modulations are able to evoke a following-response (IM-FR) that can be used to determine objective thresholds. This has potential utility for estimating thresholds in CI users, since we expect responses with significantly reduced residual artifacts in the frequency region where the response is elicited. Here, in normal-hearing listeners, IM-FRs are evoked by presenting 41-Hz amplitude modulated sinusoidal stimuli with carriers at 500, 1000, 2000, and 4000 Hz. The stimulus intensity is periodically modulated abruptly between zero and fixed intensity intervals at rates between 4 and 12 Hz.

Several stimulation levels are be used, ranging from the behavioral threshold to 60 dB above this level. EEG responses are be recorded from 66 surface electrodes using a BioSemi Active Two EEG recording system. Preliminary data indicate that IM-FR can be elicited in normal listeners at several intensities and modulation rates. Frequency responses are significant at several peaks of interest: peaks corresponding to the IM-FR and its harmonics, as well as peaks corresponding to the steady-state response and co-modulation components.

T15a: THE EFFECTS OF INTERAURAL LEVEL DIFFERENCES ON FUSION IN ADULTS WITH NORMAL-HEARING AND BILATERAL COCHLEAR IMPLANTS

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Listeners who use hearing aids (HA) and cochlear implants (CIs) will fuse pitches over a larger range of frequencies between ears compared to normal-hearing (NH) listeners (Reiss et al., 2014; 2017). Recent data collected from NH participants suggests that fusion increases when subjects are tested using published equal loudness contours, as opposed to individualized equal loudness balancing (Anderson et al., in review). One potential explanation is that equal loudness contours differ from individualized equal loudness levels and introduce interaural level differences (ILDs), which may increase fusion. The goal of this study is to investigate the effects of ILDs on fusion in NH and bilateral CI adults.

Normal-hearing and bilateral CI participants were recruited for this study. All subjects completed a five button alternative forced choice dichotic fusion range task. A reference stimulus (tone or electrode) was presented in one ear, while a comparison stimulus was varied in the contralateral ear simultaneously. The comparison stimulus was varied to find the frequency or electrode range that fused with the reference stimulus. Five conditions, including a 0 ILD, or loudness balanced condition, were used for the dichotic fusion range testing. NH participants experienced acoustic ILDs at ± 2.5 dB and ±5 dB from their 0 ILD condition. Bilateral CI participants experienced electric ILDs at ±20% and ±40% of current level from their 0 ILD condition within their electric dynamic range. NH participants were tested under headphones while bilateral CI participants were tested using experimental cochlear implant processors.

Preliminary results (3 NH and 2 bilateral CI participants; data collection is ongoing) show that in NH listeners, introducing an ILD of either +2.5 dB or -2.5 dB, but not +5 dB or -5 dB, in one ear relative to the comfortable level in the other ear increased the fusion range. Results in bilateral CI users were not consistent; however, individual differences in loudness growth with current level may be a factor in these discrepancies. Subjective loudness measurements in one bilateral CI subject indicated perceptible changes in loudness at some levels tested but not others, coinciding with ILDs at which no effects on fusion were found.

Increased fusion can lead to difficulties with speech perception. Preliminary findings suggest that ILDs in the physiological range can increase fusion range in NH listeners. Further research is needed in bilateral CI listeners to determine how both ILDs and subjective loudness differences affect fusion.

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T15b: BINAURAL PITCH FUSION IN CHILDREN WITH NORMAL-HEARING, HEARING AIDS, AND COCHLEAR IMPLANTS

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Previously, we reported abnormally broad binaural pitch fusion – the fusion of dichotically presented tones that evoke different pitches between the ears - in hearing-impaired, adult cochlear implant (CI) and hearing aid (HA) users. Wide fusion ranges can result in the averaging of mismatched rather than matched spectral information between the ears, and may help explain speech perception interference observed with binaural versus monaural hearing device use (Reiss et al., JARO 2014). The goal of this study was to measure binaural pitch fusion ranges in normal-hearing (NH) and hearing-impaired children with various hearing device combinations in order to understand how fusion ranges differ from adults as well as across groups. An additional goal was to conduct longitudinal measurements of fusion ranges to understand how fusion changes during development.

Twenty-five NH, seven bilateral HA, eight bimodal CI (CI worn with HA in contralateral ear), and sixteen bilateral CI children were recruited for the study (age range: 6.09 to 10.25 years). All subjects completed a dichotic fusion range measurement task, in which a reference stimulus (tone or electrode) was presented simultaneously in one ear with a comparison stimulus in the contralateral ear, and the comparison stimulus varied to find the frequency range that fused with the reference stimulus. Acoustic stimuli were presented via headphones and electric stimuli were presented using experimental CI processors.

Bilateral HA children exhibited wider fusion ranges (3.28 ± 1.05 octaves) compared to NH (1.24 ± 1.17 oct.), bimodal CI (1.71 ± 1.63 oct.), and bilateral CI (1.71 ± 1.25 oct.) children. No other significant group differences were seen in fusion range widths. Fusion ranges were significantly broader only for NH and HA children compared to the corresponding adult groups (0.14 ± 0.09 oct. and 1.43 ± 1.41 oct., respectively). In the pediatric bilateral CI group, a negative correlation was found between fusion range and bimodal experience before receiving a second CI ($r = -0.746$, $n = 15$, $p = 0.001$). Longitudinal data show highly variable trends within groups.

Our results suggest that children who wear bilateral HAs have broader fusion ranges than their NH, and bimodal and bilateral CI counterparts. Additionally, more bimodal experience prior to a second implant is associated with sharper fusion, raising the possibility that hearing device type may influence development of binaural pitch fusion.

T16: DEVELOPMENT OF THE STRIPES TEST AS A MEASURE OF SPECTRO-TEMPORAL PROCESSING AND THE EFFECT OF STIMULATION MODE ON COCHLEAR-IMPLANT LISTENER PERFORMANCE ON SPECTRO-TEMPORAL AND SPEECH TESTS

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A number of methods, e.g. novel speech-processing algorithms, for improving performance by cochlear implant (CI) users have been proposed. However, it has not always proved possible to demonstrate the benefits of these approaches. This may be due to the absence of a genuine benefit, or test limitations. Listeners have learnt the relationship between their regular speech processing strategy and speech segments, making it difficult to know if a new strategy is effective on the basis of a speech test, which could result in an underestimation of the benefits of a new method. This obstacle can be overcome by using psychophysical tests; however these typically require either spectral or temporal processing, but not both.

The STRIPES (Spectro-Temporal Ripple for Investigating Processor Effectiveness) test requires, like speech, both spectral and temporal processing to perform well. It is robust to learning effects and contains no recognisable phonemes, overcoming the problems associated with learned speech segments.

The test requires listeners to discriminate between stimuli comprising of temporally overlapping exponential sine sweeps (the “stripes”) whose frequencies increase or decrease over time. The task is to detect which of three consecutive stimuli contains stripes of the opposite direction to the other two. The starting time is varied in successive presentations and the onsets and offsets are masked with noise, requiring the listener to use the global, multi-channel perception of the stripe direction, not simply cues from a single spectro-temporal segment. The task difficulty is increased by increasing the sweep density (number of sweeps present at the same time). As sweep density increases, the gaps between the sweeps are reduced and the stripe direction becomes more difficult to determine.

Results from six Advanced Bionics CI users show good performance with a 12-channel map using logarithmically spaced filters and poorer performance with a 12-channel map using wider, overlapping logarithmically spaced filters, modelling the effect of increased current spread in the cochlea. All listeners produced monotonic psychometric functions, and convergent thresholds using an adaptive staircase method. A group of newly implanted CI users were also able to perform the test successfully.

We also determine whether STRIPES can consistently capture subject-by-subject differences in the effect of different stimulation methods. This is important because novel methods sometimes improve speech perception in some listeners and degrade it in others. Eighteen Advanced Bionics users were tested on STRIPES and on another spectro-temporal test (SMRT; Aronoff and Landsberger, JASA 134:EL217-EL222, 2013), using three 14-channel maps in which stimulation was in monopolar (MP), partial tripolar (pTP), or dynamic tripolar (DT; Bierer et al, ARO Midwinter meeting, 2016) mode.

Results from the first nine participants show an effect of stimulation mode for vowels (DT best). There is no evidence that either STRIPES or SMRT are sensitive to modest effects of stimulation mode on speech perception, as studied by Bierer et al (2016). This may be because (i) the stimulation mode effects studied were small, as across-subject results from the two speech scores did not correlate with each other, and (ii) the speech scores were obtained acutely, and results may correlate with STRIPES or SMRT after take-home exposure.

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T17a: REDUCTION IN CHANNEL INTERACTION FROM STIMULATION FOCUSING IN THE COCHLEA DEPENDS ON STIMULATION PULSE RATE

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It is widely believed that a major bottleneck in auditory perception with cochlear implants (CIs) lies in channel interactions. Adjacent stimulation channels may recruit overlapping neural populations and interact, particularly in monopolar stimulation mode where a presumably broad electric field is generated between intra- and extra-cochlear electrodes. One approach for reducing channel interactions is to try to focus stimulation to a narrow cochlear region. Tripolar stimulation has been suggested as a way of focusing electric field by sending out-of-phase current to two flanking electrodes on the sides of the active electrode. However, stimulation focusing with tripolar mode does not always reduce channel interactions, as measured behaviorally.

This study evaluated the hypothesis that the degree of reduction in channel interaction from stimulation focusing depends on pulse rate. In a typical CI, electrical stimulation is delivered by trains of rapid electrical pulses. The rate at which these pulses are presented may affect channel interactions, as demonstrated in a study by Middlebrooks (2004) that showed that cortical excitation overlap between stimuli presented to different cochlear regions was influenced by pulse rate. We obtained behavioral measures of channel interaction for pulse trains of different stimulation rates and focusing modes in a group of CI users. Channel interaction measures were estimated from spatial forward masking patterns obtained with masker stimuli that were presented on six flanking electrodes on both sides of a fixed single-pulse monopolar probe, as well as on the same electrode as the probe. Maskers were equally-loud pulse trains of 250 or 1500 pps (pulses per second) presented in monopolar or tripolar mode. The spatial pattern of probe masking (i.e. the difference between masked and non-masked probe thresholds) was compared for the four combinations of masker rates and modes.

Results for individual subjects showed either a significant effect of pulse rate or stimulation focusing mode, or a significant interaction of the two parameters. The way pulse rate and stimulation focusing affected channel interaction measures varied across subjects. The individual-specific effects of stimulation pulse rate and focusing on channel interactions may be related to individual differences in spread of electric field in the cochlea, neural survival and neural mechanisms that affect the temporal pattern of neural responses over the duration of pulse train stimuli (such as refractoriness and adaptation). Group analysis of channel interaction results showed a significant interaction between pulse rate and stimulation focusing. Channel interaction for tripolar stimulation (but not monopolar) was significantly better at 1500 pps than 250 pps. These results suggest that benefit from tripolar stimulation is more likely with high-rate stimulation strategies.

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T17b: EXAMINING SPATIAL NEURAL EXCITATION PATTERNS WITH VARYING STIMULATION RATE IN COCHLEAR IMPLANT USERS

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The study aimed to examine whether neural spread of excitation changes with varying stimulation rate in cochlear implant users. Previous studies showed that a greater effect of stimulation rate on detection thresholds (steeper multipulse integration function) was associated with broader stimulation of the cochlea. The results were interpreted using a recruitment theory, where an increase in stimulation rate recruits a greater number of neurons to respond to stimulus, which lowers the current needed for detection and creates a spatial spread of neural excitation. The current study explicitly tested this hypothesis by measuring spread of excitation and spatial tuning curves with varying rates.

Postlingually deafened subjects with the Cochlear Nucleus device participated in the study. One electrode was tested from each subject. The excitation patterns of two pulse trains different in rates (250 and 1000 pulses per second; pps) were measured in a forward-masking paradigm. The 1000-pps masker was set at a level that produced the same amount of masking for the on-site probe (1000 pps), as the 250-pps masker did (i.e., levels at equal masked probe threshold). All probes used a rate of 1000 pps. Spread of excitation by the two maskers was then measured by obtaining masked thresholds for probes that varied in location. Sharpness of spread of excitation was quantified by fitting linear slopes to masked probe thresholds as a function of masker-probe distance. In the second part of the experiment, rate-varying maskers were also applied to measure forward-masked spatial tuning curves. The probe of the spatial tuning curves was fixed at a rate of 900 pps and set at a level of 2 dB above its unmasked threshold. The rates of the maskers were 250 pps and 900 pps. The masker levels required to just mask the probe were obtained as a function of probe-masker distance. Again, slopes of the curves were quantified as sharpness of tuning.

There was a small but significant effect of stimulation rate on sharpness of the excitation patterns, i.e., the high-rate masker produced a slightly narrower spread of excitation pattern compared to the low-rate masker. This was opposite to our hypothesis. There was no strong evidence to indicate that the spatial tuning curves were narrower with the higher-rate maskers. The results suggested that, the greater effect of stimulation rate on detection threshold associated with spatial spread of neural excitation, might be due to an alternative mechanism, such as a better chance of sampling and stimulating neurons with better temporal responsiveness.

T18a: FACTORS AFFECTING RATE SENSITIVITY IN COCHLEAR IMPLANT USERS

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This study examines factors that may affect stimulation rate sensitivity in cochlear implant users. It is well established that cochlear implant users can perceive pitch associated with the stimulation rate of pulse trains presented on individual electrodes, but that sensitivity to such rate pitch diminishes for rates above 300 Hz. However, there have been multiple reported cases of individuals sensitive to stimulation rates well above 300 Hz. Furthermore, Goldsworthy and Shannon (2014) demonstrated that sensitivity to stimulation rate could be improved through psychophysical training. The goal of the present study is to identify factors affecting individual differences in rate sensitivity in cochlear implant users. The factors we examine include age, etiology and duration of deafness, electrode location in the cochlea, stimulation mode (i.e., bipolar versus monopolar), and spatial tuning as measured by forward masked thresholds. Adult cochlear implant users serve as subjects in a 2-week protocol that includes electrode psychophysics conducted in the laboratory and auditory listening exercises conducted at home. For the laboratory testing, the subject completes a 4-hour session once a week. For the first session, the subject's threshold and comfort levels are measured for each electrode in bipolar and monopolar stimulation modes. Forward masked thresholds are measured first using a subjectively controlled user interface, then specific electrode combinations are measured using an alternative forced choice procedure for both basal and apical masker electrodes. Rate discrimination is measured using an adaptive alternative forced choice procedure for the same apical and basal electrodes with stimulation rates of 100, 200, 400, and 800 Hz. For the second session (one week later), subjects complete two hours of rate discrimination training, then are retested on the forward masking and rate discrimination measures described for the first session. The third session (two weeks after the first), is identical to the second session. During the two weeks between the first and third session, subjects participate in auditory listening activities using a web application at home. This at-home training activity consists of 6 variations of modulation frequency discrimination, which are the 6 combinations of two carrier frequencies (500 and 4000 Hz) and 3 modulation frequencies (100, 200, and 400 Hz). The acoustic stimuli used for these at-home training exercises were designed as analogs of the electrode psychophysical stimuli. Training was given using a 4-note pattern repetition task. There were two primary reasons for conducting at-home training. First, this training familiarized subjects to psychophysical procedures and thereby minimized variations across subjects in procedural learning. Second, this training quantified subject discrimination on an acoustic analog of electrode rate discrimination, thus providing a relevant acoustic comparison. Results collected to date indicate that cochlear implant users with minimal psychophysical training can consistently discriminate rate differences at least as high as 800 Hz. Some subjects are more sensitive to rate differences in the base while others in the apex, no significant group effect of electrode location on rate sensitivity has yet to be observed. We will report on observations of the other factors including age, etiology and duration of deafness, electrode location in the cochlea, stimulation mode, and spatial tuning for this ongoing study.

Goldsworthy RL, Shannon RV (2014). Training improves cochlear implant rate discrimination on a psychophysical task. The Journal of the Acoustical Society of America, 135, 334-341.

T18b: RATE MODULATION DETECTION THRESHOLDS FOR COCHLEAR IMPLANT USERS

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The perception of temporal amplitude modulations is critical for speech understanding among cochlear implant (CI) users. The present study compared the ability of CI users to detect sinusoidal modulations of the electrical stimulation rate and electrical current amplitude at different presentation levels (80% and 40% of the dynamic range) and modulation frequencies (10 Hz and 100 Hz). Rate modulation detection thresholds (RMDTs) were compared with amplitude modulation detection thresholds (AMDTs) using a temporal integration model. Both RMDTs and AMDTs improved with increasing presentation level and decreasing modulation frequency. Modulations at the output of the temporal integration model were similar for RMDTs and AMDTs, indicating that a common temporal integration mechanism may underlie the perception of rate modulated and current modulated pulse trains.

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T19a: AMPLITUDE MODULATION SENSITIVITY AND INCREMENT/DECREMENT DETECTION IN COCHLEAR IMPLANTS

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Listeners with cochlear implants rely primarily on time-varying modulations of electrical pulse amplitude to identify sounds. Detection of modulation patterns is believed to be based on a bank of sinusoidal amplitude modulation (SAM) filters tuned to different envelope frequencies, which has been predominantly tested in listeners with normal hearing (Dau et al. 1997 a,b). In listeners with cochlear implants, sensitivity to SAM varies widely across listeners, place of stimulation, and reference level, which should impact their ability to detect other forms of modulation as well. Here, we measure both SAM detection thresholds for multiple AM rates and increment/decrement detection thresholds for multiple durations within listeners. Manipulating the duration of increments/decrements will alter the modulation spectra of these stimuli, which should influence detection thresholds in a manner consistent with the SAM detection thresholds corresponding to the increment/decrement modulation spectra. Preliminary results in listeners with cochlear implants suggest similar trends in increment and decrement sensitivity as in listeners with normal hearing, suggesting that mechanisms of modulation sensitivity found in listeners with normal hearing may generalize to listeners with cochlear implants.

T19b: CURRENT FOCUSING INCREASES SPATIAL DEPENDENCE OF LOUDNESS SUMMATION IN ELECTRIC HEARING

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In acoustic hearing, the loudness summation of multiple simultaneous frequency components depends highly upon the frequency separation of the individual components, with those separated by more than a critical band contributing more to loudness than if they fall within a critical band. This phenomenon is captured in neural excitation pattern models of loudness, which show that larger frequency separations lead to larger increases in the overall excitation pattern due to less overlap in the responses to each component. In contrast, loudness summation experiments in electric hearing have suggested that the role of spatial separation for multiple sequentially-stimulated electrodes is small relative to other effects. Due to this observation, some loudness models for electric hearing ignore any effects of electrode separation. We hypothesized that the spatial difference in loudness summation between acoustic and electric hearing is primarily based on the relatively broad excitation patterns elicited by electric stimulation using the monopolar electrode configuration. In this study, we employed multipolar current focusing in an effort to narrow excitation patterns, and show a significantly increased role of spatial separation on loudness summation in electric hearing.

Experiments were conducted in subjects with percutaneous Contour Advance cochlear implants (N=5) and with stimuli presented using custom laboratory current sources. Stimuli were presented to up to 8 channels at an overall stimulation rate of 7200 pps, consistent with the overall rate in the ACE coding strategy with 8 maxima and a rate of 900 pps/channel. Changes in loudness were characterized when distributing those 7200 pps amongst 1, 3, 5, 7, or 8 channels, with each channel loudness-balanced to a reference. Spatial loudness summation was quantified by the current adjustment needed to loudness-balance the multi-channel stimuli to the single-channel stimulus.

Results show that for the monopolar configuration, the current adjustments needed to loudness-balance the multi-channel stimuli to the single-channel stimulus were not significant, indicating that loudness was not dependent on the number or spatial extent of sequentially-stimulated channels. In contrast, the current adjustments in the focused configuration were significant, with greater loudness summation for larger number or spatial extent of sequentially-stimulated channels. These results suggest that with focused stimulation, the role of spatial separation in the loudness summation of multi-channel electric stimuli is significantly increased, relative to monopolar stimulation, and perhaps is more akin to loudness summation with multiple frequency components in acoustic hearing.

T20: ONGOING VOCAL CORRECTIONS TO BRIEF LOUDNESS SHIFTS: VOICE STABILIZATION MECHANISMS

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The utilization of a perception-production loop during ongoing vocal corrections is necessary to accurately control one's voice during conversational speech and when singing. Cochlear implant (CI) users, however, do not have access to reliable auditory information to maintain this perception-production loop and correct ongoing vocalizations. This results in difficultly with stabilizing one's fundamental frequency during ongoing vocalizations, possibly because, CI processors distort pitch. When encoding pitch, multiple harmonics can fall within one electrode's frequency allocation causing unresolved harmonics, and the frequency allocation for the most apical electrodes do not encode the lower frequencies necessary to encode fundamental frequency. Alternatively, a degradation of the perception-production loop, as a result of auditory deprivation, may be the cause of this difficulty. While non-monotonic distortions in pitch occur with CI processors, non-monotonic distortions in loudness do not occur. In order to determine whether the previous results were caused by the distortions by the processor rather than a degradation of the perception-production loop, this experiment investigated the effects of loudness perturbations on CI and normal hearing (NH) users' vocal production.

Seven cochlear implant users were tested in this experiment and 20 normal hearing. The vocal productions were recorded while a brief perturbation in loudness was introduced into the feedback that was provided back to the participant either over headphone (NH) or via direct connect (CI). The brief perturbations shifted the feedback of the participant's voice up or down by either 6dB or 10dB. This was done all while their ongoing production was recorded to determine how the participants responded to the loudness perturbation. The results show that for normal hearing individuals, brief perturbations in loudness lead to compensatory responses in the loudness of their vocalizations. This suggests that normal hearing individuals are using the perception-production loop to maintain control and stabilize the loudness of their vocalizations. In contrast, preliminary results suggest that CI users are more likely to follow the perturbation (e.g., increasing the intensity of their voice in response to an increase in the intensity of the feedback). This suggests that the period of auditory deprivation prior to implantation likely has a negative effect on the perception-production loop's ability to aid in stabilizing the loudness of an individual's voice.

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T21a: THE EFFECT OF AN ORAL MODULATOR OF FAST-ACTING POTASSIUM CHANNELS ON TEMPORAL PROCESSING BY COCHLEAR IMPLANT USERS

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Fast-acting Kv3 potassium channels restore neural membrane potentials after action potentials and are important for sustained temporally accurate firing. They exist at all levels of the auditory system, are susceptible to deprivation, and can be positively modulated by the molecule AUT00063. Recordings from cat inferior colliculus show that sustained temporally accurate firing to high-rate electrical stimuli is susceptible to auditory deprivation, and it has been suggested that this experience-dependent ‘high rate limitation’ is a neural basis for the limited ability of cochlear implant (CI) users to perform psychophysical tasks that require fine temporal processing. The effects of AUT00063 on hearing by CI users might therefore be most easily observed in such tasks, so we obtained three psychophysical measures as part of a larger double-blind placebo-controlled study. The study used a crossover design. All subjects were tested near the start and end of two 28-day periods during which they took either a placebo or 800 mg of AUT00063 daily. The two periods were separated by a 3-week washout. Twelve CI users (five Med El and seven Cochlear) completed all phases of the study. Here we report only the results of the psychophysical tests; other data including safety reports and measures of hearing via the clinical processor will be presented elsewhere.

All three tests involved direct stimulation of one apical electrode (Med-El e4 or Cochlear e20), using symmetric biphasic pulse trains presented in monopolar mode via research software and hardware. (i) The upper limit of temporal pitch – the highest pulse rate up to which pitch increases – was measured using 10 repeats of the optimally-efficient “mid-point-comparison” ranking procedure. The function relating pitch rank to pulse rate was fit with a “broken stick” and the upper limit defined as the rate at which the functions intersected. (ii) “Low-rate DLs” were measured between two pulse rates geometrically centered on 120 pps using an adaptive procedure and a 2IFC task. (iii) Gap detection thresholds for 1031-pps pulse trains were also obtained using an adaptive procedure and a 2IFC task. Inspection of the data at the start of the two periods revealed good test-re-test reliability (correlations of at least 0.89) and support for our previous observation that gap detection correlates with the upper limit but not with low-rate DLs (Cosentino et al, 2016, JARO). Data collection is complete; un-blinding will occur after the abstract deadline but well before CIAP. Drug effectiveness will be assessed by comparing performance at the end of the drug and placebo periods. Data will also be compared to the effects of other manipulations studied in our lab using similar paradigms, including the effects of chronic stimulation and stimulus level on temporal processing by CI users.

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T21b: ALIASING OF SPECTRAL RIPPLES THROUGH CI PROCESSORS: A CHALLENGE TO THE INTERPRETATION OF CORRELATION WITH SPEECH RECOGNITION SCORES

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The spectral ripple test is a popular measure of spectral resolution that, in cochlear implant (CI) listeners, has been shown to correlate with speech recognition scores. In the test, listeners distinguish between sounds whose broadband spectra contain some variable number of peaks (i.e. spectral density), with some spectral modulation depth. A meta-analysis of literature on spectral ripple tests in CI listeners shows a generally consistent ceiling level of performance around 2 ripples per octave, with some outliers performing above. Correlations might therefore be connecting two categorically distinct types of perception rather than variable performance along a single perceptual dimension. We propose that there is a critical point in spectral density at which the output of the CI transitions from representing spectral ripples to a qualitatively different signal, resulting from the interaction between the spectral peaks and the number of active device channels. Importantly, this critical point is exceeded in numerous published studies involving spectral ripples stimuli in CI listeners.

With spectral densities higher than that critical point, spectral ripples continue to change, but cease to differ in a predictable or orderly manner. That is, the transition point represents a bifurcation in a dynamical system. As a consequence, the experimenter cannot be said to still be manipulating spectral density. This problem is analogous to aliasing, but in the spectral domain.

Notably, that aliasing for ripples of higher densities creates artefactual nonlinearities that may unintentionally match the spectral envelope characteristics of speech sounds. This unintentional broad-spectrum discrimination, rather than a true metric of spectral resolution per se, might explain the predictive power of the test. Regardless of predictive power, our analyses suggest that ripples exceeding a critical spectral density cannot be defined along the same continuum as ripples below that value. We therefore recommend that experimenters utilize low-density spectral ripples and test for spectral modulation detection rather than ripple density discrimination thresholds.

T22: MODULATION DETECTION INTERFERENCE IN COCHLEAR IMPLANT LISTENERS WITHIN A FORWARD MASKING PARADIGM

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Modulation detection interference (MDI) refers to the insensitivity in processing amplitude modulation of a target in the presence of a competing, fluctuating masker. MDI plays an important role in speech recognition in noise by listeners with normal hearing. Individuals with cochlear implants (CIs) rely heavily on temporal envelope cues for speech recognition. Interference with these cues could diminish the quality of speech input; therefore it is important to investigate MDI for better understanding of speech perception by CI listeners, particularly in noise. The literature provides evidence for MDI under conditions of forward and simultaneous masking in normally-hearing individuals. Although there is evidence of MDI under conditions of simultaneous masking in CI listeners, MDI has not been reported in this population under conditions of forward masking (F-MDI). F-MDI refers to a condition in which a modulated forward masker interferes with a subject's sensitivity to AM in a subsequent probe more than an unmodulated forward masker causing comparable or greater energetic masking.

In the present study, we investigated the effects of F-MDI when the masker was: 1) amplitude modulated at the same rate as the probe (50 Hz) 2) unmodulated with an amplitude corresponding to the mean amplitude of the modulated masker (SS), and 3) unmodulated with an amplitude corresponding to the peak amplitude of the modulated masker (SSP). We quantified F-MDI as the difference in the probe's AM detection thresholds in the presence of AM and SSP forward maskers. The forward masker was located either on the same electrode as the target (on-channel) or on one of four different electrodes (off –channel). The effect of the time delay (2-100 ms) between masker offset and target onset (onset delay) was also investigated.

Although strong intersubject variability was observed, results showed that AMDTs obtained with the AM masker were higher than those obtained with the SSP masker. No significant effects of onset delay or masker electrode location were observed. These results indicate that MDI occurs under conditions of forward masking, and persists up to 100 ms after masker offset.

T23: THE CHRONICALLY IMPLANTED DTR MOUSE AS A MODEL FOR STUDIES OF MECHANISMS OF COCHLEAR IMPLANT FUNCTION

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Introduction. Previous studies from our laboratory have examined the functional effects of inner hair cell (IHC) survival and spiral ganglion neuron (SGN) density on cochlear implant function in guinea pig and non-human primate models. These models have not permitted the study of high levels of SGN density in the absence of IHCs, so the relative contributions of these elements to electrical hearing are not well understood.

The diphtheria toxin receptor (DTR) mouse (Golub et al., 2012) may be a good model to address this issue because of its robust SGN survival and complete IHC depletion following diphtheria toxin (DT) injection (Tong et al., 2015; Kurioka et al., 2016).

In this study we developed a chronic cochlear implanted DTR mouse model that can be used for obtaining psychophysics and electrophysiology data and performing comparisons to data measured in cochlear implanted humans and guinea pigs.

Previous studies in guinea pigs have shown that it can take weeks or months for electrophysiological and psychophysical data to stabilize after deafening and implantation. Therefore, a long-term stable chronically implanted DTR mouse preparation would be beneficial.

Methods. Both wild type, and DTR mice treated with DT were implanted with a cochlear implant and electrophysiological data were obtained to assess differences in responses for the two test groups as well as to monitor changes over time after implantation and determine when responses stabilized. The implant was made in house and was comprised of a single platinum/iridium 0.2mm ball electrode inserted through the round window and a 0.3-0.5mm ground ball placed in the neck muscle behind the implanted ear. The implant base was mounted to the animal’s skull with various combinations of glues and screws to determine the most stable long term head cap preparation. Electrically-evoked auditory brainstem responses (EABRs) and ensemble spontaneous activity (ESA) levels were recorded periodically under ketamine/xylazine anesthesia. The length of data collection varied based on head cap stability over time.

Results. To date 3 animals (1 wild type and 2 DTR mice) have maintained stable head caps for 30 days post implantation. Head caps that have stayed on the longest were on skulls that were scored with a scalpel blade before cementing and that had smaller amounts of acrylic. The placement of a single 5/16” stainless steel screw just off the midline on the implanted side and slightly behind bregma has added stability to the head cap and has become a reliable stimulating/recording ground for both the EABR and ESA due to the ground ball in the muscle becoming intermittent or broken over time. EABR results for both input/output function slope changes and threshold changes over time are similar to those reported for guinea pigs in that slopes are steeper on day 0, decline over time and then either recover or remain at shallower levels at least out to the 30 day time points. Continued testing will determine if slopes and thresholds are stable or recover beyond 30 days. ESA results for the DTR mice are interesting when compared to guinea pig ESA levels and patterns, but recordings from more animals are necessary to determine if the trend is real. In the few animals tested to date over time, ESA levels have improved as the cochlea heals post implantation.

Conclusions. The chronically implanted DTR mouse is a promising model for determining effects of IHC survival versus SGN survival on cochlear implant function. Further testing is needed to determine solid trends and differences between groups and species.

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T24: USING FOCUSED ELECTRICAL FIELDS TO REDUCE CHANNEL INTERACTION FOR DISTANT ELECTRODES IN COCHLEAR IMPLANT LISTENERS

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It is widely known that speech-understanding abilities are highly variable among cochlear implant (CI) listeners. A potential source of this variability is the electrode-neuron interface, which refers to how well each electrode activates the target auditory neurons. Electrode position, bone and tissue growth, and the integrity of the auditory neurons are factors that may impair transmission of speech information. Prior studies have suggested that electrical current level requirements are higher and spread of excitation is broader for electrodes distant from the neurons or those near a region of neural degeneration. Broader spread of excitation increases channel interaction, which can distort spectral information and result in decreased speech recognition. In this study, the electrode position aspect of the electrode-neuron interface was measured in CI listeners. Information about electrode position is only available through computerized tomography (CT) imaging; which is costly, exposes patients to radiation, and is not always available to audiologists. Therefore, we assessed the relationship between electrode position and a modified psychophysical method that may be useful to audiologists. Psychophysical tuning curves (PTC) is a reliable behavioral measure that has been used to estimate spread of excitation in the cochlea. Preliminary data from our lab show that the width of PTCs positively correlates with CT-estimated electrode position, such that electrodes further from the modiolus results in broader PTCs. Therefore, the current study has two goals: 1) to elucidate the relationship between CT-estimated electrode distance and PTC spread of excitation, and 2) to determine if using spatially focused stimulation on channels predicted to have distant electrodes improves speech recognition. Estimates of electrode-to-modiolus distance were based on CT-imaging, and degree of channel interaction was measured using PTCs for all available electrodes. In seven, adult participants with Advanced Bionics HiRes90K cochlear implants (four postlingually deafened, and three perilingually deafened), four listener programs were created. Two experimental programs used focused stimulation on a subset of channels with greater than the median PTC bandwidth (“Tuning”) or median distance from the inner wall (“Distance”). Two control programs were also created such that: 1) focused electrical fields were used for the inverse channels of those used in the Distance program (“Inverse), and 2) an all-channel monopolar program (“Monopolar”). For all listener programs, the participants were tested on vowel identification (in the /hVd/ context), sentence recognition (IEEE sentences), and a subjective questionnaire. Using linear mixed models, preliminary results show no significant differences between programs for the IEEE sentences; however, four participants performed best with the Distance program, and one subject with the Tuning program, relative to the controls. However, for the hVd vowels, performance with the Distance program was significantly better than the control Inverse program, indicating that when specific channels are focused, performance improves. There were no significant differences between the control Monopolar program and the Distance (CT) and Tuning (PTC) programs, indicating that acutely, subjects do at least as well as the traditional programming they are used to. With a small number of subjects, there were no significant differences between the scores for perilingual and postlingual subjects, though in general, the scores on vowel identification were better for the Tuning program for the postlingual listeners. Future studies will test these programs chronically, to provide participants with more listening experience.

T25a: LOUDNESS PERCEPT OF THE FINE-GRAIN ECAP RECORDING PARADIGM

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In a standard clinical setup, recordings of electrically evoked compound action potentials (ECAPs) are averaged over 25 to 100 repetitions to allow the detection of an ECAP within the noise floor. To obtain an amplitude growth function (AGF), these measurements are normally performed for 5 to 10 different stimulation levels. An alternative paradigm (called fine-grain) to record an AGF is to increase the stimulation intensity in quasi-continuous steps and instead of averaging repeated recordings with identical stimulation parameters, to perform a moving average over small intervals of stimulation levels [1]. The stimulation level resulting in a maximal acceptable loudness (MAL) percept is normally unknown and needs to be obtained behaviorally during the measurement. In this study we investigated the influence of the ECAP recording paradigm and stimulation rate upon the MAL.

AGF recordings from 13 subjects implanted with a MED-EL cochlear implant were obtained using the standard AGF paradigm recorded with the clinical software and the fine-grain paradigm via research software. The order of the measured paradigms was permuted between subjects. For each paradigm, stimulation rates of 20, 40 and 80 Hz were measured.

The participants showed an 8% higher MAL for the standard AGF paradigm compared to the fine-grain paradigm. The standard AGF paradigm showed an increase of the mean MAL between 20 and 40 Hz by 16% and no significant effect towards stimulation rates above 40 Hz. An increase of the mean MAL between 20 and 40 Hz by 17% was observed for the fine-grain paradigm, as well as a decrease between 40 and 80 Hz by 17%.

Further research is needed to understand if the quasi-continuous stimulation used in the fine-grain recording paradigm can explain the reduced MAL level or other factors like the subject’s awareness of the application of research software. Independent of the ECAP recording paradigm, the data suggest that higher MAL can be achieved by decreasing the stimulation rate which could be clinically advantageous in cases where the ECAP threshold is near the MAL.

[1] Gärtner L., Lenarz T., Büchner A. (2014): A novel ECAP recording paradigm to acquire fine-grain growth functions. 13th International Conference on Cochlear Implants and Other Implantable Auditory Technologies, Munich, Book of Abstracts p. 1077.

T25b: LOUDNESS PERCEPTION FOR SIMULTANEOUS ELECTRICAL STIMULATION

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Introduction
The model that can predict loudness for electrical stimulation by Cochlear Implants (CI) is useful for the evaluation of sound coding strategies. These strategies act as the transition between the acoustical information received by the microphone and the electrical stimulation pattern transferred by the electrode array in the cochlea. The balance between performance and power consumption must be considered in new strategies. In the past, models were successfully developed for the prediction of loudness for sequential stimulation. This study aimed to extend this model by systematically investigating the loudness perception elicited by simultaneous stimulation and to apply the model to reduce power consumption in CIs.

Methods
Thirteen Advanced Bionics CI users participated in the study. Participants were directly stimulated via a standard PC over the Streaming Interface Box and the Platinum Sound Processor. The software HRStream was used to create the stimulation patterns. Loudness perception for different stimulation patterns was assessed by a self-adjustment method using a rotational controller without anchors. The maximum comfortable levels (MCLs) of virtual channels consisting of two adjacent electrodes (current evenly distributed on both) were determined across the whole array. For the assessment of loudness for simultaneous stimulation, two-channel stimuli were loudness balanced to one-channel stimuli as the reference. Two-channel stimuli were comprised of a fixed channel (apical, middle or basal) and a variable channel that varied in its distance in respect to the fixed channel. The one-channel reference stimulus was always either the fixed channel or the variable channel at MCL.

Results
Adding a second channel adjacent to the one-channel stimulus reduced the current necessary for equal loudness on each channel of the two-channel stimulus compared to the one-channel stimulus. However, with a greater distance between each channel, more current is necessary for the same loudness percept. Independently of which channel of the two-channel stimulus is used as a reference, the same behavior occurs. There is a significant linear relationship between current adjustment and distance. This relationship is independent from the site of the reference stimulation.

Conclusion
A linear relationship between current adjustments necessary for equal loudness and channel separation was observed. The finding of the linear relationship was incorporated into an extended loudness model for simultaneous stimulation. The loudness model can be used to automatize the fitting parameters between sequential and parallel stimulation strategies, the latter of which may reduce power consumption of CI devices.

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T26a: EFFECTS OF THE ORDER OF ANODIC AND CATHODIC STIMULATION AND OF INTERPHASE GAP ON LOUDNESS IN COCHLEAR IMPLANT USERS.

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For safety reasons, most cochlear implant (CI) strategies use charge-balanced biphasic pulses. For such stimuli, sensitivity depends both on the phase duration and on the inter-phase gap. In addition, studies using monophasic pulses in animals and asymmetric pulses in humans have shown that both anodic and cathodic currents can elicit spikes, and it has been hypothesized that those currents activate the central and peripheral part of the spiral ganglion neurons, respectively. In humans, less anodic current is needed to induce the same loudness sensation than cathodic current, at least at stimulus levels sufficient to elicit a comfortably loud sensation.

Here we investigate the effect of the order of anodic and cathodic stimulation on loudness. To do so we used pairs of pseudomonophasic (PS) pulses, where a 43-µs high-amplitude phase of one polarity was followed or preceded by an 8 times longer and 1/8th-amplitude phase of the opposite polarity. Those two PS pulses were of opposite polarity, and were combined so that the short-high amplitude phases followed each other, separated by an inter-pulse gap (IPG). If it is assumed that neural activation was produced primarily by the short high-amplitude phases, this is equivalent to a biphasic pulse but where each phase could have independent amplitudes. In one condition the two opposite-polarity PS pulses were presented at equal loudness, thereby avoiding the loudness of the pulse pair being dominated by the anodic PS pulse. All pulse pairs were presented at a rate of 100 pps for each 400-ms pulse train.

Six users of the Advanced Bionics CI ranked stimuli in loudness using the optimally efficient mid-point comparison procedure. The stimuli had IPGs ranking from 0 to 800 µs, where the first pulse in each pair was either PS-anodic or PS-cathodic. Loudness rank increased markedly with increases in IPG up to 100-200 µs regardless of leading polarity. The results also showed that, for IPGs below 100 µS, stimuli with cathodic leading polarity are perceived as quieter than their opposite polarity counterparts. A subsequent loudness-balancing experiment showed that the size of this effect was small - about 0.4 dB - but similar for all subjects. This is consistent with a hypothesis whereby anodic and cathodic current excite central and peripheral axons, respectively, and where prior anodic current blocks the propagation of spikes elicited at the peripheral axon by cathodic current. Similar but slightly less consistent results were obtained in a condition where the two PS pulses had equal levels, rather than equal loudness. Interestingly, however, the order effect disappeared when the long-low phases were removed, leaving simple biphasic pulses. This also increased the loudness slightly, suggesting that the long low phases reduced the effects of the short high ones, presumably via charge cancellation at the nerve membrane.

T26b: PPS TOOLBOX: OPEN SOURCE, VERSION CONTROLLED AND OBJECT-ORIENTED MATLAB CODE FOR CI DIRECT STIMULATION

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In the field of Cochlear Implant (CI) psychoacoustics, it is common to run “Direct Stimulation” experiments, where the experimenter bypasses the CI speech processor and stimulates with research software and hardware. However, the variety of devices and research tools combined with the sparse example code can make the design of experiments across devices time-consuming.

The toolbox presented here tackles those difficulties by developing open-source, version controlled and object-oriented Matlab code for direct stimulation: open-source sharing intends to help researchers starting with a new hardware/software; object-oriented coding allows the implementation of new features efficiently, and enables effortless switching between different devices and manufacturers; distributed version control of the code makes it easy to collaborate across labs, to update the code when bugs are reported, and to cite a particular version of the code using a permanent Digital Object Identifier (DOI). This is in line with best practices for citing and sharing digital resources.

This poster will present and discuss on-going development of the toolbox. Current implementation includes single electrode stimulation for the three main implant manufacturers and the possibility to develop an experiment without having any hardware connected. It also includes a few examples of experimental interfaces, including the determination of most comfortable levels. To respect confidentiality agreements, neither source code nor documentation of the proprietary research software from the different manufacturers is included. Further implementations, including multiple electrode stimulation, modulated stimuli, bilateral stimulation and adequate safety checks will be discussed.

T27a: ACOUSTIC SPECTRAL RESOLUTION IN COCHLEAR IMPLANTED INFANTS: METHODS TO DETERMINE THRESHOLD

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Acoustic measures of spectral resolution (SR) correlate strongly with speech perception in cochlear implant (CI) users and can be obtained from infants as young as 3 months old. Thus, SR may be an ideal behavioral measure of auditory acuity in infant CI users. The goal of the present study is to develop a behavioral method that can be used to measure infant SR longitudinally. However, measurement of individual infants' SR is limited by their immature listening efficiency. Previously, a criterion-based behavioral procedure was shown to have a high yield for obtaining an SR threshold from an individual infant. However, the point on the psychometric function (PMF) estimated by this method is unknown. In this study, SR was measured longitudinally in infants with CIs and criterion-based thresholds were compared with those derived from the PMF. The hypothesis is that there will be a strong correlation between methods but that the criterion-based thresholds will tend to overestimate the threshold.

Subjects were 15 infants implanted prior to age 21 months old. All but one were congenitally deaf and none had neurocognitive impairments. SR was measured at two time-points (3 and 6 months post activation) using the infants' preferred clinical program in the monaural condition. Stimuli were broad-band noise bursts filtered by a sinusoidal spectral envelope with logarithmically-spaced peaks presented in soundfield. An observer-based single-interval change/no-change procedure was used to determine the highest ripple density at which a participant could detect a 90º phase shift in the spectral envelope. Ripple density was increased in log steps each time the infant reached a performance criterion. Thresholds were computed two ways: the highest density for which criterion was met versus the 70% point on the PMF. Percent yield for each method, test-test reliability, and intercorrelation were determined. To date, the yield for the criterion based method is higher than the more stringent PMF method. This is due to the fact that some infants have a flat function. For those infants who had thresholds at both time-points, scores tended to be the same or higher at the later time-point using either method. For those infants who had thresholds using both methods, the correlation between the criterion and PMF thresholds was strong and significant at both time-points. The criterion method tended to overestimate the threshold relative to the PMF at the 6m time-point only.

These findings suggest that the criterion method measures threshold close to the 70% point of the PMF in most subjects but may overestimate this point in some subjects. The tradeoff seems to be a slightly higher yield for the criterion method which is advantageous in longitudinal studies of infants. A method of constant stimuli procedure is currently being developed to compare to the current procedure.

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T27b: RELATIONSHIP OF EARLY AUDITORY ACUITY AND SPOKEN-LANGUAGE OUTCOMES IN PRELINGUALLY-DEAF INFANTS USING COCHLEAR IMPLANTS

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Measures of acoustic spectral and temporal processing have been used to characterize auditory acuity in post-lingually deaf adults and pre-lingually deaf children who use cochlear implants (CI). The goal of the present study is to determine if these acuity measures are related to development of auditory behaviors and spoken language in young infants with cochlear implants. An understanding of the relationship between early auditory acuity and clinical outcome may lead to measures of CI efficacy for infants. Previously, we have adapted behavioral tests of spectral and temporal processing for use with infants, toddlers, and school-age children with CIs. Here we present preliminary findings from an ongoing longitudinal study of spoken language outcome in implanted infants where spectral and temporal processing are measured during the first 6 months of device use.

To date, 16 infants have been enrolled in the study. All were activated prior to 20 months of age (6-20 months). No children with known neurocognitive impairments were included. Infant spectral and temporal processing was assessed at approximately 3 and 6 months post activation using an observer-based, single-interval yes/no psychoacoustic procedure. The spectral task was spectral ripple discrimination of a 90 degree shift in phase of a spectral envelope. The highest ripple density at which an infant reached criterion (80% correct performance over 10 consecutive trials) was taken as the spectral ripple threshold (SRD). SRD was measured at 10 and 20dB ripple peak/trough depth. The temporal task was amplitude modulation detection at 10Hz and 75Hz modulation rate. The smallest modulation depth that an infant passed 80% criterion was taken as the AMD threshold. Psychoacoustic tests were completed in random order over 4-5 1.5 hour sessions per time interval. Outcome measures, available from a subset of the enrolled infants, included Infant Toddler Meaningful Auditory Integration Scales (IT-MAIS) in 10/16 infants and Preschool Language Scales standard score (PLS) in 12 of 16 infants. IT-MAIS score at 6 months post activation and PLS score at 12 months post-activation were used. Statistical analyses included bivariate, 1-tailed correlations beween best AMD or SRD score and each outcome measure as well as between PLS and IT-MAIS scores.

Preliminary results show that IT-MAIS at 6 months was positively correlated with expressive and receptive PLS score. Neither outcome measure was significantly correlated with age at implantation or test. IT-MAIS scores were postively correlated with 10dB SRD and 10Hz AMD. PLS score was positively correlated with 10Hz AMD. Other correlations were in the predicted direction but did not reach statistical significance.

Due to the small sample size, these results should obviously be considered preliminary. They do suggest a modest relationship between spectral and temporal processing and outcome in prelingually-deaf infants with cochlear implants. Further data collection and enrollment is ongoing.

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T28a: SEMANTIC DIFFERENTIAL ANALYSIS OF PULSE TRAINS ACROSS ELECTRODE PLACES AND STIMULATION RATES

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For cochlear implant (CI) users, a set of stimuli varying on a single parameter such as electrode place, pulse rate, or modulation frequency can be ordered on a scale ranging from low to high. As a consequence, these parameters have been assumed to elicit a change in pitch height. It has been proposed that the sensations induced by temporal cue and place cue are independent, varying along two orthogonal perceptual dimensions linked to pitch height and timbre, respectively. The aim of the present project was to study the effect of electrode place, pulse rate, and modulation frequency on those perceptual dimensions and to assess whether they are independent from each other.

Two different sets of loudness-balanced stimuli were presented to the listeners. The first set was created by all possible combinations of electrode numbers 22, 18, 14, and 10 and pulse rates of 80, 150, 300, 600, and 1200 pps. The second stimulus set was composed of amplitude-modulated pulse trains with modulation frequencies of 80, 150, 200, 300, and 400 Hz imposed on a constant carrier of 1200 pps, presented via the same electrodes as in set 1. The listeners were asked to rate pitch and sound quality using multiple verbal attributes such as “calm”, “loud”, “clean”, “complex”, “bright”, “lively”, “rough”, “boomy”, and “humming”. Responses were collected on continuous verbal attribute scales ranging from 0 to 100. Definitions of all attributes were provided and subjects were familiarized with the stimuli prior to each session.

Results suggest that neither pitch nor timbre exclusively covary with electrode place, pulse rate, or modulation frequency. For all attributes tested, the statistical analysis revealed no significant interaction effect between temporal and place cues. A comparison between scalings for modulated and unmodulated pulse trains showed no significant difference between the two conditions in agreement with previous studies. Overall, these results indicate that place and temporal cues induce two independent dimension that can both be linked to pitch and timbre.

T28b: PULSE RATE DISCRIMINATION IMPROVES WITH SPATIAL BROADENING OF NEURAL EXCITATION IN COCHLEAR IMPLANT USERS

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Cochlear implant users do not reliably associate increases in pulse rate above 300 pulses per second (pps) with an increase in pitch. This upper limit of pitch is thought to have a central origin, because manipulations of the test stimulus, which are expected to remarkably affect the representation of the stimulus at the auditory nerve, did not have an effect on performance. The present study retested this hypothesis by comparing pulse rate discrimination (PRD) at stimulation sites with relatively broad and narrow spatial activation patterns and between monopolar (MP) and bipolar (BP) stimulation modes. It was expected that a broad activation of the cochlea will facilitate neural representation of high-rate pulse trains, therefore improving PRD. If this is true, it will provide evidence to the postulation that the upper limit of pitch in electrical stimulation is not entirely central.

Postlingually deafened Cochlear Nucleus device users participated in the study. Two electrodes, one with sharp spatial tuning and the other with relatively flat spatial tuning, were selected from each subject. These electrodes were measured for PRD in MP and BP modes using an adaptive procedure at three base rates (200, 300 and 500 pps). Stimulation levels of the twelve experimental conditions (2 sites × 3 rates × 2 modes) were loudness balanced. In the adaptive procedure, the average rate of the standard and target stimuli was always the base rate, while the rate difference (ΔR) between the standard and the target stimuli adapted. PRD was quantified as the minimum ΔR required to detect a pitch difference between the standard and target stimuli relative to the base rate, expressed in a percentage.

Consistent with the literature, PRD deteriorated as base rate increased. PRD was better at stimulation sites with broader tuning than those with sharper tuning. PRD was also better in MP than in BP stimulation mode. The improvement in PRD with broad stimulation was more prominent at high base rates. The results supported the hypothesis that broad stimulation facilitates the coding of high-rate stimuli. They also provided some evidence to indicate that temporal pitch coding with electrical hearing is at least partially constrained at the level of the auditory nerve.

T29a: WHAT DEFINES THE PLACE PITCH OF ELECTRICAL STIMULATION?

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Introduction: Changes in place of stimulation are described by cochlear implant users as changes in pitch. However, it is unknown what attribute of the stimulation produces the place pitch. Some possibilities are 1) the auditory system attends to the location providing the peak of stimulation, 2) the auditory system attends to the location providing the center of gravity of the spread of excitation, 3) the auditory system attends to either the apical or the basal edge of the stimulation pattern, or 4) some combination of the previous possibilities.

A few observations lead to the hypothesis that electrical place pitch may depend more on the apical edge than the basal edge of a spread of excitation. First, reducing both the apical and basal edges of a field by switching from monopolar to tripolar stimuli causes the pitch to increase (Landsberger et al., 2012). Second, when two non-adjacent electrodes are stimulated simultaneously, the perceptual quality is dominated by the apical electrode (Marozeau and McKay, 2016). Third, relative to the location with peak basilar membrane displacement, the traveling wave produces greater displacement basally than apically, allowing the use of the apical roll-off for a place coding cue. Although the traveling wave is not directly relevant to electrical stimulation, it is possible that the auditory system, which developed in response to the traveling wave, may be more sensitive to the apical edge of a distribution.

Methods: SuperMonoPolar (SMP) stimuli were created by simultaneously stimulating in phase on multiple adjacent electrodes. All combinations of adjacent electrodes between 2 and 8 in the Advanced Bionics system were used. It was assumed that stimulation on electrodes 5, 6, and 7 would have a similar center of gravity as stimulation on electrodes 4, 5, 6, 7, and 8 but would have different apical and basal edges to the distribution. Similarly, stimulation on electrodes 3, 4, and 5, would have a similar apical edge to stimulation on electrodes 3, 4, 5, 6, 7, and 8 but would have different centers of gravity and basal edges. In a SMP stimulus, the amplitudes of all active electrodes were equal and set to a most-comfortable level. In a given trial, stimulation alternated back and forth between a SMP and a monopolar virtual channel (MPVC). Subjects adjusted the place of stimulation of the MPVC until the pitch of the MPVC matched the pitch of the SMP. The process was repeated 10 times for each SMP stimulus. Presently four Advanced Bionics users have completed this task.

Results and Conclusions: Results from the first four subjects have been variable. For two of the subjects, the MPVC place match to the SMP stimuli are between the center of gravity and the apical edge, suggesting that place pitch may be dependent on a combination of the two. The other two subjects provided noisy data with no clear pattern of results. These subjects reported that the two sounds had very different qualities and were hard to match. If additional data is consistent with the data collected for the first four subjects, we would predict that place pitch would depend on both the apical edge and center of gravity of the spread of excitation.

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T29b: PITCH PERCEPTION WITH COMBINED PLACE AND TEMPORAL CUES ON PHANTOM ELECTRODE

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On the most apical electrode of cochlear implant (CI), partial bipolar (pBP) stimulation elicits a lower pitch than traditional monopolar (MP) simulation. The extra low-frequency channel created by pBP stimulation of the most apical electrode is called the phantom electrode (PE). The pitch of PE varies with the ratio of current returned to the adjacent basal electrode (σ), due to the change in place of stimulation. The pitch of PE also varies with the amplitude modulation (AM) rate of stimulation, based on a temporal mechanism. PE strategies to date only used temporal coding with a fixed σ. To design a PE strategy with both place and temporal coding, this study explored the interaction between place and temporal cues on PE in a pitch ranking test.

Dynamic ranges of PE stimuli with 30% and 150-Hz AM were measured for σ from 0 to 0.6. PE stimuli with different σ but the same AM rate (150 Hz) were loudness balanced to the one with σ=0.3 at the most comfortable level (MCL). Place pitch ranking was measured for these equally loud PE stimuli with pairs of σ around 0.3 (e.g., 0.25 vs. 0.35, 0.2 vs. 0.4, etc.). The pairs of σ were tested 20 times in random order. The psychometric function of place pitch ranking was fit with a sigmoid function to find the σ difference limen (DL) with d’=1 (i.e., 76% correct response). Similarly, PE stimuli with different AM rates but the same σ (0.3) were loudness balanced to the one with 150-Hz AM at MCL. Temporal pitch ranking was measured for these equally loud PE stimuli with pairs of AM rate around 150 Hz (e.g., 146 vs. 154 Hz, 142 vs. 158 Hz, etc.). The pairs of AM rate were tested 20 times in random order. The psychometric function of temporal pitch ranking was fit with a sigmoid function to find the AM rate DL with d’=1.

Place pitch ranking was then tested with congruent and incongruent changes in temporal pitch, and vice versa. In each trial, subjects listened to two equally loud PE stimuli that varied in both σ and AM rate by the same multiple (0.5, 1, and 2) of individual DLs. The same amount of σ and AM rate changes in terms of individual DLs roughly equalized the perceptual salience of place and temporal pitch changes to facilitate their interaction. Half of the trials had congruent place and temporal pitch changes, while the other half had incongruent place and temporal pitch changes. The three multiples of DLs and the two types of pairing were tested 20 times in random order. The same stimuli were used for place and temporal pitch ranking in different sessions. Stimuli with only place or temporal pitch changes were previewed to remind subjects how the different place or temporal pitches sound like. Feedback was given during the tests to help subjects keep their focus on the target pitch dimension.

Results showed that most subjects had typical S-shaped psychometric functions of place and temporal pitch ranking. The place pitch ranking d’ increased with increasing multiples of σ DLs. Subjects had higher place pitch ranking d’ with congruent than with incongruent temporal pitch changes. Similar results were found for the temporal pitch ranking d’. The results were likely due to a confusion between place and temporal pitch changes. The symmetric interaction between place and temporal cues suggests that the two cues should be coordinated to better deliver pitch cues in a PE strategy.

T30a: RELATIONSHIP BETWEEN COCHLEAR IMPLANT MAP PARAMETERS AND AUDITORY SPECTRAL RESOLUTION IN PRELINGUALLY-DEAF CHILDREN

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Acoustic spectral resolution is correlated with speech perception in postlingually-deaf as well as prelingually-deaf cochlear implant users. It has been proposed that acoustic spectral resolution might be used to assess efficacy of CI programming in children who are too young for open-set speech perception testing. The aim of this study is to investigate whether individual map parameters are related to a child's spectral resolution performance.

Subjects included two age groups of prelingually-deaf CI users. The first group is comprised of 15 school-aged children (range 7.5-15 years) who received a cochlear implant prior to 2 years of age. The second group consists of 15 infants implanted prior to 18 months of age. For both groups, all but one was born with bilateral severe to profound sensorineural hearing loss. One developed meningitis and subsequent bilateral profound sensorineural hearing loss in early infancy. No subjects had neurocognitive impairments.

All subjects were tested using their preferred clinical program and speech processor settings in the monaural condition. The right ear or first ear implanted was tested for bilaterally implanted subjects. Internal devices and speech processors from all three FDA-approved manufacturers were included. Spectral Ripple Discrimination (SRD) was used to measure spectral resolution. Infants were tested during the first 6 months after CI activation over 3-5 visits while school-aged children were tested in 1-2 visits. Stimuli consisted of broad-band noise bursts filtered by a sinusoidal spectral envelope with logarithmically-spaced peaks presented in the sound field at 65 dBA. The task was to detect a 90º phase shift in the spectral envelope. Infants were tested using an observer-based single-interval change/no-change procedure while school-aged children were tested using an adaptive 3-interval 3-alternative forced choice procedure. For both groups, ripple density was increased until the threshold to detect the spectral envelope change was obtained.

The characteristics of each user's speech processor and preferred clinical program were analyzed for number of active electrodes, frequency range, per channel stimulation rate, t-level, C (or M)-level, electrical dynamic range, and audibility (measured by sound booth detection). Programming level was converted from clinical unit to charge. Bivariate correlations were done to examine relationship between spectral resolution and map parameters separately within each device group. Bonferroni-Holm corrections were applied. A strong, significant negative correlation between per channel stimulation rate and spectral resolution was found in the school-age children utilizing Advanced Bionics devices. This finding was not found for children utilizing Nucleus devices as there was no variation in the stimulation rate between subjects. Other correlations did not reach significance. The slope of the spectral modulation transfer function, but not the x-intercept, was strongly correlated with rate indicating that faster rates were associated with better spatial resolution but not with across-channel intensity resolution.

This preliminary finding suggests that faster per-channel rates of stimulation are associated with poorer spatial resolution and thus, poorer spectral ripple discrimination. This finding may explain one reason why faster rates of stimulation have not been found to be beneficial for speech understanding in CI users. Corroboration of this result with larger sample sizes is warranted.

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T30b: PLACE PITCH AS A FUNCTION OF CURRENT AMPLITUDE IN COCHLEAR IMPLANT USERS

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Place pitch is thought to be important for speech perception in cochlear implant users. This is evidenced by the fact that cochlear implant users perform better with multi-channel stimulation than with single-channel stimulation. Typically, listeners with cochlear implants report that the pitch (or brightness) of electrodes more basal in the cochlea is higher than that of more apical electrodes. One aspect of cochlear implant stimulation that may affect place pitch is the current amplitude used for stimulation. Current amplitude could affect place pitch if changes in current amplitude result in substantial changes to the neural fiber population stimulated. This could occur due to changes in spread of excitation and due to variations in auditory neural survival along the neural fiber array. Place pitch changes with changes in current amplitude have the potential to interfere with speech perception as it is assumed in sound coding strategies that all stimulation from a given electrode has the same place pitch. Thus, we investigated the change in pitch associated with change in current amplitude in listeners with cochlear implants.

We tested 10 participants with Advanced Bionics cochlear implants using a pitch-scaling task. Stimuli were constant-amplitude pulse trains presented at 900 pulses per second to single electrodes. Six electrodes spaced out across the electrode array were used. Current amplitudes were presented at levels between 20 and 100 percent of the listener’s dynamic range. The presentation order of stimuli was randomized across electrodes and percent dynamic range. Participants scaled the pitch of the sound on a visual-analog scale.

Participants rated stimulation from more basal electrodes as higher in pitch as expected. There was variability across participants and electrodes in how pitch ratings changed as a function of percent dynamic range. Linear regression lines were fit to the pitch ratings as a function of percent dynamic range for each electrode of each participant. When slopes of the linear regression lines were significantly different from zero, they were most often positive, meaning that pitch ratings increased with increasing percent dynamic range. When negative slopes occurred, they most often occurred for the most apical electrode. On average across participants, the slopes between pitch ratings and dynamic range were significantly positive for four out of six electrodes tested. The slope of the most apical electrode was significantly lower than the slopes of four of the other electrodes.

The results suggest that for listeners with cochlear implants, the effect of current amplitude on pitch depends on the listeners and the electrode tested. Listeners tend to report that pitch increases with increases in current amplitude on all but the most apical electrode. Because the results of this study have the potential to be influenced by the bias of the listener to relate an increased loudness with an increased pitch, further investigation is needed to examine whether the results would be consistent across data collection methods.

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T31: POLARITY SENSITIVITY IN COCHLEAR IMPLANTS: RELATION WITH NEURAL SURVIVAL?

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Cochlear implant (CI) subjects show a large inter-individual variability in performance on various tasks. These differences are often ascribed to differences in neural survival. However, there is no objective way to determine the degree of neural survival in a given subject. The present study aims to test if polarity sensitivity to electrical stimulation, which has been proposed as a psychophysical correlate of neural health, is related to CI performance. Some modeling studies predict that auditory nerve fibers with peripheral processes should be more sensitive to cathodic stimulation while fibers with degenerated peripheral processes should be more sensitive to anodic stimulation. Given the degeneration of auditory nerve fibers start at the periphery, we hypothesize that polarity sensitivity on a given electrode may reflect the degree of local neural survival.

Sixteen Advanced Bionics subjects took part in Experiment 1. Detection thresholds were measured adaptively for partial-tripolar, triphasic pulses with a central cathodic or anodic phase on all electrodes of the implant. The polarity effect, defined as the difference between cathodic and anodic thresholds, varied from about -4 to +4 dB depending on electrodes and subjects. The mean polarity effect across electrodes was found to negatively correlate with performance on a spectral-temporally modulated ripple test (SMRT) which is a measure of spectral resolution. Although the strength of this relationship was moderate (r=0.56), this result is consistent with our hypothesis that relatively lower cathodic thresholds should reflect better neural survival and, consequently, lead to better spectral resolution. Rather surprisingly, the variance in threshold across the electrode array, which has been proposed as another indicator of neural survival in previous studies, was positively correlated with performance on the SMRT test.

In Experiment 2, we tested the hypothesis that both the polarity sensitivity and the electrode-to-modiolus distance (EMD) are predictors of detection thresholds. Detection thresholds were obtained for partial-tripolar, symmetric biphasic pulse trains. Cone-beam CT scans were obtained for 8 of these subjects and the EMD was measured for each electrode. Between-subject analysis showed that the mean EMD was significantly correlated with the mean threshold across the electrode array but that the mean polarity effect was not. Within-subject partial correlations showed that both the mean EMD and the mean polarity effect were correlated with detection thresholds but that they each accounted only for about 5% of the variance in threshold. This suggests that the variation in threshold across the electrode array has additional contributing factors.

To conclude, these two experiments show that polarity sensitivity at threshold is related to spectral resolution and to absolute thresholds. This suggests that polarity sensitivity may partly reflect the degree of neural survival.

T32a: THE EFFECT OF A COCHLEAR IMPLANT PROCESSING STRATEGY ON AUDITORY MOTION PERCEPTION

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Spatial hearing is often examined in bilateral cochlear implant (BiCI) users, to evaluate the benefits of having bilateral vs. unilateral inputs. Typically, the ability to localize stationary sound sources is measured, but stationary sounds are not representative of many auditory stimuli that listeners encounter (e.g., moving vehicles or children moving in playgrounds). A previous experiment conducted in our lab showed that BiCI users performed worse than NH adults in tracking the location of a moving sound.

To understand the gap in performance between BiCI users and NH adults, the present study focused on the processing strategy of the CIs. BiCI users are challenged with integrating signals from two independently operating CIs, which compromises the availability of binaural cues, including temporal coordination of the signals presented to the two CIs. Furthermore, the frequency representation of the acoustic signal is limited to a small number of channels compared to the fine spectral resolution that a NH listener has. Therefore, it was predicted that NH subjects' listening to a vocoder simulating the processing strategy that the BiCI users were fitted with, i.e., Cochlear's peak-picking strategy, would exhibit performance comparable to BiCI subjects when tracking the location of a moving sound.

Three measures of auditory tracking abilities were made: 1) motion detection, 2) direction discrimination, and 3) tracking the range of motion. Stimuli consisted of 500 ms white noise tokens (150-6000 Hz) panned between 37 loudspeakers (5˚ intervals, -90˚ to +90˚ azimuth) and binaurally recorded on a KEMAR manikin. Stationary sound sources were also recorded from one of 19 loudspeakers (10˚ intervals, -90˚ to +90˚ azimuth). Two conditions were tested for NH adults via Sennheiser HD600 circumaural headphones: 1) NH non-vocoded stimuli and 2) NH vocoded stimuli filtered through a sine-wave simulation of the ACE processing strategy provided by the Nucleus MATLAB Toolbox. BiCI users were presented the stimuli via direct audio input connection.

Results show that sound localization ability of a stationary sound source was significantly worse for BiCI users and in the NH vocoded condition compared to the NH adult non-vocoded condition. Results from auditory tracking measures were: 1) poorer performance in the detection of a moving sound source in BiCI users and the NH listeners in the vocoded condition compared to the NH non-vocoded condition, 2) significantly lower performance in discriminating the direction of movement for BiCI users and the NH vocoded condition compared to the NH non-vocoded condition, 3) larger variability in perceived range of motion for BiCI users and the NH vocoded condition compared to the NH non-vocoded condition. It is important to note that in all measures, performance in the NH vocoded condition was not significantly different to BiCI users, which implies the poorer performance with CIs is largely due to signal processing. This data suggests that future bilateral CI processing strategies need to improve the encoding of dynamic binaural cues to enhance auditory motion perception abilities of BiCI users.

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T32b: THE ROLE OF PLACE AND TEMPORAL CUES ON VOLUNTARY STREAM SEGREGATION OF COCHLEAR IMPLANT USERS

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Both music perception and speech-in-noise understanding involve auditory streaming, a perceptual process by which the human auditory system organizes sounds from different sources into perceptually meaningful elements. Despite its high relevance in many daily situations, the number of studies investigating segregation abilities of cochlear implant (CI) listeners is limited and their findings are contradictory. There are two main boundaries in auditory streaming: the temporal coherence boundary (TCB) and the fission boundary (FB). The TCB is the largest difference between two sounds at which they still can be integrated, whereas the FB represents the smallest difference between two sounds needed to segregate them. Most of the previous research investigated the TCB whereas little attention has been given to the FB. The present study investigates the FB as a function of place and temporal cues in CI listeners and aims to establish whether a two-stream percept can occur instantaneously or whether this needs time to build up. CI users participated in a delay detection task composed of a sequence of regularly presented bursts of pulse trains (“A” sequence) interleaved with a sequence of irregularly presented bursts (“B” sequence). Depending on the condition, A and B bursts were presented at different electrodes or at the same electrode with different pulse rates. The electrode or rate differences between the A and B bursts and the duration of the sequences were varied between trials. On half of the trials, a small delay was added to the last burst of the regular A sequence, and subjects were asked to indicate whether they could detect this delay. As the period between consecutive bursts of the B sequence was jittered, time judgments between the A and B sequences did not provide reliable cues to perform the task. Thus, the detection performance was assumed to improve if the subjects would perceptually segregate A and B. The results showed better performance for larger electrode and rate differences between A and B bursts, suggesting that both place and temporal cues can play an important role in the segregation of sounds. The performance was also influenced by the duration of the sequence, with longer sequences leading to better performance, demonstrating that a two stream percept needs time to build up.

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T33a: COCHLEAR IMPLANT LOUDNESS GROWTH IN FREE FIELD

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A loudness growth function (LGF) forms part of a typical cochlear implant (CI) speech processor's signal processing strategy and aims to compensate for the exponential increase in perceived loudness for linear increases in electrical stimulation current. The LGF is usually chosen to have a logarithmic or power law shape (i.e., non-linear). This shape can often be adjusted with a single parameter called the loudness growth exponent. The equivalent parameter for Cochlear's Nucleus devices is referred to as the Q-value. The ideal loudness growth exponent or Q-value is thought to be one that is selected so that the user experiences loudness growth that is comparable to that of a normal hearing listener, i.e. approximately linear on logarithmic axes (log-loudness vs. intensity in dB SPL). The LGF has an impact on both speech understanding with a CI and the subjective quality of CI-mediated sound.

While CI loudness growth has been well characterised as a function of current delivered to a single electrode, loudness growth with acoustic input signals in a free-field environment is relatively unexplored. The present research focuses on these questions: with loudness growth functions as presently implemented in typical cochlear implants, what does the actual loudness growth in free field look like when listening to sound through the CI microphone? Does a specific choice of the LGF and Q-value result in normal loudness growth? What is the subjective effect of changing the Q-value?

The work that will be presented describes a model that was developed to predict the loudness of speech-like signals when listening through a CI, as well as measurements of loudness growth when CI users are listening in free field conditions. Loudness growth data were obtained from seven cochlear implant users, and were measured using time-varying speech-like signals. Different shapes of the LGF were tested, manipulated by adjusting the Q-value.

The loudness model predicts that the Q-value of the LGF can be selected to deliver normal loudness growth on single electrodes. The Q-value can also be adjusted to obtain more compressive or expansive LGF functions. The loudness model also showed that linear, compressive or expansive loudness growth can still be obtained with multi-electrode stimuli, i.e. with electrical stimulation patterns resulting from speech-like sounds, but that this is depended on a number of parameters. Specifically, the actual loudness growth function is of more complex shape than the desired loudness growth, and desired loudness growth is typically not obtained across the entire range of input intensity. Furthermore, loudness growth is sensitive to a number of parameters, including the input dynamic range, the volume setting of the speech processor and the number of active electrode channels.

These model predictions are reflected in data obtained from CI listeners. Data show that normal loudness growth is seldom obtained with any settings of the speech processor, and that varying Q-values across the range may have little effect for some listeners. However, participants reported a large difference in the subjective quality of sound as the Q-values were adjusted. This is investigated in a further analysis in which a metric for the evaluation of the effectiveness of a selected Q-value was developed.

T33b: FACTORS THAT CONTRIBUTE TO ELECTROPHYSIOLOGICAL AND PSYCHOPHYSICAL MEASURES OF COCHLEAR HEALTH IN COCHLEAR-IMPLANTED HUMANS

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Introduction: Studies in animals with cochlear implants have shown that both electrophysiological and psychophysical measures can provide good estimates of neural survival. Specifically, some measures based on the electrically-evoked compound action potential (ECAP) and psychophysical measures of multipulse integration (MPI) individually account for about 50% of the variance spiral-ganglion-cell density in cochlear-implanted guinea pigs. Related studies in humans have shown that some of these measures also correlate with speech understanding. However, these measures might also be influenced by factors unrelated to neural health such as properties of the surrounding bone and/or tissue or specific location of the cochlear implant electrodes with respect to the auditory nerve. The current study examines the relative contributions of these extraneous factors in adult human cochlear-implant users.

Methods: Subjects were post-lingually deafened adults unilaterally implanted with Cochlear™ multi-channel electrode arrays (CI24RECA, CI512, or CI422). The following measures were collected on each electrode, for each subject: 1) ECAP amplitude growth functions (AGFs) using 7 and 30 µs interphase gaps (IPGs) and slope difference for these two IPGs (IPG effect); 2) Psychophysical detection thresholds and MPI based on thresholds at two pulse rates, 80 and 640 Hz; 3) Simple impedance measures. Some subjects underwent post-operative computerized tomography (CT) imaging to visualize cochlear electrode locations.

Results: Across-site impedance measures tended to be more variable across stimulation sites in subjects with contour arrays (CI24RECA or CI512) compared to those with straight arrays (CI422). Impedance measures tended to be positively correlated across stimulation sites with psychophysical detection thresholds, but only for subjects with contour electrode arrays. Impedance measures were negatively correlated with ECAP AGF slope measures, but again, only in subjects with contour arrays. Impedance measures were not correlated with the IPG effect or with MPI in any subjects. When comparing ECAP and psychophysical measures, the pattern was less clear but preliminary results do not indicate that these measures are highly correlated. Impedance and neural density measures are being compared to post-operative CT measures (work in progress) to determine relative contributions of electrode-to-modiolus distance and electrode placement.

Conclusions: Results thus far suggest that simple impedance measures are significantly correlated across stimulation sites with measures of both psychophysical detection thresholds and ECAP AGF slopes but only for subjects implanted with contour arrays. This might be related to differences between contour and straight electrode arrays in the magnitude of variation across stimulation sites in impedance and/or electrode position. The relationship between MPI and ECAP AGF measures is not consistent, suggesting that the underlying mechanisms differ, at least in part, for these two measures.

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T34: PITCH RANKING WITH DIFFERENT VIRTUAL CHANNEL CONFIGURATIONS IN ELECTRICAL HEARING

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Introduction: Monopolar Virtual Channels (MPVCs) use current steering to provide stimulation between physical electrodes, increasing the number of places of stimulation beyond the number of physical electrodes. The current spread created with a MPVC is similar to the spread for monopolar stimulation. The broad spreads of excitation from MP and MPVC stimulation may limit the benefits from adding extra channels using a MPVC. Quadrupolar Virtual Channels (QPVCs) use current focusing in combination with steering to provide additional sites of stimulation while reducing channel interaction. However, due to the potentially asymmetric current field generated by QPVCs, there may be distortions in the place pitch representation using this mode. Model simulations of these two modes show that the center of gravity (COG) for QPVC do not move monotonically across the array with current steering. A Virtual Tripole (VTP) stimulation mode is introduced as a current focused virtual channel with a symmetrical electric field distribution similar to the MPVC configuration. Simulations of VTP stimulation mode suggest that the COG shifts monotonically across the cochlea in a manner similar to MPVC stimulation.

Methods: A total of eight post-lingually Cochlear implant (CI) users performed a 2IFC pitch ranking task. Single electrode stimulation at different electrode locations between 4.5 and 7.5 were pitch ranked relative to stimulation at location 6, using QPVC, VTP, and MPVC configurations. The goal was to determine if place pitch shifts similarly (and monotonically) across the cochlea or if any of the stimulation modes shift non-monotonically. All stimuli were loudness balanced to reference electrode 6 at a most comfortable level. Data was fitted using sigmoidal functions to estimate the electrode position with the same pitch as the reference electrode for each stimulation mode.

Results and Conclusions: Results suggest that MPVC and VTP stimulation provide a consistent monotonic shift across cochlear positions while the place shift provided by QPVCs was more variable, which may lead to place pitch distortions. The results emphasize the importance of using spatially symmetrical stimulation modes with current steering in a speech processing strategy. Furthermore, the results suggest that VTP stimulation would be recommended instead of QPVC stimulation in a speech processing strategy.

T35a: CAN HEAD MOVEMENTS HELP LISTENERS WITH BILATERAL COCHLEAR IMPLANTS DISAMBIGUATE FRONT-BACK CONFUSIONS?

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Much of what we understand about audition in normal hearing (NH) and hearing impaired (HI) populations is based on experimental conditions that hold listeners and sound sources stationary. However, in everyday life listeners move through their environment, turn their heads in response to salient auditory and visual stimuli, and localize sound sources that are sometimes also in motion. As they move, listeners must integrate information from various sensory modalities, from motor feedback, and from cognitive processes to disambiguate their own motion from that of sound sources in their environment. At least for normal hearing listeners, self-motion, especially in the form of head-rotation, can help to disambiguate complex auditory environments. One such example is the avoidance of front-back confusions using head rotation.

On the azimuth plane, natural combinations of interaural differences of time and intensity correspond with two sound source locations, one in front, and one behind the listener. This ambiguity can result in front-back confusions, where listeners localize sound sources to the correct angular location, but behind them when the sound source is in front of them or vice-versa. Sounds with sufficient high-frequency information allow NH listeners to use spectral pinna cues to resolve front-back confusions. However, many cochlear implant (CI) patients have limited access to these cues, because of reduced spectral resolution and because of the location of the implant microphones on the head instead of in the concha. Normal hearing listeners face a similar problem when they encounter low-frequency stimuli. They can then resolve front-back confusions by tracking the rate and direction of change in binaural cues as they turn their head and comparing this to what they might expect for a sound source behind or in front of them. It is unknown whether CI patients, with their reduced auditory spatial acuity, can resolve front-back confusions using a similar strategy.

If CI patients can make use of head movements to disambiguate and simplify their auditory scene, then current estimates based on static listening conditions may underestimate the effective auditory spatial acuity of CI patients under real-world conditions. Conversely, CI patients' decreased auditory spatial acuity may render information gained during their motion useless for resolving front-back confusions. In this case, we may overestimate the effective auditory spatial acuity of CI listeners in real-world, dynamic conditions. We will present initial findings that compare the number of front-back confusions for NH and CI listeners when they are stationary versus when they are allowed to rotate their head.

T35b: INVESTIGATING BINAURAL SENSITIVITY WITH CLINICAL COCHLEAR IMPLANT PROCESSORS BY ANALYZING EYE GAZE BEHAVIOR

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For a number of years there have been attempts to understand how well bilateral cochlear implant (BiCI) users can process binaural cues, namely interaural time and level differences (ITDs and ILDs). Stimulus control can be achieved by using synchronized research processors to directly stimulate the internal implants. The typical measure (just noticeable difference, JND) is similar in some BiCI users to measures obtained in normal hearing (NH) listeners. However, it is not clear that JNDs provide comparable information in the two groups about the perceptual processing involved in binaural hearing. In this study, we tested the hypothesis that eye gaze behaviors of BiCI listeners will differ from those of NH listeners due to lower saliency in binaural cues resulting from signal processing in the implant processors. Further, the study was designed to gain insight into how BiCI users process varying magnitudes of ITD and ILD cues using a realistic speech coding strategy. In this experiment, a novel method was used to simultaneously track eye gaze to infer the time course of a perceptual response to a stimulus carrying either an ITD or ILD cue, while subjects are engaged in a left-right discrimination task.

ITD and ILD cues were presented through the clinical processors of BiCI listeners with their everyday clinical maps. Since the N of M strategy employed in Cochlear Nucleus processors typically activates eight electrodes, a complex of eight transposed tones was created with 30 Hz amplitude modulation and center frequencies chosen to match the center frequencies of electrodes 4-11. The amplitude modulation rate was selected to provide good envelope ITD with high stimulation rate in the clinical processors, and electrodes were chosen to minimize distortion of envelope cues due to the CI sound processing. Stimuli were delivered to BiCI processors through the auxiliary input port. Stimuli for NH listeners were created with center frequencies between 4000 and 8417 Hz to target similar locations along the cochlea as BiCI listeners based on the Greenwood function and played back via headphones. ITD and ILD JND thresholds were measured by presenting stimuli with different magnitudes in the binaural cue using the method of constant stimuli, while eye gaze trajectories were recorded during the same trials. The eye gaze data, obtained at binaural cue levels greater than the JNDs and near JNDs, were fit with a model that quantified latency, thus inferring the speed of decision making, and uncertainty during the decision making process.

Preliminary results showed that some BiCI listeners exhibited ITD and ILD JNDs within the range of NH listeners, but eye gaze trajectories showed that they were generally slower in making left/right judgments. For both BiCI and NH listeners, at binaural cue levels greater than the JNDs, where performance was near 95% correct, latency from eye gaze trajectory decreased as the binaural cues increased in magnitude and became more salient. These results suggest that despite achieving similar binaural sensitivity performance, processing of binaural cues is still more difficult when listening to current CI sound processors.

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T36a: THE EFFECT OF DOUBLE PULSES WITH INTERPULSE INTERVALS IN A "FACILITATION" RANGE ON RATE PITCH DISCRIMINATION IN CI USERS

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The ability of rate pitch discrimination is poor for cochlear implant (CI) users compared to normal-hearing (NH) listeners. Already at low pitch rates, the just noticeable difference (JND) is about 20% of the base rate (Baumann and Nobbe, 2004), while the NH listeners can discriminate small differences in frequency of 0.2% at 1 kHz (Zwicker and Fastl, 1990).
The results in the study of Laback and Majdak (2008) show, that introducing jitter to the stimulus improves the interaural-time difference (ITD) sensitivity and therefore allow a better sound localization. They suggested that this type of stimulation may also have a positive effect on rate pitch discrimination. A follow-up study by Hancock et al. (2012) indicates, that the substantially effect in sound location is only caused by double pulses with short interpulse intervals (IPI) introduced by the applied jitter.

This study investigates the influence of double pulses on rate pitch discrimination. Different IPIs were used. Two experiments were designed. One with a base pulse rate of 200 pps and the other with a base pulse rate of 400 pps. In both experiments the rate pitch JND for CI user for the standard single pulse and double pulses with the IPIs of 15 µs, 50 µs and 150 µs.
There was a huge inter-individual difference between subjects. This causes high standard variations in the mean results. In both test cases no significant effect in JND between the different conditions were found. A significant loudness difference between single and double pulses (all IPIs) was found.

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T36b: PERCEPTUAL DIFFERENCES IN SINGLE CHANNEL ANALOG AND PULSATILE STIMULATION

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Early cochlear implants often used analog signals to stimulate the cochlea. However, with multi-channel implants, the use of analog stimulation was phased out relatively quickly for a number of reasons including battery life conservation and reducing electric field interactions. In modern implants, temporal information is usually provided by amplitude modulations of a relatively high rate biphasic pulse train (AM) although some strategies directly encode temporal information by adjusting the rate of stimulation (RATE). While the physical differences between analog, AM, and RATE stimulation are clearly defined, the perceptual differences between them (if any) are unknown. In this study, we used both a traditional and a multidimensional scaling task to evaluate the perceptual differences between analog, pulsatile (RATE) and amplitude modulated (AM) signals.

In the first experiment, stimuli consisted of equally loud stimulation on electrode 2 of 10 Advanced Bionics users. A total of 9 stimuli were used (100, 200, and 400 Hz presented as either analog, RATE, or AM with a 1600 Hz carrier). Subjects were asked to scale “how different” all pairs of stimuli were from each other using a standard multi-dimensional scaling protocol. In the second experiment, only one stimulus was played in a trial, and subjects were asked to scale how “high” and how “clean” it sounded. In this experiment, stimuli consisted of 100, 150, 200, and 400 Hz in either Analog, RATE, or AM configurations.

A two-dimensional ALSCAL analysis reveals a dimension corresponding to frequency and a dimension separating analog from AM and RATE. For a given frequency, AM and RATE stimuli were perceived similarly. Higher rates were consistently ranked as higher pitch. Although there was variability across subjects, analog stimulation was ranked differently than AM and RATE for “clean”.

One potential explanation for the differences between analog and the pulsatile stimuli is that analog stimulation is continuous while pulsatile stimuli have relatively large periods of no stimulation (i.e. the interpulse intervals). A follow-up multi-dimensional scaling experiment was conducted to investigate if reducing the interpulse interval (by increasing the carrier pulse rate) of AM stimulation would produce a quality more similar to analog stimulation. However, preliminary analysis suggests that increasing the AM carrier rate does not produce a sound quality closer to analog.

In summary, results show that analog stimulation is perceived quite differently than either AM or RATE stimulation (which in turn are perceived similarly). However, the explanation for the difference in perceptual quality remains unclear.

T37a: PREDICTORS FOR TINNITUS RECOVERY FOLLOWING COCHLEAR IMPLANTATION

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Objectives: To develop and internally validate a prediction model for tinnitus recovery following unilateral cochlear implantation.

Methods: In this retrospective study, a questionnaire concerning pre- and postoperative tinnitus was sent to all patients who underwent unilateral cochlear implantation in the University Medical Center Utrecht between January 1st 2006 and December 31st 2015. Data of patients with preoperative tinnitus was used to develop a prediction model for tinnitus recovery using multivariable backward logistic regression ($p<0.157$). Missing data was handled using multiple imputation. The prediction model was internally validated using bootstrapping techniques.

Results: Of 138 included patients, 87 patients experienced preoperative tinnitus. The tinnitus recovery rate in these patients was 40%. Lower preoperative CVC score, unilateral localization of tinnitus and larger deterioration of residual hearing at hearing threshold 250 Hz revealed to be relevant predictors for tinnitus recovery. After internal validation of this prediction model, the area under the receiver operating characteristic curve (AUC) was 0.69.

Conclusion: Significant predictors for tinnitus recovery following unilateral cochlear implantation were identified. These findings can contribute to a better preoperative counseling of CI candidates with tinnitus.

T37b: BUILD-UP EFFECT OF AUDITORY STREAM SEGREGATION USING AMPLITUDE-MODULATED NARROWBAND NOISE

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Stream segregation is the ability to discern auditory objects within a stream of information; such as distinguishing a target speaker amongst background noise. Recent research re-examining stream segregation has challenged the traditional notion that listeners segregate information following a period of build-up (i.e., the build-up effect). Our preliminary work [Wheeler & Nie, commons.lib.jmu.edu/honors201019/216/, (2016)] noted normal-hearing (NH) listeners may form auditory streams in the absence of build-up with robust between-stream differences, unless these differences are modest. Using the same method, this project studied the build-up effect in listeners using cochlear implants (CI).

Listeners were presented 24.7-second sequences containing two sets of noise bursts, potentially at different frequencies, and various amplitude-modulation (AM) rates. Listeners indicated whether one or two auditory streams were perceived over the course of presentation. Results showed that, like NH listeners, CI listeners segregated streams at large between-set frequency differences without any period of build-up. In addition, in absence of frequency difference, NH listeners took time to build up stream segregation when AM-rate differences exceeded two-octaves. In contrast, CI listeners reported one-stream perception for all AM-rate differences, consistent with the absence of stream segregation. In short, CI listeners did not show the build-up effect based on the amounts of frequency-differences and AM-rate differences, which, however, are likely associated with different underlying mechanisms. The salience of frequency-differences and AM-rate difference will be further compared between NH and CI listeners, as well as trends in the changing of perception over time course.

Y38a: FREQUENCY DEPENDENT ILD PERCEPTION IN NH LISTENERS

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Objective: To investigate the perception of interaural level differences (ILDs) when sounds arriving at each ear differ in spectral content. Evidence from a behavioral study suggests that listeners can perceive ILDs despite a large spectral difference (1 octave) across ears. This contradicts the neurophysiological evidence from animals suggesting that ILDs arise from frequency-tuned binaural neurons. This has implications for hearing-impaired bimodal listeners that use hearing devices that do not have an identical representation of frequencies in each ear.

Study Design: 1/3-octave band noises were played simultaneously in both ears. Center frequencies of those noise bands were 1500, 1890, 2381, 3000, 3778, 4762 and 6000 Hz. Levels were varied across both ears to obtain ILDs of up to ± 25dB. Normal-hearing listeners were instructed to indicate whether they heard a sound to the left or right from midline of the head in the first session. In the second session, the participants were asked to indicate if they heard one or two sounds.

Methods: Sounds, generated in Matlab (R2016b), were presented over Beyerdynamic headphones (DT7770PRO) through a soundcard (MOTU mk3). Participants had to respond by pressing the left or right arrow on the keyboard (for left/right lateralization, and one/two sound perception). Psychometric curves were fitted to determine the threshold (dB) and 90% width (dB) as measures of accuracy and imprecision, respectively.

Results: Widths and thresholds were ~10 dB and ~0 dB for identical sounds. These sounds were always perceived as one, single sound. In stark contrast the width and threshold rose to ~50 dB and ~20 dB, respectively, for noises with maximum frequency disparity (1500 Hz and 6000 Hz). Sounds were also perceived as different in 40% of the times for sounds with a frequency disparity of 1/3rd octave.

Conclusion: Across-frequency ILD perception is weak or non-existent. For sounds to be integrated into a single percept, frequencies of sounds in both ears have to be equal or similar (within 1/3 octave band). This implies that bimodal listeners may suffer from deficits in ILD perception leading to poor sound localization ability and marginal speech intelligibility in noise

T38b: UNDERSTANDING THE IMPACT OF AUDITORY OBJECT FORMATION ON LATERALIZATION IN BILATERAL COCHLEAR IMPLANT LISTENERS

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Binaural cues such as interaural time differences (ITDs) and interaural level differences (ILDs) are known to be useful for sound source lateralization and for segregating speech from noise in listeners with normal hearing (NH). Binaural cues can also promote perceptual grouping of sound sources and auditory object formation (AOF). These functions are related, and good AOF is likely to be a prerequisite for spatial hearing in NH listeners. Other cues that promote AOF are often related to the temporal aspects of the signal (e.g. rate, envelope, onset timing, etc.). Thus greater across-ear matching of temporal information can enforce AOF and hence improve lateralization.

Little is known about the role of AOF on the abilities to use binaural cues, specifically ITDs in bilateral cochlear implant (BiCI) listeners. With clinical devices, lack of synchronized stimulation across the ears can lead to a number of limitations. For example, across-ear asymmetries in the effective rate of stimulation can arise from irregularities in “peak-picking” techniques, resulting in interaurally asymmetric timing of pulses. Additionally, clinical mapping decisions which assign different pulse rates for each ear can lead to temporal asymmetries that may further interrupt spatial hearing abilities and AOF. Here we took a unique approach to investigating AOF, where we combined interaural rates and ITDs to investigate how well listeners accurately group these two types of cues across the ears. We hypothesized that asymmetric rates would be more detrimental to the ability of NH listeners to form objects compared with BiCI users because NH systems are more sensitive to rate differences across the ears. In contrast, BiCI users were hypothesized to have more tolerance for mismatched rates because prior studies have shown that they generally have poor sensitivity to temporal information.

BiCI users and NH listeners participated in a single interval, six-alternative forced-choice task. Listeners reported where and how many sounds were heard. Stimuli for BiCI listeners were diotic and dichotic, constant amplitude biphasic electrical pulse trains at a single pair of electrodes. NH listeners were presented with diotic and dichotic acoustic pulsatile stimuli (Gaussian Envelope Tones centered at 4 kHz). In the dichotic condition, one ear received a fixed rate of 100 pulses per second (pps), and the other ear received a variable rate (between 75-300 pps). The proportion of responses reported as being heard as “one” vs. “two” was calculated. Three ITDs were tested: 0, -/+500.

In NH listeners, highest proportion of “one sound” responses and correct lateralization of the sound occurred for diotic stimuli, while a sharp drop in the proportion of “one sound” responses occurred for small amounts of interaural rate asymmetry. In contrast, BiCI listeners had a larger range of “one sound” responses for greater interaural asymmetries in rate. Also, lateralization appears to be independent of the presented ITD with increasing interaural rate asymmetries. Results suggest that signal processing in BiCIs might need to incorporate temporally symmetric across-ear pulsatile stimuli to achieve optimal AOF and lateralization.

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T39a: SUBJECTIVE EVALUATION WITH UT-DALLAS RESEARCH INTERFACE FOR COCHLEAR IMPLANT USERS

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Improvements in sound processing technology have played a critical role in the advancement of cochlear implant (CI) devices. Research tools/interfaces commonly provided by implant manufacturers generally have limited computation power to support sophisticated signal processing strategies in real-time and are not suitable for conducting a broad range of experiments. Portability, wearability, and ease of programmability limits existing research interfaces to benchtop/laboratory use. The CCi-MOBILE platform, developed by our center at UT-Dallas, aims to address these shortcomings by providing the research community with an open-source, software-flexible, and a highly flexible re-configurable research interface suitable for acute and take-home chronic studies with CI devices manufactured by Cochlear Corporation.

In order to assess the efficacy of the research interface, subjective evaluations were carried out with CI users. The aim of the study was to evaluate speech recognition performance of CI users with the CCi-MOBILE research interface and compare performance with their clinical processor. Ten post-lingually deafened adult CI users participated in this study. The assessment of speech recognition was accomplished with AzBio and IEEE sentences presented in quiet, 10dB, and 5dB signal-to-noise ratios as well as with CNC words/phonemes. Study participants were tested in free-field, both with their clinical processor and the research platform. Both devices were programmed with standard ACE sound coding strategy. On all measures of test material, our custom-built mobile research interface produced equivalent performance levels (μ=54.348±6.163) to each individual's clinical processors (μ=52.276±6.318). Repeated Measures Analysis of Variance (ANOVA) revealed no statistically significant difference between the two processor types. The results from this study indicate that performance levels with the research platform are comparable to the clinical processor, and therefore able to accurately duplicate the user's existing clinical configuration. This result suggests great potential for conducting reliable speech assessments in future studies with the CCi-MOBILE research platform.

The CCi-MOBILE research platform is intended as an open-source contribution to the cochlear implant field and will be freely distributed to the research community. This one-of-a-kind research platform is orders of magnitude more flexible and computationally powerful than existing clinical processors/research interfaces with corresponding software suite and development support. It can be used for conducting scientific studies not only in laboratory settings but also in real world environments for extended periods of time. This is likely to facilitate true chronic assessment of novel sound processing strategies and help researchers to realize their scientific ideas that are not presently possible. The platform holds potential for rapid and easier transition of academic research to commercial assimilation.

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T39b: INTERNET-OF-THINGS AND SMART ASSISTIVE HEARING DEVICES

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Ubiquity of smart technology, (e.g., smartphones, sensors, and devices integrated with Internet-of-Things (IoT)), has created unique opportunities to reinvent traditional stand-alone human-assist computing devices. The number of connected devices today is approximately 20B, and it is projected to surpass ~50B+ by the year 2020. Traditional devices, such as PCs, tablets, and smartphones will represent only a small fraction of the devices connected to the internet. IoT is rapidly evolving with inroads into our daily lifestyle, including home, office, automotive, healthcare, energy, agriculture, security, etc. Mundane objects such as a trash-bin are becoming smart. Home-automation is a perfect example of how smart-technology is integrating with our daily lives. The growth in smarter consumer electronics is driven by both high demand and expanding market potential. Healthcare/medical devices present some additional challenges, such as privacy and security; but it is only a matter of time as to when IoT will permeate to the healthcare and medical device market as well.

Assistive hearing devices can be revolutionized, both technically and scientifically, in countless ways with the adaption of IoT, big data, and smart concepts. Our center has recently been involved in the development of portable mobile research platforms/tools that can be used for both laboratory and take-home field experiments with cochlear implants (CIs). We have successfully integrated Personal Digital Assistant (PDA) devices, PCs, tablets, and Android smartphones with CIs and hearing aids (HAs). Such a setup has evolved into a highly versatile and portable research platform, which enables researchers to design and perform complex experiments with CIs with great ease and flexibility. One of the unexplored opportunities this platform presents is its ability to leverage the versatility of a smartphone that houses state-of-the art computing infrastructure, broad-range of sensors, and most importantly internet connectivity with location knowledge. Consider a scenario where audio sensors in a smartphone and microphones in Behind-the-ear (BTE) processors are able to form a synergy and transform into a microphone array system. Such a system could be configured for applications like beam-forming, noise cancellation, and speech enhancement strategies. Another example is the use of geo-location to automatically configure sound processors according to the environment type (i.e., a “smart room” which links with the HA/CI to share noise and speaker profiles for that room and time). As our homes and public/work environments become smarter, smart-rooms could potentially connect and relay memory based room acoustics profiles to an individual’s processor, to reconfigure the sound processing parameters for optimal hearing. As a proof-of-concept, we conducted a simple experiment using the CCi-MOBILE platform. By using Wi-Fi tagging, the sound processor was able to switch between different noise suppression strategies which were optimized for the specific room scenario.

There are countless possibilities and opportunities in ways hearing assistive devices can leverage emerging sensors, computing and networking technology to impact a change. Sound processors will soon join the emerging IoT ecosystem and re-invent themselves as connected, data-driven, smarter devices, which will hopefully lead to better hearing solutions for the users.

This work was supported by the grant R01 DC010494-01A from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health.

T40a: A BINAURAL CI RESEARCH PLATFORM FOR OTICON MEDICAL IMPLANTS ENABLING ITD/ILD AND VARIABLE RATE PROCESSING

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The Oticon Medical research platform (OMRP) is a safe, portable, binaural, real-time research platform for Oticon Medical cochlear implants. The platform is essentially a software programmable behind the ear processor (BTE) capable of processing signals from 4 microphones simultaneously and producing synchronized binaural outputs capable of driving two (bilateral) implants. Subject safety is achieved by loading the subject's CI fitting data directly into the hardware where a hardware limiter module automatically limits outputs in real-time. The platform consists of hardware and software parts. The hardware is responsible for: (1) digitizing the 4 microphone signals typically coming from ear-worn microphone systems and (2) generating the final electric outputs needed to drive two antenna coils. The software is responsible for processing the four audio input signals and then generating two synchronized electrodograms as stimulation outputs.

The platform can control electrode timing to better than 1 microsecond accuracy and also supports simultaneous CI/vocoder output allowing investigators to compare CI user's performance to normal hearing listeners' performance or to preview stimulation strategies while working on them.

T40b: IMPLANTABLE MICROPHONES AS AN ALTERNATIVE TO EXTERNAL MICROPHONES FOR COCHLEAR IMPLANTS

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INTRODUCTION
Totally implantable cochlear implants should be able to address many of the problems cochlear implant users have around cosmetic appearances, discomfort and restriction of activities. The major technological challenges that need to be solved to develop a totally implantable device relate to implanted microphone performance. This presentation reviews implantable microphone systems and discusses the technology behind them. We discuss our own series looking at a new fully implantable microphone.

METHODS
We carried out 40 temporal bone dissections to establish the best method of coupling of a new implantable microphone. Four fixation positions (free, cartilage, cemented, touching) and 3 coupling options (contact, cemented, cement bridge) were tested. Outcome measures included sensitivity, POLQA measurements, body noise simulation and music clarity.

RESULTS
Microphones can be implanted under the skin or act as sensors in the middle ear. Surface contact and physiological noise are the main barrier to success in subcutaneous microphones. Evidence from totally implantable active middle ear implants suggest body and contact noise can be overcome by converting ossicular chain movements into digital signals. Our research has established the most robust position for microphone placement.

CONCLUSION
Potential benefits of a fully implantable cochlear implant are obvious, however, implantable microphones must also produce a sound quality that matches or exceeds external counterparts. To date, most commercial products are confined to subcutaneous devices and although most have equivalent hearing thresholds, surface contact or physiological noise are posible barriers to successful implantation. Positioning implantable microphones in the middle-ear avoids this and potentially takes advantage of directionality cues and amplification provided by the external ear. A clinical trial is planned to establish in vivo microphone performance.

T41a: LIGHT-DRIVEN CONTACT HEARING AID: A REMOVABLE DIRECT-DRIVE HEARING DEVICE OPTION FOR MILD TO SEVERE SENSORINEURAL HEARING IMPAIRMENT

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The most common treatment for mild to severe sensorineural hearing impairment is acoustic hearing aids, however middle ear implants also target a portion of the sensorineural hearing loss market. Acoustic hearing aids have been limited in their ability to provide amplification for frequencies above 5 kHz due to the inability to deliver output and gain at sufficient levels to provide audibility of speech signals at high frequencies, for which the speech energy is relatively low and the hearing loss is typically rather large (Moore et al., 2008). Signal processing strategies to increase gain by methods such as cancelling the feedback are known to degrade sound quality and are still insufficient to greatly extend the upper limit of amplification (Chasin and Russo, 2004). Additionally, in acoustic hearing aids the earmold must be fully occluded in order to provide sufficient output at low frequencies, and fully plugging the ear canal can have negative effects on the user's perception of their own voice (the occlusion effect). Middle ear implants (MEIs) offer several potential advantages to address these challenges, and the use of implantable hearing aids that function by delivering amplification via direct vibration of the middle ear have been studied in a variety of implementations (Backous and Duke, 2006; Rameh et al., 2010; Puria, 2012). Typically, a magnet or other transducer is surgically implanted and attached to an ossicle in the middle ear, which is then actuated to produce the perception of sound (Silverstein et al., 2005). The potential advantages of such a system over a conventional air conduction hearing aid include a broad frequency range with low-frequency output (while still being able to leave the ear canal open) and large amounts of functional gain (Kraus et al., 2011). A light-driven contact hearing aid option is available for mild to severe sensorineural hearing loss which offers the advantages of directly driving the ossicles while being non-surgical. The mechanism of action of the contact hearing device as well as how the devices is able to be maintained to dwell long-term in the ear non-surgically will be explained. The differences between the contact hearing aid, middle ear implants, and air conduction hearing aids will be reviewed. The contact hearing aid system performance including maximum output, maximum gain, and functional gain will be compared to both MEIs and air conduction hearing aids. Results from several clinical studies with the contact hearing aid will be presented which include objective and subjective outcome measures. Advantages and disadvantages of the device as well as areas of future investigation will be explored.

T41b: DESIGN OF AN OPTICAL COCHLEAR IMPLANT

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Optogenetics and stimulation with infrared light, also called infrared neural stimulation (INS), have been proposed for neural stimulation in cochlear implants. It has been postulated that increased spatial selectivity with optical stimulation can result in more independent channels to transfer information to auditory neurons. To translate the idea to a clinical feasible device, several constraints of optical stimulation must be addressed.

The power required for optical simulation is larger than that for electrical stimulation, a factor of about 10 for optogenetics and a factor of about 100 for INS. This requires the careful configuration of the light delivery system for optical stimulation. Power consumption can be minimized by optimally placing the optical sources or by positioning the light delivery system (LDS). Distance and orientation of the radiation beam are critical to target the neurons. Another important aspect in designing the LDS is its size and physical property. The LDS can be an array of miniature light sources, a bundle of optical fibers, or a bundle of waveguides. Likewise, a combined opto-electrical hybrid approach must be considered. Both, optogenetics and INS are limited by another crucial factor, the pulse repetition rate. While the rate-limiting factor in optogenetics relates to the expression rate of the channels in the membrane of the neuron and by the channel dynamics, for INS it is the heat deposition. With each light pulse heat is delivered to the tissue and can lead to tissue heating with subsequent damage of the neural structures. At present, sustained pulse repetition rates for optical stimulation are typically below 250 pulses per second (pps). It has been argued that with contemporary coding strategies such rates are too slow to encode acoustic information. Therefore, a novel coding strategy must be implemented that accommodates low average pulse repetition rates without giving up the performance with contemporary coding strategies.

The poster will discuss in detail the design control parameters required for a human optical cochlear implant prototype.

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T42a: DEVELOPMENT OF THE MANDARIN MATRIX SENTENCE TEST IN NOISE

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Speech audiometry is one of the most important tools for modern audiology and hearing research. Since speech audiometric tests are usually limited to a certain language, their formats and construction principles should yield a high comparability across languages (such as closed-set speech tests like the Digit Triplet Test or the Matrix test, see Kollmeier et al., IJA 54, 2015, pp. 3-16). One major challenge of developing test materials in Mandarin, more often referred to as Putonghua in Mainland China, is the diversity of dialects in spoken Mandarin due to the accent, the vocabulary, the educational status etc. This also calls for a closed-set format which makes the Matrix sentence recognition test a good candidate for standard sentence intelligibility measurements in noise for Mandarin. The Matrix test is already available in a compatible way for at least 16 languages thus allowing for multicenter and multilingual studies. The limited vocabulary and simple sentence format is suitable for potential broader Mandarin users in various regions of China, for both adults and children of school age. Furthermore, the test construction offers the opportunity of high repeatability within one subject.

This study aims at developing a Mandarin Matrix test (CMNmatrix) according to the international standard procedure for both diagnostic and research purposes. The CMNmatrix consists of a corpus of phonologically balanced 50 words, with a construction of 10 names, 10 verbs, 10 numerals, 10 adjectives, and 10 nouns. All sentences have identical syntactical structure and unpredictable semantic content for minimizing the memorization effect. The details of the development of CMNmatrix will be presented including the test design, the speech material selection, the sentence, recording, the subsequent cutting and reconstruction procedure, the optimization and the preliminary multi-center evaluation.

This work was funded by the DFG EXC 1077 hearing4all and EFRE-Project VIBHear.

T42b: SPEECH DISCRIMINATION SCORE DEVELOPMENT OVER TIME AFTER COCHLEAR IMPLANTATION

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Background:
During the first weeks and months after receiving cochlear implants (CI), speech discrimination of the CI recipients improves gradually. The rate of improvement over time is different across subjects. The knowledge of a normal range for this rate may be relevant for quality control as part of a clinical CI program.

Patients and methods:
In this retrospective study, we selected 35 functionally deaf adult patients who were fitted with CI, 29 of them with postlingually and 6 with prelingually acquired hearing loss. Speech discrimination was tested with the standard German Freiburg monosyllabic and two-digit numbers speech intelligibility test at timepoints of 1, 3 and 6 months after implantation. The test was performed at 50, 65 and 80 dB speech level. The performance levels were approximated by a function $y = a \cdot (1 - \exp(-t/\tau))$. Our aim was to explore the recovery time τ in dependence of patient history, age at hearing loss and time of implantation, in order to create a range of expectation values for the development of speech intelligibility after implantation. The time constant τ is closely related to the initial slope of the function at $t = 0$ (i.e. first fitting).

Results:
In postlingually functionally deaf adults, the average speech recognition of two-digit numbers at 65 dB increased from 62.5% at 1 month to 84.3% at 3 months and 94.5% at 6 months after implantation. The fit of the function $y = a \cdot (1 - \exp(-t/\tau))$ to the data yielded a recovery time τ = 1.2 months for postlingually deaf patients. From the same treatment of the data corresponding to the recognition of monosyllables at 65 dB the result τ = 1.9 months was derived. The patient cohort of prelingually deaf adults was too small to develop a mathematical function which would accurately describe the improvement in speech recognition post implantation.

Conclusion:
The improvement of speech recognition depends on the time at which patients are supplied with a CI. We have shown that for postlingually functionally deaf patients post implantation, the development of speech recognition can be described by the formula $y = a \cdot (1 - \exp(-t/\tau))$ and it could therefore be possible to foresee an individual patients improvement in speech recognition. The recovery time τ amounts to 1.2 months for the discrimination numbers and 1.9 months for monosyllables. In order to determine the recovery time for prelingually deafened adults, a larger sample of patients would be necessary.

T43a: ARTIFACT REDUCTION AND LOUDNESS GROWTHS IN ELECTRICALLY EVOKED AUDITORY STEADY STATE RESPONSES

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Acoustically evoked auditory steady state responses (ASSR) can be used to objectively estimate hearing sensitivity in individuals with normal hearing and with various degrees and configurations of sensorineural hearing loss. Recently, the use of electrically evoked auditory steady state responses (eASSR) with cochlear implant (CI) patients was reported in several studies (e.g. Hofmann and Wouters JARO, 13, 2012, pp. 573-589). One critical problem of eASSR is the artifact related to the electrical stimulation. Unlike random noise which can be reduced by averaging responses to increase signal-to-noise ratio (SNR), the CI stimulation related artifacts are synchronous with stimulation and cannot be removed by averaging. These phase locked stimulus artifacts overlap with the evoked response in both, time and frequency domains, such that conventional time windowing and frequency filtering are incapable of removing stimulus artifacts without distorting the evoked response, particularly for high-rate eASSR.

The primary goal of this study was to develop a high-rate eASSR recording system for MED-EL CI users, by using near speech processor stimulation rates. In addition, the loudness growth function (LGF) of eASSRs and some other objective or subjective based LGFs of the same subjects were measured and compared. Direct stimulation via the research platform RIB II instead of the CI users'own processors was used. eASSR recordings from both, a CI dummy and CI users were obtained in the method development stage. The CI dummy consisted of the CI and the eASSR recording electrodes suspended in a brain tissue equivalent saline solution. Different parameters, e.g., stimulation rates, modulation frequencies, and stimulation polarities were investigated. A series of artifact reduction methods based on [Hu et al. Biomed Signal Process Control, 21, 2015, pp. 74-81] were developed. The results show that the CI stimulation artifacts can be reduced to some extent, but could not be totally removed at this stage. eASSR can be recorded even at 1000 pulses per second, but cautions should be taken in interpreting the results.

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T43b: DOES BIMODAL HEARING PROVIDE AN ADVANTAGE TO BILATERAL BRAINSTEM DEVELOPMENT?

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Objective: To evaluate whether a period of bimodal stimulation provides an advantage for bilateral brainstem development in bilateral CI users.

Background: Children require timely access to balanced bilateral input in each ear for symmetric brainstem development, binaural processing and development of binaural/spatial hearing. Prolonged unilateral stimulation in children who are bilaterally deaf abnormally strengthens pathways from the stimulated ear which impedes later efforts to restore binaural hearing with a second implant. Combined acoustic-electric (bimodal) hearing may provide an advantage by stimulating pathways from both ears, thereby protecting the binaural system for later bilateral CI use. Moreover, the amplified acoustic sound delivers fine temporal structure, important for pitch and music perception, which is not available through CIs. On the other hand, bimodal stimulation introduces significant (>1 ms) stimulus conduction delays which may impede binaural processing in the brainstem.

Hypotheses: 1) Bimodal hearing stimulates bilateral auditory pathways thereby promoting bilateral symmetry and integration with bilateral CIs. This will be measured by smaller wave eV and inter-wave asymmetries in a cohort of children who received bilateral CIs after bimodal listening rather than peers who used unilateral implants alone before bilateral implantation. 2) Bilateral cochlear implants provide better access to high-frequencies than bimodal stimulation as measured by more symmetric speech perception.

Methods: In this study, 19 bimodal users who received a second CI were followed over the first ~6 months of bilateral CI use. They received their first CI (left ear n = 13, right ear n = 6) at (mean ± SD) age 5.5 ± 3.9 years and had used bimodal hearing for 4.5 ± 3.7 years. Average pure tone hearing thresholds in their first and second implanted ears were 97.2 ± 11.3 and 88.6 ± 11.5 dB HL respectively. Speech perception for each ear was collected at 1.0 ± 1.0 years before and 0.9 ± 1.4 years after bilateral implantation. Electroencephalography was used to record brainstem responses during bimodal and early bilateral CI use. Responses were evoked by 11 Hz acoustic clicks delivered via an insert earphone to non-implanted ears and biphasic electrical pulses delivered to an apical electrode for implanted ears. Stimuli were presented monaurally and binaurally with no timing or level difference (levels were judged as balanced). Absolute response peak latencies and inter-wave latencies will be compared for brainstem asymmetries during bimodal use and following bilateral implantation. These responses will be compared to previously described cohorts of bilateral CI users who had different inter-CI delays (Gordon et al, 2007).

Results: Preliminary results indicated significantly asymmetric speech perception in favour of the first CI (35.4 ± 29.3%; p = 0.007) which reduced within 0.9 ± 1.4 years with bilateral CIs (14.4 ± 23.2%; p=.08). Brainstem wave eV latencies at CI2 activation were variable (range -.5 to .75ms) but on average 0.15±0.1ms longer for CI2 (p = 0.18). Analyses of responses following activation will reveal whether responses become symmetric and exhibit integration, as evidenced by the presence and latency of binaural difference measures. Furthermore, comparison to other bilateral CI cohorts will demonstrate whether a bimodal advantage for brainstem function exists. Analyses regarding the contributions of residual hearing, age and duration of acoustic, bimodal and bilateral CI experience will be described.

Conclusion: This study will add to the understanding of bilateral development and inform timing of bimodal to bilateral implantation.

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T44a: HOW CAN WE FURTHER IMPROVE REAL-LIFE OUTCOMES FOR CHILDREN WITH EARLY COCHLEAR IMPLANTS? BILATERAL IMPLANTATION AND OTHER NEW PREDICTIVE FACTORS.

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Introduction: Reports of language, academic, and psychosocial development in children with cochlear implants (CIs) compared to children with normal hearing (NH) show mixed outcomes, and the effect of bilateral CIs has not yet been thoroughly investigated. This study investigated whether language, academic and psychosocial development differed significantly between children with NH and those with early CIs, and aimed to identify new predictors for outcomes. Methods: The cognitive, language, academic (mathematics, oral language, reading and written language) and psychosocial development of 159 children aged 5-8 years was measured as part of a longitudinal outcomes study of children with CIs using a range of standardized assessment tools and a normed psychosocial questionnaire. Parental involvement was also assessed using a rating scale.

Results: Many of these children with early CIs achieved language, academic and psychosocial outcomes similar to those of typically developing children with normal hearing. The proportion of children scoring in within or above one standard deviation of the mean was slightly lower than that for typically developing children with normal hearing for language and across all academic areas, and was lowest for mathematics. The strongest area of academic performance was written language. The children did not differ significantly from their peers with NH in their psychosocial development, except for significantly poorer prosocial behavior development. When other factors were controlled for, children with sufficient bilateral experience had significantly better language and academic outcomes than did children with unilateral CIs. Having bilateral CIs also predicted significantly fewer difficulties with psychosocial development, with earlier age at bilateral implantation increasing the effect size of the second CI for emotional symptoms and peer problems.

Outcomes were also significantly predicted by a range of factors related to demographic, parenting and child characteristics, including some previously unidentified factors related to family and parenting practices. Marginal effects modelling quantified the effects of changes in the predictive factors examined.

Conclusions: Development in many of these children with early CIs was found to be similar to that for peers with NH. Having bilateral CIs predicted significantly better outcomes. A number of new predictive family/parenting factors were found for development in all areas. These results should be shared with parents and professionals to increase their understanding of the large impact of changes in these practices on developmental outcomes for children. Incorporating this knowledge into parenting practices and clinical management may help to facilitate improved language, academic and social outcomes for children with CIs.

T44b: VERBAL LEARNING AND MEMORY IN ADULTS WITH COCHLEAR IMPLANTS

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To understand degraded speech, such as through a cochlear implant (CI) or when spectrally degraded by noise-vocoding, the listener must utilize language knowledge and cognitive abilities to interpret the incoming signal. However, the experience of prolonged severe-to-profound hearing loss may contribute to deficits in these language and cognitive skills. This study compared non-auditory verbal learning and memory abilities between CI users and normal-hearing (NH) age- and nonverbal IQ-matched peers, and examined these abilities as predictors of degraded speech recognition.

Twenty-five postlingually deaf adults who were experienced CI users and twenty-five age- and nonverbal IQ-matched NH controls underwent testing of verbal learning and memory using a visual version of the California Verbal Learning Test-II (CVLT), a multiple trial free recall task that permits assessment of a number of cognitive processes: verbal learning, short-term memory, primacy and recency effects, proactive and retroactive interference, and semantic/serial clustering. Participants also completed tasks of word and sentence recognition in the clear (CI users) or using noise-vocoded speech (NH controls). Two hypotheses were tested: (1) CI users would demonstrate poorer scores on CVLT measures than NH peers, as a result of their prolonged auditory deprivation. (2) For both groups, scores on the CVLT would predict performance on the speech recognition tasks.

Results demonstrated that most CVLT measures were equivalent between groups, except that CI users showed a greater magnitude of proactive interference (PI) than NH controls. PI also served as the largest predictor of word and sentence recognition outcomes, but only for the CI group. Interestingly, in CI users, magnitude of PI correlated positively with duration of hearing loss prior to implantation.

In conclusion, although most scores on the CVLT were equivalent between CI and NH groups, CI users demonstrated a greater magnitude of PI, which was related to their duration of auditory deprivation. For CI users only, PI predicted speech recognition outcomes. Thus, PI appears to be affected by hearing loss and contributes to speech recognition in CI users. Moreover, findings suggest that components of the CVLT, tested visually, may possess utility as prognosticators of speech recognition abilities during the preoperative evaluation of patients considering cochlear implantation.

This work was supported by the American Otological Society Clinician-Scientist Award to Aaron C. Moberly.

T45: DEFICITS IN VOICE EMOTION PRODUCTION BY CHILDREN WITH COCHLEAR IMPLANTS

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The number of children with hearing loss receiving cochlear implants (CIs) at an early age is increasing steadily (more than 38,000 in the US alone). Limitations of the device may impact prelingually deaf pediatric CI recipients differently from their post-lingually deaf adult counterparts. While post-lingually deaf adult CI users learned to speak and to hear primarily with normal or good acoustic hearing, child CI users who lost their hearing early in life or were born deaf acquire spoken language primarily through degraded input via electric hearing. An important limitation of present-day CI devices is the lack of salient pitch cues transmitted to the listener. This can affect the perception and production of speech prosody, lexical tones, melodic contours, etc.. The focus of this study is on the production of vocal emotion in speech by children with CIs (CCI). Seven CCI (ages 7.00-18.10 years) who were all implanted before 2 years of age, and nine children with normal hearing (CNH; ages 6.60-18.10 years) participated. The children read a list of 20 sentences, each with a happy and a sad emotion. No training or feedback was provided. A different set of child NH listeners (ages 6.50-18.50 years) and adult NH listeners also participated. These listeners heard each production and indicated which of the two emotions it was associated with (single-interval, two-alternative, forced-choice procedure: response choices: happy, sad). In addition, a second group of child NH (ages 7.90 – 14.00 years) and adult NH listeners heard the same happy/sad productions and indicated which of five possible emotions they were associated with (single-interval, five-alternative, forced-choice procedure with response choices: happy, sad, neutral, angry, scared). Results (rationalized-arc-sine-transformed percent correct scores) showed significant deficits in the recognizability of CCIs' happy/sad productions relative to the CNHs' productions in both the two-alternative and the five-alternative tasks. In addition, the confusion matrices obtained in the five-alternative task showed that the CCIs' happy/sad productions were more frequently mislabeled as "neutral" by the NH listeners, suggesting greater uncertainty regarding the intended emotion. While the CCI in this study showed deficits in their production of emotional prosody, the sentences they produced were highly intelligible: a group of NH adults heard and repeated back each of the sentences produced by the CCI, and keywords correct were recorded (mean = 96.44% correct, s.d. = 2.65%). Although the sample size of talkers is relatively small, a linear mixed-effects analysis showed that factors including the talkers' age at implantation, duration of device experience, and the listeners' chronological age, were predictive of the results in the two-alternative forced-choice task. In conclusion, these results show that while present-day CIs and clinical habilitation protocols allow pediatric CI users to achieve excellent phonetic speech production, significant deficits remain in their production of speech prosody.

T46: EFFECTS OF DEVELOPMENT ON THE ACOUSTIC CHANGE COMPLEX: A WITHIN-SUBJECT STUDY OF PEDIATRIC CI USERS

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Recently we completed a cross-sectional study of the effects of development on cortical responses that was based on data collected from 60 early-implanted CI users and 100 normal hearing listeners who ranged in age from 3 to 20 years [1]. Two obligatory cortical responses were measured using speech sounds (/u/-/i/ and /i/-/u/): the P1-N1-P2 complex evoked if the subject detects a stimulus onset and the acoustic change complex (ACC) evoked if the subject perceives a change in the acoustic signal. We learned that the ACC had a similar but longer developmental trajectory compared to the onset P1-N1-P2 response. In quiet, both onset and ACC responses changed in similar ways for early-implanted CI users and NH listeners. When correlations were calculated between waveforms at each age group and NH adult responses, with age early-implanted CI recipients reached strong positive correlation coefficients, greater than 0.9 and 0.8, for the P1-N1-P2 and the ACC respectively. In background noise, while the developmental patterns of the ACC recorded from CI users were similar to those exhibited by the NH listeners, CI recipients' ACC responses obtained in late teens and twenties reached only moderate correlations at best with NH adults. While the results of this study described the developmental trends that can be expected for pediatric CI users, no longitudinal data was reported.

In this report, we describe cortical responses recorded in a subset of 10 pediatric CI users who were repeatedly tested over time using the same stimuli and recording procedures. Preliminary analysis shows changes observed in the cross-sectional study are also apparent in the data recorded from individual subjects followed over time using a within-subject design. For example, a CI subject tested twice at 12 and 14 years old showed morphologic changes especially in the ACC. When tested in background noise, this CI user had a prominent P1 alone in the ACC at 12 years of age, but two years later N1 and P2 components appeared in the ACC. Also, an NH subject showed developmental changes within two recordings measured at 14 and 18 years old. In quiet, both onset and ACC responses were slightly enhanced at 18 years of age compared to those obtained at 14 years of age. In noise, his ACC responses significantly increased showing N1-P2 components dominant in the waveform which is seen in adults but not observed in his recording at 14 years old. These findings may suggest that trends apparent in group mean data are also measurable in the responses recorded from individual subjects.

This work was supported by NIH-NIDCD grants, R01DC012082, P50DC000242, University of Iowa Foundation.

[1] Jeon, E. (2016). The effect of development on cortical auditory evoked potentials in normal hearing listeners and cochlear implant users (Doctoral dissertation). University of Iowa, Iowa City.

WEDNESDAY POSTER ABSTRACTS

W01a: A MODEL BASED SOUND CODING STRATEGY FOR LASER STIMULATION IN COCHLEAR IMPLANT USERS WITH RESIDUAL HEARING

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Introduction. Electric acoustic stimulation (EAS) provides large improvements in speech understanding when compared to electric stimulation alone. However, some EAS users do not use acoustic amplification through a hearing aid because of comfort issues. A way to circumvent this problem is to substitute the hearing aid by intra-cochlear acoustic amplification through laser stimulation, also known optoacoustic stimulation (OAS). Studies have demonstrated that pulsatile laser stimulation can elicited a pulse train of sound pressure waves. Hence, this principle can be used to transmit the speech envelope through amplitude modulation of laser pulse trains. However, the acoustic pulses generated by intra-cochlear laser stimulation are not ideal and this may impact the efficiency of this technique to transmit high quality speech sounds. The purpose of this study is to model these laser generated acoustic pulse trains and assess whether these pulses compromise speech intelligibility and quality of a sound coding strategy for laser stimulation in EAS users.

Method. Five MED-EL Flex20 electrode users with ipsilateral residual hearing in the low frequencies participated in the study. Speech intelligibility and quality was compared between a conventional and a laser based sound coding strategy, termed EOAS. Note that the EOAS strategy delivers acoustic stimulation and no laser light was delivered to the cochlea.

The EOAS sound coding strategy splits the audio signal into a high pass filtered and a low pass filtered component. The high pass filtered signal is transmitted directly to the recipient’s cochlear implant speech processor. In conventional EAS, the low pass filtered signal is amplified by a hearing aid. In the EOAS strategy, the low pass filtered signal was processed by two models of pulsatile laser stimulation generating acoustic pulse train. The first model (model 1) resembles an ideal acoustic pulse train and the second model (model 2) is based on an in vitro measurement of real laser stimulation in a human temporal bone. These models account for different distortions potentially introduced by laser stimulation. The conventional EAS and the two model based sound coding strategies were compared in speech intelligibility, based on the adaptive OLSA speech test, and sound quality (naturalness, pitch and clarity of speech and music), based on a subjective questionnaire.

Results and Conclusions. Subjects with relatively good residual hearing obtained a clear benefit (5.58 dB in speech reception threshold; SRT) from the hearing aid with respect to the electric stimulation alone. The same benefit was observed for the EOAS strategy, 5.67 dB SRT and 5.94 dB SRT for model 1 and model 2 respectively. No significant differences in speech and music quality ratings were found between all sound coding strategies. These findings suggest that intra-cochlear laser stimulation has the potential to be used in future EAS devices to substitute the conventional hearing aid.

This work was supported by the DFG Cluster of Excellence EXC 1077/1 “Hearing4all” and the FP-7 EU-ACTION project.

W01b: IMPROVING CHANNEL SELECTION CRITERIA IN N-OF-M STRATEGIES FOR COCHLEAR IMPLANTS

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Approximately 324,000 adults and children in the United States have been fitted with a cochlear implant according to a (2012) report from the National Institute of Health. Popular in clinical cochlear implant devices, the ‘n-of-m’ sound processing strategies are based on selecting ‘n’ frequency bands out of ‘m’ available channels in each stimulation cycle. Channel selection is usually based on dominant spectral energy in each frequency band, e.g. Advanced Combined Encoder (ACE) strategy. Although robust in quiet conditions, such approach is prone to selection of noise-dominant channels at low signal to noise ratios (SNR), which may result in decreased speech intelligibility. Since formant frequencies contain important cues for intelligibility of voiced speech, a supplementary channel selection strategy is proposed to assign priority to frequency channels corresponding to the location of these frequencies, independent of the instantaneous SNR. A hybrid formant estimation algorithm was developed based on existing strategies to determine the first three formant frequencies (F1, F2, and F3) within each speech analysis window and assigned priority to formant channels irrespective of the specific spectral energy content. In this study, the proposed formant-estimation strategy was directly implemented within the ACE processing framework and evaluated with 6 CI subjects using the CCi-Mobile research platform (developed at CRSS-CILab, University of Texas at Dallas). Three strategies were compared: standard ACE strategy, the formants-ACE (fACE) [Ali et al.], and v-fACE (fACE with an additional voiced/unvoiced activity detector). The following tests were used to assess speech recognition of each strategy: IEEE sentences presented in quiet, speech-shaped noise (10 and 5dB SNR), reverberation, and reverberation+noise, AzBio sentences in quiet, multi-talker babble noise (10 and 5dB SNR), CNC words/phonemes. Subjective evaluation indicates improved performance with both fACE and v-fACE compared to standard ACE for reverberant conditions with T60 values of 300 and 600ms. Statistically significant improvement was achieved with the proposed strategies for 5dB SSN and babble noise. The data from this study suggests that formant-priority channel-selection in n-of-m sound processing strategies have potential to improve speech recognition with CIs, especially in adverse listening conditions.

This work was supported by the grant R01 DC010494-01A from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health.

Ali, H.; Hong, F.; Hansen, H.L.; Tobey, E., “Improving channel selection of sound coding algorithms in cochlear implants,” IEEE ICASSP, Florence, Italy, pp. 905-909, 2014.

W02a: REAL-TIME SPECTRAL CONTRAST ENHANCEMENT APPLIED TO COCHLEAR IMPLANT CODING STRATEGIES

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Cochlear implant (CI) users' speech recognition is adversely affected by reduced spectral contrast (the decibel difference between peaks and valleys in the spectrum) and spectral resolution (the ability to resolve a complex sound into its frequency components) compared to normal hearing listeners (Loizou and Poroy, 2001). Among other factors, this issue has been attributed to the very small electrical dynamic range and the broad spread of neural excitation (Cohen et al., 2003), which cause smearing of spectral detail and a reduction of the tonotopic selectivity in a CI. Moreover, two-tone suppression (2TS) is not reproduced in current CI sound processing schemes. This nonlinear property of the healthy cochlea is characterized by a decrease in the evoked response to a tone in the presence of a second tone and it is thought to be the primary mechanism to improve the spectral contrast and the signal-to-noise ratio (SNR) of the stronger components in the spectrum (Rhode and Greenberg, 1994; Stoop and Kern, 2004). Last, the addition of background noise to speech filling in the valleys between the spectral peaks can reduce their prominence (contrast), complicating the problem of speech recognition in noise for CI users.

Several spectral contrast enhancement (SCE) algorithms have been proposed to alleviate this problem for CI users (Loizou and Poroy, 2001; Turicchia and Sarpeshkar, 2005; Bhattacharya et al., 2011; Nogueira et al., 2016). The majority of SCE algorithms have focused on mimicking 2TS with the goal of making the peaks in the spectrum more prominent while attenuating the valleys. While some approaches proved to be promising to some extent (Bhattacharya and Zeng, 2007; Bhattacharya et al., 2011), they were limited by their dependency on block processing with relatively long time segments (20–30 ms) and/or significant computational complexity in order to have sufficient frequency resolution for SCE to occur in real-time. On the other hand, other real-time algorithms did not seem to provide sufficient improvement in speech recognition to warrant further development (e.g. Nogueira et al., 2016).

Here, we propose a real-time SCE algorithm for CI that provides direct control over the spectral contrast applied to the stimulation pattern with the goal of partly compensating for the smearing of spectral detail caused by the spread of electrical fields occurring in CIs. The proposed algorithm was integrated as back-end processing in the ACE™ coding strategy of Nucleus® devices running on a Speedgoat xPC Target™ machine (Goorevich and Batty, 2005) and was clinically validated on a restricted group of CI users. Spectral modulation detection, speech recognition in noise, and preference ratings in speech and music were measured with the SCE algorithm turned on/off. The results from the clinical validation will be presented together with an overview of the algorithm.

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W02b: FREQUENCY ADAPTATION AND SUBJECTIVE TESTING

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A common approach in cochlear implant, CI, processing is to mimic the cochlea’s frequency-to-place transformation of sound by encoding different audio frequencies to spatially separated electrodes. The spectral analysis of the incoming sound is often performed by using the Fast Fourier Transform, FFT, due to its computational efficiency.

The output of an FFT analysis is an estimate of the signal power in equally distributed frequency bands from 0 Hz and up the Nyquist frequency of the system. As the distribution of frequency bands is directly dependent on the sampling rate of the system, changes in clock-frequency of a CI will affect the frequency-to-place mapping of incoming audio to electrodes. It is an open question whether a CI patient can easily adapt to small changes in sampling frequency, or whether a new rehabilitation period is required.

This project investigated whether CI patients would be able to distinguish a small change of sampling rate (16.667 kHz to 16 kHz, - 4 %) in a series of A/B comparison tasks on speech. The patients were all Neuro 1 users (Oticon Medical), with at least 6 months experience.

All stimuli were presented through the Neuro 1 sound processor, and the difference in sampling rate was simulated by modifying stimuli offline through a phase-vocoder+resampling (first time-stretching the audio and subsequently resampling). Through this, the frequency-components of the audio-samples were scaled in a way equivalent to changing the sampling rate, without changing the temporal properties of the signal.

The results of the study indicate that the patients were not able to distinguish between the two sampling rates tested, suggesting that the Neuro 1 patients would be able to migrate to the new CI sound processor with a slightly lower sampling rate without significantly modifying the auditory percept of the CI patients.

W03a: DYNAMIC CURRENT FOCUSING: A NOVEL APPROACH TO LOUDNESS CODING IN COCHLEAR IMPLANTS.

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Background: In an attempt to improve spectral resolution and speech intelligibility, several current focusing methods have been proposed to increase spatial selectivity by decreasing intra-cochlear current spread. For example, tripolar (TP) stimulation administers current to a central electrode and uses the two flanking electrodes as the return pathway, creating a narrower intra-cochlear electrical field and hence increases spectral resolution as compared to monopolar (MP) stimulation. However, more current is required and in some patients, specifically the ones with high electrode impedances, full loudness growth cannot be supported because of compliance limits. The present study describes and analyses a new loudness encoding approach, which uses TP stimulation near threshold and gradually broadens the excitation (by decreasing compensation coefficient σ) to increase loudness without the need to increase overall current. It is hypothesized that this dynamic current focusing (DCF) strategy increases spatial selectivity, especially at lower loudness levels, while maintaining maximum selectivity at higher loudness levels, without reaching compliance limits.

Material and Methods: Eleven postlingually deafened adult CI recipients, with at least 9 months of experience with their HiRes90K implant, were selected to participate in this study. Baseline performance regarding speech intelligibility in noise (Dutch matrix sentence test), spectral ripple discrimination at 45 and 65dB and temporal modulation detection thresholds were assessed using their own clinical program, fitted on a Harmony processor. Subsequently, the DCF strategy was fitted on a research Harmony processor. Threshold levels were determined with σ=0.8, which means 80% of current is returned to the flanking electrodes and the remaining 20% to the extra-cochlear ground electrode. Instead of increasing overall pulse magnitude, σ was decreased to determine most comfortable loudness. After 2-3 hours of adaptation to the research strategy, the same psychophysical measures were taken.

Results: At 45 dB, average spectral ripple scores improved significantly from 2.4 ripples per octave (RPO) with their clinical program to 3.74 RPO with the DCF strategy (p=0.016). Eight out of eleven participants had an improved spectral resolution at 65dB. Although average scores increased from 3.27 to 4.07 RPO, this difference was not statistically significant (p=0.170). Both speech in noise and temporal modulation detection thresholds were equal for MP and DCF strategies. Subjectively, two participants preferred the DCF strategy over their own clinical program, two preferred their own strategy, while the majority of the participants had no preference. Battery life was decreased and ranged from 1.5 - 4 hours.

Discussion, conclusion and future perspectives: The DCF strategy gives a better spectral resolution, especially at lower loudness levels. It is promising that speech perception in noise with the DCF strategy is equal to the one with the patients' own MP strategy, despite the acute test set-up. As spectral ripple tests are ideally suited for acute testing and correlated with long-term speech perception, while speech tests need adaptation time, one could hope for improved speech scores with the DCF strategy on the long term. Based on our experiences described above, we have optimized the power consumption, resulting in a battery life of at least eight hours. Currently, we are running a take-home trial, with very promising initial results. As the data collection will be completed prior to the 2017 Conference on Implantable Auditory Prostheses, we will be more than happy to present these novel results.

This research was supported by non-restrictive research funding from Advanced Bionics.

W03b: CLINICAL APPROACH TO OPTIMIZE ACTIVATED COCHLEAR IMPLANT ELECTRODES AND SPECTRAL MODULATION DETECTION OUTCOMES

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The aim of this study was to determine if using a clinical method to deactivate electrodes identified to have poor electrode-neural interface would result in improved spectral modulation detection outcomes. Subjects were asked to participate in a clinically-based psychometric channel discrimination and pitch-ranking task to determine electrodes to be deactivated. Results from the Quick Spectral Modulation Detection Task were recorded in the baseline program, with the experimental program on the day it was implemented, and after a 3-6 week acclimation period. Thirteen out of 19 participants (68.42%) had at least one pitch-confused electrode pair. Results recorded after an acclimation period indicated significant improvement in Spectral Modulation Detection for the data to date. Current results suggest that deactivating electrodes with pitch-confusion is a clinically-applicable task that may result in improved sound perception in adult cochlear implant users and is feasible for clinical implementation.

W04a: IMPROVING SOUND SOURCE LOCALIZATION BY HEAD SHADOW ENHANCEMENT WITH BEAMFORMERS

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Background
Beamforming, or spatial filtering, is a method to discriminate sounds based on their direction of incidence. The human ear acts as an acoustic beamformer: due to the head shadow, each ear naturally focuses on sounds that arrive from its ipsilateral side. On the one hand, this introduces interaural level differences (ILDs) which can be used to localize sounds in the horizontal plane. On the other hand, it can attenuate noise sources such that it improves speech understanding. Unfortunately, this behaviour is (1) relatively weak for low frequencies, and (2) ambiguous for larger angles. Therefore, this mechanism cannot be used optimally by (1) bimodal cochlear implant users, who often do not perceive high frequencies in their non-implanted ear, and (2) bilateral cochlear implant users, who rely almost completely on ILDs for localization.
We present a method to artificially enhance the head shadow effect, to obtain level differences which are broadband and unambiguous.

Methods
The directivity pattern in each ear is enhanced with a beamformer. Each beamformer is achieved with a microphone array consisting of two or more microphones. Most auditory prostheses are already supplied with two (or more) microphones behind each other to achieve frontal directionality. However, to achieve an enhanced head shadow, we introduced left-right asymmetry in our microphone array. We present two options: (1) add one (or more) microphone(s) to each device, or (2) use audio streaming between devices.

Results
A device with 3 non-collinear microphones seems the most promising to achieve a strongly exaggerated broadband head shadow, while also keeping some frontal directionality. Beamforming with audio streaming only works for low frequencies (up to around 800 Hz), because of the large distance between the respective microphones. This might be useful if we are only interested in exaggerating the head shadow in this frequency region; e.g. for bimodal users, who often have profound hearing loss in the high frequencies.
Results of psychoacoustical evaluation (localization ability and speech-in-noise understanding) will be presented at the conference.

Conclusion
A constant directivity beamformer is a promising solution to enhance the head shadow effect. This can result in better localization ability and speech understanding in spatially separated noise for bimodal and bilateral cochlear implant users.

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W04b: MEASURING THE ABILITY OF CLINICAL PROCESSORS TO ENCODE BINAURAL CUES IN THE SIGNAL ENVELOPE

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For listeners with bilateral cochlear implants, performance in sound localization and speech understanding in noise is worse than for normal hearing listeners. While various factors may decrease binaural hearing performance with cochlear implants, the most commonly noted factors are: lack of synchrony between processor clocks and the independent encoding in the two sound processors. In theory, the signal processing in clinical processors should be able to encode binaural cues, especially interaural time and level differences between the stimulus envelopes. However, very little data from processor measurements exist to verify these claims.

The aim of this work is to advance the field, and ultimately improve performance of bilateral cochlear implants, by determining how well clinical processors can encode binaural cues. Here we measured the fidelity with which current clinical processors are able to encode envelope cues of stimuli with different frequency content. Transposed tones were used for these measurements to provide precise knowledge of the properties of the input stimulus. The transposed tones had an envelope modulation rate of 30 Hz, and the carrier frequency was chosen to match the center frequency (CF) of the frequency allocation table of the clinical processor. Single-CF and multi-CF complexes were used for these measurements. The stimuli were presented to the processors either through direct connect cables connected to the processors' auxiliary input port, or in the free-field through loudspeakers. In free-field measurements, processors were placed next to each other, or on the ears of a KEMAR manikin. A National Instruments data acquisition card (NIDAQ) was used to record the electrical stimulation pattern generated by the processors for the input stimulus. The NIDAQ has a sampling rate of up to 500 kHz on a single channel which allows us to observe processor stimulus encoding errors down to 2 µs. Cochlear N5 and Advanced Bionics Naida Q70 processors were measured.

Single-CF measurements on N5 processors showed that the stimulus envelope can be well preserved and with only a small amount of jitter in the onset of the envelope. This implies that interaural timing differences can be encoded with a high degree of fidelity. However, electrodes adjacent to the target electrode could also be activated but this depended on the location on the electrode array. In contrast, single-CF measurements with the Q70 processors always activated adjacent electrodes. This activation of additional channels proved to have a deleterious effect on envelope encoding for some multi-CF tone complexes and implies that spurious interaural level differences can be introduced by the signal processing.

The results show that clinical processors have the potential to encode binaural cues in the signal envelope with some degree of fidelity. However, this is dependent on the complexity of the stimulus and the way the cochlear implant signal processing strategy converts the acoustic signal into electrical stimulation.

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W05a: EXTRACOCHLEAR ELECTROCOCHLEOGRAPHY DURING INSERTION OF COCHLEAR IMPLANTS: INTRAOPERATIVE RESPONSES AND POSTOPERATIVE HEARING PRESERVATION

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Intra-insertion trauma during cochlear implantation (CI) is an important factor leading to poor speech and hearing outcomes. A new approach that is under development among several laboratories and implant manufacturers is to use electrocochleography (ECochG) to monitor responses to auditory stimuli as a marker for cochlear trauma during implantation. The monitoring can be performed by recording from the electrode tip as it advances or from a stable extracochlear location during the insertion. Both the intracochlear and extracochlear recording locations have strengths and weaknesses, and, ultimately, could be used in combination.

The purpose of this study was to characterize extracochlear ECochG responses during CI insertions for a broad range of subjects and lateral wall array types. In 55 CI recipients (16 children and 39 adults), ECochG was performed at the round window (RW) before CI insertion and at an extracochlear site throughout CI insertion. Tone bursts were presented to the ipsilateral ear using a Natus Bio-Logic AEP Pro. The frequency which elicited the largest RW response at 90 dB nHL (typically 500 Hz) was used as the stimulus frequency during CI insertion. The extracochlear electrode was a custom-built copper probe which remained fixed on the promontory via a retractor-clamped mount. For surgeries where hearing preservation was a goal, intraoperative responses were related to hearing outcomes.

Response changes throughout insertion fell into one of three categories depending on whether the extracochlear response magnitude 1) stayed within 5 dB of the starting point throughout CI insertion, 2) permanently dropped more than 5 dB by the end of CI insertion, 3) or had a drop greater than 5 dB during the insertion which recovered by the end of CI insertion. The vast majority of responses stayed within 5 dB throughout insertion (33/55), with permanent drops occurring in 11 subjects and reversible drops in 11 subjects. All drops in response which occurred within the first 15 mm of insertion were at least partially reversible, whereas drops after 15 mm were more likely to be permanent. The presence of reversible changes in response magnitude throughout insertion indicates that a simple drop in magnitude may not be an absolute metric for trauma.

In subjects with significant preoperative residual hearing, low frequency thresholds were maintained postoperatively in roughly 70% of subjects. Most cases where hearing was preserved showed atraumatic insertions based on ECochG, but some of those who lost hearing also showed atraumatic insertions, suggesting post-operative factors were the likely cause of hearing loss.

W05b: A MACHINE LEARNING APPROACH TO MITIGATING REVERBERATION IN COCHLEAR IMPLANTS

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Reverberant conditions remain one of the challenging listening conditions for cochlear implant users. Previous work by Desmond et al. (J. Acoust. Soc. Am., 2014, 135(6), EL304-EL310) proposed separating reverberation effects into two categories, self- and overlap-masking, for mitigation. While self-masking effects that occur when reverberation interferes with active speech may be difficult to mitigate without an estimate of room characteristics and source/receiver positions, overlap-masking, which consists of reverberation echoes between active speech segments may potentially be mitigated simply by removal. The study by Desmond et al., (2014) suggests that mitigation of overlap-masking alone has the potential to significantly improve speech recognition performance. The challenge is to develop an algorithm that automatically detects overlap-masking using techniques that are feasible for real-time operation.

A machine learning algorithm can be trained to discriminate between self- and overlap-masking patterns in cochlear implant pulse trains, with a mitigation strategy initiated upon detection of overlap-masking (Desmond, J.M., 2014, PhD dissertation, Duke University). This approach has the potential for real-time implementation if the design of the pulse-based features that the algorithm processes is restricted to be causal. Classification is achieved by scoring the pulse-based features and comparing to a threshold value, termed a classifier operating point, to categorize features as self- or overlap-masking. Due to disparate reverberant effects across the frequency spectrum, channel-specific classifiers are trained. A preliminary study conducted in normal hearing listeners will be presented that demonstrates the potential for this approach to lead to significant improvements in intelligibility.

This preliminary study relied on a single operating point for all of the channel classifiers; however, selecting the same operating point across the channel-specific classifiers might not always be optimal. There are likely different trade-offs between correctly detecting or misclassifying overlap-masking segments depending on the importance of the information contained in a specific channel for speech intelligibility. However, an exhaustive search over the effects of all possible sets of operating points on speech intelligibility is infeasible. Different metrics have been proposed to predict intelligibility based on analysis of speech material (Falk et al., IEEE Signal Process. Mag., 2015, 32(2), 114-124). In a follow-on study, intelligibility metrics will be used to estimate optimized operating points. The intelligibility obtained for the reverberation mitigation algorithm utilizing optimized operating points will be compared to the intelligibility obtained when utilizing a constant operating point across channels.

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W06: A NEURAL TIMING CODE IMPROVES SPEECH PERCEPTION IN VOCODER SIMULATIONS OF COCHLEAR IMPLANT SOUND CODING

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Cochlear implant (CI) advancements have brought significant hearing benefits to those with profound deafness. However, CI users have very limited speech perception in noisy environments. Improving CI sound-coding strategies could potentially provide the needed speech understanding benefit. Timing of auditory nerve action potentials, or spikes, has been well-studied, but have yet to be explicitly utilized in CI coding schemes. Our recent work has developed a model of optimal neural spike timing, which predicts a minimum-error neural code given a metabolic energy constraint. This model has successfully predicted the times of experimental spikes from sensory neurons. To initially assess whether including such a model could improve speech coding in CIs, we created a vocoder incorporating this neural model, where the information of the sound signal was based on the timing of the pulses rather than their amplitude. These pulses were precisely timed to mimic encoding with action potentials, and were then utilized to optimally encode the sound waveform.

This study compares the new spike-time vocoder with a standard noise carrier vocoder to test normal-hearing listeners' speech perception and sound localization abilities. Experiment 1 tested listeners' speech perception for the vocoders using the Hearing in Noise Test (HINT) with diotic presentation of identical waveforms. In Experiment 2, to investigate spatial release from masking, the HINT was conducted with the signal and noise co-located at 0 degrees azimuth, and with the signal presented at the 0 degrees azimuth and the noise spatially separated by 90 degrees in the azimuth plane. In Experiment 3, listeners' localization abilities were tested using a short speech sound processed with head related transfer functions recorded from a KEMAR to create spatial cues from 12 possible locations behind the head separated by 15 degrees.

In the case of both Experiment 1 and Experiment 2 with co-located speech and noise, the normal-hearing listeners demonstrated a significant improvement of 2-3 dB in speech reception thresholds (SRT) using the spike-time vocoder. When speech and noise were spatially separated, the SRT for the new spike-time vocoder were 8.3 dB lower than the standard vocoder. Finally, Experiment 3 showed that the subjects, using the spike-time vocoder, localized stimuli with 3.5 degrees less error than the standard vocoder. These results show it is possible to design a vocoder based on the principles of optimal neural spike timing to improve speech perception and sound localization when compared to a standard vocoder. The precise pulse timing of the spike-time vocoder may help encode important perceptual information, which has possible implications for cochlear implant sound-coding. Work supported by NIH/NIDCD R03-DC013380 and authors were also partially supported by National Science Foundation grants EFRI-BSBA-0938007 and IGERT 0903622.

W07a: PERCEPTUAL DIFFERENCES BETWEEN MONOPOLAR AND PHANTOM ELECTRODE STIMULATION IN COCHLEAR IMPLANT USERS

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Introduction
Phantom electrode (PE) stimulation is achieved by simultaneously stimulating out-of-phase two adjacent intra-cochlear electrodes with different amplitudes. The most apical electrode is stimulated with the current I whereas the adjacent electrode is stimulated with -I*σ. The ratio of the current between the compensating and the primary electrode is defined as σ. The resulting electrical field is pushed away from the electrode providing the lower amplitude (i.e. apically) and produces a lower pitch. There is great interest in using PE stimulation in a processing strategy as it can be used to stimulate cochlear regions more apical (and producing lower pitch sensations). However, it is unknown if there are perceptual differences between monopolar (MP) and PE stimulation other than a shift in place pitch. Furthermore, it is unknown if the effect and magnitude of changing from MP to PE stimulation is dependent on electrode location. This study investigates the perceptual changes (including pitch and other sound quality differences) at different electrode positions using MP and PE stimulation using both a multidimensional scaling procedure (MDS) and a traditional scaling procedure. From the scaling experiments, only relative pitch shifts between the stimuli can be estimated. To estimate absolute pitch shifts associated with PE stimuli, a pitch matching experiment in single sided deafened (SSD) subjects between PE/MP stimulation and acoustic pure tones is being conducted.

Methods
10 Advanced Bionics (AB) users scaled the perceptual differences between 5 single electrode (typically 1, 3, 5, 7, and 9) stimuli in either MP or PE (σ=0.5) mode. Subjects were asked to report how perceptually different each pair of stimuli were using any perceived differences except loudness. Each pair was presented 5 times (500 total pairs). Subsequently, each stimulus was presented in isolation and subjects scaled how “high” or how “clear” each sounded. Each stimulus was presented 15 times. 2 additional SSD AB users participated in the pitch matching experiment. The experiment consisted of pitch matching acoustic pure tones delivered to the normal hearing ear with constant pulse trains delivered to the CI with σ=0 (MP) and σ=0.5 (PE).

Results & Conclusions
Results from the MDS task revealed that perceptual differences between MP and PE can be explained by a single dimension. The traditional scaling illustrated no significant differences in sound quality between PE and MP stimulation. However, PE stimulation elicited lower pitch perceptions than MP stimulation in all cochlear regions suggesting that the single dimension is place pitch. Analysis of cone beam computer tomography data (CBCT) revealed differences in the amount of perceptual shift dependent on cochlear location. Preliminary results from the pitch matching experiment in 2 SSDs demonstrate a pitch shift between PE and MP stimulation of 0.24 octaves towards lower frequencies (ranging from 0.20 to 0.29). From these results, it can be concluded that PE stimulation can be used for new sound coding strategies in order to extend the pitch range for CI users without perceptual side effects.

W07b: PRELIMINARY STUDY OF A HARMONIC CODING STRATEGY TO IMPROVE SOUND PROCESSING IN COCHLEAR IMPLANTS

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Harmonics carry crucial acoustic cues for speech and music perception, however sound processing in current cochlear implants are unable to track and encode them efficiently. In our previous studies, a harmonic coding strategy (Harmonic Single Sideband Encoding-HSSE) has been proposed and evaluated by off-line signal processing and showed promising results. Recently, a real-time version of HSSE has been implemented on the Nucleus Freedom clinical speech processors. In the real-time HSSE, an autocorrelation-based (implemented with FFT & IFFT) pitch tracker was used to estimate the pitch (or fundamental frequency value) and then harmonic components were separated to extract pitch-synchronized envelopes. The real-time HSSE was initially evaluated on three cochlear implant subjects.

In addition, to assess pitch discrimination ability with the harmonic coding strategy, a pitch pattern discrimination test was developed. A total of 6 pitch patterns were created using a regular pulse excited linear predictive coding (LPC) filter. The excitation pulse time interval would determine the pitch period. Each pitch sequence consisted of three consecutive harmonic tones at either a low or a high pitch value with a specified difference. An adaptive tracing paradigm was used to find the minimum pitch difference a subject can achieve. The pitch pattern discrimination test would allow us to experiment with different pulse modulation patterns that produce better pitch perception. It then could potentially serve as a fast and useful tool for optimizing harmonic coding.

Subjects and Methods: In our preliminary study, three cochlear implant subjects participated in the real-time HSSE evaluation. Two of the three subjects were acutely tested with the UW CAMP (Clinical Assessment of Music Perception) battery after being fitted with the real-time HSSE. One subject (English-speaking) performed an additional Mandarin tone test. Two normal hearing subjects participated in the pitch pattern discrimination experiments. The base frequency was initially set to 150 Hz.

Results: One cochlear implant subject showed better timbre recognition compared to his clinical ACE strategy (88% HSSE vs 54% ACE) and another subject had similar performance (58% HSSE vs 58% ACE) in the timbre test. The cochlear implant subject tested with Mandarin tones could recognize 52% the tones compared to 42% with his clinical processor. In the pitch pattern recognition experiment, both subjects showed reasonable threshold (<10 Hz) but worse threshold with processed pitch pattern through an 8-band noise vocoder (>50 Hz). More cochlear implant patients are being tested with the real-time HSSE.

W08a: EVALUATING MUSIC PERCEPTION WITH A NEUROPHYSIOLOGICALLY-BASED COCHLEAR IMPLANT CODING STRATEGY

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Present day coding strategies for cochlear implants such as ACE or CIS are quite successful in conveying speech information, which is characterized by relatively simple spectro-temporal structures. However, these coding strategies struggle with more complex signals, for instance with music, where a good representation of the harmonic (spectral) components is essential. In general, ACE favors higher amplitude components and may therefore ignore lower amplitude components, while CIS typically has a lower frequency resolution available due to the smaller number of fixed channels.

More recent neurophysiologically-based coding strategies such as ECC (Excitability Controlled Coding) are able to represent more of an input signal's spectral content while maintaining the same overall stimulation rate and number of active channels as ACE. To demonstrate the benefits of this increased spectral representation, suitable test material with higher spectral complexity must also be identified, since simple signals will be equally well represented by ECC or ACE.

An electrodographic analysis of the harmonic contents of various musical instruments taken from a Music Database (Goto, Hashiguchi et al. 2003) was first conducted. Several instruments with high harmonic content over the frequency range up to 8 kHz were identified, and 3 instruments selected for testing. The same recorded musical notes from the database were then used to construct 3-note melodic contours (Galvin, Fu et al. 2007) for an identification test. The constructed melodic contours were then processed by a neural-based CI simulator (El Boghdady, Kegel et al. 2016) for presentation to 8 normal hearing listeners.

Test results showed highly significant improvements in melody contour identification with ECC compared to ACE for the cello and the organ. In particular, the first harmonic is often missing with ACE, resulting in misleading pitch reversals. In comparison, ECC seldom leaves out harmonics since it is able to represent much more of the input signal spectrum. With the alto saxophone, no significant differences were found between ACE and ECC but this could be clearly explained by a detailed electrodographic analysis of their respective output signals. With ACE, all the tones tested consistently had a missing first harmonic, and although the pitch may be wrongly represented, unexpected pitch reversals did not occur as a result.

In conclusion, the benefits of ECC arising from its increased spectral representation compared to ACE can be clearly demonstrated using suitably selected instruments for melodic contour identification.

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W08b: DEEP NEURAL NETWORKS FOR IMPROVING SOUND SEGREGATION IN COCHLEAR IMPLANT USERS

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Competing voices are part of everyday challenges for those with hearing loss including cochlear implant users. To enhance segregation we explore the use of Deep Neural Networks (DNN), which compared to conventional methods have been shown to provide substantial advantages in source separation. In this work, we employed a DNN-based single-channel source separation method for two-talker mixtures. The method was used to predict time-frequency masks, which were in turn used to separate the sources from the mixed signal. We tested a number of DNN variants as well as ideal separation. The processed signals were subsequently vocoded by means of the Oticon Medical real-time research platform and presented to normal-hearing test persons. To measure segregation performance for the separated mixtures, we employed a new Competing Voices Test (CVT). Compared to traditional speech tests, the CVT has two or more equally important targets and simulates a situation where the listener must pay equal attention to two competing voices, such as in a dinner table conversation or interruptions while watching TV. The CVT has been validated earlier using simple spatial contrasts and has been applied in a series of tests on normal-hearing and hearing-impaired listeners. In this work, we present both subjective and objective measures of source separation with DNN for two-talker mixtures. We discuss the potential benefits of DNN application for source segregation for cochlear implants and propose the use of a new CVT for evaluating performance in multiple-talker scenarios.

W9: LOMBARD EFFECT PERTURBATION PRE-PROCESSING STRATEGY FOR COCHLEAR IMPLANT USERS

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The Lombard effect (LE) (Lombard, 1911) is the involuntary tendency of speakers to alter their vocal production characteristics based on auditory feedback from environmental noise. This phenomenon causes an increase in vocal effort (e.g., vocal intensity) and changes in glottal spectral slope, fundamental frequency, phonemic duration, and formant structure. These speech production changes enhance the audibility/intelligibility of a speaker's voice during communications. Several past studies have considered the analysis of speech production under LE (Lane and Tranel, 1971; Garnier et al., 2010). LE has been also been used to formulate front-end speech processing algorithms to improve performance of automatic speech recognition (ASR) and speech identification (SID) systems (Hansen, 1988; Junqua, 1992). Some groups have employed LE traits to improve acoustic models for speech recognition by modifying neutral speech (e.g., spectral contour, F0 structure, duration) (Bou-Ghazale and Hansen, 1996). These advancements have been leveraged extensively in speech technology for ASR and SID, however none have ever been explored for hearing aid/CI sound processing. We have demonstrated presence of Lombard effect in speech production of normal hearing listeners as well as postlingually deafened CI users in our prior work (Lee et al., 2015). Our experimental data from CI users indicate speech with LE perturbations improves overall speech intelligibility (Lee et al., 2016). Motivated by these findings, the present study focused on developing a novel speech enhancement algorithm based on LE properties. The proposed algorithm artificially adds LE traits to neutral speech. The LE traits considered here were: (1) dynamic gain adjustment, (2) spectral contour adjustment, and (3) an increase in overall sentence duration. The dynamic gain adjustment was used to increase gain for high intelligibility speech segments (e.g., consonants and vowel-consonant boundaries), which are critical cues for speech understanding. A cochlear-scaled entropy (Stilp and Kluender, 2010) was employed to estimate the information bearing segments. The spectral contour adjustment was aimed to emphasize the high frequencies, which convey consonant cues to the listener. This was achieved by using a time-invariant filter estimated by computing spectral difference between neutral and Lombard speech. Finally, overall sentence duration was increased to provide listeners more time to anchor to acoustic cues, and thereby improve CI decoding opportunity. TD-PSOLA technique (Moulines and Charpentier, 1990) was employed to account for the duration variation. The proposed algorithm was evaluated with five post-lingually deafened adult CI users. Subjects listened to the neutral and Lombard processed AzBio sentences in quiet and in large crowd noise (at 15dB and 10dB SNR). On average 15% improvement in speech understanding scores was observed with Lombard processed speech in noisy environments as compared to the neutral speech. The strength of this approach is that it lifts the speech up from the underlying background noise, without creating distortion artefacts or disturbing the fine time-frequency structure of speech signal, which is a common drawback in most speech enhancement strategies.

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W10a: SMILES, CHUCKLES, AND LAUGHTER: ESTABLISHING A COMPUTATIONAL SIMULATION OF COCHLEAR IMPLANT STRATEGIES FOR AMUSED SPEECH CLASSIFICATION

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Many cochlear implant (CI) users have difficulty perceiving the social-linguistic and personal information conveyed in speech. For instance, previous studies have shown that CI users perform worse than normal-hearing controls on tasks involving the classification of different types of tones or emotions. In the present study, we analyze just the emotion of positive valence: amusement. Specifically, our research concerns the paralinguistic or non-verbal expressions in amused speech that occur in daily conversations. For analysis, we used an amused speech classification task that requires discriminating 1) Smiled vowels (alteration of speech due to smiling), 2) Chuckling vowels (shaking vowels altered by some sort of tremolo), and 3) Laughter syllables (succession of unvoiced and voiced phone-like sounds constituting a laughter syllable). Each of these amused speech components involve the voluntary flexing of muscles at the side of the mouth and the involuntary rhythmical and often audible contractions of the diaphragm. Therefore, these physical reactions can directly alter the fundamental frequency, the repetitive rhythm of glottal stops and fricatives, and the amplitude contour of a speech signal.

In this preliminary work, we first established baseline results using a computational simulation for the classification of smiled vowels, shaking vowels, and laughter syllables [1]. Computational methods for evaluating CI speech processing strategies [2-4] have been previously utilized as high-throughput screening systems [5, 6] for the advantages of predicting speech recognition accuracy with higher efficiency, better process control, and faster analysis time. The computed results for amused speech classification showed the type of input representation for the artificial neural network had significant effects on the performance.

Next, we established baseline CI-vocoder results for normal-hearing controls using the exact same parameters as in the computational simulations. The results of both human hearing and machine hearing indicate that the CI processing strategy parameters should be optimized for improving amused speech classification. In future work, we will combine our 1) computational and 2) normal-hearing CI-vocoder analysis with 3) actual CI user performance to determine an appropriate statistical approach for optimizing amused speech components classification. This type of cross-disciplinary analysis will be especially useful and also important since the ability to provide cues that are reliable regarding a talker's communicative intent will be critical for a CI user's language and emotional development (e.g., "infant-directed speech").

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W10b: MODULATED PHASE CODING STRATEGY FOR COCHLEAR IMPLANTS

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Cochlear Implant (CI) users' performance decline in challenging listening environments and for music. Contemporary CI coding strategies rely on Continuous Interleaved Sampling to restrict adjacent electrodes from firing at the same time and reduces the ability of CIs to stimulate frequency channels simultaneously. Overlapping stimulation lowers the number of independent channels and the frequency resolution. While this restriction is important in terms of disallowing cross-talk between channels, it also restricts the processor's ability to provide temporal fine structure (TFS) to the patient. In particular, TFS is important in distinguishing speech in noise, and for music appreciation.

We developed and tested a novel method of converting sound for cochlear implants called Frequency Modulated Phase Coding (FMPC). It encodes sound by varying pulse rate instead of amplitude; in other words, level changes are encoded by rate changes and pitch by place of the electrode. FMPC keeps current amplitude levels low so parallel electrode stimulation is possible. Additionally, pulse rate encoding allows for the possibility of recreating temporal fine structure in the pulses applied to the cochlea.

This study compared speech recognition scores of patients utilizing both their own processing strategies and the novel FMPC method. CI users with two different CI brands were included in the study. For FMPC, after a 5-minute adaptation period, one manufacturer's patients saw an average speech recognition score of 44% while the other saw an average score of 65% (compared to the 70% average of traditional coding strategies after 1 month of use). The latter manufacturer's group had 4 out of 7 users score above 80% with FMPC. Moreover, FMPC potentially saves a significant amount of power over current strategies due to a lower average pulse rate (under 200 Hz per channel compared to >1000 Hz fixed rate per channel in current strategies).

Conclusion: The impact of this research will also have a broader reach, as this novel method can be applied to other neural interfaces, such as spinal cord stimulators and retinal implants.

W11: OBJECTIVE SPEECH TRANSMISSION IMPROVEMENTS WITH A BINAURAL COCHLEAR IMPLANT SOUND-CODING STRATEGY INSPIRED BY THE CONTRALATERAL MEDIAL OLIVOCOCHLEAR REFLEX

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We have recently shown that cochlear implant users could enjoy better speech reception in noise and enhanced spatial unmasking with binaural audio processing inspired by the inhibitory effects of the contralateral medial olivocochlear reflex on compression (Lopez-Poveda et al., 2016, Ear Hear 37:e138-e148). The perceptual evidence supporting those benefits, however, is limited to a few target-interferer spatial configurations and to a particular implementation of contralateral MOC inhibition. Here, we use the short-term objective intelligibility index to (1) objectively demonstrate benefits over many more spatial configurations, and (2) investigate if the benefits may be enhanced by using more realistic MOC implementations. Results corroborate the advantages and drawbacks of MOC processing indicated by the perceptual tests. They also suggest that the benefits may be enhanced and the drawbacks overcome by using longer time constants for the activation and deactivation of inhibition. Compared to using two functionally independent processors, the better MOC processor improved the signal-to-noise ratio in the two ears between 1 and 6 decibels by enhancing head-shadow effects, and was advantageous for all tested target-interferer spatial configurations.

W12a: DAILY DATALOGS, NEED AND FEASIBILITY

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The Nucleus CP900 series sound processor enables the clinician to view the datalogs from the recipient. The time on air, time in speech, accessory usage and program usage is helpful for counselling. The changes made to volume and sensitivity is helpful for programming. The datalogging information is also useful for habilitationists. Currently, clinicians are able to view the averaged data from the last programming session to the next. The feedback from clinicians has been that datalogging could be made even more useful if the data could be obtained at a more granular level. Such granular data would also be useful for recipients or their carers to monitor device usage. Since granular datalogs is not available in most other devices, the level of granularity required and the specific use cases are unclear.

A novel method was developed that allows storage and retrieval of datalogs at a more granular level. However, more granular the data is made the more it impacts the size of data that can be stored. This study aimed at 1) evaluating the need for and level of granular datalogs for recipients and clinicians and 2) to test the feasibility of obtaining granular datalogs with cochlear implant recipients

Methods: A survey was conducted with clinicians, parents of paediatric recipients and adult CI recipients from all over the world on the potential benefits of having access to more detailed datalogs. A clinical study was conducted to test the feasibility of obtaining granular datalogs using a novel method of datalog capturing. Data was recorded from ten adults and seven paediatric cochlear implant recipients using the sound processor.

Results: The survey results showed that parents of paediatric recipients, and clinicians valued the availability of granular datalogs. The clinical study results showed that it was feasible to collect detailed datalogs using the novel datalogging method.

W12b: EVALUATION OF SPECTRAL MUSIC COMPLEXITY REDUCTION METHODS FOR COCHLEAR IMPLANT LISTENERS BY MEANS OF A PERCEPTUAL MUSIC QUALITY PREDICTION MODEL

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Cochlear implant (CI) listeners are often not satisfied with the perceived quality of music. This can be attributed to the low frequency selectivity provided by CIs which leads to severe distortions of timbre and pitch. Recent approaches have shown that reducing the complexity of music signals by remixing leading voices and accompaniments at increased signal-to-interference ratios (SIR) [1,2,6] or by frequency-domain reduced-rank approximations [3] provides an effective means for increasing preference rates of CI listeners. The advent of such music preprocessing methods raises the demand for instrumental evaluation procedures as an alternative for time-consuming listening tests. While there exist numerous measures to predict improvements in speech quality or intelligibility achieved by speech enhancement algorithms, comparable metrics for assessing the quality of (processed) music as perceived by CI listeners are not well established.

Therefore, in this contribution we present and revisit a recently proposed prediction model for perceptual music quality ratings of CI listeners [4]. To obtain the model we performed a listening test with CI users who rated selected music pieces on six bipolar perceptual scales such as „unpleasant vs. pleasant“ or „complex vs. simple“. Signal features extracted from these music pieces were used to train a principal component regression model which predicts the median ratings across CI listeners for each scale. By applying a leave-one-out strategy the prediction accuracy is evaluated leading to maximal Pearson correlation coefficients between 0.9 and 0.95 (depending on the scale). Additionally, the prediction model is applied to excerpts of classical chamber music which have previously been spectrally simplified either by computing reduced-rank approximations based on principal component analysis (PCA) or partial least-squares (PLS) analysis or by performing supervised source separation and subsequent remixing (with SIR increases of up to 6 dB) [3]. The results predict significant improvements on the bipolar scales if less than the first 15 PCA or PLS components are used for the reduced-rank approximations. Conversely, for the remixing procedure the predicted ratings do not vary significantly in the considered SIR range with respect to the unprocessed music signals. A comparison of the spectral complexity reduction methods reveals a significantly better performance for the reduced-rank approximations. We can therefore conclude from the model predictions that reduced-rank approximations of music signals can increase the pleasantness of music perception and reduce the perceived signal complexity for CI listeners. This underpins listening test results obtained by normal-hearing listeners in combination with a cochlear hearing loss simulation [3] and by CI listeners [5].

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W13a: THE "TEMPORAL LIMITS ENCODER" FOR COCHLEAR IMPLANTS: ITS POTENTIAL ADVANTAGES AND AN FFT-BASED ALGORITHM

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Place coding and temporal coding work in both normal hearing (NH) and cochlear implant (CI) hearing. However, the lack of fine structure representations in both spectral and temporal domain within CIs makes CI users cannot own as good auditory abilities as NH listeners like in speech-in-noise recognition, melody and timbre perception, and sound localization. Spectral fine structure across channels might be improved by future electrode arrays and stimulation modes. Using state-of-the-art hardware, the temporal fine structure (TFS) within individual channel also might be improved through signal processing methods.

Recently we proposed a method, named as temporal limits encoder (TLE), to enhance the TFS representations 1, 2. In TLE, the band signal is frequency-downshifted to a low frequency range (e.g., 50-300 Hz or 200-500 Hz), in which the corresponding temporal fluctuations can still be perceived or discriminated in the sense of pitch. This frequency-downshifting operation produces a signal which has the same bandwidth with the original band signal. That means the signal frequency differences are preserved. The new band signal is used for stimulus generation instead of conventional temporal envelope. Some potential advantages on pitch discrimination and speech-in-noise perception with unilateral CIs were observed through vocoder simulation experiments in NH.

In order to evaluate TLE in actual CI users, a Fast Fourier Transform (FFT) based algorithm was developed. In current CI products, FFT is widely used, so it is convenient to compare FFT-based TLE with state-of-the-art strategies like the advanced combination encoder (ACE) of Cochlear Limited. In each windowed frame, TLE can directly uses the complex number results of FFT and then only some simple operations are introduced to produce the frequency-downshifted band signal. Comparing its computational complexity with ACE, TLE introduces only some additional simple computations like two dozens of cosines and a dozen of additions and uses less square root operations for a dozen of times. The same compression and pulse modulation modules in ACE can be used in TLE.

Electrodograms were generated to compare TLE and ACE. In global view of the electrodograms, TLE always preserved the same temporal envelopes as ACE. However, zooming in revealed that TLE introduced some informational temporal fluctuations within individual channel. These fluctuations can be seen as novel slow TFSs introduced by TLE. Electrodograms from bilateral CI encoding showed that bilateral TLE introduced some interaural time differences through the slow TFS. A bilateral vocoder simulation experiment in NH listeners was carried out recently and actual CI experiments have been started. The results of this ongoing study will be presented in the conference.

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W13b: LIMITING TEMPORAL INFORMATION ON MIDDLE AND BASAL CHANNELS

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It has been shown that presenting fixed-amplitude pulse trains with relatively low pulse rates via electrodes situated in the middle and basal regions of the cochlea typically produces poorer quality percepts when compared to percepts elicited by pulse trains with the same stimulation rates presented via electrodes in the apical region of the cochlea (e.g., Landsberger et al., 2016, Ear Hear 37(3): e149-e159). We performed pitch matching experiments with single-sided deaf cochlear implant users, first with low-rate pulse trains and again with high-rate pulse trains that were amplitude modulated at frequencies equal to the low pulse rates. Results showed that pure tone pitch matches were statistically indistinguishable between the two representations of low-frequency cues. It was also recently suggested that low-rate pulse trains and amplitude modulated high-rate carriers produce similar quality percepts (Stupak et al., 2017, Poster 29 at the ARO MidWinter Meeting, Baltimore, Maryland, USA). Based on the prior subjective ratings and new pitch matching data, we hypothesized that modulations in the temporal envelopes on middle and basal electrodes that occur during normal operation of cochlear implant audio processors may give rise to percepts with an unfavorable quality.

Research sound processors were constructed in which envelope extraction was achieved via rectification and lowpass filtering, and we manipulated the 3-dB cutoff frequency of the lowpass filter between 25 Hz and 250 Hz for middle and basal channels. A fixed representation of low-frequency cues was maintained for apical channels. Speech reception thresholds were measured, and feedback regarding the quality of the various processing conditions was collected.

While manipulating the envelope cutoff frequency did not have a significant effect on speech reception thresholds, reductions in the cutoff frequency of the lowpass filter applied during envelope extraction tended to produce an increase in voice pitch and decrease in quality. These findings suggest that temporal envelope cues may have a greater effect on the overall pitch associated with cochlear implant stimulation than previously thought.

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W14a: IMPROVING THE PERFORMANCE OF NEURAL-NETWORK BASED SPEECH ENHANCEMENT FOR NOVEL SPEAKERS

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Understanding speech in background noise represents a significant challenge for cochlear-implant (CI) users. Speech enhancement methods that employ neural network algorithms (NNSE) can significantly improve speech understanding in noise for CI users [1]. The performance of NNSE is greatest when both the speaker and the masking noise employed in the training stage are similar to those employed in the testing stage; performance drops considerably for novel speakers or masking noises. In order to improve the performance for novel conditions, a large number of training data may be required that incorporate more variation in terms of the acoustic properties.

Noise perturbation—generating large amounts of noise data by warping a small initial data set—has been shown to improve performance of NNSE algorithms to unheard noise samples [2]. Similarly, speech perturbation has been found to improve speaker generalization in automatic speech recognition systems [3]. Here, we test whether a system that enhances speech from novel talkers can be trained using perturbed speech from a single talker rather than using a multitude of original speakers. STRAIGHT [4] a high-quality vocoder, was used to scale speech recordings from a single female speaker to simulate 40 speakers with a range of vocal tract lengths and glottal pulse rates, covering the parameter space typical for adults.

The performance of NNSE for the different training sets was assessed using objective measures (STOI, NCM, HIT-FA) on noise-vocoded CI simulations. Similar performance was found for the perturbed-speaker training set as for the multi-speaker training set, indicating that the proposed method could be used to improve the performance of NNSE for novel speakers. Still, objective scores were lower than those obtained with a speaker-dependent system. Simulation experiments with normal-hearing listeners are planned to verify the findings from the objective measures. These results present a step towards the application of speech enhancement algorithms that improve speech perception in noisy environments for CI users.

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W14b: A REAL-TIME ANDROID APP FOR MULTI-TALKER BABBLE NOISE REDUCTION.

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Cochlear implant users typically have difficulty understanding speech in the presence of competing talkers (i.e. multi-talker babble). The non-stationary nature of the multi-talker babble and its spectral similarity to the target speech are two of the main reasons which make it difficult to effectively eliminate the babble using conventional techniques. To address this problem, we have designed a real-time algorithm with relatively low latency which can effectively enhance the speech quality when the speech is corrupted by multi-talker babble.

The algorithm first classifies the incoming frames of the noisy speech as either babble dominated or speech dominated frames. In the classifier, we have used novel features that are sensitive to the level of the babble in the noisy speech. We use a Tunable Q-Factor Wavelet Transform (TQWT) to denoise the classified frames. The flexibility for changing wavelet parameters of the TQWT provides the ability to fine tune the algorithm. This facilitates the real-time implementation of the algorithm within the computational power constraints of a smartphone.

Another advantage of using TQWT is the fact that the representation of the clean speech samples in an oversampled TQWT exhibits some limited degree of “group sparsity” which does not exist in babble samples. We have designed an adaptive group thresholding technique which employs this group sparsity property and eliminates the coefficients originating from multi-talker babble in TQWT domain.

One of the biggest dilemmas when designing a noise reduction algorithms using threshold based techniques is the tradeoff between maximizing the noise removal and minimizing the distortion resulting from thresholding process. To address this problem, we propose a parallel de-noising approach in which we simultaneously de-noise the noisy speech using multiple TQWTs with different settings. Thus, we obtain multiple different de-noised versions of the same signal. If the wavelet parameters are selected carefully, the normalized average of the above mentioned de-noised versions will be noticeably less distorted than each de-noised version.

We have completed a prototype version of a real-time Android app (for cell phones and tablets) based on this algorithm. The app has three modes: 1- Non-real time mode, in which the user can record the noisy speech and then de-noise the saved audio; 2-Real time mode, in which the audio is received by a microphone (either the cellphone’s built-in microphone or an external microphone) and after de-nosing, the de-noised signal will be streamed to an external device which could be a headphone or a cochlear implant sound processor; 3-Wireless mode, in which the noisy speech is received from a remote device (e.g., another cellphone, smart watch etc.) via Wi-Fi or Bluetooth and the received audio is denoised real-time and streamed to the CI device or microphone.

A demo of the cell phone app will be available during the presentation.

Funding: Work is supported by an Applied Research Support Fund (ARSF) grant from NYU.

W15: USING PULSE-SPECIFIC FEATURES FOR REVERBERATION MITIGATION IN COCHLEAR IMPLANT PULSE TRAINS

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Cochlear implant (CI) users are disproportionately affected by reverberation, showing an exponential decrease in intelligibility with a linear increase in reverberation time (Kokkinakis, Hazrati, and Loizou, 2011). Generally, for mitigation, reverberation is removed using inverse filtering, but this strategy is not suitable for cochlear implants since inverse filtering requires estimates of such condition characteristics as the speaker location and room dimensions which can be difficult to obtain for real-time correction. Here, we employ a different mitigation strategy, in which reverberation is broken down into its two components: overlap-masking and self-masking. Self-masking occurs when reverberation echoes interact with active speech while overlap-masking refers to echoes between active speech. As indicated by the results in (Desmond et al., 2014), solely mitigating overlap-masking could have substantial benefits to CI users. Overlap-masking mitigation is a promising strategy for reverberation removal as it is simple (overlap-masking pulses must only be removed from the pulse train) and feasible in real-time (pulses can be detected using machine learning, as demonstrated by Desmond in her thesis: Using Channel-Specific Models to Detect and Mitigate Reverberation in Cochlear Implants, 2014).

The approach taken by Desmond only considers channel-specific features, and here we propose to improve classification by including cross-channel information. Cross-channel information has the potential to improve performance due to correlation in channel behavior during speech. Groups of channels typically enter self- or overlap-masking states at approximately the same time based on the phoneme being spoken. Thus, when deciding whether the stimulus in a particular channel is a result of overlap-masking, it may be informative to observe that other channels appear to be in an overlap-masking state as well.

This study presents the development of cross-channel features, and demonstrates the potential for improving classifier performance substantially by leveraging this additional information. Using channel specific and cross-channel features, a relevance vector machine (RVM) classifier was able to discriminate between self-masking and overlap-masking pulses with 80% accuracy. Performance of normal hearing subjects on an intelligibility test of reverberant speech mitigated by this algorithm will be reported.

W16a: IMPLEMENTATION AND EVALUATION OF A SINGLE-CHANNEL NOISE REDUCTION METHOD IN COCHLEAR IMPLANTS

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Cochlear implant (CI) users often have great difficulty understanding speech in background noise, partially due to the limited spectral resolution with their device. Various signal processing algorithms (e.g., beamforming using two-microphones, single-channel noise reduction, etc.) have been proposed to improve CI users' speech understanding in noisy environments. Previous studies have shown that CI users can benefit from beamforming technology when the targeted speech and interfering speech or noise are spatially separated. Single-channel noise reduction methods can be used to enhance the target speech when speech and noise are co-located. Previous single-channel noise-reduction algorithms have shown mixed results in terms of improved performance and sound quality, especially when tested dynamic noise or interfering speech. In this study, a novel single-channel noise reduction algorithm (eVoice™) was implemented in Nurotron Venus™ CI system. Here, we report preliminary results in terms of speech understanding in noise and subjective sound quality ratings.

Sentence recognition was measured in quiet and in noise with and without the eVoice algorithm in 11 adult, Mandarin-speaking CI subjects, all of whom used the Nurotron Venus™ device. Sentence recognition in noise was tested using speech-shaped noise (SSN) and 12-talker babble presented at 2 signal-to-noise ratios (SNRs; 5 dB and 10 dB). Subjective sound quality ratings was also collected in the same group of subjects using an eight-item questionnaire after a two-week habituation period. Preliminary data showed significant improvements in sentence recognition scores with the eVoice™ algorithm. With SSN, mean scores improved by 5.6 and 7.6 percentage points for the 5 dB and 10 dB SNRs, respectively. With 12-talker babble, mean scores improved by 8.0 and 7.8 percentage points for the 5 dB and 10 dB SNRs, respectively. No significant difference in performance was found in quiet. In terms of subjective sound quality ratings, most CI patients preferred the speech processor with the eVoice™ algorithms under everyday listening environments. These preliminary data suggest users of the Nurotron Venus™ CI device may significantly benefit from the eVoice™ single-channel noise reduction algorithm.

W16b: COMPARE THE SPEECH INTELLIGIBILITY BENEFITS OF F0-INFORMED SPEECH ENHANCEMENT WITH COCHLEAR IMPLANT LISTENERS BETWEEN STATIONARY NOISE AND NON-STATIONARY NOISE

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In this study, we evaluate the effects of F0-informed speech enhancement on cochlear implant (CI) listeners in terms of speech intelligibility. Both stationary noise and non-stationary noise are included in our study. Fundamental frequency (F0) - informed speech enhancement algorithm is motivated by the fact that speech energy is most carried by harmonic partials in voiced speech. The estimation of fundamental frequency and harmonic structure can facilitate to discriminate the speech spectrum from noise spectrum. Thus speech spectrum can be preserved while noise spectrum is suppressed according to the harmonic structure. We evaluate our F0-informed speech enhancement algorithm with 6 CI subjects in both stationary noise and non-stationary noise in terms of speech intelligibility benefit. The results show that the F0-informed speech enhancement algorithm can improve the speech intelligibility of CI subjects in both stationary and non-stationary noise. However, in the non-stationary noise, CI subjects achieve higher speech intelligibility benefit from F0-informed speech enhancement processing than in the case of stationary noise. Based on this phenomenon, we deduce that: i) In stationary noise case, CI subjects are more sensitive to speech distortion than noise interference. ii) In non-stationary noise case, CI subjects are more sensitive to noise interference than speech distortion. Moreover, from our experiments, we conclude that the tolerability tradeoff between speech distortion and noise interference needs to be considered when developing speech enhancement algorithm for CI listeners.

W17a: PRESERVATION OF RESIDUAL HEARING AFTER ELECTRODE INSERTION BY TOPICAL APPLICATION OF IGF-1

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Recently, cochlear implants using electro-acoustic stimulation (EAS) have widely been accepted as a standard therapy. In addition, some groups including our group have been trying to fabricate intracochlear piezoelectric micro-electrical-mechanical systems (MEMS), in which sound vibration is converted to electric signals by piezoelectric materials. In both EAS cochlear implants and intracochlear piezoelectric MEMS, preservation of remaining auditory function after surgery is included in critical problems. Previously, we have reported the potential of insulin-like growth factor-1 (IGF-1) for protection of cochleae against noise, ototoxic drugs and ischemia in animals. In addition, our previous clinical trials have demonstrated the safety and efficacy of topical IGF-1 application for treatment of sudden deafness. In the current study, we examined the capability of topical IGF-1 application for prevention of hearing loss due to surgery for electrode insertion.

Four-week old Hartley guinea pigs were implanted with a dummy electrode through the round window. An experimental group was topically applied IGF-1 onto the round window immediately after surgery, and controls was applied normal saline. Auditory brainstem responses (ABRs) were measured before, 1, 2, 4, and 8 weeks after surgery. ABRs demonstrated significant attenuation of surgery-induced hearing impairment, indication the potential of topical IGF-1 therapy for preservation of residual hearing after insertion of electrodes or devices into cochleae.

W17b: CAN A LATE HEARING LOSS AFTER HYBRID-L IMPLANTATION BE PREDICTED BY IMPEDANCE CHANGES?

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Preservation of residual hearing is one of the goals in current cochlear implantation surgery. Especially for this purpose smaller and softer electrode carriers were developed that are to be inserted through the round window membrane to minimise trauma. By using these electrodes and insertion technique, residual hearing can be preserved in a large number of patients. Unfortunately, some of these patients with preserved residual hearing after cochlear implantation lose it later on. The reason for this is unknown but it is speculated that there is some correlation with an increase in impedance.

The purpose of the current study was therefore to check this hypothesis. All adult patients (n=137) receiving a Hybrid-L implant at MHH between 2005 and early 2015 were retrospectively evaluated. Impedance values in CG mode as measured during clinical routine and referring audiological test data (hearing threshold) were collected.

Group mean values of impedances were between 5 and 7 kOhm and stable over time with higher values on basal electrodes compared to apical electrodes. Average hearing thresholds at the time of initial fitting were between 40-50 dB (250 Hz) and 90 dB (1 kHz) with a loss of about 10 dB compared to pre-op values.

When evaluating the 20 patients with the largest impedance changes during the observation period (all >1kOhm from one appointment to the next one), some patients were found where hearing loss is timely connected and highly correlated with an unusual impedance change. But large impedance changes were also observed without affecting hearing thresholds and hearing loss was found without impedance change. Therefore, we conclude from the current status of data evaluation that changes in impedance can not be taken as indicator for a late hearing loss.

W18: SPATIAL RELEASE FROM MASKING IN ACTUAL AND SIMULATED BIMODAL AND SINGLE-SIDED DEAF COCHLEAR IMPLANT LISTENERS

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A growing number of cochlear implant (CI) users consist of contralateral acoustic hearing with either normal (single-sided deaf, SSD) or impaired audiometric thresholds (bimodal CI users). The access to additional acoustic hearing provides improvements in speech intelligibility, especially in spatial situations, which, however, is far from that of normal-hearing (NH) listeners. The goal of this study is to compare speech-in-noise performance between simulated and actual bimodal and SSD listeners using different spatial scenarios. A special focus is put on the benefit obtained from spatially separating speech and noise (spatial release from masking, SRM) and on the question to what extent better-ear-listening is present in each listener group.

Eight bimodal and eight SSD listeners participated in the experiment. The participants received the acoustic stimuli via audio cable to their own CI and contralateral using in-ear headphones. Speech reception thresholds (SRTs) were measured using an adaptive procedure with sentences in stationary noise with long-term speech spectrum. Three different noise azimuth angles and frontal speech incident were simulated using virtual acoustics.

Simulation of bimodal or SSD users has been realized by presenting twelve NH listeners with vocoder-processed speech. A further development of the vocoder of Williges et al. (2015) was used for simulating electric hearing, including signal processing details of two CI manufacturers, as well as the application of electric field spatial spread. Simulation of contralateral acoustic hearing has been realized using either unprocessed stimuli (unaided NH) or stimuli processed by a hearing aid algorithm in combination with a hearing impairment simulation.

Actual bimodal CI listeners showed poorer SRTs and higher inter-subject variability than actual SSD listeners. Within the simulations, SRTs were poorer for more severe acoustic hearing, but were very similar across the two simulated CI manufacturers. SRM was found to be 8 dB for bilateral NH, 3-4 dB for simulated and actual SSD and 2-3 dB for simulated and actual bimodal CI listeners. Comparisons of simulated with actual bimodal and SSD listeners revealed a very similar pattern of SRTs and SRMs, dominated by a better-ear-listening strategy with only a few exceptions, e.g., if the head shadow lead the two ears to have similar speech performance [Financed by DFG JU2858/2-1].

W19: PERCEPTUAL AND NEURAL REPRESENTATION OF PULSE TRAINS DELIVERED BY ABI (AUDITORY BRAINSTEM IMPLANT) ELECTRODES

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Auditory brainstem implants (ABIs) provide an opportunity to restore hearing to profoundly deaf individuals who cannot benefit from cochlear implants (CIs). This is achieved by stimulating auditory pathways via electrodes placed on the surface of the cochlear nucleus. Current ABI devices use the same coding strategies as those used in CI devices. However, the strategies that were developed for stimulating auditory nerve may not be the best for conveying important speech information in ABIs. In fact, only a small percentage of ABI users achieve the level of speech perception performance comparable to that of average CI users.

In the currently used coding strategies, the envelope in each frequency band of the signal is coded by modulating the level of electric pulses delivered by an implant electrode that is assigned to that frequency band. One reason for poor ABI performance may be that ABIs do not transmit envelope modulations as well as CIs. Cochlear nucleus, the stimulation site of ABIs, is located higher in the auditory processing hierarchy than the auditory nerve, and its anatomy is complex and contains different types of neurons that play various roles in sound processing in an intact auditory system. It is possible that cochlear nucleus activity in response to stimulation provided by ABI electrodes does not represent important stimulus information, or that the neural activity represents stimulus information but it does not project to the higher centers that are the most appropriate for processing that information.

The aim of this study was to evaluate two hypotheses. First, that the pattern of neural activity in response to pulse train stimuli, as measured using electrically-evoked compound action potentials or ECAP, can be different between cochlear nucleus and auditory nerve. Second, that cochlear nucleus activity underlies perception of electrical stimulation by ABI users. Cochlear nucleus ECAP recordings were obtained in response to individual pulses of pulse train stimuli of different rates presented on a single electrode. Perceptual sensitivity to different electrical stimulation patterns presented on the same electrode was measured using discrimination and identification tasks. Results were compared to the typical results obtained from CI users with the same physiological and perceptual tests and the same stimulus patterns.

The preliminary ECAP results provide evidence that for the same pulse train stimuli, cochlear nucleus activity could be different from that of auditory nerve. In some ABI subjects, cochlear nucleus ECAP responses were more strongly affected by pulse rate than the typical ECAP responses obtained in CI users. This suggests that recovery from refractoriness and adaptation may be longer for some cochlear nucleus neurons than auditory nerve. The pattern of cochlear nucleus activity could explain some of the perceptual results, such as discrimination and loudness judgement of different pulse rates. The results suggest that atypical cochlear nucleus activity may underlie poor transmission of stimulus features with some ABI electrodes.

This study was supported by NIH/NIDCD.

W20a: AUDITORY-VISUO-MOTOR TEMPORAL PROCESSING IN COCHLEAR IMPLANT USERS

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The capacity to process and integrate information coming from different senses - multisensory integration – is altered in cochlear implant (CI) users. Multisensory integration allows complex cognitive tasks from daily life such as focusing on a particular conversation in a cocktail party or dancing to the rhythm of music. Altered multisensory integration in CI users is likely caused by brain reorganization during deafness. Deafness-induced brain reorganization impacts cochlear implantation outcomes; research suggests that individual differences in implantation success may depend on the ability to combine information from multiple senses following implantation. Therefore, in order to achieve the best outcomes, optimal rehabilitation programs should be designed based on individual sensory integration profiles, by coupling clinical neuro-imaging with behavioral investigations. However, most studies to date have focused on the behavioral aspect of multisensory integration and have ignored the motor component.

The present study is a neuro-behavioral assessment of the integration of auditory, visual and motor information, during temporal perception and production, in CI users. To do so, we used an innovative, implant-compatible, brain-imaging paradigm to investigate the brain dynamics of temporal perception and production across the senses. Participants either attended or actively synchronized to auditory, visual and auditory-visual signals, while their brain activity was recorded with high-density electro-encephalography. Behavioral performance and brain steady-states potentials were computed and compared to normal-hearing matched controls. Scalp topographies were extracted for each sensory component, allowing disentangling each sensory contribution and their interactions. In order to correlate behavioral and brain markers with clinical outcomes, relevant factors were collected: speech scores, duration of profound hearing loss, duration of CI experience, and age of implantation.

This is the first study to assess the neural correlates of multisensory integration of auditory, visual and motor information in cochlear implant users. Approaches such as the one presented here might provide cost-effective insight into the type of rehabilitation strategy that is best suited for an individual with significant hearing loss, as well as an objective measurement of multisensory integration than can be tracked longitudinally.

W20b: SOUND LOCALIZATION IN REAL-TIME VOCODER SIMULATIONS OF BILATERAL AND BIMODAL COCHLEAR-IMPLANT USERS

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OBJECTIVES. To investigate the effect of cochlear implant (CI) speech processing on sound localization of bilateral and bimodal CI users by the use of a real-time vocoder in normal-hearing (NH) listeners.

INTRODUCTION. Bilateral and bimodal CI users are poorer at localizing sounds than NH listeners. This performance gap is due to the degradation of the binaural and monaural cues for sound localization by an unknown combination of device-related and patient-related issues. For example, on the device side, the inability of the CI to provide the temporal fine structure of a sound, the independent processing of sounds at both ears, and positioning of the microphone outside the pinna deteriorate interaural timing differences, binaural coherence, and spectral pinna cues. On the patient side, poor residual hearing loss (in a non-implanted ear) and degradation of auditory neural pathways associated with a patient's hearing loss might prevent the patient from obtaining a clear spatial percept. The present study aims to exclusively investigate the device-related issues by measuring sound localization performance in NH subjects listening to free-field stimuli processed binaurally and monaurally by a real-time CI vocoder. The use of a real-time vocoder is a new approach that enables testing in free-field environments, which provides better normal-hearing sound localization performance than testing in virtual acoustic space.

DESIGN. Absolute free-field sound localization performance in the frontal hemifield was tested acutely in 11 NH subjects for three listening conditions: NH, bilateral (2CI, binaural vocoder) and bimodal (1CI, monaural vocoder). The real-time vocoding was achieved by the Cochlear Human Interface Research Platform (cHIRP) provided by Oticon Medical. Sound stimuli consisted of 150 ms bursts of broad-band, high-pass and low-pass filtered Gaussian white noise at 50, 60, and 70 dBA. Listeners were instructed to orient a head-fixed laser pointer to these noise bursts as quickly and as accurately as possible. Through linear regression analysis, sound localization performance was determined in terms of gain (stimulus-response slope), bias (offset in deg) and response variability (standard deviation of the residuals, in deg), for three target azimuth ranges (left [<-15 deg, CI side in 1CI], center [between -15 and 15 deg], and right [>15 deg, NH side in 1CI]).

RESULTS. In the NH listening condition, subjects accurately (gain near 1, bias ~0 deg) and precisely (response variability ~6 deg) localized all sounds both in azimuth and elevation for all three target ranges. In the 2CI listening conditions, subjects lateralized sounds (gain and response variability were ~0.2 and ~16 deg for all ranges, respectively; bias was ±35 deg for left and right range, respectively), and sound elevation localization was absent (gain ~0) across the entire azimuth range. In the 1CI listening condition, a weighted localization response was observed, with poor localization performance on the CI side (gain ~0), and fairly accurate performance on the NH side (gain ~0.9), both in azimuth and elevation.

CONCLUSION. Simulated bilateral and bimodal localization in NH is poor, suggesting that the inaccurate sound localization performance of actual bilateral and bimodal CI users is largely due to device processing issues. Although lack of binaural coherence prevents binaural fusion for 2CI listeners, they can at least lateralize sounds by determining in which ear the louder signal is presented. Binaural fusion in the 1CI listening condition is also lacking, yet monaural cues enable sound azimuth localization on the non-vocoded NH side. Sound elevation localization is a binaural process in which the monaural spectral cues of both ears lead to a weighted spatial percept.

W21: MULTI-STUDY EVALUATION OF OBJECTIVE MEASURES THAT PREDICT COCHLEAR IMPLANT SPEECH INTELLIGIBILITY

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Several objective measures have been proposed for the prediction of speech intelligibility in cochlear implant recipients. The majority of these objective measures have been evaluated with either data from vocoder simulations tested on normal-hearing listeners or with data from a single cochlear implant study. Therefore, it is unclear how well the predictive power of these measures generalize. In this study, an evaluation of existing objective measures is presented using data from approximately 30,000 different cochlear implant stimulation sequences, which were collected in connection to multiple independent clinical studies from three different research centers and approximately 50 different cochlear implant recipients. All studies in the evaluation employed monaural cochlear implant stimulation and used sentence-level testing of speech intelligibility in noise. The studies primarily investigated the impact of distortions that are introduced by noise or noise reduction algorithms. A variety of objective measures were considered, including the speech transmission index (STI), the normalized covariance metric (NCM), the short-time objective intelligibility measure (STOI), and the hit rate minus false alarm (H-FA). In the calculation of each metric, either sentences reconstructed from the stimulation sequences or the stimulation sequences themselves were used. This evaluation quantifies the relative predictive abilities of existing objective measures and provides a basis for further development of objective measures accounting for cochlear implant speech intelligibility.

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W22a: CCI-MOBILE PLATFORM FOR COMBINED ELECTRIC AND ACOUSTIC STIMULATION

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A large population of hearing impaired listeners are fitted with combinations of hearing-aid(s) (HA) and cochlear implant(s) (CI) devices. There exists compelling evidence to support benefits obtained by bimodal hearing (i.e., CI in one ear and HA in the contralateral ear) for improved speech recognition in quiet and in noise, as well as for lateralization and localization issues [1, 2]. Furthermore, individuals with residual hearing who use hybrid implants are able to receive a combined benefit of electric and acoustic stimulation (EAS) (i.e., CI and HA in the same ear with partially inserted electrode array). Scientific studies support the preservation of acoustic hearing, as combined EAS aids speech understanding in complex listening environments as well as in identification of musical structure and content [3, 4]. As medical interventions for hearing loss have evolved, the complexity of sound processing solutions for assistive hearing devices have also increased. This has created unique opportunities for researchers to design and perform complex experiments that involve combinations of electric and acoustic stimulation modalities. However, there is a severe lack of research tools and systems capable of supporting the growing needs of the research community. In our previous work, we developed a mobile research interface (CCi-MOBILE) for studies involving CI devices alone. In the present work, we have extended the functionality of our platform to include dual channels of synchronized acoustic stimulation in addition to the electrical stimulation. With this unique versatility, the platform can be configured to drive two hearing-aids and two cochlear implants simultaneously. Functional working of the system is as follows. The acoustic signal is first acquired from BTE units and is sampled digitally by an on-board stereo codec. The sampled signal is transmitted to the computing platform via USB-serial interface. The computing platform, which could either be a personal computer (PC) or a portable device, such as a smartphone/tablet, receives packets of stereo acoustic data, and processes them simultaneously through CI and HA sound processing strategies on a frame-by-frame basis. The processing generates electric stimulus profile for the implant and processed acoustic data for HA. The stimulus data is transmitted back to the interface board where it is streamed to CIs and acoustic transducers concurrently. Parallel architecture of the FPGA-based CCi-MOBILE platform ensures delivery of acoustic signal and electric pulses with precise timing, which ensures time-synchronized EAS.

The CCi-MOBILE research interface offers researchers excellent opportunities to explore new research paradigms in this emerging field. It should also be noted that plans are underway to make this research platform available in an open-source-like scenario to the community for research use.

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W22b: THE COCHLEAR CATHETER FOR CELL AND DRUG DELIVERY DURING COCHLEAR IMPLANTATION

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Introduction:
In order to reduce insertion trauma and growth of fibrous tissue after cochlea implantation and thus increase the chance for hearing preservation and lower impedances, local cell and drug delivery to the inner ear might be an option. Using a cochlear catheter, more apical regions of the cochlea can be provided with cells and drugs without structural harm of the cochlear microstructure.

Methods:
The Cochlear Catheter (Med-EL, Innsbruck) consists of a 20 mm long electrode-shaped silicone body with a hollow lumen and an opening at the tip to deliver fluids also into apical regions of the cochlea. Patients without relevant residual hearing (> 80dB hearing loss at 250Hz) were included in the present study and received a cochlear flushing with either diluted triamcinolone (4mg/ml; n=5) or autologous mononuclear cells derived from the bone marrow (n=3) via the cochlear catheter just prior to cochlear implantation with a Med-El Flex 28 electrode. Impedances and the slope of the eCAP amplitude growth function (AGF) were measured directly after implantation in the OR, on days 3, 10, 17 and 24 and at first fitting for the patients receiving triamcinolone. For patients receiving mononuclear cells, impedances and speech recognition were determined at different time points postoperatively. Results were compared to recipients of the same electrode without use of the catheter or steroids.

Results:
Impedances were stable until day 10 post-OP in patients that received a treatment with the cochlear catheter. Further, the impedance rose between day 10 and day 24 post-OP. First results of the eCAP AGF slopes will be presented. Within the cell therapy group, no differences in the impedances were observed when compared to the control group. Speech understanding was comparable to the other patients showing a good acceptance of autologous cell transplantation via the cochlear catheter.

Conclusions:
Steroid treatment with the cochlear catheter before implant insertion seems to have an impact on the behavior of electrode impedances. By contrast, this impact was not observed for the patients receiving bone marrow-derived mononuclear cells or by patients with no supplemental treatment.

W23a: TOWARDS A BIO-INSPIRED CODING STRATEGY FOR COCHLEAR IMPLANTS

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Temporal response properties of auditory nerve fibers (ANFs) in addition to the spatial spread of neural excitation can impose limitations for electrical stimulation of cochlear implants (CIs) (Boulet et al., 2016; Cohen, 2009; Undurraga et al., 2012). Thus, a coding strategy that takes into consideration such neurophysiological characteristics would be more effective for the selection of channels with highest energy content. The aim of this study is firstly to extract these characteristics such as refractory recovery, facilitation (also referred to as temporal summation) and spatial spread of the electric field (spread of excitation) with neural response telemetry (NRT) recordings and then integrate the extracted characteristics in a bio-inspired coding strategy for CIs. Only the results of the first part of the study will be discussed here.
CI users implanted with Nucleus™ implants took part in the study and individual amplitude growth functions were first recorded for test electrodes (apical, middle, and basal) with a masker offset (the current level of the masker relative to the probe) of +10CL. Electrically evoked compound action potentials (ECAPs) for refractory recovery and facilitation were then measured with the method described by Miller et al. (Miller et al., 2000). The probe CL for each test electrode varied between visually detected threshold of ECAP (vT-ECAP) to the current level that yields 100 µV response amplitude. The masker probe intervals (MPIs) varied between 13 µs to 6000 µs and the masker offset was decreased in steps of 5 CL from +10 to -15 CL. Spread of excitation was measured for the test electrodes with the standard “forward masking” artefact cancellation technique and 0 CL masker offset.

Although the facilitation effect has been reported in CI recipients, ECAP measurements at short MPIs have not been systematically recorded to define this effect. Thus, a function for the facilitation effect will be fitted to data collected from all the CI participants and the results will be discussed. The facilitation effect is expected to be more pronounced for lower CLs (e.g. at or below vT-ECAP) and shorter MPIs. As mentioned before, the facilitation effect together with other ANFs’ neurophysiological characteristics can eventually be used for better selection of electrodes in CI coding strategies.

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W23b: AN ALGORITHM FOR ENHANCEMENT OF NATURALLY-OCCURRING LEVEL DIFFERENCES IN BILATERAL COCHLEAR IMPLANTS

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To a large extent the prevalence of binaural hearing in bilateral cochlear implant (BCI) listeners depends on the optimal processing of interaural level differences (ILDs) and faithful access to robust interaural time differences (ITDs). Access to both types of spatial cues would ideally allow individuals wearing BCIs to understand and localize speech well, even in complex auditory scenes (e.g., noisy and reverberant environments). In practice, clinical sound processors only transmit envelope cues through a small number of channels and discard acoustic temporal fine structure information impairing access to ITDs. Moreover, the saliency of ILD information transmitted by the sound processors is reduced due to acoustics (e.g., reverberation) and differential processing as the processors compress the dynamic range and adjust gain control independently across the two implanted ears. Confronted with no access to ITDs and limited access to moderately useful ILDs, BCI listeners tend to benefit exclusively from the head-shadow effect, may only occasionally experience spatial release from masking, and exhibit little to almost no spatial benefits derived from binaural unmasking.

In this study, we undertake a fresh new approach towards mitigating the impoverished delivery of binaural level cues imparted by clinical processors by imposing a frequency transformation on the head-related transfer functions (HRTFs), which produces interaurally magnified level differences across the two ears. Perceptually, it is hypothesized that this type of processing can lead to an increase in discriminability between two competing sound sources and subsequently enhanced gains due to spatial release from masking in a typical speech-in-noise task. To evaluate the overall clinical potential of this strategy, the target speech stimuli originating from the front and spoken by a male talker were delivered in the presence of a two-talker babble emanating from the right hemifield under spatial conditions with a fixed and relatively small angular separation. Under these spatial locations, four BCI and ten NH listeners were asked to identify the sentences spoken by the male target talker in the presence of the distractor. Stimuli were rendered using either unprocessed (natural) or processed (magnified) head related transfer functions and presented via direct line inputs (BCI) or headphones (NH). NH listeners were tested with eight-channel noise-vocoded signals. Speech reception thresholds (SRTs) in both groups of listeners were measured for each combination of spatial location and processing condition. The benefit due to spatial release from masking (SRM) was calculated by subtracting the SRTs obtained in the spatially separated conditions from the SRTs observed in the co-located configurations.

For both the BCI listeners and NH listeners tested, the mean benefit due to SRM when presented with stimuli containing natural (unprocessed) ILDs was found to be only marginally greater than zero in all spatial locations tested. In contrast, both NH and BCI listeners benefited substantially when the stimuli were rendered using magnified (processed) ILDs. A consistently large spatial release advantage ranging between 6-11 dB was observed across the various locations tested in both groups of listeners. These findings suggest that the ability to hear speech in noise is expected to increase as the proposed interaural magnification aids in better spatial segregation of speech from background noise. Still, additional experiments are needed to determine to what extent this imposed nonlinear remapping of the extracted spatial cues is generalizable and amenable to implementation in commercially available bilateral clinical processors.

W24a: IMPACT OF REVERBERATION TIME ON SPEECH PERCEPTION IN NOISE IN COCHLEAR IMPLANT USERS

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Introduction: Recipients of cochlear implants (CIs) oftentimes suffer from degraded speech perception in noise compared with normal hearing subjects. In closed rooms, reverberation can cause an additional detrimental effect. Speech perception in everyday reverberant conditions is hard to assess in laboratory settings since the reflections are spatially distributed. The aim of the study was to investigate speech perception in CI recipients using a loudspeaker-based room simulation setup.

Method: 38 subjects with CIs divided in four subgroups and a control group of 17 nor-mal hearing participants (NH) took part in the study. CI subgroups were (1) bimodal (BM, n=10), (2) bilateral CI (BL, n=14), (3) electric-acoustic stimulation bimodal (EAS-BIM, n=8) and (4) electric-acoustic stimulation bilateral (EAS-BIL, n=6). An auditorium was chosen as a typical reverberant listening condition. Based on reflectograms calcu-lated with the room simulation software ODEON, each early reflection (up to 100 ms) was presented with correct frequency-dependent amplitude and delay to the nearest loudspeaker of a horizontal 128 loudspeaker array according to the calculated azimuth. For the diffuse reverberation a stochastic model was used. Speech reception thresholds (SRTs) in noise were assessed with the Oldenburg sentence test in free-field conditions and for reverberation times of 350 ms and 500 ms. Direct sound of speech (S) and noise (N) were either both presented from 0° (S0N0) or spatially separated (S0N60).

Results: In all test conditions, mean SRTs in the control group were 4.1-5 dB lower than in all CI groups ($p<0.001$). No significant differences between CI subgroups were found. The EAS-BIL group showed a tendency of better SRTs than all other CI groups. SRTs increased with increasing reverberation time between 2-3 dB in the S0N0 condi-tion and up to 8 dB in the S0N60 condition. Only the control group showed spatial re-lease from masking in the reverberant conditions.

Discussion: A detrimental effect of moderate reverberation times was found in all sub-ject groups. The relative effect of reverberation on speech perception in CI users was in the same range as for normal hearing participants. However, the negative impact in everyday life is expected to be higher for CI users since their free-field baseline was up to 5 dB worse and due to potentially higher reverberation times in real room acoustics. In following studies, SRTs for modulated noise and possible beneficial effect of EAS in reverberation will be investigated.

W24b: PROSPECTIVE MULTICENTER EVALUATION OF A PARTIALLY AUTOMATED CI FITTING METHOD COMPARED TO THE CLINICALLY ESTABLISHED PROCEDURE

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Background: Adjusting the sound processor parameters to the individual needs of a CI recipient is time-consuming and challenging, especially with children. In an effort to provide more standardization in the fitting procedure and to enable less experienced audiologists to fit the sound processor more efficiently, a new tool, NFS (Nucleus Fitting Software), was introduced. The proposed method is based on automatic measurements of an ECAP threshold profile and behavioral estimates of the overall loudness and sound equalization. This study aimed to evaluate whether NFS provides CI recipients with the same hearing performance compared to the fitting procedures used in clinical routine.

Materials and Methods: A prospective, randomized, double-blind study was initiated at three CI centers. Two NFS modifications, NFS-5 and NFS-22, with either 5 or 22 postoperatively measured ECAP thresholds were compared with the established clinical routine procedure. 48 newly unilaterally implanted, postlingually deaf adults were enrolled and distributed among six randomization groups. The fitting procedures were permuted within each group in an ABCA sequence. Seven evaluation sessions over a 15-months period per patient allowed at least a three-month acclimatization to the different maps. Hearing performance was assessed by aided thresholds, speech intelligibility tests and questionnaires.

Results: Four participants were excluded from the analysis because of clinic-related protocol deviations. Three patients left the study prematurely for private reasons and in five patients the NFS procedure had to be terminated because of clinical complications. The interim results for speech intelligibility did not reveal a significant treatment effect of the three fitting methods. The NFS-5 method may lead in some cases to inferior results.

Conclusion: For most participants the partially automated CI fitting method yielded hearing outcomes comparable to the clinically established procedures.

W25a: THE DESIGN, FABRICATION, AND IN VITRO EXPERIMENTS OF A MEMS THIN FILM COCHLEAR ELECTRODE ARRAY

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Contemporary cochlear implants commonly deploy wire-bundled electrode array designs that not only are labor intensive but also limit the number of electrodes. Here we developed a biocompatible MEMS (Micro-electromechanical Systems) thin film electrode array that potentially enables automated batch fabrication and overcomes the electrode density limitation. The electrode arrays are of 8 mm or 16 mm in length. The basal and apical width of electrode arrays are 1 mm and 0.7 mm respectively. The diameter of the exposed circular electrode is 80 µm. The minimum electrode interval is 150 µm. The minimum width and gap of interconnecting wires are both 15 µm. The maximum electrode density is 16 sites/ 8mm. The whole electrode array has a thickness of 6 µm and the electrode is protruded in shape with a height of 1 µm above the surface of the electrode array. The electrode arrays employ Parylene C, which is biocompatible, as the substrate and insulating layer. Titanium/Platinum is used as the conducting material. Due to the small thickness of the electrode array and the great flexibility of Parylene C, the whole device is flexible. It can be easily attached to a preshaped Polymide tape to get enough stiffness for implantation into the scala tympani.

Fabrication starts with a sputtered Aluminum film as the sacrificial layer. Then positive photoresist is coated and patterned as the mould of the electrode. Parylene C and Pt/Ti are deposited as the substrate and conducting layer. Electrodes and wires are patterned with a lift-off process, followed by the deposition of the Parylene C insulating layer. The electrode array is finally etched with oxygen plasma to define the contour shape and to expose the electrode pads.

Several in vitro experiments have been conducted with the fabricated devices using 0.01 mol/L phosphate buffer saline (1×PBS) to emulate the cochlear perilymph environment. The electrode array in PBS was driven with a current source. Voltage across the current source was measured with an oscilloscope. Different input signals including sinusoid and pulse train were tested. The results show that all of the electrodes are electrically conducting without short circuit failure between them. Typically, in monopolar mode, with 1 kHz sinusoid signal input, the impedance of one electrode channel is 7.6 to 13.2 kΩ.

In this study, we showed that the fabricated MEMS thin film cochlear electrode arrays have desired characteristics for further in vivo experiments. This approach is promising in increasing electrode density and simplifying fabrication process.

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THURSDAY POSTER ABSTRACTS

Th01a: COMPUTER ASSISTED SELECTION OF ELECTRODE DEACTIVATION IN CI USERS

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Channel interaction is widely recognized as one of the main bottlenecks that limit performance in CI users. A body of research has developed to investigate the reduction in channel interaction resulting from selective deactivation of stimulating electrodes. This approach is necessarily selective because it is practically impossible to try all combinations of stimulating electrodes. For example, mathematically speaking, the number of ways to provide a subset of 16 electrodes (from only one electrode up to and including all 16) is 216 = 65536 possible combinations. Instead, the more principled approach has been to measure a perceptual or anatomical feature associated with each electrode and to deactivate the electrodes that are deemed “poorer” according to some definition. Methods for defining "poorer" electrodes have included pitch discrimination, masked AM modulation detection thresholds, tripolar or monopolar detection thresholds, and electrode location with respect to the spiral ganglion. Electrode deactivation based on these methods have resulted in improved speech perception outcomes in some CI users, but not others. One problem is that there is no systematic guidance as to which of the poorer electrodes, or how many of them, to deactivate for a specific CI user. Furthermore, the methods listed above do not necessarily result in the same proposed set of electrodes to remove.

In the present study, a computational modeling approach is proposed that considers both the listener’s sensory abilities associated with an electrode and how speech information is distributed across electrodes. By taking both aspects into account, the proposed approach predicts the effect of electrode deactivation on speech perception for all possible subsets of stimulating electrodes and offers an optimized subset of stimulating electrodes that can maximize speech perception for an individual CI user, specific to their sensory strengths. As a proof of concept, the model was applied to hypothetical cases of CI users with randomly generated JNDs for place of stimulation (ranging from 0.1 to 4 electrode distances for each electrode). It was found that deactivation of electrodes with poorest JNDs produced significant, but modest improvements in speech perception in comparison to the 22-electrode condition. For example, removal of the 10 poorest electrodes resulted in more improvement than removing only the 5 poorest electrodes (12% vs 5% improvement). Interestingly, model-selected deactivations resulted in even greater improvements than removal of the poorest electrodes (mean increase in vowel scores of 25% and 10%, respectively, for 10- and 5-electrode deactivation conditions).

Hence, in addition to identifying poorer-encoding electrodes, an algorithmic approach to electrode deactivation may yield more optimal user-specific benefit.

Th01b: REDEFINING THE NUMBER OF EFFECTIVE CHANNELS FOR CONTEMPORARY COCHLEAR IMPLANT LISTENERS

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The introduction of multi-channel cochlear implants was a disruptive innovation over single-channel auditory prostheses and led to the first successful cases of open-set speech recognition in the profoundly deaf. While hearing performance with a cochlear implant generally improves with increasing numbers of electrodes, previous studies show that scores on speech tests only improve up to about 8 to 10 electrodes, and increasing the number of electrodes beyond this point yields no additional gains in speech understanding. However, with technical advances in cochlear-implant designs and evolving patient demographics, today's devices and patients might successfully transmit and receive greater spectral detail than previously reported. In this study we reexamine the number of effective channels and explore how recently-implanted patients perform on speech tests while varying the number of stimulation channels.

Nucleus recipients (N=10) were tested with their clinical maps containing up to 22 channels/electrodes as well as reduced maps using only 4, 8, and 12 electrodes. These experimental maps were created using the “double channel” mapping technique available in Custom Sound, which allows for the output of multiple frequency channels to be assigned to a single electrode, with electrodes spaced evenly along the array. Frequency boundaries and total stimulation rate were held constant across maps. Speech recognition was measured using matrix sentences presented with a competing talker, while the number of active electrodes and the target-to-background ratio was varied. Subjects also took a spectro-temporal modulation detection test and the reading span test to investigate the potential role of peripheral and central factors.

Results show that, on average, the full-channel condition provided significantly better speech recognition than any of the reduced-electrode maps. However, not all subjects derived the same benefit from greater numbers of electrodes. Some subjects showed little improvement above 4 electrodes, while other subjects continued to improve up to 22 electrodes. The change in performance from 4 electrodes to all electrodes was significantly correlated with spectro-temporal resolution across subjects in the full-channel condition, while the reading span test was not associated with individual variability. These findings suggest that: 1) individual cochlear-implant users with good spectro-temporal resolution may benefit from additional information beyond that provided by the conventional notion of only 8 to 10 effective channels, and 2) technology developments aimed at improving the electrode-neural interface may yield meaningful speech perception benefits if they succeed at increasing spectro-temporal resolution.

Th02: EARLY IMPLANTATION IMPROVES VOCAL-TRACT LENGTH PERCEPTION FOR VOICE DISCRIMINATION IN ADULTS WITH PRE-LINGUAL DEAFNESS

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Tracking the voice of a specific talker of interest has high ecological importance, as it contains valuable information regarding his or her gender, physical characteristics, and affect. It is also essential for segregating talkers in a multi-talker environment, an ability found to improve speech perception in noisy conditions. Adult cochlear implant (CI) users find it extremely difficult to discriminate between talkers, as well as to identify the specific talker of interest. Recent studies suggest that CI users with postlingual deafness, who had prior acoustic experience, make only limited use of vocal-tract length (VTL) cues for gender discrimination, basing their judgement almost entirely on fundamental frequency (F0) cues. The aim of the present study was to assess the ability of prelingually deafened adult CI users, i.e. adults who had no prior acoustic experience, to use VTL cues, F0 cues, or both in order to discriminate between re-synthesized "talkers". Difference limens (DLs) were assessed in 18 CI adult users using an oddball procedure with two-down one-up adaptive tracking procedure. Half of the CI users (n=9) were "early-implanted" (up to 4 years of age) and the other half were "late-implanted" (6 years of age and older). Performance was compared to that of normal hearing (NH) individuals (n=9), listening either to degraded stimuli, using a noise-excited channel vocoder, or non-degraded stimuli. Results show that: (a) there was a strong positive association between age of implantation and the ability to exploit VTL cues, but not F0 cues for voice discrimination; (b) VTL perception was positively associated with speech recognition scores in quiet and in noise, but not with frequency discrimination of pure tones or cognitive test scores. The results suggest that early implantation may facilitate high-level reorganization of spectral representation of sound, and/or boost the construction of associations between the acoustic stimuli and the vocal tract characteristics of the speaker. Thus, it can enable CI users to utilize limited spectral resolution, maintaining a relatively high level of auditory competence in adulthood.

Th03a: COCHLEA-IMPLANTS IN THE ELDERLY

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Introduction
About 9% of the general german population is affected by hearing loss up to high-grade or functional anacousia. 54% of the population older than 70 years report a subjective impairment of their hearing. Cochlear Implants (CI) are increasingly used to treat high-grade hearing loss, whether congenital or aquired. Nevertheless, there is little information regarding hearing rehabilitation outcomes in elderly patients with CI.

Material and methods
Our collective comprised 43 patients that have been implanted and were older than 80 years at the time of analysis. Speech reception for monosyllables and numbers was investigated using the Freiburg speech audiometry tests. Patients who had received their implants less than three months ago or had insufficient active knowledge of the german language were excluded from this study.

Results
Of the 42 patients 17 were female and 25 male. Their average experience with the CI was 4,2 years (median: 3,8 years). The age of this group was 84 +/- 3,2 years (mean +/- SD) (median: 82,8 years). The average of the age at the first fitting was 78,5 +/- 5,9 years (mean +/- SD) (median: 79 years). The average speech perception for monosyllables preoperatively was 11,9% (median: 0%). Postoperatively, the patients had an average speech recognition score of 56,4% (median: 60%).

Conclusion
In comparison, the postoperative speech recognition scores increased significantly to the preoperative scores. Our results show that a considerable increase in speech discrimination can also be achieved in patients older than 80 years. Further investigations concerning the potential outcome predicting parameters and the individual learning curve are needed.

Th03b: COCHLEAR IMPLANT USERS AND THEIR ABILITY TO RECALL SPEECH IN NOISY ENVIRONMENT

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This study examines the role of working memory (WM) for speech understanding in cochlear implant (CI) users. WM is essential for hearing in difficult listening situations. WM supports the reconstruction of missing fragments from the degraded incoming speech signal. WM is additionally needed for cognitive order processing of the incoming speech signal. The capacity of WM is limited, which means if speech understanding requires more resources because of an impaired auditory transduction, less resources are available for the higher order processing (for instance taking part in a discussion; Rönnberg et al. 2013).). This study examines the impact of WM load on memory performance and on processing effort required for speech understanding. A German version of the Sentence-final Word Identification and Recall test (SWIR; Ng et al. 2015) was applied. The SWIR was used to measure speech understanding WM processing and recall in CI users. In the SWIR test, sentences are presented via loudspeaker and with a 4-talker babble in the background. Participants’ task was to repeat back the final word of each sentence. In the no-recall condition, the task was only to repeat back, but in the recall condition cognitive load was systematically changed by recalling either 3 vs. 7 words. In other words, in the recall condition, either after three or seven sentences, they were asked to repeat back as many of the final words as possible. While performing the SWIR, participants’ pupil size was recorded with an eye-tracking camera. The pupil size is a measure to quantify processing effort required in speech understanding. Furthermore, the pupil diameter is associated with task load and cognitive processing and it increases with increasing task difficulty (Zekveldt et al. 2010). It was hypothesized that higher WM load (recall and 7 vs. 3 words) will lead to both lower speech understanding and lower recall performance. The pupil size is expected to increase with increasing WM load. Furthermore, the recall in itself should have an impact on the processing effort, indicated by increasing pupil size, compared to no-recall. Moreover, it was hypothesized, that within one block the increasing WM load (1st sentence to 3rd respectively 7th sentences) is represented by a gradual increase of participants’ pupil size. The first results of the CI users indicate that the German version of the SWIR works in CI users in a similar way as in hearing aid users. The results will be discussed in terms of pupil size at the conference.

Th04a: NEW PERSPECTIVES ON THE CONTRIBUTION OF MUSIC ACTIVITIES TO THE PERCEPTION OF SPEECH AND LANGUAGE DEVELOPMENT IN CHILDREN WITH CIS

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The ability to perceive prosodic sentence and word stress, and to access speech rhythm, which in part is conveyed by such stress patterns, seems to be particularly important for the development of spoken language (1). The beneficial effects are thought to be related to the role of stress in speech segmentation, in mediating attention to the speech signal, and in enhancing perception of phonemes when stress is expected, and also to oscillatory activity in the brain (2,3). That is, speech perception depends partially on neural tracking of the temporal patterns in speech at different timescales. Stress patterns are related to delta-band activity and may help in binding the information together for the final speech percept (3).

For normal-hearing (NH) children, musical activities enhance phonemic awareness and language skills in general. These findings are related to results showing that musical activities enhance perception of acoustic cues for prosodic stress and speech rhythm, and induce plastic changes in the brain (4,5). A new direction in music research is to study the role of musical rhythm in the prediction of speech stress placement, in the perception of phonemes, and in oscillatory activity in the brain. For example, because musical rhythm is more predictable than speech rhythm, musical rhythm preceding the speech signal enhances perception of those phonemes that occur at times when stress is predicted (2). Moreover, compared to adult-directed speech, more rhythmic (more predictable) infant-directed speech and music may induce changes in oscillatory activity in the brain (3), which may be highly beneficial for the development of connectivity, prediction, temporal attention and therefore, for speech perception.

Our studies of children with CIs have shown that the more the parents and children sing predictable children's songs, the better these children sing the rhythms of songs, while attention-related brain responses (P3a) for predictable changes in music (pitch, intensity, duration, timbre, pauses) are stronger and earlier (5,6). Music activities are also associated with better perception of speech in noise (7). These findings can be related to the effects of the rhythm of song on prediction and temporal attention, connectivity and oscillatory activity in the brain. Moreover, we have found that children with CIs who participate in musical activities are better at the perception of pitch, intensity, sentence and word stress than other children with CIs, while as much as 71 % of the variance in word finding (naming) skills and 48 % of the variance in verbal IQ can be explained by the perception of prosodic stress, and the musical activities of the child and those of the parents.

In this presentation, we will bind together our results and give suggestions for further studies on children with CIs from the perspectives music, brain and perception of prosody.

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Th04b: INCREASED QUALITY OF THE AUDIOVISUAL SPEECH SIGNAL REDUCES SENSITIVITY TO AUDIOVISUAL ONSET ASYNCHRONY

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We examined the behavioral and neurophysiological relationship between the quality of the visual and acoustic signal and sensitivity to audiovisual onset asynchrony (AVOA) in spoken language. Subjects watched AV videos of naturally spoken tri-syllabic nonwords that varied along three dimensions: 1) asynchrony: videos were asynchronous in onsets of the visual and acoustic speech, in which the acoustic speech lagged by 250, 375 and 500 ms relative to visual speech; 2) visual fidelity: visual speech was clear or blurred; 3) acoustic fidelity: acoustic speech was noise-vocoded at 32- or 4-channels. Subjects made judgments on whether they perceived the AV speech as in-sync or out-of-sync. Results showed that subjects tolerated more AVOA (perceived in-sync more often) for smaller than larger delays, for clear than blurred visual speech and for 32- than 4-channel vocoded speech. Neurophysiologically, tolerance for AVOA along all dimensions was reflected in reduced P2 auditory evoked potential (AEP). The current findings suggest that enhanced quality of the AV signal induces the auditory and visual systems to expand their window s of integration leading to enhanced tolerance for AVOA. This process is partly mediated by reduced sensitivity to acoustic onsets at the auditory cortex, i.e. reduced P2 AEP.

Th05: SPECTRO-TEMPORAL TRANSMISSION OF SPEECH FORMANTS IN A NEW COCHLEAR IMPLANT SOUND CODING STRATEGY – MEASUREMENTS AND PREDICTIONS OF VOWEL PERCEPTION

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Current cochlea implant (CI) speech coding strategies transmit speech formant information only via the place of the stimulated electrode. In acoustic hearing, however, formant frequencies are additionally coded by groups of adjacent auditory nerves, firing coherently with temporal rates corresponding to formant frequencies. This study presents a novel CI coding strategy ("Formant Locking (FL)-strategy") that varies stimulation rates in relation to extracted fundamental and formant frequencies for voiced sounds. This variation is done in addition to the classical place coding of spectral information.

Simulated auditory nerve activity resulting from electric stimulation shows that the FL-strategy triggers coherent spike rates in groups of adjacent fibers whose frequencies are related to the formant frequencies, similar as in normal hearing. In contrast, the standard continuous interleaved sampling (CIS) strategy shows greatly different simulated auditory nerve activity, which does not reflect this fine-grained temporal code. An automatic speech recognition (ASR) system discriminating five different vowels embedded in consonants showed 25% improvement of speech intelligibility of the FL-strategy compared to CIS.

Vowel recognition was then measured in seven MED-EL users via direct (acute) stimulation of their electrode array both with CIS and the FL-strategy. The FL-strategy resulted in significantly increased scores of the vowels /u/ and /i/. However, at the same time, a decrease in scores for /o/ and /e/ occurred, such that the overall improvement was small. A good agreement of vowel confusion patterns between the ASR predictions and the measurements for the FL-strategy was observed. Especially those CI listeners benefitted from the additional formant cues transmitted by the FL- strategy, who have access to good acoustic hearing via their contralateral ear and thus are somewhat used to near-normal auditory coding.

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Th06a: PROCESSING SPOKEN WORDS WITH AND WITHOUT SEMANTIC CONTEXT: EFFECTS OF SPECTRAL DEGRADATION AND COCHLEAR IMPLANTATION

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Purpose: Two aims underlie this study. In Experiment 1, the purpose was to examine lexical influences on spoken word recognition in post-lingually deafened adult cochlear implant (CI) users and understand the role that spectro-temporal degradation play in processing spoken words, using a gated word recognition paradigm. In Experiment 2, the aim was to evaluate the influences of semantic context on the gated words presented in high and low predictability sentences (HP, LP) by CI users and understand the effects of spectro-temporal degradation.

Method: Twelve post-lingually deafened CI users and twenty-four age-matched Normal hearing (NH) adults participated in both experiments. In Experiment 1, the CI users listened to unprocessed (full spectrum) speech and NH individuals listened to full spectrum or vocoder-processed speech. The minimum amount of initial speech information required to recognize spoken words (Isolation Points, IPs) were determined for both groups who listened to gated CNC lexically controlled words. In Experiment 2, R-SPIN sentences were chosen based on their lexical properties of the final words, and IPs were determined for the CI group for unprocessed speech and the NH group for unprocessed or vocoded stimuli.

Results: In Experiment 1, the results showed that IPs were delayed in CI users and in NH listeners who listened to vocoder-processed stimuli, compared to the NH group who listened to unprocessed stimuli. In Experiment 2, the results indicated that listeners from both groups benefited from contextual cues despite the spectral degradation but performed poorly on LP sentences.

Conclusions: CI users clearly demonstrated significant problems in processing spoken words. This difficulty accessing their mental lexicon could be primarily due to poor signal fidelity. However, CI users could overcome these challenges if contextual cues were available, at least in quiet listening situations. Findings from these experiments suggested that the top-down mechanisms have some limitations, and when the speech input is severely degraded and/or highly ambiguous, these mechanisms fail to operate.

Th06b: SPECTRAL RESOLUTION AND SPEECH CONTEXT EFFECTS IN COCHLEAR-IMPLANT USERS

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The perceived identity of a speech sound may change as a function of the long-term spectrum of preceding speech sounds even though its acoustics remain constant. These phenomena, termed speech context effects, have been demonstrated in normal-hearing (NH) listeners in many previous studies by showing that the categorization of speech sounds along continua, such as /ba/-/ga/, /i/-/u/, and /t/-/k/, is shifted by the spectral context of a preceding sentence. Speech context effects are spectrally contrastive so that if low frequency acoustic energy is present in the preceding sound, listeners will likely to categorize subsequent target sound as possessing higher frequency energy, and vice versa. Such context-dependent responses to speech sounds may reflect the ability of our auditory system to extract reliable spectral characterstics of surrounding sounds in order to compensate for the voice characteristics of different speakers, or the spectral colorations caused by different listening environments, to maintain perceptual constancy.

Speech context effects have not been studied in cochlear implant users, but there is evidence from studies on auditory enhancement, another type of context effect, that enhancement effects are absent or reduced in CI users and hearing-impaired listeners, probably due to poor spectral resolution. Such spectrum-related context effects are one aspect of perception that could in principle be manipulated and restored through signal processing in the CI. Thus, a better understanding of speech context effects in CI users may help in developing techniques to compensate for perceptual differences between CI users and NH listeners. In this study, we investigated the speech context effect on the phoneme categorization boundary between /I/ as in bit, and /ɛ/ as in bet, in both CI users and NH listeners through a 16-channel tone-excited envelope vocoder. In addition for NH listeners, 12 dB/oct filter slopes were used to simulate current spread in order to futher examine the effect of limited spectral resolution.

Our preliminary data show that CI users had shallower psychometric functions in the vowel categorization task but they showed consistent speech context effects that were larger than those found with NH listeners. The size of speech context effect in NH listeners through the 16-channel vocoder without any spread was comparable to that without vocoding. Adding current spread made the psychometric function shallower and increased the size of context effect. Our results suggest that poor spectral resolution not only reduces the availability of important spectral cues for speech perception but can also exaggerate the effects of spectral compensation, which could in turn introduce more ambiguity when distinguishing between different speech sounds.

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Th07a: THE IMPACT OF PERCEPTUAL CUE WEIGHTING STRATEGY ON SPEECH PERCEPTION AND LISTENING EFFORT FOR CI USERS

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This ongoing study investigates the impact of acoustic cue weighting strategies for cochlear implant (CI) users on their sentence recognition and listening effort. Previous studies suggest that CI users who weight the spectral cues more than the temporal cues have better word recognition. Our recent study testing normal hearing (NH) listeners using CI acoustic simulations also shows that listeners with more weighting on the spectral cue are more efficient in using cognitive effort for speech recognition than listeners weighting more on the temporal cue. Therefore, it is hypothesized that heavier perceptual weighting of the spectral cue in CI users would predict better sentence recognition performance and less listening effort.

7 CI users were recruited. They were first tested with sentences in quiet in order to determine their maximum performance level. Following that, adaptive procedures were used to determine Speech Reception Thresholds (SRTs) for sentences in speech-shaped noise, to obtain 50% of their performance level in quiet. They were then tested with sentences fixed at this signal-to-noise ratio (SNR) and both their cognitive load (assessed through pupillometry) and performance measured. Listeners' relative perceptual weighting on duration and spectral cues were measured with a tense and lax vowel categorization task in quiet. Their auditory sensitivity to spectral and duration cues was measured using a three-alternative forced-choice (3AFC) test procedure. To look at how much between-individual variance in sentence recognition and listening effort could be explained by individual differences in acoustic cue weighting strategy and auditory sensitivity, a mixed effect logistic regression model will be fitted in order to predict performance level in the fixed SNR test, with listeners' pupil responses, acoustic cue weighting strategies and auditory sensitivities as predictors.

Findings from the current experiment will extend the line of studies investigating factors contributing to the great variability in speech perception and listening effort among CI users. It will also highlight the importance of looking at the efficiency of using cognitive resources for speech perception.

Th07b: EXTENDING FEATURE INFORMATION TRANSMISSION ANALYSIS (FITA): NEW APPROACHES AND APPLICATIONS

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The features that underlie human speech perception have often been studied to advance the scientific understanding of speech perception and to aid in the development of hearing prostheses. Miller and Nicely (1955, JASA vol. 27 pp. 338-352) developed the feature information transmission analysis (FITA) technique to obtain quantitative estimates of the amounts of information conveyed by individual features in a closed set phoneme identification task. The work that will be presented advances and extends the FITA technique in four directions.

Firstly, FITA was originally developed in the context of consonant identification, for which the perceptual features are categorical. A categorical feature is defined by how it assigns stimuli to different categories. For example, the voicing feature assigns consonants to voiced and unvoiced categories. Several problems (Oosthuizen and Hanekom, 2016, Speech Communication vol. 82 pp. 53-66) have been identified with the application of this FITA technique to continuous features, such as formant frequencies, which may assume any value within a continuous range. The extended technique, the continuous FITA, overcomes all the identified problems.

Secondly, FITA results are often difficult to interpret due to the multitude of factors that could influence the transmission of information. Generally, these factors include the stimuli selected by the researcher, the ethnicity of the speaker and listener, signal processing applied to the stimuli and any hearing impediments of the listener. If the listener is a cochlear implant (CI) user, this list expands to include CI-related listener-specific parameters, such as electrode insertion depth, number of surviving neurons, age of onset of deafness and age of implantation. A framework for the construction of experiment-specific information transmission models is presented. These models reflect the path of information flow in an experiment, aiding in experiment design and interpretation of FITA outputs. Specifically, the models help to ensure that all feature information to be investigated are present in the stimuli and to prevent a researcher from overlooking a factor that could have influenced results.

The third extension allows a researcher to compute multidimensional measures, such as the combined effect of multiple features, the amount of redundancy in a set of features, the amount of unique information conveyed by a single feature and the degree of completeness of a feature set. The last measure describes whether a set of features contain all information present in the stimuli or whether more features should be considered. Multidimensional features, such as formant frequency contours, can also be analysed with this extension.

Until now, FITA has been limited to the analysis from identification experiments, as it requires a confusion matrix as input. The final extension lifts this restriction, enabling researchers to measure feature information transmission for ranking, discrimination, detection, estimation and balancing experiments.
This poster is available from www.up.ac.za/bioengineering.

Th08a: PREDICTING SPEECH RECOGNITION USING THE SPEECH INTELLIGIBILITY INDEX (SII) FOR COCHLEAR IMPLANT USERS AND LISTENERS WITH NORMAL HEARING

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Although the AzBio is well known, has effective standardization data available, and was chosen as a gold standard for cochlear implant (CI) evaluation, no attempt has been made to derive a Frequency Importance Function (FIF) for its stimuli. In this study (FIFs) were first derived for AzBio sentence lists using listeners with normal hearing. After the FIFs were established, the Speech Intelligibility Index (SII) and transfer functions (TFs) were determined for listeners who use cochlear implants (CIs) using the obtained FIFs. Traditional procedures described in studies by Studebaker and Sherbecoe (1991) were applied for these purposes. A total of 36 participants (21 listeners with normal hearing and 15 CI users) participated. In Phase 1, participants with normal hearing listened to AzBio sentences that were high- and low-pass filtered under speech-spectrum shaped noise at various signal-to-noise ratios (SNRs). A curve bisectional method (Studebaker & Sherbecoe, 1991) was used to derive the FIFs for 1/3 octave frequencies. The obtained FIFs were used to determine the SII in CI listeners (Phase 2). The TF curves were drawn to compare predicted scores from the SII with obtained speech recognition scores. Factors that influence the variance in correlation between predicted and obtained speech recognition (e.g., duration of CI) were investigated. Recommendations were made regarding ways to facilitate predicting speech perception for CI listeners on the basis of these data.

Th08b: A COMPARISON OF PREDICTORS OF COCHLEAR IMPLANT SPEECH INTELLIGIBILITY

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The speech intelligibility of cochlear implant (CI) recipients is conventionally measured with time-consuming sentence-in-noise tests. Metrics that predict CI intelligibility have been proposed as an alternative for evaluating and optimising CI sound processing algorithms. Recipient scores on a sentence-in-noise test, plotted as a function of the input signal-to-noise ratio (SNR), form a sigmoidal curve known as a psychometric function. Thus, the simplest predictor of scores is SNR even though this metric takes no account of CI sound processing. An improved predictor would include the capacity to predict changes in scores between conditions that have the same SNR. More generally, in the quest for improvements to CI performance, a predictor would be able to predict the Speech Recognition Threshold (SRT), or the SNR at which 50% of words in a sentence were understood, in response to changes to sound processing strategies and algorithms.

The Short-Term Objective Intelligibility (STOI) metric (Taal et al. 2011) can measure the audio quality at the input to a CI sound processor, and has been used in predictions of CI intelligibility with noise reduction pre-processing algorithms (Falk et al. 2015). To evaluate sound processing changes occurring after the CI filter bank, a vocoder was applied to the CI sound processor output, and STOI calculated for the reconstructed audio signal (VSTOI metric). The Output Signal-to-Noise Ratio (OSNR) metric (Khing et al. 2013) first calculates the gains that are applied by the sound processor to the combined speech and noise. Those gains are then used to process speech and noise separately and determine the perceived SNR at the CI sound processor output. The present study compared the predictions of STOI, VSTOI and OSNR metrics on three existing CI data sets.

Data set 1 (Hu et al. 2015) used a fixed speech presentation level of 65 dB SPL, with an adaptive SRT procedure. STOI, VSTOI, and OSNR were equivalent to SNR in their prediction of SRT.

Data set 2 (Dawson et al. 2011) also used an adaptive SRT procedure with fixed presentation level. STOI and OSNR gave equally good predictions of the differences in scores between city noise, party noise, and stationary speech-weighted noise. STOI and OSNR were better predictors than VSTOI.

Data set 3 (Khing et al 2013) varied the presentation level from 55 to 89 dB SPL, with two fixed SNRs (10 and 20 dB) and two AGC types. As STOI considers envelope correlation it was ineffective in predicting the large change in scores as presentation level varied. OSNR was a better predictor than VSTOI of the changes in scores with presentation level and AGC type.

Overall, OSNR was the most accurate predictor of CI recipient scores across these three data sets.

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Th09a: IMPACT OF ROOM ACOUSTIC PARAMETERS ON SPEECH AN MUSIC PERCEPTION WITH COCHLEAR IMPLANTS

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Besides numerous other factors, listening experience with cochlear implants is substantially impaired by room acoustics. Even for persons without hearing impairment, the perception of auditory scenes, e.g., concerning speech intelligibility, acoustic quality or audibility, is considerably influenced by room acoustics (Meyer 2004; Zahorik & Brandewie 2016). For CI users, complex listening environments are usually associated with heavily losses (Iglehart 2016; Kokkinakis & Loizou 2011; Roy et al. 2015).

The aim of the present study is to determine room acoustic criteria that particularly influence audability and speech intelligibility for CI users. Therefore, speech material of the Oldenburg Sentence Test (Oldenburger Satztest, OLSA) as well as basic music material (major and minor triads in different positions) were auralized using the software Auratorium. The constructed rooms for speech stimuli were based on the standard DIN 18041:2016-03 about acoustic quality in rooms, the binding standard referred to by room acoustic consultants in Germany, including specifications for 'inclusive applications' in schools. For the music perception tests, two typical concert halls of different sizes were modeled.

The auralized test stimuli were unilaterally presented to 10 CI users via their auxiliary input as well as to 18 participants with typical hearing via headphones (control group). Acoustic quality was evaluated using modified MUSHRA-tests (Schoeffler et al. 2016), and a discrimination test consisting of paired comparison and multiple choice tasks. A strong preference of small source to listener distances by CI users was found, but no significant preference of room acoustic attenuation exceeding the recommendation for inclusive applications in schools. The analyses of the energy-time-structures suggest that a dense concentration of early reflections makes a beneficial impact on CI listeners pleasantness ratings. Music materials were distinguished more consistently without any room acoustic impact, while no significant difference was observed between different room sizes and chord positions.

Th09b: EFFECT OF REVERBERATION ON SPEECH INTELLIGIBILITY IN COCHLEAR IMPLANT RECIPIENTS CONSIDERING REALISTIC SOUND ENVIRONMENTS

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The impact of room reverberation on speech intelligibility in cochlear implant (CI) recipients is not very well understood. Currently, results in the laboratory show a more detrimental effect than recipients experience in their daily life. The goal of this study is to further investigate the reverberant conditions in which CI recipients experience difficulties in understanding speech using a virtual sound environment based on a three-dimensional array of loudspeakers. Sentence recall was measured in eight unilateral CI recipients in twelve different reverberation conditions (four acoustically distinct rooms with reverberation times ranging from 0.4s to 2.2s, and three different talker-listener distances). For each of these conditions, an additional noise condition was incorporated in which four pairs of talkers were placed around the listener having one-on-one conversations. In all conditions, the speech level was fixed at 60 dBSPL and, where applicable, the noise level was adjusted to provide an SNR that was 3dB above the recipient's individual speech reception threshold obtained in anechoic conditions. Evaluation of the results show that the effective SNR (SNRe) appears to be a good indicator of unilateral CI speech intelligibility performance in rooms.

Th10a: THE ROLE OF SPECTRAL RESOLUTION IN COCHLEAR IMPLANT PROCESSING UNDER COCKTAIL-PARTY SCENARIOS

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While speech intelligibility in quiet is good for many cochlear-implant (CI) users for everyday communication, understanding speech in the presence of two or more simultaneous talkers poses challenges even for the best CI users. One possible cause of this limitation is the suboptimal representation of vocal cues, such as the fundamental frequency (F0), and the vocal tract length (VTL) cue, delivered by the implant. Previous data have shown that CI users only rely on F0 cues to identify a speaker's gender, as opposed to NH listeners who utilize both F0 and VTL cues (Fuller et al., 2014). Since the VTL cues rely more heavily on the spectral dimension of the speech signal, the possibility of manipulating spectral resolution (SR) in the implant in terms of its effect on vocal cue perception and speech-on-speech (SOS) intelligibility was investigated in this study from two different perspectives: (i) from the front-end processing side (Experiment 1), and (ii) from the electrode stimulation pattern side (Experiment 2).

In Exp. 1, the signals' SR was enhanced at the front-end processing pathway by activating the Spectral Contrast Enhancement algorithm (SCE) (Nogueira, Rode, & Buechner, 2016). This setting was compared to standard ACE in 13 CI users with Cochlear devices. In Exp. 2, the SR was manipulated by specifying the electrode stimulation pattern in 11 Advanced Bionics CI users. Three such patterns were used: Sequential stimulation (2 adjacent electrodes were simultaneously stimulated at a time, yielding the highest SR condition), Paired stimulation (4 simultaneous electrodes), and Triplet stimulation (6 simultaneous electrodes; lowest SR). In both experiments, F0 and VTL just-noticeable differences (JNDs) (Task 1) and SOS intelligibility (Task 2) were measured for each stimulation strategy (ACE vs. SCE, and Sequential vs. Paired vs. Triplet). In Task 2, four different maskers were used: same female, male voice obtained by manipulating both F0 and VTL of the original female speaker, only an F0 manipulation (male-F0), and only a VTL manipulation (male-VTL). JNDs were only measured for the male, male-F0, and male-VTL voices.

When SR was enhanced at the front-end processing (Exp. 1), no significant improvements in JNDs for either F0 or VTL (Task 1) could be observed. However for Task 2, a significant albeit small improvement in SOS intelligibility scores was manifest as a general effect of strategy, specifically when the masker was the male-VTL voice, but not when it was male-F0. This suggests that improvements from SCE may be too small to be captured by the JND task. On the other hand, when SR was reduced at the electrode stimulation side in Exp. 2 (from Sequential to Triplet and from Paired to Triplet stimulation, but not from Sequential to Paired), a significant deterioration in performance was seen for both Tasks 1 and 2, with no significant interaction effects between voice dimension and stimulation pattern. The lack of such an interaction suggests that degradations in performance for both tasks are persistent across the vocal dimensions (F0 and VTL) manipulated in this experiment. This implies that the electrode stimulation pattern may be affecting more than just spectrally related cues.

Taken together, the results from both of these experiments show that the tests used in both experiments in combination with new front-end processing methods and electrode stimulation patterns may have potential to show optimization benefits for vocal cue and SOS perception in CI users.

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Th10b: COMPUTER-BASED CONNECTED TEXT TRAINING OF SPEECH PERCEPTION IN NOISE FOR COCHLEAR IMPLANT USERS

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Cochlear implant (CI) users face considerable challenges in adapting to the degraded and distorted speech information provided by their implants. Computer-based training that facilitated adaptation and improved speech perception would provide a highly cost-effective intervention. Here, we assessed an interactive method for training speech perception in noise in CI users. The method employed recordings of connected narratives divided into phrases of 4-10 words, presented against a background of 20-talker babble. After each phrase was played one or two key words were displayed along with foil words that sounded similar to words from the phrase. Selecting a foil led to the whole phrase being replayed. Once the required key words were correctly identified the phrase was displayed orthographically and replayed. The method targets both bottom-up processes involved in discrimination of phonetic contrasts, and top-down processes related to contextual and semantic knowledge. Post-lingually deafened adult CI users carried out a total of 12 hours of the training over a four week period in approximately daily sessions of 30 minutes. Training was carried out at home on tablet computers. Training alternated between a male and a female talker within each session. Signal-to-noise ratio was varied adaptively based on performance over blocks of 10 phrases. The primary outcome measure was sentence recognition in babble. Vowel and consonant identification in speech-shaped noise were also assessed, along with digit span in noise. Each speech test was carried out with male and female target talkers, different from those used in training. In order to control for procedural learning the test battery was administered three times prior to the commencement of training, at approximately weekly intervals. Performance was then assessed immediately after training and again after a further four weeks during which no training occurred. Initial data has been collected from six CI users who each had at least 9 months experience with their device. For each participant, sentence recognition in babble, assessed in terms of speech reception threshold (SRT) averaged across test talker and sentence type, improved after training by between 1-2 dB (mean improvement across participants = 1.5 dB). After a further four weeks mean SRTs had either remained the same or continued to improve (mean benefit relative to pre-training performance = 1.8 dB). Changes in performance on other tasks were less consistent across individuals, although there were small increases in mean performance after training in each case. The consistent, albeit relatively modest, increases in sentence recognition obtained in this initial data suggest that this form of computer-based training has the potential to provide a clinically viable intervention for CI users.

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Th11a: PERFORMANCE TESTING WITHOUT THE SOUND BOOTH

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Performance testing like aided thresholds and speech perception tests is routinely conducted in many cochlear implant clinics during programming sessions. They help in determining benefit with the implant, programming, rehabilitation and troubleshooting. In some countries it is also required for obtaining reimbursement or is an important part of medical records.

Performance testing is sometimes is not conducted due to the non-availability of the sound booth. When conducted a sound treated room is required; however, since fitting is not usually conducted there, the need to transfer the recipient to the sound booth causes inconvenience.

ASSE Coala and Shoe Box audiometry app are new software applications that enable performance tests without a sound booth by directly presenting the calibrated signal to the CP910 sound processor.

Methods:
Study 1: The study aimed at comparing the speech test scores with ASSE Coala and the same tests in a sound booth. Fifteen adult CI recipients were tested with CNC words @60dB in booth and also with ASSE Coala.
Study 2: Fifteen adult CI recipients were recruited for the study. The study aimed at comparing the aided thresholds with Shoebox audiometer and with an audiometer in a sound booth.

Results:
Study 1: No significant differences were found between the speech test scores in booth and ASSE Coala.
Study 2: No significant difference were found between the aided thresholds with shoe box audiometer or the standard audiometer in a sound booth.

Th11b: VOWEL PERCEPTION IN A DENSELY-POPULATED SPACE: BEHAVIORAL AND EEG INDICES OF VOWEL IDENTIFICATION BY ADULT CI LISTENERS

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This study examines two hypotheses regarding vowel recognition by postlingually-deafened adult CI recipients. The first is that vowel recognition is linked to performance in sentence perception in noise. The second is that vowel recognition is reflected in the adjuvant effect observed in cortical scalp-recorded event related potentials, whereby electrical amplitude increases in conditions where subjects attend to the stimuli. Our study was completed in Danish, a language in which there are approximately 18 vowels that populate a dense vowel space. We measured vowel identification with 7 long vowels, nested in a disyllable, which was ‘mVle’. We removed intrinsic durational cues from the vowels and spliced the same final syllable into all items. The same disyllables were also used to elicit ERP responses while subjects attended to the stimuli and when they performed a visual discrimination task. Two sentence reception thresholds were also measured with the Danish HINT, where an unmodulated background noise was adaptively varied to yield the mean signal-noise ratio at which subjects scored 50%. Sentence reception thresholds were compared with vowel recognition and component data from event-related and global-field potentials. These results are of interest to rehabilitation, where linkages between speech perceptual domains could inform task selection, and also to our understanding of the perception of the natural spectral content of speech by CI recipients.

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Th12a: SPEECH PERFORMANCE PLATEAU IN PRELINGUALLY AND POSTLINGUALLY DEAFENED ADULT COCHLEAR IMPLANT USERS

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The aim of this retrospective cohort study is to assess speech perception stability postimplantation in prelingually and postlingually deafened adult cochlear implant users separately. A second aim of this study is to identify patient related factors that influence postimplantation speech perception improvement. Our third aim is to explore the boundaries due to ceiling effects of the administered Dutch speech perception tests used for clinical follow-up of adult cochlear implantees.

The setting of this study was a single tertiary referral center. Patients were >150 prelingually and >550 postlingually deafened patients, unilaterally implanted at 18 years or older.

Hearing evaluations took place preimplantation, postimplantation after 1 month, after 3 months, after 6 months and yearly thereafter. Preimplantation, pure tone average and CVC phoneme scores were measured. Postimplantation, CVC monosyllabic word and phoneme scores, Vrije Universiteit [Plomp & Mimpen 1979, Versveld 2000] sentence and syllable scores and also continuous discourse tracking scores were measured. The sentence and continuous discourse tracking tests were measured in three presentation conditions: auditory only, auditory-visual and visual only.

Speech perception performance growth and plateau were modelled mathematically. Preimplantation pure tone average and CVC phoneme scores, duration of deafness, age at implantation, etiology of deafness, hearing aid use, gender and side of implantation were correlated with postimplantation speech perception improvement using longitudinal analyses instead of cross-sectional analyses.

Keywords: speech perception, performance plateau, plateau phase, Dutch speech perception tests, consonant vowel consonant test, sentence test, prelingual, postlingual

Th12b: EARLY SENTENCE RECOGNITION IN ADULT COCHLEAR IMPLANT USERS

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Normal listeners listening to acoustic simulations of cochlear implants (CI) can obtain sentence scores near 100% in quiet and in 10 dB SNR noise (e.g. Friesen et al, JASA 110, 2001, HINT sentences). In the current study we reduced CI users' longitudinally-collected sentence recognition scores to an underlying single variable "initial" score corresponding to the intercept of the function obtained from logarithmic regression. "Initial" score equated to an improved estimate of 1-month score and integrated the time to rise above zero score for poorer performing subjects. Our aim was to see what factors may prevent CI users from achieving vocoder-like scores.

Recognition scores (100 words/list) for French MBAA sentences presented in quiet and in noise using CI alone were collected for all adult unilateral CI users implanted in our centre over four years. Demographic, device and medical data were available for 118 subjects who met standard CI candidacy criteria: CT evaluation of the position of the electrode array was available for 96. The effects of predictive factors on initial scores were analysed using step-wise multiple linear regression. The relative importance of predictors was estimated as partial r2 obtained using the LMG method described by Grömping (J Stat Soft 17, 2006), and statistical significance tested with type II ANOVAs.

More than 60% of CI users had initial scores >50 in quiet; the aetiologies chronic otitis and autoimmune disease were associated with significantly lower scores in the long term and so these subjects were excluded from further analyses. Congenital hearing loss was associated with significantly lower initial scores in quiet (r2 0.23, p<0.001), as was longer duration of hearing loss (r2 0.12, p<0.001, -0.76 pts per year). Initial scores were negatively correlated with insertion depth (r2 0.09, p<0.001, -0.1 pts per degree) and at the same time with the proportion of the active electrode array found in scala vestibuli (r=0.14, p<0.01, coefficient -20). Similar overall results were obtained for 10 dB SNR.

Taking into account aetiology and duration of deafness, CI users with insertion depths of one turn obtained the highest early sentence recognition scores in quiet and in noise, and these were comparable to those found in the literature for normal listeners listening to 8 12 channel vocoder simulations. The results support the hypothesis that at positions in the cochlea greater than one turn the increased density of SG neurons and the lack of interscala septum may result in poor spatial selectivity and place confusions (e.g; Kalkman et al, Hear Res 315, 2014) and therefore ineffective channels (e.g. Başkent & Shannon, JASA 117, 2005). Although the "best" CI users would have place-frequency mismatches they appear to have rapidly overcome any effect this may have had on their sentence recognition within the first month.

Th13a: THE DECISION BETWEEN DIRECT ACOUSTICAL COCHLEAR STIMULATION AND COCHLEAR IMPLANTATION: A RETROSPECTIVE ANALYSIS OF RESULTS

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Introduction: The new implantable hearing system Codacs™ was designed to close the treatment gap between active middle ear implants and cochlear implants in cases of severe-to-profound mixed hearing loss. The cochlear implant (CI) is an established treatment option for profound deaf patients. Steady technical improvements increased the speech intelligibility outcome after cochlear implantation. Particularly, the electro-acoustical stimulation moved the indication criteria for cochlear implantation towards the patients with significant residual hearing. The aim of the presented study was to compare the outcome of patients with the Codacs device to patients which had a cochlear reserve within the current Codacs indication criteria but received a CI due to no alternative treatment at the time of implantation.

Methods: In a retrospective study, we compared the clinical outcome of 66 patients with the Codacs implant to 54 CI patients with comparable pre-operative bone conduction (BC) thresholds that were potential candidates for both categories of devices. Patients were grouped according their post-operative pure tone average bone conduction thresholds at 0.5, 1, 2 and 4 kHz (BC PTA). As control group CI patients with a pre-operative BC > 80 dB at 0.5, 1, 2 and 4 kHz were selected from our patient pool, independent of the manufacturer or implant type. Audiological testing was performed during routine visits three month (Codacs patients) and two years (CI patients) post-activation. Word recognition scores (WRS) were determined using the Freiburg monosyllables in quiet at 65 dB SPL speech level and speech intelligibility in noise with the HSM sentences test at 65 dB SPL (+10 dB SNR).

Results: The reason for conductive part of the combined hearing loss was otosclerosis or congenital stapes ankylosis in 39 Codacs patients. Ony one patient (3%) from this group showed a BC decrease to non-measurable thresholds leading to no benefit with the direct acoustic cochlea stimulation. Four out of 27 Codacs patients (15%) with a mobile stapes footplate became deaf after Codacs implantation. These five patients were reimplanted with a CI. In all other patients, the cochlear function was preserved and the speech intelligibility with the Codacs device was evaluated.

The gross average of WRS outcome in CI patients was 60% (mean and median, IQR: 30%) and was not dependent on the preoperative BC thresholds. Codacs patients with a BC PTA better than 60 dB HL had a significantly better WRS of 80 % mean (85% median, IQR: 20%). In Codacs patients with a BC PTA worse than 60 dB, WRS score was not significantly different from the CI patient group. The average score in the HSM sentence test at +10 dB SNR was 79% (mean, 85% median, IQR: 32%) in the whole Codacs cohort. Even the performance of Codacs patient subgroup with BC thresholds worse than 69 dB HL was on average 54% (45% median, IQR: 43%) significantly better than the speech intelligibility in noise of the entire CI patient cohort: 30% mean (25% median, IQR: 50%).

Conclusion: Our results indicate for patients with sufficient cochlear reserve that speech intelligibility in noise with the Codacs™ hearing implant is significantly better than with a CI. In quiet, the advantage of acoustical amplification was significant only for patients with pre-e operative BC PTA above 60 dB HL. The risk to induce additional hearing loss by Codacs implantation is significantly higher in patients with a mobile footplate.

Th13b: EVALUATION OF THE LOW POWER SPEECH CODING STRATEGY MP3000™

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Introduction. The clinically released MP3000™ speech coding strategy selecting 4-6 spectral components per frame has been shown to provide non-inferior speech intelligibility and 24% longer battery life compared with the ACE strategy using 8 to 10 spectral components for cochlear implant stimulation [1]. The aim of the present study was to evaluate whether further battery life savings can be achieved by a reduction of stimulation rate without compromising the speech intelligibility of the cochlear implant patients. Additionally, the influence of T-level setting on soft speech was examined.

Methods. A take home trial was conducted for the following four conditions, providing two weeks of accommodation: ACE 8 maxima with 900 pps/ch, MP3000 6 maxima with 720 pps/ch, MP3000™ 5 maxima with 720 pps/ch and MP3000 5 maxima with 500 pps/ch. Fourteen subjects using combined electric and acoustic stimulation, and 17 subjects using electrical stimulation only were tested for speech intelligibility in quiet and in noise. To investigate the effect of the T-Level setting on speech understanding, eight subjects with electrical stimulation only were tested with identical T-levels between the ACE 8 maxima, 900 pps/ch and MP3000™ 5 maxima, 720 pps/ch as well as with slightly elevated T-levels.

Results. Subjects using electrical stimulation only as well as subjects with additional acoustical stimulation showed no significant difference between ACE and MP3000 for speech perception in quiet at normal conversation levels (65 dB SPL). However, the performance significantly decreased at soft stimulation levels in conditions with identical T-levels between ACE and MP3000. An adjustment of T-levels recovered the speech intelligibility to the ACE control condition for the soft presentation levels. Speech intelligibility in noise decreased significantly by 1.3 dB SNR in subjects using electrical stimulation only and showed no significant difference in subjects with additional acoustical stimulation.

Discussion. The presented results indicate largely stable speech intelligibility as well as longer battery life with the MP3000 speech coding strategy for cochlear implant patients. Beside adjustment of the C-level profile, MP3000 fitting should also include T-levels adaptation in order to preserve speech intelligibility at soft levels. Longer adaptation time might be necessary to enhance the speech in noise performance of the low power speech coding strategy.

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Th14a: ADVANCED TONE-VOCODER SIMULATIONS OF THE EFFECT OF CURRENT SPREAD ON COCHLEAR IMPLANT USERS' SPEECH INTELLIGIBILITY - IMPLICATIONS FOR THE CHANNEL INTERLEAVING STRATEGY

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Cochlear implant (CI) spread of excitation (SOE), is commonly believed to limit CI users' speech intelligibility in noise (SpIN) beyond 8 'effective' channels (Friesen et al., 2001). Consequently, a faithful CI simulation should exhibit a lower number of effective channels as simulated SOE is increased. Oxenham and Kreft (2014) proposed a tonal vocoder that incorporates SOE as an exponential decay function. SOE distributes envelope contributions from a set number of channels to the same number of tonal carriers. Such a vocoder, however, fails to show the expected effect of SOE on the number of effective channels. SPIRAL, our proposed vocoder, decouples the reconstruction stage from the analysis stage by using a fixed, large number (>50) of ERB-spaced, random-phased tonal carriers intended to better represent the continuous spiral ganglion. This enabled manipulation of the number of activated electrodes without changing the reconstruction stage.

In a first set of experiments employing SPIRAL, the expected effect was found for digit-triplet and IEEE-sentence SRTs in speech-shaped noise. Increasing SOE significantly elevated thresholds, but a knee-point remained when no current spread was simulated. Thus, SOE is not the only limiter of effective electrodes. The spectral distribution of speech information may also contribute. Percent-correct measures with IEEE sentences reinforced the SRT findings.

A second set of experiments addressed potential weaknesses of SPIRAL: (1) SRTs were found to be independent of the number of carriers (20-160) in 20-channel simulations, suggesting that beats between tones are not detrimental to speech intelligibility; (2) a 20-channel noise-vocoded simulation, according to Bingabr et al. (2008), exhibited much higher thresholds, when SPIRAL led to SRTs that better matched CI user performance; (3) SRTs did not significantly change as the envelope modulation cut-of frequency was changed from 50 to 400 Hz, suggesting that the 50 Hz cut-off used in SPIRAL is adequate for a steady noise masker.

A third set of experiments simulated the bilateral channel-interleaving strategy, with which Tyler et al. (2010) aimed to reduce channel interaction (by disabling even channels in one ear and odd channels in the other), but found mixed outcomes in CI users. Aronoff et al. (2016) later suggested that pitch matching the ears was essential to demonstrate a spectral resolution improvement. The 20-channel (Bingabr et al.) noise vocoder failed to reveal a benefit of interleaving. 20-channel SPIRAL simulations, however, succeeded, but yielded a very modest SRT improvement (<1.5 dB) for SOE decay slopes below 32 dB/oct and with ideal frequency-place matching. 12-channel SPIRAL simulations showed no benefit with SOE and a detriment without, suggesting that NH listeners did not fully merge, at a central level, the complementary percepts from the two ears. The above findings may shed some light as to why CI users' outcomes with interleaving remain mixed.

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Th14b: "TURN AN EAR TO HEAR": HOW A MODEST HEAD ORIENTATION AWAY FROM A TARGET TALKER CAN IMPROVE COCHLEAR IMPLANT USERS' SPEECH INTELLIGIBILITY IN NOISE, EVEN IN A HIGHLY REALISTIC RESTAURANT SIMULATION

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Cochlear implant (CI) users typically struggle to follow a conversation in noisy social settings because of their limited spectral resolution and lack of access to temporal fine structure. These limitations not only elevate their speech reception thresholds (SRTs) by 10-20 dB, but also severely impede their ability to exploit cues such as dip-listening, F0 segregation or binaural unmasking. Spatial release from masking (SRM) is traditionally measured as the SRT improvement from spatially separating interfering sources from a frontal target. However, the Jelfs et al. (2011) model of SRM predicted a substantial benefit of listeners facing away from the target speech when an interferers were spatially separated (Culling et al., 2012). Testing patients in a sound-treated room for the benefit of head orientation, Grange & Culling (2016) showed how unilateral and bilateral CI users could reap a benefit of a 30° head orientation (up to 5 dB) similar to that of normal-hearing listeners, without compromising their lip-reading benefit. This was explained by better-ear listening, i.e. attending to the ear/CI acoustically favored by the head shadow. A highly realistic simulation of a restaurant was rendered possible by the acquisition of 972 impulse responses from a B&K manikin made to either face or face 30° away from a loudspeaker that emulated a talker sat across one of 18 tables. Convolution of the impulse responses with target IEEE sentences, interfering speech-shaped noise or voices, followed by presentation over headphones, enabled the virtual immersion of normal-hearing (NH) listeners in the restaurant, as though they were sat at one of six selected tables, across from the target speaker, with nine interfering noises or voices evenly distributed across other tables. Adaptive SRT measurements with this advanced simulation showed that, despite reverberation and spatial distribution of interferers, listeners could always benefit from a 30° head orientation away from directly facing the talker (by ~2 dB).

The present study repeated the Grange & Culling paradigm, additionally simulating CI listening with the SPIRAL vocoder (see separate poster/talk). Again, SRTs in the noise-interferer conditions were highly correlated with model prediction ($r = 0.86$, $p<0.001$). The benefit of head orientation (mean 1.6 dB) was again highly significant. Compared to the NH simulation, SRTs were elevated by 12 dB on average. SRTs with interfering voices were elevated by 6 dB, compared to those obtained with noise interferers (when they were similar in the NH simulation), because the CI simulation removed any access to the dip-listening, F0 segregation and binaural unmasking cues that NH listeners could use to compensate for any informational or modulation masking produced by the voice babble. Interestingly, significantly more benefit of head orientation (increased from 1.6 to 2.8 dB) was obtained with interfering voices, an interaction not found in the NH simulation. A NH listener could differentiate between the locations of the target and the close-by interfering voices. For a simulated CI user, however, spatial perception was reduced to a difference in lateralization of the competing voices, none of the interfering voices being intelligible and the babble produced sounding like babble-modulated noise. The enhanced benefit of head orientation with interfering voices suggests that the release from what is presumed to be modulation masking varies faster with speech-to-noise ratio at the better ear than the release from energetic masking by steady-state noise.

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Th15: ROLE OF COGNITIVE FACTORS IN VARIABILITY OF HEARING OUTCOMES IN COCHLEAR IMPLANT USERS AND NORMAL-HEARING LISTENERS WITH SIMULATED CURRENT SPREAD

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Anatomical, physiological, and surgical factors at the level of the auditory periphery have been studied extensively in an attempt to explain the substantial individual differences in performance between cochlear implant (CI) users. Despite these efforts, the proportion of variance in speech perception abilities accounted for by other measures, such as spectral resolution, is generally small. In this study, our aim was to determine the degree to which non-peripheral factors, unrelated to cochlear implantation, may affect performance. We tested CI users in measures of high- and low-context sentence recognition in quiet and noise, working memory, general intelligence, and spectral resolution. We compared their results with those from normal-hearing younger and older adults, who were presented with sounds via tone-excited vocoders designed to simulate the poor spectral resolution experienced by CI users. Preliminary results suggest that CI users make more use of context in sentences than do normal-hearing listeners, and that greater variance in cognitive measures within the older CI user group than within the young-adult group (often used as control subjects in CI research) may account for some of the individual differences observed in speech-based measures in CI users. Overall, the work suggests that it is important to determine the extent of more central contributions to variability when attempting to understand the effects of more peripheral factors.
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Th16: HOW CLOSE CAN WE GET TO A REAL CI WITH ACOUSTIC SIMULATION?

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Hilkhuysen and Macherey (2014) have recently proposed pulse spreading harmonic complexes (PSHCs) as an alternative acoustic carrier for channel vocoders. PSHCs have less intrinsic modulations than noise bands and may, therefore, be closer to the electrical pulse trains delivered by CIs. In the quest for a closer match to real CI we compare stimulation with CIs versus three different carriers in CI users with single-sided deafness (SSD). We also investigated the mismatch between analysis and carrier frequency that may result due to the specific position of CI electrode contacts.

Nine single-sided deaf patients with CIs performed a forced-choice comparison task. On each trial, subjects heard two intervals, each containing the same recorded sentence. In the first interval they were presented with speech processed via the CI only followed by speech processed via a six-channel vocoder simulation (presented via a single earphone Etymotic ER1). In the second interval, the same CI-processed sound was followed by a different vocoder simulation. The latter differed in the two intervals by carrier either type (PSHC, Sine or Noise) or carrier bandwidth (no mismatch - carrier bandwidth the same as input bandwidth, shifted up by ½ octave, shifted up by 1 octave). Subjects were then asked to state in which of the two intervals the sounds were most similar. Two sentences were presented, one with a male and the other with a female speaker.

For each of the six comparisons, a mixed-effect logistic regression with a random intercept-only model was fitted to the data. The analysis showed that, overall, PSHC carrier was preferred over sine and noise carriers but that there was no significant difference between the sinusoidal and noise carriers. Furthermore, no mismatch and 1/2-oct. mismatch were not different from each other but were both preferred over 1-oct. mismatch.

The analysis of individual subject’s data revealed that only one subject was not sensitive to carrier type: PSHC carriers were judged significantly more similar to CI than sinusoidal carriers by 5/8 of the remaining subjects and more similar to CI than noise carriers by 3/8. Noise carriers were judged significantly more similar to CI than sinusoidal carriers in 4/8 subjects. Sinusoidal carriers were preferred over PSHC carrier in only 1/8 subject and in 3/8 subjects over noise carriers. 5/9 subjects were not sensitive to carrier mismatch: In the remaining subjects no mismatch in vocoder bandwidth was judged significantly more similar to CI than a 1-octave upward shift by 4/4. These latter data will be interpreted with respect to electrode contact positions determined from post-operative CT scans.

These initial findings suggest that speech vocoded using the PSHC carrier type is closer in sound quality to electric hearing via a CI than conventional noise or sinusoidal carriers for most CI subjects. Yet, similarity ratings suggest that these simulations remain qualitatively different than the sound of a CI and that more research is needed to find a better match. In addition we currently estimate that some SSD CI subjects may adapt or accommodate to the mismatch in frequency-to-place mapping with respect to the spiral ganglion characteristic frequency function.

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Th17a: BIOINFORMATIC ANALYSIS OF THE HUMAN INNER EAR: UNDERSTANDING THE STATUS OF THE PERIPHERAL AUDITORY SYSTEM IN COCHLEAR IMPLANTATION

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Despite improvements in implant design, cochlear implant outcomes are still variable. Outcomes can be affected by the integrity of the peripheral auditory system or by the capacity of the central auditory system to decode input from the periphery. A variety of approaches have been proposed to determine causes of poor implant outcomes. To date these approaches have focused on physiologic measures or measurements of cognition. Despite advances in genetics, most causes of hearing loss and their impact on the function of the inner ear are poorly understood. Accessing the cochlea during implantation gives us the opportunity to understand the molecular pathology affecting the inner ear and can potentially increase our understanding of implant outcomes. We analyzed the human inner ear transcriptome and compared it to expression of proteins and micro RNAs in the perilymph obtained during surgery. Neurotrophic factor function which has been implicated in spiral ganglion health can potentially be assayed through perilymph sampling. Biomarkers in the perilymph potentially can predict the neuronal status of the inner ear and can be used to predict which patient could benefit from additional trophic factor support to optimize spiral ganglion survival and function and improve implant outcomes

Th17b: THE BIMODAL BENEFIT ON SPEECH UNDERSTANDING IN FLUCTUATING AND STATIC NOISE

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Purpose. Normal-hearing listeners have better speech understanding scores in fluctuating noise than in static noise, because they take advantage of the temporal gaps. In contrast, cochlear implant (CI) users have more difficulty understanding speech in fluctuating noise than in static noise. This is thought to be at least partly due to the fact that most CIs only process the speech envelope and discard the fine spectral cues in the signal (Nelson et al., 2003). Acoustic amplification of the other ear in bimodal listeners may complement the speech information from the CI with spectral fine detail. In this study, we compared the bimodal benefit on speech understanding in fluctuating noise and in static noise. We additionally compared the bimodal benefit when applying noise reduction algorithms, namely multichannel beamforming and a single-channel noise reduction algorithm on both the CI and hearing aid.

Methods. Unilaterally implanted subjects (n= 7) wearing a single Naida CI were contralaterally fitted with a Naida Link hearing aid. Study inclusion criteria included unaided hearing thresholds of ≤80 dB at 125 – 500 Hz in the contralateral ear, and a CVC score of ≥80% using their CI in quiet. The Dutch Matrix test (Houben et al., 2015) was used to determine SRTs. Diffuse fluctuating noise was generated by playing eight individual single-talker babble noise files (ICRA) over eight speakers. The homogeneous, diffuse static noise was similarly generated using the standard noise file that accompanies the Dutch Matrix test. The loudspeaker with the speech signal was placed at 0 degrees and the eight loudspeakers generating the noise were positioned all around the subject.

Results. Average SRT scores were substantially worse in fluctuating noise (+3 dB) than in static noise (-4 dB) in the CI-only condition using omnidirectional microphone settings. The bimodal benefit in the omnidirectional setting was larger in fluctuating noise (1 dB) than in static noise (0.5 dB), but this difference was statistically insignificant (paired t-test, P= 0.4). The bimodal benefit when using beamforming, as compared with the CI-only condition with omnidirectional microphone settings was also larger in fluctuating noise (4 dB) than in static noise (3 dB), but the difference was insignificant (P= 0.3). The addition of single-channel noise-reduction strategies on the CI and HA had no added benefit in either the omnidirectional setting or when using beamformers in fluctuating or static noise.

Conclusions. We were able to show bimodal benefits in fluctuating and static noise fields. However, the benefit in fluctuating noise was not significantly larger than in static noise. This held true under omnidirectional microphone settings, when using beamforming, and when using a single-channel noise reduction algorithm. Beamformers improved the SRT by 4 dB. Hence, we conclude that beamforming is an effective way of improving speech understanding in bimodal listeners, regardless of the type of noise. However, single-channel noise reduction proved ineffective.

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Th18a: REVEALING PHONETIC UNCERTAINTY IN COCHLEAR IMPLANT LISTENERS

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When hearing an ambiguous speech sound, listeners show a tendency to perceive it as a phoneme that would complete a real word, rather than completing a nonsense/fake word. For example, a sound that could be heard as either /g/ or /k/ is perceived as /g/ when followed by “ift” but perceived as /k/ when followed by “iss.” Because the target speech sound is acoustically identical across both environments, this effect demonstrates the influence of top-down lexical processing rather than simply bottom-up processing in speech perception (known colloquially as the “Ganong effect”). In other words, listeners demonstrate “lexical bias” that arises because of auditory uncertainty. We hypothesized that listening with a cochlear implant (CI) would render speech stimuli more ambiguous, and thus an increased tendency to rely on lexical bias should be observed. Participants with CIs or normal hearing (NH) heard three speech continua that varied by spectral cues of varying speeds, including fast (stop formant transitions), medium (fricative spectra), and slow (vowel formants). Stimuli were presented with clear spectral quality for CI listeners, or with varying amounts of spectral degradation using a noise vocoder for NH listeners. Responses were analyzed using binomial logistic regression, revealing increased lexical bias effect with cochlear implantation or degraded vocoder resolution. This test is proposed as a simple measure of how auditory uncertainty can lead to an individual’s increased reliance on top-down processing for simple phonetic categorization. It is possible that accumulation of such increased cognitive load could contribute to more effortful processing as listeners must continually resolve acoustic ambiguities using top-down processing.

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Th18b: SEVERE DEFICITS IN PERCEPTION OF ANTICIPATORY COARTICULATION IN COCHLEAR IMPLANT LISTENERS

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Hearing loss can lead to not only decreased overall word recognition, but also poor access to cues that help us identify words more quickly in context. One such cue is coarticulation, or the overlap of articulatory gestures in neighboring sounds, which is utilized by normal hearing listeners to more quickly identify an upcoming word. This study measures benefit of coarticulation when the incoming speech signal is spectrally degraded, as it is for listeners who use a cochlear implant. In a visual world eye-tracking paradigm, listeners looked to four pictures of named objects while listening to speech stimuli in which the vowel preceding a target word contained natural cooperating coarticulation cues, conflicting cues (for a different word), or neutral cues (no coarticulation). The benefit of coarticulation was measured as quicker eye movements toward the target object when they were presented with the cooperating acoustic cue compared to neutral cues, or the increase in latency of eye movement toward the target object when they were presented with conflicting cues; both situations would show evidence of sensitivity to coarticulation. Preliminary results suggest that NH listeners gain a 200ms head start in word recognition when hearing cooperating coarticulation. This ability is remarkably deficient in cochlear implant listeners, having latencies up to 350 ms longer; this delay is longer than the entire target word duration. These results suggest a disadvantage in the speed of word recognition that would not be evident in conventional word recognition scores – especially those with a neutral carrier phrase. Comparison of normal-hearing and CI results suggest what while NH listeners are able to predict upcoming words rapidly, CI listeners tend to wait a much longer time before committing to a perceptual response – sometimes well after the word has already ended.

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Th19a: ADJUSTMENT TO VARIABLE VOICE ACOUSTICS BY COCHLEAR IMPLANT LISTENERS

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There are a number of vocal acoustic characteristics that can vary based upon the sex of the talker. For example, frequency components in voices are lower for men than for women, including fundamental frequency, as well as higher vocal-tract resonances like formants and spectral peaks for fricatives. Listeners must adjust to these acoustic differences. For example, for men's voices that have globally lower frequency components, the perceived boundary between relatively high ("s") and low ("sh") fricatives is accordingly shifted down, relative to that for talkers with smaller vocal tracts. In light of the large amount of variability across talkers, listeners with normal hearing and with cochlear implants must accommodate for the range and different combinations of these variants to determine which phoneme was produced.
Despite impoverished spectral resolution and poor pitch coding in CIs, accommodation of phoneme boundaries shows that CI listeners have access to sufficient talker information within the speech signal that influences their speech categorization. However, it is not clear what acoustic cues they are using. Previously, we have shown that normal hearing (NH) listeners adjust to differences in talker sex by relying mostly on formant spacing cues that signal vocal tract length. The current study was designed to evaluate if a similar or different accommodation strategy is utilized in listeners who use cochlear implants.

In this study, we examined various acoustic cues that underlie accommodation to talker sex, including fundamental frequency (F0), vocal tract length (formant spacing), and spectral tilt as they affect fricative perception. Stimuli included a fricative continuum between "sh" and "s", and a variety of vocalic contexts spoken by women and men that were controlled to vary by the aforementioned cues. CI Listeners identified "sh"- or "s"-onset words, and responses were analyzed to measure whether the contextual cues affected fricative categorization; such effects would indicate accommodation of talker variability.

Results demonstrate that, despite the dominance of formant spacing as a cue for the accommodation effect in NH listeners, CI users tend to rely more heavily on F0 of the talker, despite the dissociation between F0 and vocal tract properties that would demand accommodation. This could indicate that formant coding is so poor for CI listeners, that temporal coding of the talker's F0 is used as a proxy for perception of vocal tract resonances normally conveyed by the spectrum.

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Th19b: VOICE EMOTION RECOGNITION BY MANDARIN-SPEAKING PEDIATRIC COCHLEAR IMPLANT USERS

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As cochlear implants (CIs) do not transmit salient voice pitch cues, lexical tone recognition is impaired in tonal-language-speaking CI users. As tonal languages place a high demand on the pitch-encoding mechanism for everyday speech recognition, perception of emotional prosody, which relies on related acoustic cues, may be significantly impaired in tone-language-speaking children with CIs who are still developing linguistic and cognitive skills. In this study, we examined emotion recognition by school-aged Mandarin-speaking children. Stimuli were Mandarin sentences spoken in five different emotions (happy, angry, sad, neutral, scared) uttered in a child-directed manner (i.e., exaggerated prosody) by adult talkers. Participants were school-aged children with CIs and children with normal hearing (NH). The stimuli were presented in a single-interval, five-alternative forced-choice task. The NH children also heard noise-vocoded versions of the original (unprocessed) stimuli. Results showed that the NH children's identification accuracy declined with poorer spectral resolution in the noise-vocoded stimuli. Compared to their NH peers, the CI children's identification accuracy with the unprocessed stimuli was also lower, with scores similar to NH children's range of identification accuracy with 4-8 channel noise-vocoded speech. The CI users' performance was correlated with their sensitivity to dynamic changes in the pitch of a harmonic complex, as measured in a psychophysical study. These results are qualitatively consistent with parallel findings in English-speaking children with CIs, and indicate that difficulties in recognizing emotional prosody are shared across CI users speaking tonal and non-tonal languages.

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Th20: REDUCING SIMULATED CHANNEL INTERACTION LEADS TO IMPROVED SPEECH PERCEPTION FOR NORMAL-HEARING CHILDREN AND ADULTS

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Introduction: Channel interaction likely limits speech perception abilities of cochlear implant (CI) users. This study examined the role of channel interaction in the ability of normal-hearing (NH) children and adults to recognize spectrally degraded speech. Simulations of CI hearing that varied the number of processing channels and the degree of current spread were employed. The aim was to assess speech perception as a function of age, spectral resolution and degree of channel interaction in NH children, and to relate these findings to NH adults and CI users.

Methods: NH participants included children (age 8-17 years) and adults (age 22-35 years). The CI listeners were post-lingually deafened adults (age 37-84 years). Speech stimuli were medial vowels and consonants. The stimuli were processed using a noise-band vocoder with 8, 12, and 15 channels and synthesis filter slopes of 15 (for NH adults only), and 30 and 60 dB/octave (all NH subjects). Steeper filter slopes (larger numbers) simulated less current spread and therefore less channel interaction. For CI users, unprocessed speech recognition was assessed for each implanted ear using the participants' everyday settings.

Results: Phoneme recognition was better for older NH children, and showed different patterns across conditions compared to adults. For both adults and children, simulating reduced current spread led to improvements in vowel and consonant recognition. However, children continued to benefit from reduced current spread beyond where adult performance plateaued. The number of processing channels did not impact consonant recognition for adults or children, but vowel recognition improved when the number of channels increased from 8 to 12 (adults and children age 13-17) or from 8 to 15 (children age 8-12). Of note, this pattern of vowel recognition was observed regardless of filter slope for adults, but only occurred in the steepest filter slope condition for children. Comparison to adult CI users revealed that their consonant recognition was similar to that of NH adults in the conditions with the highest degree of simulated current spread (15 dB/octave). On the other hand, CI users' vowel recognition was comparable to that of NH adults in conditions with less channel interaction (30-60 dB/octave), but with poor spectral resolution (8 channels).

Conclusion: Consistent with previous studies using vocoded stimuli in NH adults, vowel recognition generally improved when the number of processing channels increased from 8 to 12, whereas consonant recognition did not change with number of channels. Furthermore, recognition of spectrally degraded vowels and consonants improved with reduced simulated current spread, particularly for children. The differences observed between NH children and adults suggest that maturation of spectral resolution continues through adolescence, and that children may receive greater benefit from reduced channel interaction than adults. Comparison to adult CI users shows that they are performing similarly to NH adults listening to simulations with relatively poor spectral resolution (vowels) and high degrees of channel interaction (consonants).

Th21a: ACCESSIBILITY OF SPEECH INFORMATION AT VARIOUS SIGNAL-TO-NOISE RATIOS IN COCHLEAR IMPLANT PROCESSING

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Cochlear implant (CI) users often have difficulties understanding speech in noise, even those with good speech recognition in quiet. In many real-life situations considered “quiet”, a low level of background noise is actually present. The objective of this study is to determine the highest signal-to-noise-ratio (SNR) at which speech information is obscured by noise in both a CI processing strategy and unprocessed speech stimuli. Software implementing an Advanced Combination Encoder (ACE) stimulation strategy (by Cochlear company) was used to produce vocoded sound simulations of sentences at a fixed level mixed with steady-state speech shaped noise at various sound levels. Speech recognition was measured in 25 normal-hearing subjects for both unprocessed and vocoded sentences in quiet and at a wide range of SNRs. After vocoding, speech files were either low- or high-pass filtered to prevent ceiling effects at high SNRs. We used a short training session and a Latin square experimental design to account for learning effects in vocoded speech recognition. The SNR at which speech recognition performance reaches a plateau was determined by curve fitting of the average data. We look specifically for differences between the vocoded sentences and unprocessed sentences. Finally, the results were compared to the SNR at which speech recognition no longer increases with decreasing noise level as predicted by the SII model. The results provide insight in the minimal SNR at which an auditory scene can be considered optimal for speech recognition for a CI-user and a normal-hearing listener.

Results will be presented at the conference.

Th21b: SPATIAL RELEASE FROM INFORMATIONAL AND ENERGETIC MASKING IN BIMODAL AND BILATERAL CI USERS

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Spatial separation of target and masker(s) can improve speech understanding for listeners with normal hearing (NH), an effect referred to as spatial release from masking (SRM). Bilateral cochlear implant (CI) users may receive some benefit from spatial separation, although the magnitude of improvement can be considerably poorer than normal. This is likely due to the poor transmission of temporal fine structure with current CI coding strategies preventing perception of fine-structure based interaural time differences (ITDs) (Culling et al., 2004). Similarly, bimodal listeners lack access to both ITD and high-frequency interaural level difference (ILD) cues, and thus, exhibit poorer than normal SRM. Bimodal listeners, however, do have access to F0 and low-frequency fine structure information in the non-CI ear. This access to fine structure information may facilitate speech understanding in noise via glimpsing and/or segregation; however, greater fine structure representation may make bimodal listeners more susceptible to informational masking (e.g. Pyschny et al., 2014). Our primary hypothesis was that bimodal listeners would exhibit greater release from informational masking than bilateral CI users. Secondarily, since most of the existing literature has examined SRM using asymmetric noise configurations, thereby allowing for head shadow cues to dominate (as opposed to binaural cues), we hypothesized that listeners would exhibit little to no SRM in the symmetric noise configurations used here.

Speech understanding was assessed in a “cocktail party” paradigm, using speech (informational) and signal-correlated noise (energetic) maskers. A single female or male talker presented at 60 dBA originated from 0-degrees azimuth and the maskers (two different male talkers or SCN) were positioned at either 0 degrees, 45 & 315 degrees, or 90 & 270 degrees. The background noise levels used for testing were determined by finding the signal-to-noise ratio at which listeners got approximately 50% correct with the best CI alone with noise presented from 0 degrees.

Preliminary data from 25 adult participants (16 bimodal, 9 bilateral) reveal that 1) both groups showed no SRM in the symmetric noise configurations used here; rather, performance declined with increasing spatial separation, 2) for a female target talker, bimodal and bilateral participants showed similar degrees of release from informational masking (approximately 10-percentage points for all masker locations), and 3) for a male target talker, bimodal participants exhibited a significantly larger release from informational masking ($p < 0.05$), especially when noise was presented from 90 and 270 degrees (33-percentage points versus 22-percentage points for bimodal and bilateral, respectively).

In support of our hypotheses, preliminary findings suggest that when the test paradigm forces listeners to utilize binaural timing cues, SRM was absent for both bimodal and bilateral CI users. Further, bimodal listeners are more susceptible to informational masking as demonstrated by a greater improvement in performance when switching from a 2-talker distracter to signal-correlated noise. This is likely due to access of low-frequency fine structure present in the acoustic hearing ear allowing for both segregation and/or glimpsing of the target talker’s fundamental frequency.

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Th22a: THE RELATIONSHIP BETWEEN SPECTRAL MODULATION DETECTION AND SPEECH RECOGNITION: ADULT VERSUS PEDIATRIC IMPLANT RECIPIENTS

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Cochlear implant (CI) recipients have relatively poor spectral resolution; however, adult CI recipients demonstrate a reliable and significant relationship between spectral modulation detection and speech understanding. Prior studies documenting this relationship have focused on postlingually deafened adult CI recipients—leaving an open question regarding the relationship between CI-mediated spectral resolution and speech understanding for adults and children with prelingual onset of deafness. Here we report CI-only performance on measures of speech recognition and spectral modulation detection for 210 cochlear implant recipients (236 ears) including 154 postlingual adults, 33 prelingual adults, and 23 prelingual pediatric CI users. The results demonstrated a significant correlation between spectral modulation detection and various measures of speech understanding for the 187 adult CI recipients (208 ears). For the 23 pediatric CI recipients (28 ears), however, there was no relationship between spectral modulation detection and speech understanding in quiet or in noise nor was spectral modulation detection correlated with listener age. These findings suggest that pediatric CI recipients, with prelingual onset of deafness, may not depend upon spectral resolution for speech understanding in the same manner as adult CI recipients who presumably have mature spectral processing. It is possible that prelingually deafened pediatric CI users are making use of different cues, such as those contained within the temporal envelope and accessible via envelope-based CI signal processing, to achieve high levels of speech understanding. Further investigation is warranted to investigate the relationship between spectral and temporal resolution and speech recognition to describe the underlying mechanisms driving peripheral auditory processing in pediatric CI users. This holds potential for clinical implications regarding recommended signal processing strategies and therapeutic recommendations for pediatric CI users.

Th22b: HOW WELL DO ADOLESCENTS WITH COCHLEAR IMPLANTS LEARN A SECOND LANGUAGE IN HIGH SCHOOL?

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Mastering a second spoken language (L2) has many direct advantages. To date, it has not been quantified to which degree implanted adolescents are able to master learning a L2 after their native language. The purpose of this project is two-fold: (1) to evaluate the abilities of implanted adolescents to learn a second language in the current school settings compared to normal-hearing peers; (2) to identify and quantify environmental, sensory and cognitive aspects that affect second language acquisition in implanted adolescents. In the current poster, we will address the first objective by presenting preliminary L2 proficiency measure results.

Participants are aged 12 – 17 years and fall into two groups: adolescents with paediatric cochlear implantation (CI group) and with normal hearing (NH group). All of the NH group and the majority of the CI group attend mainstream high schools. All participants are Dutch native speakers and attend English classes in school. Thus, Dutch is their first language (L1), English is their L2. General L2 proficiency will be measured with a C-Test. L2 listening and L2 reading will be measured with accuracy scores on a Sentence Verification Task.

Due to their English classes at school, we expect that all CI participants master L2 learning to some degree. However, the extend of this L2 learning will only be mapped out in detail with this systematic approach.

In line with L1 research, we expect that the CI group will show greater variability in all proficiency measures compared to the NH group (e.g., Boons et al, 2012). In addition, we expect that the CI group will present lower general L2 proficiency, due to the degraded auditory input of the CI. This is because even for NH populations, L2 processing is more effortful than L1 processing (Weber & Broersma, 2012) and L2 processing is more affected by difficult listening situations than L1 processing (Rogers et al, 2006). Furthermore, while L1 and L2 performance tested auditorily can be affected greatly by CI use, L1 research suggests that reading abilities can still be within NH range for some implanted adolescents (Geers & Hayes, 2011). Therefore, we expect to find great differences between the groups regarding L2 listening scores, whereas differences in L2 reading scores should be smaller.

Th23: THE NOVEL COMBINED LINGUISTIC AND INDEXICAL SPEECH PERCEPTION ASSESSMENT (CLISPA) REVEALS BOTTLENECKS IN THE PERCEPTION AND INTEGRATION OF SPEECH CUES BY COCHLEAR IMPLANTS

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Some cochlear implant users achieve ceiling levels of speech perception on some of the most difficult measures available. These users who are also in careers that require complex communication relate that the increased cognitive load required to perceive speech impairs higher-ordered processing of the speech stream. This increased cognitive load may interfere with the simultaneous perception and integration of indexical speech cues. We hypothesized that the number of indexical cues that a listener perceives while simultaneously maintaining maximal levels of linguistic speech perception is significantly less than assessment as a single outcome measure.

We re-recorded the AzBio Sentence Lists to include emotion cues and an additional speaker to create the Combined Linguistic and Indexical Speech Perception Assessment (CLISPA).

Experiment 1: This experiment assessed the inter-list equivalency of the new stimuli and tested the central hypothesis at the group level. These stimuli were processed through an 8-channel noise band vocoder to simulate a cochlear implant. Three different groups of normal hearing listeners (N = 15 each) used the same sentence lists. The Sentences-only group performed traditional sentence discrimination. The Indexical-only group identified the gender, speaker, and emotion in the sentence. The primary task of the Sentences + Indexical subgroup was sentence perception followed by the secondary task of identifying indexical cues.

Experiment 2: The central hypothesis was tested in post-lingually deaf cochlear implant subjects and a control group with normal hearing listeners using non-vocoded CLISPA sentences. Two lists per condition were used (e.g. Sentences-only, Indexical-only, and Sentences + Indexical).

In the first experiment, indexical performance was significantly worse in the Indexical + Sentences group for gender and emotion identification. Sentence completion times were greater in the Sentences + Indexical condition. These times also suggested that linguistic and indexical perception were discrete and additive tasks as opposed to synergistic tasks processed in parallel with one another. Accumulating results in the cochlear implanted subjects approximated the 8-channel vocoder model of normal hearing listeners in Experiment 1.

Spectrally degraded speech decreased the perception of indexical cues as well as their integration with linguistic cues. This decreased information transfer occurred despite quiet conditions and near ceiling linguistic speech perception scores. CLISPA is a novel outcome measure that simultaneously provides information on both the encoding and cognition of speech. CLISPA may be used to design behavioral interventions and assess the efficacy of new speech processing strategies for cochlear implants.

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Th24: RELATIONSHIP BETWEEN NUMBER OF ACTIVE ELECTRODES, ELECTRODE-TO-MODIOLUS DISTANCE, AND SPEECH PERCEPTION OUTCOMES IN ADULTS WITH COCHLEAR IMPLANTS

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OBJECTIVE: To determine the relationship between number of active electrodes and the average electrode-to-modiolus distance along the electrode array for both lateral wall and perimodiolar electrode arrays for maximum speech understanding and sound quality.

BACKGROUND: A relationship has long been assumed between electrode-to-modiolus distance and accuracy of stimulating target spiral ganglion (SG) cells. Cochlear implants send electrical pulses through the highly conductive intracochlear fluids resulting in spread of excitation functions spanning one third or more of the array (e.g., Hughes et al., 2013; Padilla and Landsberger, 2016). Thus, CI recipients experience significant spectral smearing of incoming stimuli evidenced by poor spectral resolution. Our hypothesis was that a closer placement of the electrode array to target SG cells would allow for greater utilization of more independent channels, because stimulation is more precise, leading to the recipient reaching maximum speech scores and sound quality ratings with a greater number of electrodes.

METHODS: Electrode-to-modiolus distance was determined by CT imaging using validated CI position analysis software (Noble et al, 2014) in 16 implanted ears, 8 perimodiolar and 8 lateral wall, with Cochlear Limited devices. Each subject was tested with 7 different maps with electrode counts ranging from 4 to 22. Maxima were set to equal the number of active electrodes, with the exception of the 22-channel program which used 16 maxima due to software limits. Active electrodes were chosen using two different methods: 1) image-guided selection techniques (e.g., Noble et al., 2013, 2014), using electrode-to-modiolus distance measurements to select electrodes that were least likely to yield channel interaction, and 2) evenly spaced across the array to replicate the conditions used by Friesen et al. (2001). Each map was tested using a variety of auditory and speech measures, as well as sound quality ratings.

RESULTS: At the group level, performance reached asymptote with 16 electrodes for most measures ($p < 0.05$). For each measure a performance-by-electrode function was plotted and fit with linear regression. Individuals requiring a higher number of electrodes for maximum performance exhibited a steeper slope. These slopes were compared to the individuals' averaged electrode-to-modiolus distance across the electrode array. We found a significant correlation between the slope of the regression function and the averaged electrode-to-modiolus distance across the array ($r = -0.61$, $p = 0.0027$). We did not, however, observe a relationship between maximum speech understanding scores and average electrode-to-modiolus distance ($p = 0.71$) suggesting that lateral wall and perimodiolar electrodes yield similar performance.

CONCLUSIONS: Individuals with a closer overall electrode-to-modiolus distance took advantage of a greater number of electrodes to achieve maximum performance on a number of auditory and sound quality measures. Thus it may not be the case that modern CI recipients with precurved arrays only take advantage of 6-8 channels as previously thought. Clinical implications including suggestions for the number of maxima to use for perimodiolar electrode will be discussed.

Th25: SELF-EXPLORATION OF MAPS BY COCHLEAR IMPLANT USERS

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Programming cochlear implants (CIs) involves not only measurement of basic psychophysical data (thresholds and comfort levels) but also adjustment of various parameters of the speech coding strategy. Proper programming is the key to user satisfaction, and it is critical to ensuring the translation of scientific discovery and technological breakthroughs into improvements of quality of life for CI users. Typically, programming is done in an iterative manner, with the clinician establishing one of more sets of programming parameters ("MAPs") interactively with the user at the clinic. The new settings are then trialed for a period of a few weeks or months, until the user's next visit to the clinic where further adjustments are made according to user feedback. In current clinical practice, programming is quite resource intensive, involving hours of direct clinician-client contact which often go unreimbursed. As a result, in many clinics CI users are often given MAPs that differ little from the default suggested by the manufacturer, without an extensive search for the optimal settings for the individual user's needs and preferences.

In the present project, we propose a new software platform which enables CI users to explore various programming options on their own without constant interaction with clinicians. The software, developed for Nucleus devices, allows the user to explore various options for the ACE speech coding strategy. While there are almost infinite possible combinations of settings, we limit the number of options at this stage of investigation to make the task manageable. Therefore, the following parameters and values for each parameter are adjustable in the software: stimulation rate (500, 900, 1200 and 1800 Hz), maxima (8, 10 and 12), frequency boundary table (manufacturer default and two experimental boundaries), gain (±2 dB for apical, mid, and basal electrode groups) and on-off switches for individual channels (to allow the user to opt out certain electrodes). To evaluate a selected set of parameters, the user can play pre-recorded speech samples at their own pace. We avoided technical jargon in the design of the software, making it easy for users to explore on their own without constant clinician supervision. The software prompts the user to provide a satisfaction rating of the MAP on a scale 1 to 5 after every fifth sentence sample is played. The data of user ratings for each MAP are sent directly to our server for analysis.

The study is conducted at two sites: Washington University School of Medicine and Gallaudet University. Most participants are post-lingually deafened CI users at the former and pre-lingual CI users at the latter. The most notable observations made to date are that 1) subjects were eager to embrace combinations of parameters which differed from the settings of their own processors, and 2) they gave highly favorable ratings to some of the new MAPs after using them to listen to the recorded speech samples.

The following aspects of the results are to be presented at the meeting: 1) the reliability and consistency of their ratings, 2) comparisons of speech recognition measures among those MAPs marked as "favorable," 3) further analyses of statistical interactions among parameters (once the interaction of one or more parameters with others are found non-significant, it/they can be easily separated from others for further MAP adjustments), 4) consideration of individual factors and variabilities, such as pre-vs. post-lingual users and personality), and 5) strategies to streamline the process for clinical application.

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Th26a: INSIGHTS INTO SPEECH UNDERSTANDING BY COCHLEAR IMPLANT AND BIMODAL LISTENERS GAINED FROM ROVING LEVEL AND HARMONIC AND DISHARMONIC INTONATION TESTS

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To minimize test-retest variability, speech tests generally control variation in the material as much as possible. However, this risks underestimating the difficulties faced in everyday communication due to variability in the target speech. To address this, the STARR tests rove presentation level on a sentence by sentence basis. Additionally, Harmonic and Disharmonic Intonation (HI and DI) tests assess the ability to detect changes in low-frequency components that reflect the use of temporal fine structure information. This work explores whether these tests might be applied to identify improved parameters for CI or bimodal listening.

Testing was conducted for 29 British English and 29 Italian cochlear implant recipients and for 14 Italian bimodal users. British and Italian version of the STARR test were applied, where sentences were presented at either 50, 65 or 80 dB SPL. The level of a competing speech-shaped noise was adapted to estimate a speech reception threshold (SRT), where 50% of the sentences were understood. The Italian participants were tested on the HI and DI tests where, respectively, the frequencies of either a 200 Hz fundamental and its first three harmonics, or the fundamental only, were manipulated adaptively to find the smallest interval with which the frequency altered tone could be distinguished from the unaltered tone. Bimodal users were tested in both CI only and bimodal modes on STARR, HI and DI tests. A pilot group of CI users was tested with compression parameters selected to address weaknesses found in STARR testing: individually set T-levels, reduced compression threshold for dual-action AGC and reduced near-instantaneous compression.

Around 60% of the CI users could achieve an SRT score of better than 20dB. For these participants the British and Italian SRTs were 9.4 and 8.6 dB respectively: still some 15 dB poorer than normal hearing performance on this test. The CI pilot group tested with modified program parameters achieved a 6 dB improvement in SRT. Just noticeable differences for the HI and DI tests were poor at 27 Hz and 147 Hz respectively, highlighting the lack of temporal fine structure information available via electrical hearing. Bimodal use led to significant improvements on both HI and DI tests, as well as a drop in STARR SRT from 17.3 dB to 8.1 dB. The STARR outcomes were significantly correlated with the DI outcomes ($p < 0.05$).

The STARR and DI tests show promise for gaining insights into how speech perception is being limited and may guide the customization of CI program parameters. The DI test may help support the fine tuning of bimodal listening. Such results are relevant for difficult listening situations where target speech is either, reduced in level, or masked by competing noise, and hence are relevant to everyday listening situations.

Th26b: PERCEIVED SOUND QUALITY OF NOISY AND NOISE REDUCED SPEECH

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Speech enhancement strategies have become an integral part of assistive hearing devices to aide listeners in speech understanding in noisy environments. While effects of noise-suppression strategies in intelligibility gains are well documented/reported, the negative effects of distortions introduced by signal processing (both in spectral and temporal domains) on speech quality are not well understood. Factors such as signal-to-noise ratio, sound intensity, noise type, and level of noise-suppression contribute to the resulting sound quality. Front-end noise-suppression strategies are generally formulated from a mathematical signal processing perspective as stand-alone/independent algorithms. When combined with speech coding strategies of the assistive hearing device, gain functions may interfere and degrade the overall sound quality of enhanced speech. Such methodology could yield better speech intelligibility, but may lead to poor sound quality. In addition speech enhancement techniques generally focus on reducing the level of noise relative to the level of speech (i.e. estimated signal-to-noise ratio) to achieve a minimum physical difference between the original clean speech and the enhanced speech. Speech enhanced under this assumption may not provide the necessary sound quality for speech perception with reduced cognitive-load and requires another metric.

The goal of this study was to characterize and model the non-linear distortions introduced by noise reduction algorithms and their impact on perceived sound quality. Both normal hearing and hearing impaired listeners participated in this study. Subjects were asked to rate the perceived sound quality of speech that had been systematically subjected to various forms of distortions at different levels of speech and noise. AzBio sentences were presented to the participants in quiet, multi-talker babble, and cafeteria noise at 55dB, 65 dB and 75 dB SPL-A. Signal intensities of speech and noise were varied in a way to create an additional dimension of relative sound intensities. For example, speech sentences at 75dB SPL and noise intensity at 65 dB SPL was considered a different condition than sentences at 65dB SPL and noise at 55 dB SPL (although both were at same SNR, i.e., 10dB). In addition, two popular noise reduction techniques, iterative Wiener filtering and psychoacoustically-motivated masking, were evaluated. For hearing aid and cochlear implant users, the sentences were linearly amplified by NAL formula and presented via their devices' auxiliary input using direct audio cable. For normal hearing and hearing impaired (un-aided) listeners, sentences were presented via Sennheiser HD600, with linear amplification for the later group. Test order and conditions were randomized across subjects. Each listener rated the perceived sound quality twice to obtain individual consistency in ratings between trials.

Preliminary data from normal hearing and hearing impaired listeners indicates better perception of sound with higher sound pressure level of speech against a lower level keeping constant SNR. Speech perception has been found to be more adversely affected by distortion when SPL of noise is higher than a lower SNR.

Th27a: THE EFFECT OF LATERAL WALL VS. PERIMODIOLAR ARRAYS ON AUDIOLOGIC OUTCOMES

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Background: It is well documented that cochlear implant (CI) outcomes are better when soft surgical techniques are used to insert and maintain the electrode array entirely within the scala tympani (ST). A recent study comparing lateral wall (LW) and perimodiolar (PM) electrode arrays found LW arrays are associated with higher rates of ST insertion and better speech recognition scores. There is little other evidence supporting that audiologic outcomes are superior with a LW array compared to a PM array. Further inconsistencies exist, including a case series showing improved speech outcomes when a LW array is explanted in favor of a PM array and audiologic observations of reduced impedance fluctuation with PM arrays.

Objectives: The goal of this study is to (1) compare speech perception scores between recipients of Cochlear LW (CI522) and PM arrays (CI512) and (2) compare map stability between recipients of the two arrays.

Methods: Charts were reviewed for patients receiving a CI from one of three experienced neurotologists between 2010 and 2016. Inclusion criteria were as follows: adults (18+) at time of implantation, English-speaking, post-lingually deafened, with documented pre- and post-operative AZ Bio sentence and/or CNC scores, and no more than 10 years without amplification prior to implantation. Patients were excluded if they underwent a revision surgery or received a cochlear implant array other than those listed above. Az Bio sentence scores and CNC word scores were evaluated across groups. Map stability was compared by evaluating average impedance fluctuations across groups.

Results: Ten subjects with PM and 9 subjects with LW arrays were identified for preliminary analysis. Results revealed a significant difference in monosyllabic word recognition and sentence recognition scores between LW and PM array recipients ($p<0.01$ in both comparisons), with CI512 recipients scoring higher on Az Bio sentences (M=91%, 95% confidence interval: 85.44-97.23) and CNC words (M=76%, confidence interval: 67.45-82.95) than recipients of CI522 (Az Bio M=77%, confidence interval: 35.16-86.18; CNC: M=58%, confidence interval: 31.34-66.44). Impedance fluctuations for both LW and PM groups were highly variable.

Conclusion: Contradictory to the most comprehensive recent finding, superior outcomes were observed for recipients of the perimodiolar electrode array in a preliminary analysis. This finding warrants further analysis with increased sample size, and adds to the importance of healthy electrode-neural interfaces. Additional analyses of recipient variables such as duration of deafness and residual hearing will determine how potential confounders may contribute to group differences in performance.

Th27b: SUBJECTIVE SELF-ASSESSMENT OF BIMODAL FUSION

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Today, an increasing number of patients are bimodal users. They might perceive sounds differently with their hearing aid (HA) and cochlear implant (CI). In fact, it has been observed that some bimodal users hear two sounds, i.e. they are not able to fuse the acoustic sound from the HA and the electric sound from the CI into a single percept of one sound source. It is likely that those users would benefit from a fused percept in their daily lives in terms of reduced listening effort, better localization of sounds and better ability to attend to a single speaker in a noisy environment.

In this study, 36 bimodal users were given a questionnaire for self-assessing the perceived differences across devices on five different scales related to: the absolute difference across devices, difference in pitch, loudness, sound localization and sound quality. The SSQ5 is a normalized questionnaire that includes self-evaluated performance in speech understanding with an interfering talker, sound localization, assessment of sound clarity and listening effort.

The results indicate that 11 of 36 users report to have fused percepts, whereas the majority reports to perceive sounds differently across their ears, including higher pitch and louder sound in the CI. Members of this group also rate their ability to understand speech in noise, sound clarity significantly lower and listening effort significantly higher compared to participants who report fused percepts. Thus, users appear to profit from being able to fuse electric and acoustic sound inputs into a single percept.

Th28a: INTERAURAL TIME DIFFERENCE PERCEPTION WITH A COCHLEAR IMPLANT AND ONE NORMAL EAR

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The interaural time difference (ITD) is an important cue to localise sound sources. It has been established that some bimodal listeners, with a cochlear implant and severe/profound hearing loss in the non-implanted ear can be sensitive to ITDs, with widely varying thresholds. It is unclear whether the electrically or acoustically stimulated side limits performance.
There is currently a growing population of people with normal hearing in one ear and a cochlear implant in the other (sometimes called SSD/CI). We measured ITD sensitivity in this population, (1) to support the development of novel signal processing strategies that better transmit ITD information, (2) to investigate whether normal hearing in the acoustically stimulated ear yields better ITD sensitivity than a severe/profound hearing loss, (3) to determine how the acoustical and electrical signals can be synchronised at neural level, and (4) to determine the best match between electrodes and acoustic frequency ranges for ITD perception.

Methods. As a stimulus we used 100-pps pulse trains on the electrical side and 100-Hz, 1-oct wide filtered click trains on the acoustical side. Based on (E)ABR wave V latencies and a comprehensive lateralisation experiment, we determined the required delay of the electrical stimulus for simultaneous excitation of both auditory nerves, and the corresponding interaural level difference yielding a centred percept. We then measured the ITD discrimination threshold in an adaptive procedure. This was all done for 3 electrodes across the array and different acoustic frequency ranges. We also asked the subjects to report the degree to which sounds from the two ears were fused into a single sound image.

Results. For half of the subjects, sounds were not well fused for any electrode/acoustic range combination we tried, and they were not sensitive to ITD. For the other half of the subjects, we could find electrodes and corresponding acoustic stimuli which yielded a fused sound image, and ITDs could be detected with a wide range of sensitivity across subjects, comparable to bimodal listeners. Based on ITD sensitivity we were able to match acoustic frequency ranges to electrodes. The delay of the electrical stimulus needed to evoke simultaneous activation of the auditory nerves, increased with decreasing acoustic frequency range, and was comparable to the interaural difference in wave (e)V latency.

Conclusions. Cochlear implant users with a normal-hearing non-implanted ear show similar ITD sensitivity as bimodal listeners, so the acoustically stimulated ear does not seem to be the limiting factor in ITD sensitivity. Acoustic frequency ranges can be matched to electrodes based on ITD sensitivity which may serve as a method to allocate acoustic frequency ranges to electrodes when fitting a CI to a subject with normal hearing in the other ear.

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Th28b: USING BINAURAL BEAT SENSITIVITY TO PROBE BINAURAL SENSITIVITY AND SPECTRAL MATCHING IN PEOPLE WITH SINGLE-SIDED DEAFNESS AND A COCHLEAR-IMPLANT

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Patients with single-sided deafness (SSD) have difficulty localizing sound and understanding speech in noisy backgrounds. Recently, some SSD patients have received a cochlear implant (CI) in their deaf ear. Current implant fitting strategies aim to maximize speech perception by allocating all spectral information across the electrode array without regard to anatomical electrode placement. However, SSD+CI patients may benefit more from a CI fitting approach that best complements information from the normal-hearing ear. The primary hypothesis tested here is that performance will be improved by better matching the CI electrode map to the tonotopic organization of the normal-hearing ear. Measures of binaural interactions have been suggested as one way to determine the best interaural spectral match, but with SSD+CI patients, the baseline interaural time difference (ITD) between the acoustic and electric ear is unknown. This study, therefore, explores the use of dynamic ITD (beat) detection, which should be independent of the baseline ITD.

Sensitivity to binaural temporal-envelope beats was tested as a function of stimulus bandwidth and interaural spectral match for both normal-hearing listeners and SSD+CI listeners. Results were compared with a more standard measure of ITD discrimination as a function of spectral mismatch and baseline ITD. Preliminary results for 2 of 20 planned SSD+CI listeners show high accuracy for detection binaural beats in the broadband (4-oct.) condition. Preliminary data from 2 of 20 planned NH listeners show frequency tuning for both binaural-beat detection and standard ITD sensitivity with a 0-ms baseline ITD. However, when a baseline difference in ITD of 1 ms or more was introduced, performance was much poorer, and tuning was more difficult to establish. Based on these NH listeners, at least, it seems that binaural beats may provide a more reliable measure in cases where the fixed ITD offset is unknown. This approach may provide new methods for which to fit cochlear implants to SSD patients and other candidates with significant residual hearing in the contralateral ear.

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Th29a: RELIABILITY AND LEAD LEACHING OF PZT INTRA COCHLEAR MICROACTUATORS

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The authors have previously developed a lead zirconate titanate (PZT) intra cochlear, acoustic microactuator, which can cooperate with a shortened electrode array to realize combined acoustic and electric stimulation. We demonstrated in an acute guinea pig model that the acoustic microactuator in the scala tympani stimulates auditory brainstem responses across the spectrum of human hearing without causing a loss of hearing [1]. Reliability and safety of the micro-actuator, however, must be studied thoroughly before advancing to chronic tests.

A reliability test was performed in air and in artificial cochlear fluid. First, the PZT microactuator was driven at 40 kHz in air for one month, and no significant drop in performance was observed. Then the microactuator was submerged in artificial cochlear fluid and was driven at 10 kHz. The microactuator survived 814 hours (~34 days) of continuous operation in artificial cochlear fluid totaling 29 billion cycles before failure.The lifespan at physiologic auditory frequencies is predicted to be much longer because failure of PZT devices is typically related to total cycles.

The failure mechanism appears to be current leakage and short circuit. It is believed that a parylene coating that isolates the microactuator from the surrounding fluid has failed as a result of its poor adhesion to metal (gold and platinum) and metal oxide (PZT). Such failure typically occurs at pattern boundaries due to stress concentration, allowing fluid to penetrate the interface between the top electrode and PZT layer. Finally, a short circuit is formed and the device fails. The above failure analysis is supported by impedance measurements, microscope observations and frequency response analysis.

Leaching of lead from a PZT device has also been a theoretical concern that the authors have investigated. After the extended in vitro reliability test, the lead concentration of the artificial fluid was measured. The total release of lead is at most 1.23ng/ml, whereas CDC guideline for allowable lead in blood is 100 ng/ml and EPA guideline for allowable lead in drinking water is 15 ng/ml.

References:
[1] ChuanLuo, Irina Omelchenko, Robert Manson, Carol Robbins, Elizabeth C. Oesterle, G. Z. Cao, I. Y. Shen, Clifford R. Hume, 2015 “Direct Intracochlear Acoustic Stimulation using a PZT Microactuator,” Trends in Hearing, Vol. 19, pp.1-14.

Th29b: VERBAL LEARNING AND MEMORY IN ADULTS WITH COCHLEAR IMPLANTS

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To understand degraded speech, such as through a cochlear implant (CI) or when spectrally degraded by noise-vocoding, the listener must utilize language knowledge and cognitive abilities to interpret the incoming signal. However, the experience of prolonged severe-to-profound hearing loss may contribute to deficits in these language and cognitive skills. This study compared non-auditory verbal learning and memory abilities between CI users and normal-hearing (NH) age- and nonverbal IQ-matched peers, and examined these abilities as predictors of degraded speech recognition.

Twenty-five postlingually deaf adults who were experienced CI users and twenty-five age- and nonverbal IQ-matched NH controls underwent testing of verbal learning and memory using a visual version of the California Verbal Learning Test-II (CVLT), a multiple trial free recall task that permits assessment of a number of cognitive processes: verbal learning, short-term memory, primacy and recency effects, proactive and retroactive interference, and semantic/serial clustering. Participants also completed tasks of word and sentence recognition in the clear (CI users) or using noise-vocoded speech (NH controls). Two hypotheses were tested: (1) CI users would demonstrate poorer scores on CVLT measures than NH peers, as a result of their prolonged auditory deprivation. (2) For both groups, scores on the CVLT would predict performance on the speech recognition tasks.

Results demonstrated that most CVLT measures were equivalent between groups, except that CI users showed a greater magnitude of proactive interference (PI) than NH controls. PI also served as the largest predictor of word and sentence recognition outcomes, but only for the CI group. Interestingly, in CI users, magnitude of PI correlated positively with duration of hearing loss prior to implantation.

In conclusion, although most scores on the CVLT were equivalent between CI and NH groups, CI users demonstrated a greater magnitude of PI, which was related to their duration of auditory deprivation. For CI users only, PI predicted speech recognition outcomes. Thus, PI appears to be affected by hearing loss and contributes to speech recognition in CI users. Moreover, findings suggest that components of the CVLT, tested visually, may possess utility as prognosticators of speech recognition abilities during the preoperative evaluation of patients considering cochlear implantation.

This work was supported by the American Otological Society Clinician-Scientist Award to Aaron C. Moberly.

Th30a: TODDLERS WITH SINGLE SIDED DEAFNESS AND A COCHLEAR IMPLANT: FIRST RESULTS

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Every year, neonatal hearing screening services in Flanders (Belgium) detect single sided hearing loss in approximately 60 neonates, of whom about 16 have a profound sensorineural hearing loss, also called single sided deafness (SSD). As these children have no binaural hearing, they often will experience difficulties with localization of sounds and with speech intelligibility in noisy situations. Furthermore, an increasing body of research suggests that single sided hearing loss is a risk factor for speech-language delays.

A cochlear implant (CI) on the deaf side has the potential to restore binaural hearing. For congenital SSD, recently positive results have been reported for two children implanted early in life, but not for four children implanted at an older age. It is likely that early implantation is critical for bilateral auditory development.

We currently report on data of six infants with SSD who received their CI at the age of resp. 0;8, 1;0, 1.2, 1;2, 1;9 and 2;2 (yr;mo) and are tested with age-appropriate materials at regular intervals. We compare behavioral and questionnaire data of these children to those of matched normal hearing peers and matched children with SSD without a CI. The children are tested with regard to their receptive and expressive language skills (Bayley-III language subscales or the Schlichting Language Tests), their cognitive abilities (Bayley-III cognitive subscale or WPPSI-III) and from four years of age onwards their ability to localize sounds and speech in noise understanding. Also, their language environment is studied (LENA system) and parents are asked to complete questionnaires on auditory behavior (Littlears and/or PEACH+), language development (N-CDI) and social-emotional and adaptive behavior (Bayley-III questionnaires or Vineland Screener).

Results of 2 months pre implantation and 4(/10/16/22) months post implantation, will be presented at the conference.

Th30b: BENEFITS OF COCHLEAR IMPLANTATION FOR SINGLE SIDED DEAFNESS: PRELIMINARY DATA FROM THE HOUSE CLINIC-USC-UCLA FDA TRIAL

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For patients with single-sided deafness (SSD), cochlear implants (CIs) have been shown to reduce tinnitus severity and improve quality of life (QoL). A total of 10 patients have been enrolled in this FDA-approved study of for cochlear implantation for SSD. Here, we report preliminary data for 8 patients who have thus far completed the protocol. Audiological thresholds, localization, speech perception in quiet and in noise, tinnitus severity, dizziness severity, and QoL were measured before implantation and during the six-month period after CI activation.

All patients had normal hearing (NH) in one ear and severe-to-profound deafness in the other ear. All patients were implanted with Med-El Flex 28 CIs and used the Sonnet processor for the duration of the trial. No surgical complications were reported. All patients were clinically mapped according to standard guidelines for unilateral CI fitting.

Audiological thresholds were quantified as pure-tone average (PTA) thresholds across 0.5, 1.0, and 2.0 kHz. Speech understanding in quiet was measured using CNC words and HINT sentences. Localization was measured in sound field using a 12-speaker array. Sentence recognition thresholds (SRTs), defined as the signal to noise ratio (SNR) needed to produce 50% correct word recognition for HINT sentences in noise, were adaptively measured for three spatial conditions: 1) speech and noise from the center (S0N0), 2) speech from center, noise to the CI ear (S0Nci), and 3) speech from the center, noise to the NH ear (S0Nnh). Tinnitus severity was measured using a visual analog scale (VAS) with the CI off or on, and using the Tinnitus Functional Index (TFI). Dizziness severity was measured using the Dizziness Handicap Inventory (DHI). QoL was measured using modified versions of the Glasgow Hearing Aid Benefit Profile (GHABP) and the Spatial, Speech, and Quality (SSQ) questionnaires.

Mean pre-surgical PTA thresholds were >92 dBHL in the ear to be implanted; six months after CI activation, mean PTA thresholds in the CI ear improved to 39 dBHL. Mean CNC word recognition in the CI ear improved from 0% correct before implantation to 53% correct six months post-activation. Mean HINT sentence recognition in the CI ear improved from 0% correct before implantation to 85% correct six months post-activation. For bilateral localization, the mean RMS error improved from 48° before implantation to 34° six months post-activation. For bilateral speech understanding in noise, mean SRTs improved from -0.9 dB before implantation to -4.1 dB six months post-activation for S0N0, from -7.1 dB before implantation to -7.9 dB six months post-activation for S0Nci, and from 0.4 dB before implantation to -2.5 dB six months post-activation for S0Nnh. The mean tinnitus VAS score before surgery was 4.2/10; Mean VAS scores six months post-activation were 3.9/10 with the CI off and 2.7/10 with the CI on. Mean TFI scores were 49/100 before implantation and 26/100 six months post-activation. Mean DHI scores were 28/100 before implantation and 20/100 six months post-activation. Across all listening scenarios in the GHABP, mean difficulty was 3.3/5 before implantation and 2.5/5 six months post-activation; patients generally found the CI to be helpful (3.4/5) and were moderately satisfied with the CI (3.6/5). For the SSQ, mean scores improved from 48/140 before implantation to 84/140 six months post-activation for speech perception, from 45/170 before implantation to 94/140 six months post-activation for spatial perception, and from 105/190 before implantation to 126/190 six months post-activation for quality perception.

These preliminary data suggest that cochlear implantation can substantially improve SSD patients' sound awareness, speech understanding in quiet and in noise, sound source localization, and QoL, while reducing tinnitus severity and no increase in dizziness severity.

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Th31a: INTERACTION OF ELECTRIC AND ACOUSTIC STIMULATION AND ITS EFFECT ON BINAURAL CUES AND SPATIAL RELEASE FROM MASKING

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Combined electric and acoustic stimulation (EAS) resulting from hearing preservation yields significant benefit for speech in complex listening environments as well as various spatial hearing benefits including localization and perception of interaural time difference (ITD) cues. Research has shown a significant correlation between ITD sensitivity and the degree of speech understanding benefit derived from preserved acoustic hearing in the implanted ear (Gifford et al., 2013, 2014). Having access to low-frequency fine structure timing cues may also drive binaural unmasking in complex noise environments. Cochlear implant signal processing does not faithfully convey ITD fine structure due to the low-pass filtering, half-wave rectification, and fixed pulse rates across channels. Onset ITD cues are similarly unreliable due to the lack of synchronization of pulses across ears and possibility for different channel and overall stimulation rates across ears. Individuals with hearing preservation in the implanted ear, however, have potential for access to both envelope and fine structure ITD information. The purpose of the current study was to further investigate the underlying mechanisms driving EAS benefit with respect to ITD sensitivity. Our hypothesis was that there would be a significant correlation between perception of fine structure ITDs and the degree of binaural unmasking of speech for CI recipients with acoustic hearing preservation.

We assessed speech understanding in a cocktail-party environment with target speech presented from zero degrees azimuth and distracters either co-located or separated at ±90 degrees. Both speech and signal-correlated noise maskers were tested to assess contributions of energetic and informational masking. Fine structure ITD thresholds were measured by presenting 250-Hz sinusoids with diotically-gated onsets and offsets, and an adaptive phase delay between ears. The contribution of spectral resolution from the acoustic hearing in each ear was also assessed by measuring psychophysical tuning curves centered at 250 Hz for each ear.

Preliminary results (n=2) showed that listeners obtained relatively little spatial release from masking for symmetrically-placed speech or noise maskers. Individuals with the lowest ITD thresholds and best spectral resolution tended to demonstrate greater spatial release from masking, though the largest benefit was observed in the bimodal condition rather than the EAS condition. ITD thresholds were not significantly correlated with EAS benefit in this cocktail party condition, which was 15-percentage points, on average. Release from informational masking of approximately 20-percentage points was obtained in both the bimodal and EAS conditions. It is possible that low-frequency interaural level difference cues, though small in magnitude and duration, are also contributing to the observed spatial hearing benefits observed thus far and may be weighted differentially depending on the listening condition. Data collection is ongoing and additional information will be gathered and presented. We anticipate data collection to be completed for 8 to 10 participants prior to the meeting.

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Th31b: LONG TERM MONITORING OF THE INNER EAR FUNCTION DURING AND AFTER COCHLEAR IMPLANT INSERTION USING COCHLEAR MICROPHONICS

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Introduction:
To preserve residual hearing during cochlear implant (CI) surgery it is desirable to use intraoperative monitoring during the electrode insertion. A promising method is the recording of cochlear microphonics (CM). The aim of the monitoring is to identify critical steps as well to modify the ongoing insertion procedure immediately if necessary. Within this project the relation between intraoperative recorded CMs and long term preservation of residual hearing shall be investigated.

Method:
During the insertion of hearing preservation electrodes, different modes of intraoperative CM recordings were performed. In one mode the potentials were recorded extracochlear using a cotton wick electrode at the promontory wall before, during and after insertion. In a second mode the potentials were recorded intracochlear directly after insertion and postoperative during the follow up appointments. These recordings were done using the CI electrode (MedEl) and a special software tool. The stimulation was done acoustically using insert earphones and tone bursts (250 Hz, 500 Hz, 1000 Hz). The follow up recordings are planned to take place up to one year after insertion. Up to now 10 patients are included who currently have passed diverse appointments.

Results:
Extracochlear recorded CMs showed peaks of maximal 0.5 µV in the according spectra for most patients. Intracochlear peaks of up to 30 µV were detected. In the first data, the amplitude of long term CMs seem to be in line with the audiometrical pure tone thresholds.

Conclusion:
The recording of CMs is very good possible with both methods. The amplitudes of intracochlear recorded CMs were detected to be much larger than the extracochlear recorded CMs.

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Th32: POSTOPERATIVE ELECTROCOCHLEOGRAPHY FROM HYBRID COCHLEAR IMPLANT USERS: AN ALTERNATIVE ANALYSIS PROCEDURE

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Objective: Shorter electrode arrays and soft surgical techniques allow for preservation of acoustic hearing in many cochlear implant (CI) users. For Nucleus Hybrid CI users, we can stimulate using an acoustic signal and use the Custom Sound EP software to record neural responses from an intracochlear electrode (Abbas et al., 2017). Unfortunately, the recording procedure is time consuming, limiting potential clinical applications. This report describes results obtained using more efficient recording technique we refer to as the “short window” recording method. In this report, our focus is on 1) assessing accuracy and stability of the recordings over time, 2) comparing results obtained using this more efficient method with results reported by Abbas et al. (2017), and 3) comparing these peripheral measures to audiometric thresholds in Hybrid CI users.

Method: Thirty-one postlingual adult Hybrid CI users participated in this study. 20 msec tone bursts were presented via an insert earphone at four frequencies (250, 500, 750, and 1000 Hz) and at several levels in both condensation and rarefaction polarities. The most apical electrode in the intracochlear array was used for recording. Recordings obtained using rarefaction and condensation tonebursts were subtracted to emphasize the cochlear microphonic (CM/DIF) and added to emphasize the auditory nerve neurophonic (ANN/SUM). Response thresholds were determined based on visual inspection of the time waveforms and peak-to-peak analysis techniques were used to quantify response amplitudes. Direct comparison of responses measured using both recording techniques were obtained for four subjects. Test-retest variance was measured for 13 subjects. Correlations between CM and ANN measures using the short window recording method and audiometric thresholds are based on measures obtained in all 31 study participants.

Results: Regardless of the recording method, CM/DIF responses were larger than ANN/SUM responses. Recordings using the more efficient short window method were similar to those obtained using the traditional recording method. Amplitude measures were stable over time for subjects with stable acoustic hearing. Four subjects experienced hearing loss after surgery, and showed increases in both CM/DIF and ANN/SUM thresholds and decreases in peak-to-peak amplitudes. Correlations between CM/DIF and ANN/SUM thresholds and audiometric thresholds at all four test frequencies were significant ($r2 = 0.4263$, 0.3395 at 250Hz; $r2 = 0.6479$, 0.5446 at 500Hz; $r2 = 0.6481$, 0.4048 at 750Hz; $r2 = 0.4048$, 0.8454 at 1000Hz; for CM and ANN, respectively). Differences between physiologic and behavioral thresholds were largest for low frequency tone bursts.

Conclusion: Generally, results obtained using this more efficient recording procedure were consistent with measures obtained using the traditional recording methods and were stable over time. Correlations between these evoked potential thresholds and audiometric thresholds were similar to those we have reported previously that were collected using the more time consuming method and were analyzed in the frequency domain (Abbas et al., 2017). Improving the efficiency of data collection is important if we want to record these acoustically evoked neural responses in clinical settings. The major limitation of this method is that peak-to-peak analysis of the CM/DIF and ANN/SUM waveforms can be challenging and subjective, particularly for small amplitude responses or responses where the periodicity in the recordings is not obvious.
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Th33a: A POTENTIAL PHYSIOLOGICAL CORRELATE OF ELECTRIC-ACOUSTIC PITCH MATCHING IN COCHLEAR IMPLANT USERS

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Some cochlear implant (CI) users to have enough residual hearing in the non-implanted ear to compare the pitch percepts elicited by electrical stimulation with those elicited by acoustic hearing. We propose to use the changes in pitch percepts elicited by a given electrode as a metric to examine the perceptual process in adapting to the frequency mismatch between acoustic stimulation and the characteristic frequency of neurons stimulated by the electrode in quest, after implantation. The goal of this study was to identify an objective physiological correlate of electric-acoustic pitch matching in unilaterally implanted cochlear implant (CI) participants with residual hearing in the non-implanted ear.

This study utilized a method of presenting electrical and acoustic stimuli that continuously alternated across ears using our real-time pitch matching platform that can be used with either Cochlear or Advanced Bionics (AB) CI patients. These stimuli were either matched or mismatched in pitch. Auditory Evoked Potentials (AEP) were obtained from 9 CI patients (3 AB CI patients and 6 Cochlear CI patients) using a Neuroscan system. The Cochlear CI patients received electrical stimulation in electrode 20 which is associated with a frequency band centered at 500 Hz in the clinical map and the other ear was stimulated with six different acoustic frequencies, ranging from 250 to 1000 Hz and including the frequency that was pitch matched to electrode 20 by each individual. The AB CI patients were stimulated in similar manner with electrical stimulation in electrode 3 which is associated with a frequency band centered at 540 Hz in the clinical map. Each pair of electric and acoustic stimuli was repeated 500 times and the evoked potential response to the onset of the acoustic stimulus was recorded.

The main findings were: 1) N1 latency in CI participants decreased when the acoustic frequency of tones presented to the non-implanted ear increased, and 2) there was additional shortening of N1 latency in the pitch-matched condition. The frequency-N1 latency data from each individual CI participant was also fitted to a non-linear exponential function. Both patterns were found to be statistically significant. This is our first attempt to explore the potential relationship between electroacoustic pitch matching and AEPs. N1 latency could potentially provide a neurophysiological correlate of pitch matching across ears in CI participants and may serve as a metric to monitor the adaptation process of CI users to their devices.

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Th33b: PITCH MATCHING BETWEEN EARS IN PATIENTS WITH NORMAL HEARING CONTRALATERAL TO A COCHLEAR IMPLANT

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Modern cochlear implants approximately replicate the tonotopy stimulation characteristic of normal hearing by providing high-frequency information in the basal region and low-frequency information in the apical region of the cochlea. Conventional cochlear implant recipients typically experience an improvement in speech perception abilities that plateau approximately 6 to 12 months after activation of the external audio processor. During this acclimatization period, recipients report sound quality changes, which may result from changes in pitch perception with electric stimulation. Cochlear implant users with normal hearing contralateral to the cochlear implant offer an opportunity to better understand the role of pitch perception in acclimatization. In this population pitch perception associated with the cochlear implant can be characterized via comparison with the normal-hearing ear. The present report investigated the pitch perception of 19 cochlear implant recipients with unilateral hearing loss over the first 12 months of listening experience. Evaluation intervals included one, three, six, and twelve-months post-initial activation. Pitch perception was evaluated on electrodes E1 through E5, which are associated with low-to-mid frequency information. Subjects listened with their audio processor, stimulated through the clinical programming software. Individual electrodes were continuously stimulated at 80% of the dynamic range in 300-ms bursts, with a 700-ms gap between bursts. Comparison stimuli in the contralateral (normal-hearing) ear were either bandpass filtered clicks or pure tones, presented via an insert earphone. The task was a two-alternative forced choice, where the subject indicated whether the comparison stimulus in the normal-hearing ear was higher or lower in pitch than the stimulus delivered to the cochlear implant, and the frequency content of the acoustic stimulus was adjusted to estimate a pitch match to the cochlear implant stimulus. Results for the majority of subjects were consistent with the Greenwood function at the 1-month interval for both the click and the tone stimuli. Performance was relatively stable within subjects through the 12-month interval.

This project was supported by a research grant from MED-EL Corporation.

Th34a: BILATERAL EFFECTS IN THE CENTRAL AUDITORY SYSTEM AFTER UNILATERAL COCHLEAR IMPLANTATION OF SINGLE-SIDE DEAFENED GUINEA PIGS

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Little is known about binaural interactions induced by simultaneous acoustic and electrical stimulation of the auditory system in patients with unilateral deafness. Since large differences exist between the loudness coding for electrical and acoustic hearing, plastic changes would be expected in structures which receive acoustic and electric input in binaural hearing. This study therefore, aimed to investigate the structural consequences of unilateral chronic intra-cochlear electrical stimulation within the ascending auditory pathway in an animal model.
Normal-hearing guinea pigs were single-side deafened by the insertion of a standard HiRes 90k® cochlear implant with a HiFocus1j electrode array into the first turn of the cochlea. Four to five electrode contacts were used for stimulation. Six weeks after surgery, the speech processor (Auria®) was programmed based on tNRI-values and mounted on the animal's back. Three experimental groups were stimulated with a HiRes strategy using stimulation rates of 275, 1500 or 5000 pulses per channel per second. The experimental groups' data were compared to a unilaterally deafened control (implanted but not stimulated). Experimental and control animals experienced a standardized free field acoustic environment (16 h/day). After 90 days of stimulation, cell densities were determined in the ascending central auditory pathway for the, cochlear nucleus, inferior colliculus, medial geniculate body and primary auditory cortex structures.

There was no correlation between the different stimulation rates and measured cell densities. However, stimulation intensity had a significant effect on cell density. The lowest intensity led to a bilateral preservation of cell density in the entire auditory pathway, whereas electrostimulation with the highest intensity induced a significant cell loss in the auditory brain structures investigated.

In conclusion, early unilateral cochlear implantation in single-side deafness is intended to support the restoration of homeostatic balance within the innervated neural network and preserve central auditory structures bilaterally. Stimulation at high intensity (also due to habituation) should be avoided to prevent adverse effects on neuronal properties.

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Th34b: PLACE-ADAPTED STIMULATION RATE CAN RESTORE THE TONOTOPIC RELATIONSHIP IN THE SECOND COCHLEAR TURN

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Introduction: There is an ongoing debate about the benefit of electrical stimulation using cochlear implants (CIs) with “long” electrode arrays, where distal electrodes can deliver information to apical parts of the cochlea. Poor pitch discrimination is expected with deeply inserted electrodes in addition to detrimental effects of “cross-turn” stimulation whereby electrical current flows to spiral ganglion neurons located 360 degrees basal to the apical point of stimulation. In this study, we investigate the effect of place adapted stimulation rate on pitch perception in CI users suffering from single-sided deafness (SSD) which received long electrode arrays.

Method: Pitch matching was conducted in 15 experienced SSD CI users implanted with 28 or 31 mm electrode arrays (Flex28 and FlexSoft, respectively; MED-EL, Innsbruck) and with normal hearing in the opposite ear . In the adapted rate condition, the rate of single-channel biphasic electrical stimulation was individually calculated by estimating intracochlear electrode locations (Stenvers view radiographs) and mapping them to place-frequency using a modified Greenwood function. In the fixed rate condition, a fixed rate of 800 pulses per second (pps) was used. Pitch matching was conducted for all 12 electrode channels where subjects’ task was to control and match the pitch of a sinusoid delivered by headphones to the normal-hearing ear to the CI ear with adapted or fixed rate of electrical stimulation. Initial acoustic frequency was selected randomly and stimulus presentation alternated between electrical and acoustical during the procedure. Pitch matching was repeated 6 times for each channel and condition.

Results: Estimated angle of insertion (AOI) varied for the most apical electrode between 400 and 650 degrees, with a median of 560 degrees. For electrodes located farther than 375 degrees, average pitch matching results in the fixed rate condition did not show the expected tonotopic relationship, whereas in the adapted rate condition, pitch matches appeared to correlate with the modified Greenwood function. In contrast, basal electrodes showed mismatches in both conditions and had a shallower slope compared with the Greenwood function. Pitch matching accuracy showed generally high variation between subjects as well as between each condition, while less variation was observed for apical electrodes in the adapted rate condition when compared with the fixed rate condition.

Discussion: Average pitch matching results obtained in SSD subjects suggest that fixed high rate stimulation in the cochlear apical region does not convey tonotopic pitch information. One possible explanation could be the mismatch between place and rate of stimulation as the origin of distorted pitch perception. The application of place-adapted stimulation rate can restore the tonotopic relationship in the second cochlear turn.

Th35a: LONGITUDINAL RESULTS FOR ADULT COCHLEAR IMPLANT RECIPIENTS WITH ASYMMETRIC HEARING LOSS

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Objective: Asymmetric hearing loss (severe to profound hearing loss [SPHL] in one ear and better hearing in the other ear) results in a lack of bilateral input and is detrimental to communication. Individuals with asymmetric hearing loss report difficulty with sound localization, speech understanding in noise, reduced sound quality and increased listening effort. Although study outcomes have been promising for implantation of the poor ear in adults with asymmetric hearing, results are limited by relatively few studies, small sample sizes and variations in test measures. This study objective was to evaluate behavioral outcomes and quality of life measures in a larger than previously reported group of individuals with asymmetric hearing who receive a cochlear implant (CI) in the poor ear and have a range of hearing asymmetry.

Design: Forty-seven post-lingual adults participated. Test materials included objective and subjective measures meant to elucidate communication challenges encountered by those with asymmetric hearing, i.e. testing at soft levels and in spatially separated noise, evaluating localization and quality of life. Testing occurred pre-implant and at 6 and 12 months post-implant. Pre-implant testing was completed in participants' Everyday Listening condition which varied by participant: bilateral hearing aids (HAs; n = 9), HA better ear (n = 29), no HAs (n = 9). Post-implant, each ear was tested separately and in the bimodal condition.

Results: Group mean longitudinal results in the Everyday listening condition pre-implant compared to 6 and 12 months post-implant (bimodal) indicated significantly improved sentence scores at soft levels and in noise, improved localization, higher ratings of perceived communication function by six months, and stable performance between 6 and 12 months. Group mean, 6-month post-implant results for all test measures were significantly better in the bimodal condition compared to either ear alone. The poor ear alone had significantly improved audibility and word recognition compared to pre-implant. CI alone performance correlated with six month, bimodal outcomes in noise but not quiet. Age at CI correlated with speech in noise and localization, onset of SPHL correlated with localization, and degree of hearing in the better ear correlated with all speech recognition measures but not localization. To provide clinical relevance and better understand the impact of better ear hearing on outcomes, participants were divided into three groups based on the better-ear pure-tone average (Group 1 PTA ≤ 40 dB HL; Group 2 PTA = 41-55 dB HL; Group 3 PTA = 56-70 dB HL). At the 6-month test interval, all groups showed improved localization and ratings of perceived communication. Groups 2 and 3 showed bimodal benefit on most speech recognition measures, and Group 1 showed no bimodal benefit for the speech recognition measures in this study.

Conclusion: Improved post-implant audibility and speech recognition was advantageous to these participants with asymmetric hearing. Benefits were evident by 6-months post-implant. Factors reported as significant for traditional CI candidates also impacted results for this population. In general, older recipients had poorer bimodal speech recognition in noise and localization abilities than younger recipients. Recipients with early SPHL onset had better bimodal localization than those with later SPHL onset, and recipients with longer SPHL duration had poorer CI-alone speech understanding in noise but not in quiet. Participants with more hearing in the better ear (Group 1), showed less bimodal benefit but greater bimodal performance for speech recognition than Groups 2 and 3. Sound localization and self-reports of communication benefit were significant and not related to better-ear hearing. Inclusion of sound localization and adaptive speech recognition measures with spatially separated noise in the test battery for individuals with asymmetric hearing is critical for capturing the deficits of hearing loss and benefits of treatment reported by this patient population.

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Th35b: SPATIAL RELEASE FROM MASKING IN ACTUAL AND SIMULATED BIMODAL AND SINGLE-SIDED DEAF COCHLEAR IMPLANT LISTENERS

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A growing number of cochlear implant (CI) users consist of contralateral acoustic hearing with either normal (single-sided deaf, SSD) or impaired audiometric thresholds (bimodal CI users). The access to additional acoustic hearing provides improvements in speech intelligibility, especially in spatial situations, which, however, is far from that of normal-hearing (NH) listeners. The goal of this study is to compare speech-in-noise performance between simulated and actual bimodal and SSD listeners using different spatial scenarios. A special focus is put on the benefit obtained from spatially separating speech and noise (spatial release from masking, SRM) and on the question to what extent better-ear-listening is present in each listener group.

Eight bimodal and eight SSD listeners participated in the experiment. The participants received the acoustic stimuli via audio cable to their own CI and contralateral using in-ear headphones. Speech reception thresholds (SRTs) were measured using an adaptive procedure with sentences in stationary noise with long-term speech spectrum. Three different noise azimuth angles and frontal speech incident were simulated using virtual acoustics.

Simulation of bimodal or SSD users has been realized by presenting twelve NH listeners with vocoder-processed speech. A further development of the vocoder of Williges et al. (2015) was used for simulating electric hearing, including signal processing details of two CI manufacturers, as well as the application of electric field spatial spread. Simulation of contralateral acoustic hearing has been realized using either unprocessed stimuli (unaided NH) or stimuli processed by a hearing aid algorithm in combination with a hearing impairment simulation.

Actual bimodal CI listeners showed poorer SRTs and higher inter-subject variability than actual SSD listeners. Within the simulations, SRTs were poorer for more severe acoustic hearing, but were very similar across the two simulated CI manufacturers. SRM was found to be 8 dB for bilateral NH, 3-4 dB for simulated and actual SSD and 2-3 dB for simulated and actual bimodal CI listeners. Comparisons of simulated with actual bimodal and SSD listeners revealed a very similar pattern of SRTs and SRMs, dominated by a better-ear-listening strategy with only a few exceptions, e.g., if the head shadow lead the two ears to have similar speech performance.

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Th36a: INTEGRATION OF ACOUSTIC AND ELECTRIC HEARING IS BETTER IN THE SAME EAR THAN ACROSS EARS

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Advances in cochlear implant (CI) technology allow for acoustic and electric hearing (AEH) to be combined within the same ear (electric-acoustic stimulation, or EAS) and/or across ears (bimodal listening). However, it is unclear whether acoustic and electric stimulation patterns are best combined within the same ear (EAS) or across ears (bimodal listening). The goal of this study was to evaluate factors that affect the integration of acoustic and electric hearing in EAS and bimodal listening modes. Vowel recognition was measured in normal-hearing subjects listening to simulations of unimodal, EAS, and bimodal listening. The input/output frequency range for acoustic hearing was 0.1-0.6 kHz. The output frequency range of the CI simulations was 1.2-8.0 kHz, similar to the limited extent of a short electrode array. The input frequency range for the CI simulations was varied to preserve different amounts of acoustic information while introducing different amounts of tonotopic mismatch. The CI input high-cutoff frequency was always 8.0 kHz. The CI input low-cutoff frequency was 0.2, 0.5, 0.8, or 1.2 kHz. When the CI input low-cutoff frequency = 0.2 kHz, there was maximal information within the CI, but with 9.8 mm of frequency mismatch at the apical end of the simulated electrode array; the CI input frequency range also greatly overlapped the AH input frequency range, meaning that information between 0.2 and 0.6 kHz would be delivered to different places in the cochlea. When the CI input low-cutoff frequency was 1.2 kHz, there was reduced information within the CI, but no tonotopic mismatch and no overlap between the AH and CI input frequency ranges.

In general, performance was best for EAS and poorest when the CI input low-cutoff frequency was 0.2 kHz. For unimodal listening, performance was significantly poorer only when the CI input low-cutoff frequency was 0.2 kHz; performance was similar but generally poor among the remaining simulations. Bimodal and EAS performance was significantly better than with AH or with the CI simulations when the input low-cutoff frequencies are 0.5 kHz or higher. Bimodal and EAS performance significantly worsened for CI input low-cutoff frequencies are 0.5 kHzor lower. Integration efficiency (IE; the ratio between observed and predicted AEH) is used to estimate how well acoustic and electric hearing are combined. In general, IE was significantly better for EAS than for bimodal listening; IE was sensitive to tonotopic mismatch for EAS, but not for bimodal listening. These simulation results suggest acoustic and electric hearing may be more effectively and efficiently combined within rather than across ears, and that tonotopic mismatch should be minimized to maximize the benefit of AEH, especially for EAS.

Th36b: COMPUTER MODELS SUGGEST OPTIMAL CHOICE OF CROSS-OVER FREQUENCY FOR IPSILATERAL ELECTROACOUSTIC LISTENER'S SPEECH INTELLIGIBILITY

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Preservation of ipsilateral residual acoustic hearing in cochlear implant (CI) users after surgery supports these electro-acoustic (EA) listeners with the benefits of two different stimulation modalities. However, it is currently unclear what the optimized cross-over frequency for each individual listener's speech intelligibility is. The cross-over frequency is the frequency which determines how the bandwidth of the input acoustic signal should be divided between acoustic modality and electric modality. Either the full frequency bandwidth of the input acoustic signal (overlapping map) or a restricted one (non-overlapping map) can be transferred to the CI. The audiogram alone does not seem to provide sufficient information to determine an optimized map. Therefore, in this study we aimed at investigating the effect of a factor that is less considered in this context, the spread of electric field (SoE) for the choice of different fitting maps.

A computer model of speech intelligibility (Zamaninezhad et al., 2017) based on an automatic speech recognition approach was used to create hypothetical EA-listeners. Two experiments were designed. The first experiment investigated which may be the optimal map for individual EA-listeners. Speech reception thresholds (SRTs) as a function of SoE for two different maps and two listening conditions (electric-only and electro-acoustic) were predicted. The results showed improved SRTs with the non-overlapping map for listeners with large SoE, who consist of sufficient residual hearing above 500 Hz. This result was found for both electric-only and for electro-acoustic listening condition. For small SoE, performances with the two different maps were comparable.

The second experiment investigated the underlying reason for these differences in SRTs due to different fitting maps at large SoE. Therefore, the speech information in different frequency channels was systematically distorted by time de-synchronization with respect to other channels. In the overlapping map, this distortion did not affect speech intelligibility, showing that these channels were not important contributors due to large channel interaction. In the non-overlapping map (using a subset of electrodes) the time de-synchronization decreased speech intelligibility. This indicated that channels of the non-overlapping map are less interacted than in the overlapping map, providing more reliable speech cues.

Th37a: REDUCTION IN HAIR CELL LOSS AFTER COCHLEAR IMPLANTATION FOLLOWING PRE-TREATMENT BY NEAR-INFRARED-LIGHT

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The protection of residual hearing is becoming increasingly important in cochlear implant (CI) surgery. Various drug based approaches have been investigated for the prevention of cochlear apoptosis/necrosis. Physical intervention is a technique currently under investigation. Specific wavelengths within the near-infrared light (NIR)-spectrum are known to influence cytochrome-c-oxidase activity which leads in turn to a decrease of apoptotic mechanisms. It has been shown previously that NIR can decrease the cochlear hair cell loss significantly if applied daily after noise exposure. Recently, studies by our group indicated that even a single NIR-pre-treatment has the ability to reduce auditory threshold shifts and rescue cochlear sensory tissue when applied immediately before loud sound exposure. Therefore, the present study investigated the efficacy of a single NIR pre-treatment before cochlear implantation in an animal model.
During a cochlear implant surgery, normal hearing adult guinea pigs had one cochlea pre-treated with NIR-light (808 nm, 120 mW) for 15 minutes. Immediately after light exposure, a CI electrode array, specifically designed for guinea pigs, was inserted through a cochleostomy into the scala tympani of the first cochlear turn. The contralateral ear received a similar treatment (CI insertion) but was sham-exposed only and served as an intra-individual control.
Four weeks after implantation, outer hair cell loss was measured in histological cochlear samples and data were compared between the two ears (with or without NIR pre-treatment) in each animal.

The data demonstrate that hair cell loss was significantly reduced in NIR-pre-treated ears compared to the contralateral side (implanted only). Moreover, it could be shown that the effect appeared to be most prominent particularly in the first turn of the cochlea, representing the area of highest mechanical impact during electrode positioning.

Our results suggest that a very effective protection of cochlear structures is possible during cochlear implantation by a single NIR pre-treatment. A 15 minute 120 mW application appears to be an effective dosage. The results could be of high relevance for the protection of residual hearing in otoneurosurgery.

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Th37b: HEARING PRESERVATION COCHLEAR IMPLANTATION WITH DIFFERENT TYPES OF ELECTRODES

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Background:
Atraumatic lateral wall FLEX electrodes (MED-EL, Austria) with different lengths (16mm, 20mm, 24mm and 28mm) were designed for hearing preservation surgeries. This variety of electrodes allows an individual cochlear implantation meaning a patient specific choice of electrode length based on residual hearing and cochlea geometry.
The 16mm electrode was especially designed for patients suffering from high-frequency hearing loss with insufficient speech understanding in noise and a stable good hearing in low-frequencies. By preserving the low-frequency hearing for an acoustic stimulation and stimulating the high frequencies electrically the patients can benefit from combined electric and acoustic stimulation (EAS).

Methods:
At the Hannover Medical University implantation of FLEX electrodes were performed in over 400 cases. To document hearing preservation outcomes, differences between the pre- and postoperative unaided air-conducted pure tone thresholds (PTA) in low frequencies (125Hz..1.5kHz) were determined in N=152 patients treated with FLEX16 (n=12), FLEX20 (n=56), FLEX24 (n=34) or FLEX28 (n=40). To evaluate hearing performance HSM sentence test in noise (10 dB SNR) was performed at 6 months of device use.

Results:
The median hearing loss at first activation was 12.5 dB for FLEX16 (n=12), 18.0 dB for FLEX20 (n=56), 20.0 dB for FLEX24 (n=34) and 24 dB for FLEX28 (n=40).

The group of patients with very good hearing preservation (HL≤15 dB) was 58 % for FLEX16, 41 % for FLEX20, 29 % for FLEX24 and 15 % for FLEX28. At 6 months the median hearing loss was 9 dB for FLEX16 (n=7), 14 dB for FLEX20 (n=42), 16 dB for FLEX24 (n=30) and 27.5 dB for FLEX28 (n=32).

At 6 months, EAS users achieved a median score in HSM in noise of 88 % with FLEX16 (N=5) and of 59 % with FLEX20/FLEX24 (N=14) electrodes. Patients using ES-only achieved 25% with FLEX20 (N=23) and 45% with FLEX24 (N=24) electrodes; with a longer FLEX28 electrode (N=35) significant better results of 53% were achieved.

Conclusion:
Hearing preservation is possible throughout all FLEX electrode lengths. Good hearing preservation rates were achieved with FLEX16 and FLEX20 electrodes. In electric-acoustic stimulation, very good hearing performance results can be achieved. Patients with high-frequency hearing loss and very good low-frequency hearing and preservation achieved excellent results in EAS, when treated with FLEX16.

ES patients with a longer electrode (FLEX28) showed the best speech results in quiet and in noise compared to patients with shorter electrodes (FLEX20, FLEX24).

Th38a: RANDOMIZED CONTROLLED TRIAL ON COCHLEAR IMPLANTATION VERSUS CONTRALATERAL ROUTING OF SOUND SYSTEMS AND BONE CONDUCTION DEVICES FOR SINGLE-SIDED DEAFNESS

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Background:
Speech perception in noise and directional hearing is degraded in patients with single-sided deafness (SSD). Moreover, they frequently suffer from tinnitus and may have a lower quality of life (QoL). Current treatment modalities (Contralateral Routing of Sound systems [CROS] and Bone Conduction Devices [BCD]) often do not sufficiently help these patients. A cochlear implant (CI) seems a promising treatment for SSD based on low-Level-of-Evidence studies. Our aim is to evaluate treatment options for SSD in a Randomized Controlled Trial (RCT).

Patients and methods:
Adult SSD patients were randomized into one of three groups: 1) CI, 2) trial period of ‘first BCD, then CROS’ or 3) trial period of ‘first CROS then BCD’. After the trial periods, patients chose their most beneficial treatment: CROS, BCD or No treatment. Outcomes of interest were changes between baseline and 3 months follow-up (‘FU3m’) on speech perception in noise (speech directed to the poor ear - noise to the better ear (SpeNbe), vice versa (SbeNpe) and both from front (S0N0)) and sound localization (15°, 30° and 60° angle between loudspeakers). Furthermore, tinnitus burden and disease-specific QoL were measured using several questionnaires.

Results:
The results of 47 patients after 3 and 6 months follow-up are presented (CI n=11; BCD n=3; CROS n=15; No treatment n=16). In SpeNbe, patients with CI and CROS had significantly improved speech perception. However, patients with a CROS experienced a significant deterioration in the SbeNpe configuration. In S0N0, no significant differences were observed. For sound localization, there was a significant increase for only the CI group. Moreover, there was a significant decrease in tinnitus burden for the CI group at FU6m compared to baseline, and compared with the CROS group and No treatment group. The improvement on disease-specific QoL questionnaires at FU6m compared to baseline was largest in the CI group.

Conclusions:
Our RCT demonstrates that cochlear implantation could be a good treatment option for adult SSD patients improving speech perception in noise, sound localization, tinnitus burden and QoL.

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Th38b: THE SOUND OF A COCHLEAR IMPLANT INVESTIGATED IN PATIENTS WITH SINGLE-SIDED DEAFNESS AND A COCHLEAR IMPLANT

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Background:
A cochlear implant (CI) restores hearing in patients with profound sensorineural hearing loss by electrical stimulation of the auditory nerve. It is unknown how this electrical stimulation sounds. Patients with single-sided deafness (SSD), who have normal hearing in one ear and were implanted with a CI in their deaf ear, can compare the sound of their CI to simulations of the CI sound played to their normal hearing ear. In our study with SSD patients, we aimed to answer the intriguing question: ''What does a CI sound like?''.

Patients and methods:
We examined 10 SSD patients implanted with a CI of Cochlear Ltd. We tested six stimuli (Speech: female Dutch speaker, male Dutch speaker, female English speaker and unintelligible speech; Music: guitar and piano). In Phase I, patients listened to the original stimulus (presented from a loudspeaker) with their CI ear while their normal hearing ear was masked. We asked if they could identify the gender of the speaker, or the musical instrument. In Phase II, patients listened to two CI simulations (created with a vocoder) with their normal hearing ear alone. They selected which of the two CI simulations had greatest similarity to the sound as perceived by their CI ear, and they provided grades for similarity (on a scale 1 to 10). We tested three different vocoder scripts: two vocoder scripts from literature and one vocoder script from the CI company. Furthermore, two different carriers (noise, sine) and several frequency bands were tested for each vocoder script.

Results:
Listening with their CI, patients were generally able to identify the gender of the speaker and musical instrument. Carrier noise and the vocoder scripts from literature were most often selected as best match to the sound as perceived by the CI ear. Patients generally selected broad frequency bands. The average grade for similarity was 6.8 for speech stimuli and 6.3 for music stimuli. We did not observe a correlation between the choice for vocoder scripts or carriers and patient characteristics.

Conclusions:
Based on the patients' grades for similarity of the CI simulations, we have a fairly good idea of what a CI sounds like to our patients. We will present some of the sound files that were rated with the highest similarity scores. Furthermore we will present future directions of this research, that are directed to longitudinal follow up of patients.

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Part of the costs of this study is funded by Cochlear Ltd. as a non-restrictive research grant.

Th39: ELECTROPHONIC AND ELECTRONEURAL RESPONSE IN THE INFERIOR COLLICULUS

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Electric stimulation of a hearing cochlea generates hair-cell responses (electrophonic, EP) as well as direct neural responses (electroneural, EN). EP responses appear at the dominant frequency component of the electrical stimulus time function while EN responses appear at the cochlear position of the active electrode (Sato et al., 2016, J Neurosci). To investigate the characteristics of these two responses, normal hearing guinea pigs were implanted with a cochlear implant through a cochleostomy keeping most of the hearing intact. A Neuronexus double-shank 32-channel electrode array was stereotactically placed within the inferior colliculus parallel to the tonotopic axis. The electrical stimuli were single, charge-balanced biphasic electric pulses (100μs/phase). Threshold and onset latency were computed from local field potential and multiunit activity in the midbrain. The cochlea was subsequently deafened with the implant left in place. Post stimulus time histograms (PSTH) before and after deafening were compared.

The thresholds for responses to cochlear implant stimulation were compared at the characteristic frequency (CF) of dominant EP response (near 5 kHz) and at the CF of dominant EN response (9.5 kHz). The threshold of EP response (threshold in hearing condition, mean 45.2±2.6 dB att., 0dB att. ~ 10 mA pp) was significantly lower than the threshold of EN response (threshold in deafened condition, 30.5±5.1 dB att.). The mean onset latency at EN thresholds (i.e. threshold in deafened condition) was 5.2±0.4 ms in CF ~ 5kHz and 4.6±0.6 ms in CF=9.5kHz. At the current level of EN thresholds in hearing condition (i.e. before deafening) the mean latency was 3.9±0.4 ms in CF ~ 5kHz, 3.4±0.0 ms in CF=9.5kHz. Consequently, EN response is observed at high suprathreshold levels (i.e. at the stimulus level lower than 30 dB att.) in hearing condition and has shorter onset latency. The mean onset latency at EP threshold (i.e. threshold in hearing condition at the CF near 5kHz) was 6.6±1.5 ms, significantly longer than at EN threshold. The mean onset latency in hearing condition in CF=9.5 kHz, the place of the dominant EN response, was 5.8±1.5 ms. The comparison of mean peak latencies showed similar tendency as onset latencies.

The long onset latency of the response at 5 kHz region in hearing condition confirms that this response is predominantly hair-cell-mediated (EP). A direct neural response with correspondingly short latencies (EN), on the other hand, was observed regardless of the CF in deafened condition, and also in the hearing condition at high stimulus levels. The short latency response in the hearing cochlea at stimulus levels below the threshold of the deaf condition suggests that the direct neural stimulation has lower threshold in the hearing cochlea. The latency data confirm that EP response dominates at the place of dominant temporal information and is responsible for lower electrical thresholds in the hearing condition.

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Th40a: EFFECT OF FREQUENCY COMPRESSION ON SPATIAL HEARING OF BIMODAL LISTENERS

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OBJECTIVES. The present study aimed to investigate the effect of frequency compression on spatial hearing of eight bimodal listeners, using a cochlear implant (CI) and a contralateral conventional hearing aid (HA).

INTRODUCTION. Typically, bimodal users have poor spatial hearing, as they have no or only poor access to the two primary acoustic cues for horizontal sound localization: interaural time- and level differences (ITDs and ILDs). ITDs are poorly accessible because of the inability of the CI to provide fine structure of a sound signal, while ILDs are poorly transmitted because of poor high-frequency residual hearing in the non-implanted ear. Frequency compression of high frequency information in the HA into the audible low-frequency range might potentially enhance ILD cues, and thus help improve spatial hearing abilities of these listeners.

DESIGN. Two experimental frequency compression (FC) algorithms were applied in the Phonak Naida S IX UP hearing aids of eight bimodal listeners: a static FC algorithm, that compressed all of the incoming sound, and a signal-adaptive FC algorithm, that compressed only the consonants while preserving the vowels. Smaller compression ratios between 1.45 and 2.7 were applied compared to compression ratios of up to 4 used in previous studies. Owing to the limited residual hearing extremely low knee-point frequencies of 160 Hz and 480 Hz were chosen based on an individual's hearing loss in order to double the audible bandwidth. Absolute sound localization performance and speech understanding in noise (S0N0) were tested for all three listening conditions (no FC, static FC, adaptive FC). Static FC was tested after an acclimatization period of 2-4 weeks, while adaptive FC and no FC were tested acutely.

RESULTS. The bimodal listeners localized broadband, high-pass and low-pass sounds in the horizontal plane poorly independent of the frequency compression. Mean absolute error of more than 40 degrees was found. A bias dominated by the better ear is observed in the sound localization response. Under standard bimodal settings participants localized high pass and broadband sounds towards the cochlear implant and low pass sounds towards the ear having the hearing aid; however, two participants localized high pass sounds towards the hearing aid and low pass sounds towards the cochlear implant ear after the application of frequency compression. An ILD model predicting the sound localization bias was developed based on the aided thresholds in both ears. Speech reception thresholds (50% correct) with mean SNRs of 4.2 dB, 5.6 dB and 5.2 dB were found with no FC, static FC and adaptive FC respectively.

CONCLUSION. Localization was poor and did not improve with static or adaptive frequency compression. It is therefore concluded that frequency compression did not improve access to ILDs. Overall, the bimodal benefit for speech understanding in noise was not affected by frequency compression, even in the static version that distorted the harmonic content of vowels.

Th40b: EFFECTS OF COMPRESSION IN VOCODER SIMULATIONS OF COCHLEAR IMPLANTS FOR SINGLE-SIDED DEAFNESS IN VIRTUAL COCKTAIL PARTY ENVIRONMENTS.

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A cochlear implant (CI) can improve speech perception in noise for listeners with single-sided deafness (SSD) by providing access to the ear with the better signal-to-noise ratio (head-shadow benefit) or by providing spatial cues for the perceptual separation of concurrent talkers (contralateral unmasking). Because CIs do not relay temporal fine structure information, both effects are likely mediated by contrasts between the interaural level differences (ILDs) associated with target speech and interference originating from different spatial locations. Due to processing constraints and the characteristics of the electrode-neural interface, CIs have a reduced dynamic range and abnormal loudness growth compared to an acoustic ear, which are likely to distort ILDs and alter the speech-perception benefits experienced by SSD-CI listeners. This study investigated how amplitude compression and expansion could affect contralateral unmasking and head-shadow benefit using vocoder simulations of SSD-CI listening presented to normal-hearing listeners.

Head-related transfer functions (HRTFs) were used to simulate free-field listening for seven normal-hearing listeners. For the left ear, non-vocoded signals were processed using a pinna HRTF. For the right ear, signals were processed with a behind-the-ear microphone HRTF, then with an eight-channel noise-vocoder. Experiment 1 (contralateral unmasking) presented target speech from an azimuth of 60º on the left (non-vocoded) side and two same-gender interfering speech from 60º on the right (vocoded) side. Experiment 2 (head shadow) examined the converse arrangement, with target speech presented on the vocoded side. Instantaneous compression or expansion was applied independently to the envelope in each vocoder channel. Five compression ratios were tested: 0.25 and 0.5 (compression), 1 (linear) and 1.5 and 2 (expansion). Speech-identification performance for coordinate response-measure sentences was evaluated over a range of target-to-masker ratios in both monaural (non-vocoded ear only) and bilateral configurations.

Results showed a negative effect of compression in both experiments, with compression more deleterious in the head-shadow case. Expansion slightly increased contralateral unmasking but decreased the head-shadow advantage. The negative effects of compression can be understood in terms of a reduced relative level difference between the target and maskers in the vocoded ear. While we hypothesized that expansion would have an opposite (beneficial) effect, this was only slightly borne out in the contralateral unmasking case, while expansion hurt performance in the head-shadow case. It is likely that envelope distortion corrupted the available speech cues, which was especially deleterious in the head-shadow case were listeners rely more heavily on hearing the target speech in the vocoded ear. Taken together, these results suggest that if compression could be altered in such a way as to not distort critical speech cues, this could be a potential parameter to optimize clinically to improve speech perception in noise for SSD-CI listeners.

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Th41: THE INCONSISTENCY OF DIFFERENT MEASURES OF INTERAURAL PLACE-OF-STIMULATION FOR COCHLEAR-IMPLANT USERS WITH SINGLE-SIDED DEAFNESS.

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Current clinical practice in programming a cochlear implant (CI) for individuals with single-sided deafness (SSD) is to maximize the transmission of speech information, with the implicit assumption that this will also result in improved spatial-hearing abilities. However, binaural processing is very sensitive to interaural place-of-stimulation mismatch, a likely occurrence with a standard CI frequency-to-electrode allocation table. As a step toward reducing interaural mismatch, this study compared two psychoacoustic methods for estimating the interaural place-of-stimulation mismatch for SSD-CI listeners: interaural-time-difference (ITD) and pitch discrimination.

Four SSD-CI listeners (11 electrodes) were tested in both pitch and ITD discrimination. ITD discrimination was measured by presenting 500-ms bursts of 100-pulses-per-second (pps) electrical pulse trains to a single CI electrode and bandlimited pulse trains with variable carrier frequencies to the acoustic ear. Listeners discriminated between two “reference” intervals (four bursts each with constant ITD) and a “moving” interval (four bursts with variable ITD). Interaural pitch discrimination was measured by presenting pure tones or 25-pps acoustic pulse trains with variable carrier frequencies to the acoustic ear and 900- or 25-pps pulse trains to a single CI electrode. Listeners judged whether the pitch of the acoustic stimulus was higher or lower than the pitch of the electric stimulus, with the 50% point (equal likelihood of higher or lower) taken to be the acoustic frequency representing the pitch match. Three acoustic-stimulus frequency ranges were used for each electrode to control for non-sensory biases.

For most of the electrodes tested, there was a clear peak in the function describing the relationship between ITD-discrimination performance and acoustic carrier frequency. This peak occurred on average 0.42 octaves above the standard CI frequency allocation (range: −0.5 to 0.9 octaves). The pitch-discrimination data showed a substantial effect of the acoustic-stimulus frequency range, suggesting a non-sensory bias (i.e., monaural assessment of pitch) rather than an interaural pitch comparison. On average, the pitch-discrimination estimates of electrode position were 0.6 octaves lower than the ITD estimates and were 0.18 octaves below the standard frequency allocation.

The repeated observation of frequency-range effects for the pitch-discrimination estimates in our SSD-CI users may preclude determining the intracochlear place-of-stimulation using pitch-discrimination tasks. ITD discrimination was a more promising method of estimating intracochlear place-of-stimulation, yielding performance peaks that for most listeners and electrodes were consistent with the expected upward frequency shift relative to a standard CI frequency-to-electrode allocation.

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Th42a: SHEEP AS A LONG-TERM SURVIVAL MODEL FOR HEARING PRESERVATION COCHLEAR IMPLANT EVALUATION: PILOT ELECTROPHYSIOLOGICAL OUTCOMES

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OBJECTIVES: Cochlear implant (CI) candidacy criteria have relaxed and CI electrode array designs have improved in the last decade. Insertion trauma can be minimized and acoustic low-frequency hearing can be preserved in the implanted ear with the use of both short and long electrode arrays (van Abel et al, 2015; Gantz et al, 2016; Hunter et al, 2016; Scheperle et al, 2017). Here we describe preliminary surgical, electrophysiological, and histological experiences using sheep as a model for long-term assessment of hearing preservation cochlear implants. We specifically focus on electrophysiological findings, as detailed imaging and histological analysis is pending.

PRODECURE: Six adult female Suffolk sheep were implanted with standard length cochlear implants at limited insertion depths. Prior to surgery, cochlear microphonics (CMs) and auditory brainstem responses (ABRs) were obtained using subdermal needle recording electrodes placed on the mastoid. Stimuli were high-level tone bursts from 1000 to 32000 Hz. Subsequently, a mastoidectomy was performed. The round window was exposed by retrofacial approach. A ball recording electrode was then placed at the round window (RW) niche and used to obtain cochlear microphonics (CMs) and auditory nerve neurophonics (ANNs) for 40 millisecond tones from 1000-32000 Hz. The cochlear implant electrode array was then advanced through the RW membrane. The RW ball electrode was once again used to record CMs and ANNs. Subsequently, the RW electrode was removed and fluoroscopy was used to confirm placement of the electrode array. Upon closure of the surgical incision, CMs and ABRs were obtained via the subdermal needle electrodes. At 30 days post-operatively, CMs and ABRs were again obtained via subdermal needle electrodes. Fluoroscopy confirmed stability of electrode placement. Animals were euthanized, and their cochleae are currently undergoing histology.

RESULTS: Implants were successfully inserted at depths ranging from 10 to 12 mm prior to resistance. Intraoperative CMs and ANNs were successfully obtained for all cases. In some cases, CMs and ANNs were reduced post-implantation, possibly reflecting immediate changes in cochlear mechanics and/or insertion trauma. CMs using surface electrodes were obtained for all three time points (pre-op, immediately post-op, and 30 day); however, ABRs could not reliably be measured. Similar to RW recordings, reductions in CMs were evident in some cases. The reduction in CMs at the 30 day time-point may reflect longer term changes in cochlear status. Imaging and histological analysis is pending but will be compared to electrophysiological data.

CONCLUSIONS: These preliminary findings suggest that Suffolk sheep are a feasible large animal, long-term survival model for hearing preservation implants and assessment of hearing changes over time. The combination of electrophysiology, imaging, and histology data can potentially provide information regarding cochlear hair cell and neural health post-implantation.

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Th42b: RELATIONSHIP BETWEEN POST-OPERATIVE ELECTROCOCHLEOGRAPHY AND GENETIC PHENOTYPE IN HYBRID COCHLEAR IMPLANT USERS

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OBJECTIVE: The OtoSCOPE® platform sequences all genes known to cause non-syndromic hearing loss and non-syndromic hearing loss mimic genes (Shearer et al., 2013). These genetic variants can affect cochlear hair cells and/or spiral ganglion cells and account for some of the variance in cochlear implant (CI) outcomes (Shearer et al., 2017). For CI users who present with residual acoustic hearing in the implanted ear, electrocochleography (ECoG) can be recorded from an intracochlear electrode in response to an acoustic tone burst (Campbell et al., 2013; Abbas et al., 2017; Koka et al., 2017). The ECoG reflects contributions from both hair cells and spiral ganglion cells and as such, may inform the genetic phenotype. In this preliminary report, we compare results of ECoG testing with the site of lesion (hair cell vs neural) indicated by results of genetic testing.

PRODECURE: Genetic testing was performed on 46 postlingually deafened Nucleus Hybrid CI users who presented with residual acoustic hearing in the implanted ear. Five users were diagnosed with a genetic variation in a gene expressed in hair cells (TMC1, KCNQ4, MYO15A, MYO6, and LOXHD1). Three other users carried deleterious variants in the TMPRSS3 gene, which is expressed in spiral ganglion cells. ECoGs were recorded in all 8 subjects in response to a 500-Hz tone burst presented at maximum acceptable levels at low and high stimulation rates (procedures detailed in Abbas et al., 2017). Separate recordings for rarefaction and condensation polarity tone bursts were performed. Subtracting the two recordings from one another emphasizes the cochlear microphonic (CM), reflecting primarily hair cell responses. Adding the two waveforms minimizes the CM and emphasizes the auditory nerve neurophonic (ANN), biased towards the neuron. Recognizing that these techniques do not cleanly separate the CM and ANN from one another, we refer to the CM response as the “DIFF” response and the ANN response as the “SUM” response.

RESULTS: We compared results of electrophysiologic testing, genetic diagnoses, and speech perception between groups. For the neural (TMPRSS3) group, we hypothesized that SUM amplitudes and SUM/DIFF ratios are smaller, reflecting low neural responses, and that increasing stimulation rate leads to greater adaptation of neural responses. The clinical correlate is hypothesized to be low speech perception scores. Individual and group results are discussed in context of these hypotheses.

CONCLUSIONS: These proof-of-principle data suggest that intracochlear electrophysiologic measures may provide a more detailed phenotype than previously available and thereby offer insight into site of lesion for individual Hybrid CI users.

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Th43: SINGLE-SIDED DEAFNESS PATIENTS TEACH US WHAT A COCHLEAR IMPLANT SOUNDS LIKE

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What does a cochlear implant (CI) sound like? The answer to this seemingly simple question has been elusive, perhaps because verbal descriptions of sound quality can only provide a limited sense of the subjective experience. With the increase of CIs in patients who have near perfect hearing in the unimplanted ear (“Single-sided deafness” or SSD), a unique opportunity has presented itself to answer this question. We can now ask SSD CI users to compare speech sent to the implant to speech processed by an acoustic model of a CI (noise or tone vocoder) delivered only to the normal hearing ear. Then we can ask patients to adjust parameters of the acoustic model until it sounds as similar to the CI as possible. The parameter selections made by different listeners can provide important insights about the nature of auditory plasticity after cochlear implantation. We also take advantage of the SSD population to assess the similarity between CI and acoustic models, in an effort to validate these models which have been used so extensively in cochlear implant research.

Eighteen SSD subjects were tested with an acoustic model selection tool that sends a recorded sentence to the listener’s CI via direct audio input, and then the same sentence is processed through an acoustic model and presented to the normal hearing ear. In all versions of the tool, the input filter bank has the same exact, fixed frequency range as the subject’s speech processor. What’s adjustable is the frequency range of the tones or noise bands used in the output stage. Version 1 of the tool allowed subjects to modify the low- and high-frequency edges, and whether the output consisted of tones or noise bands. Version 2 of the tool added a third adjustable parameter, channel interaction, where possible values were 0 (for tones), 0.5 (non-overlapping noise bands), 1 (adjacent noise bands), 2, 4, and 8 (for noise bands with greater amounts of overlap). Subjects explored the parameter space until the model sounded as similar as possible to the percept provided by the CI, resulting in a “self-selected” (SS) model. We used speech perception measures and subjective ratings to evaluate the similarity between various acoustic models and the CI. The evaluation included SS models (whose tones or noise bands may be mismatched in frequency with respect to the analysis filters) and “standard” models whose analysis filters and tones or noise bands are frequency-matched. There were two types of standard models, one with 6 channels, and one with the same number of channels as in the clinical device.

Most subjects were able to find acoustic models that were deemed reasonably similar to the CI both in terms of subjective ratings and speech perception scores. Taken together, the SS models were a better match to the CI than either type of standard model. On the other hand, 6-channel standard models were rated as quite different from the CI, even when speech perception scores were similar. With very few exceptions (which tended to be patients with deeper electrode insertions) the low frequency edges of SS models were higher than those of the clinical filter banks.

In conclusion, none of the acoustic models we tested were perfect. However, there is evidence that SS acoustic models that both “sound like the implant” and result in roughly similar speech perception scores as the CI can be determined. In addition, results about the low frequency edge suggest incomplete adaptation to clinical frequency table settings for many patients. Overall our study suggests that the widely used standard acoustic models provide inaccurate representations of the percepts actually heard by some cochlear implant users. Further testing is needed to determine what possible acoustic model might be a more appropriate representation of how a cochlear implant sounds.

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Th44a: ADAPTATION TO FREQUENCY-PLACE FUNCTIONS IN SINGLE-SIDED DEAFNESS LISTENERS

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Cochlear implants (CIs) impose a frequency-place function that may not match the correct physiological one, that is, the one postlingually deaf patients experience before losing their hearing. This frequency mismatch problem may be mitigated by a listener’s adaptability to novel sensory input. This adaptation process can be investigated behaviorally in patients with residual hearing, for example by performing pitch matching experiments that aim to find the acoustic pitch associated with stimulation of a given electrode. The availability of single-sided deafness (SSD) patients provides a new and improved opportunity to characterize the post-implantation adaptation process, because the normal hearing in the contralateral ear provides a well-calibrated reference. In this study we use three different behavioral methods to assess adaptation to frequency-place functions in SSD patients.

The Vowel Space method utilizes a two-dimensional grid where each point is associated with a different vowel. First and second formant change gradually across the x and y axes. The task is to find the regions in the grid that correspond to different vowel targets (/i/, /a/, and /u/). This is done with the CI ear only, and results are compared within-subject to those obtained using the same subject’s normal ear. The Acoustic Model Selection method allows the listener to select the frequency of the noise bands or tones in an acoustic model that is adjusted to sound as similar as possible to the implant. Lastly, a traditional adaptive method is used to determine the psychometric curve describing pitch ranking between a given intracochlear electrode and tones of different frequencies. All three methods were used longitudinally in SSD patients whose mean hearing thresholds in the non-implanted ear were less than 25dB HL for frequencies 250-4000Hz. Depth of insertion of the electrode array was estimated for each patient using intraoperative x-rays.

The results varied greatly, some subjects showed complete adaptation to the expected frequency table in their sound processor within a few months while others did not. In the case of the subject with the deepest electrode insertion, measures obtained one week post-initial stimulation showed very little frequency mismatch, making adaptation unnecessary. Another subject showed evidence of frequency mismatch that was not, however, compensated by adaptation over time.

There is clear evidence of frequency-place mismatch in many postlingually deaf patients shortly after implantation, which seems to be influenced by electrode location (deeper insertion=less mismatch) and by experience (longer length of CI experience=less mismatch). We cannot be sure that adaptation is always complete, and at least some individuals show little evidence of adaptation in response to frequency mismatch. One important caveat is that SSD patients may be less motivated than traditional CI patients to adapt to frequency mismatch. This is because the latter may depend on that adaptation process to improve communicative outcomes whereas the former can use oral communication very successfully based on the normal hearing ear. Nonetheless, this new clinical population (SSD patients) is providing important insights into the way humans adapt to a modification in their peripheral sensory input.

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Th44b: THE SOUND SENSATION OF ELECTRIC STIMULATION IN SINGLE-SIDED DEAFENED COCHLEAR IMPLANT RECIPIENTS

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In a previous study, the sensation evoked by the most apical electrode was characterized in cochlear implant (CI) recipients with contralateral residual hearing. Psychoacoustic evaluation of the percept involved fundamental frequency (F0), filter characteristics and harmonicity factor using an original multidimensional sound quality judgment task. This experiment was extended to CI users with single-sided deafeness (SSD) and to an apical (e20) and a medial (e14) electrode.

Ten unilateral CI users with SSD were asked to vary the parameters of an acoustic sound played to the normal-hearing ear, in order to match its perception with that of the electric sensation of e20 and e14. The experiment was divided in three consecutive conditions in which the nature of the acoustic sound and the controlled parameters varied. In the first condition the subject had to vary the frequency of a pure tone. In the second condition, the subject varied the center frequency and the bandwidth of a filter applied to a harmonic complex sound which F0 was determined by the result of the first condition. In the last condition, the subject had to vary F0 and the harmonicity factor of a complex sound processed through the bandpass filter determined during the second condition.

Six subjects performed the experiment at three and twelve months after activation to evidence a possible effect of brain plasticity. One subject performed the three-month session only, and three additional subjects performed the twelve-month session only.
Results were compared using a mixed-linear model.

Averaged F0 of the pure tones matching e20’s and e14’s pitch were significantly different ($p=0.02$, 506 Hz and 901 Hz respectively). In the second condition, the average center frequencies of the band-pass filters were 864 and 2.85 kHz for e20 and e14, respectively ($p<0.005$); the Q-Factors, respectively 6.2 and 6, were not significantly different ($p>0.05$). In the third condition, the average F0s were 307.5 Hz and 433 Hz for e20 and e14; the harmonicity factor was 1.7 for both electrodes. In this latter condition no significant effect of electrode place was found ($p>0.05$). A significant effect of session was observed between three and twelve months only in the third condition for F0.

The results of the first condition confirmed that the pitch sensation induced by a pulse train follows the tonotopy of the basilar membrane when matched with a pure tone. However, this frequency cannot be solely predicted by the Greenwood function nor by the manufacturer frequency allocation map. This may be explained by the mismatch between the cochlear tonotopy and the placement of the electrode-array, the spread of excitation that stimulates several nerve fibers at the same time, and a fixed stimulation rate lacking temporal coding consideration. In the second condition, the results indicated a significant difference in filter center frequency between e20 and 14. As this parameter is known to relate to sound brightness, e14 seems to evoke a brighter sound than e20. In the third condition, no significant difference (F0, inharmonicity rate) was found between the two electrodes. Although this last result must be interpreted with care – as F0 of an inharmonic sound cannot reliably predict its pitch -, the present study suggests that the sound sensation of different electrodes is more linked to a difference in timbre (brightness) than to a difference in pitch, and is more similar to an inharmonic complex sound than to a pure tone. Finally, a one-year follow up was not sufficient to show any plasticity. No consistent shift of the psychoacoustic parameters were observed over time.

Th45a: MEASUREMENT OF ACOUSTIC AND ELECTRIC BIASING OF ELECTROPHONIC RESPONSE IN THE GUINEA-PIG INFERIOR COLLICULUS

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In recent years great effort is made to improve surgical techniques of cochlear implantation to preserve residual hearing of patients. Combined electrical and acoustical hearing (EAS) is known to enhance listening experience of cochlear implant (CI) users by providing acoustic low frequency information in addition to the electric stimulation. However, besides direct stimulation of auditory nerves, electrical currents evoke also an electro-motile response in the functioning cochlea (electrophonic effect). This mechanical excitation results in acoustic-like response (Nuttall & Ren., 1995) that travels to the low-frequency region of the cochlea and might interfere with the residual acoustical hearing (Sato et al, 2016). We are investigating the effect of an additional acoustic tone or electric DC current on the electrophonic response using a guinea pig model.

Neural responses are recorded by a 32-channel electrode array along the tonotopic axis of the inferior colliculus and acoustic responses in the ear canal (EEOAE) are monitored by an otoacoustic emission probe. Short electrical sinusoid stimulation of 8ms duration is presented via a CI inserted into the Scala Tympany. In one experiment, 100ms long acoustic biasing tones with various levels and frequencies corresponding to the characteristic frequency of the direct electric stimulation place are presented simultaneously with the electric sinusoids. In a second experiment 100ms long biasing DC current signals with positive and negative polarities and various levels are delivered to the cochlea additionally to the electric sinusoids.

First results using a 1600Hz electric sinusoid show no alteration of electrophonic response neither by the biasing acoustic tones nor by the DC currents. On the other hand enhanced neural activity is observed along the IC's tonotopy at loci corresponding to approximately 3200Hz and 6400Hz. EEOAE signals are also detected and currently analysed.

EEOAE might prove useful as a non-invasive diagnostic tool for characterising remaining electro-motility and electric-acoustic interaction in CI patients. Future efforts will attempt to find electrical pulse shapes that minimise the disruptive effects of electro-motility on the low-frequency acoustical signal in combined hearing.

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Th45b: SPEECH INTELLIGIBILITY IN NOISE FOR LISTENERS WITH SINGLE-SIDED DEAFNESS WITH AND WITHOUT A COCHLEAR IMPLANT IN THE CONTRALATERAL EAR

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Individuals who have single-sided deafness (SSD), and rely on monaural hearing, have difficulty functioning in complex acoustic environments. In recent years there has been growing interest in providing a cochlear implant (CI) in the deaf ear of individuals with SSD (henceforth SSD[CI]), but little is known about what benefits, if any, arise from having a CI combined with a normal-hearing (NH) ear. A few studies indicate that adding the CI leads to improved sound localization, suggesting that SSD[CI] patients might be able to integrate acoustic signals from one ear with electric stimulation in the other ear.

The present study focused on measuring speech intelligibility in the presence of spatially separated or spatially co-located interferers, for patients with SSD. Some of the SSD patients were tested prior to receiving a CI (unilateral) and will also be tested again after receiving a CI in their deaf ear. Other patients were tested in post-CI mode only (bilateral). Target stimuli were IEEE sentences (male talker) and interfering stimuli were AzBio Sentences (two different male talkers). Percent correct speech intelligibility scores were measured in five conditions, one in quiet and four with interferers in various locations. In addition, pupil dilation was measured on those same trials (Eyelink 1000 eye tracker) as a proxy for listening effort.

Results thus far show that: (1) With the acoustic ear alone, speech scores were better in the quiet condition than in interferer conditions, except in a condition with interferers located on the side of the deaf ear. Further, performance was poorest when interferers were located close to the acoustic ear. (2) With the addition of the CI (SSD[CI]), performance improved when the interferers were close to the acoustic ear. In Quiet, performance with the CI was similar to or better than with the acoustic ear alone. (3) Reduced pupil dilation (interpreted as listening effort) correlated with improvement in the speech intelligibility scores.
These findings suggest that in patients with a normal acoustic ear and a deaf ear, adding a CI does not interfere with speech intelligibility in any of the conditions tested. Further, it is possible that SSD[CI] patients may be able to integrate electric and acoustic signals across the ears when listening to speech in the presence of interferers. Finally, pupil dilation as a proxy for listening effort is related to improved speech understanding, at least for some patients in some conditions. Further work is being conducted to better understand the relationship between sound localization, speech understanding and listening effort in SSD[CI] patients.

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